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MANUFACTURING TECHNOLOGIES

HANDBOOK
for full-time students of specialty
1-25 01 07 "Economy and Management at the Enterprise"

ПРОИЗВОДСТВЕННЫЕ ТЕХНОЛОГИИ

ПОСОБИЕ
для студентов специальности 1-25 01 07
«Экономика и управление на предприятии»
дневной формы обучения

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Приведены основные понятия дисциплины «Производственные технологии». Рассмотрены сырьевая база и производственная структура Республики Беларусь. Изложены особенности технологий получения металлов, металлических и керамических изделий, полимеров, продуктов переработки нефти.

Для студентов специальности 1-25 01 07 «Экономика и управление на предприятии» дневной формы обучения.

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Manufacturing technology or **production technology** describes transformation of raw material (or *commodity*) to finished goods using different processes: chemical, biological, mechanical. In accordance with the process, there are different kinds of manufacturing (technology):

- chemical manufacturing (technology)
- biological manufacturing (technology)
- mechanical manufacturing (technology)

This transformation can be illustrated through the technological chain:

***Commodity* (Raw material)**	**Technology**	**Product**
C	T	P

1. Chemical manufacturing (technology)

Chemical manufacturing (technology) is a manufacturing when raw material (*commodity*) is transformed to finished product using chemical reactions. Thus chemical composition of commodity and chemical composition of finished product is different.

Example:

Metallurgy

C	**T**	**P**
Metal ore FeO	Metallurgy Metal reduction by C reductant $FeO + C \rightarrow Fe + CO_2$	Metal Fe

2. Mechanical manufacturing (technology)

Mechanical manufacturing (technology) is a manufacturing when raw material (*commodity*) is transformed to finished product using mecanical operations: casting, plastic forming, forging, die shearing, bending, grinding, milling, boring and so on. Thus, chemical composition of commodity and chemical composition of finished product are the same.

Examples:

Casting

C	T	P
Metal	Metalworking: Casting	Goods

Polygraphy

C	T	P
Paper, printing ink	Polygraphy (printing)	Book

Weaving

C	T	P
Thread	Weaving	Textile

3. Biological manufacturing (technology)

Biological manufacturing (technology) is a manufacturing when raw material (*commodity*) is transformed to finished product using biological objects: microorganisms in general (bacteria and yeast).

Thus chemical composition of commodity and chemical composition of finished product are different.

Examples: bread-baking, winemaking, pickling, yogurtmaking. The base of these technologies is fermentation process.

Fermentation is a metabolic process which occurs in bacteria and yeast. These microorganisms produce organic acids, gases, or alcohol by the glucose (or sugar) eating. There are two types of bacteria: heterofermentative bacteria (Examples include Leuconostoc mesenteroides, Lactobacillus bifermentous, and Leconostoc lactis) and homofermentative bacteria. Heterofermentative bacteria produce several products, for example: one mole of glucose is converted to one mole of lactate as well as CO_2 and acetic acid or ethanol. Homofermentative lactic acid fermentation converts a six-carbon glucose molecule to two lactic acid molecules.

Examples:

Bread-baking

C	T	P
Wheat flouer	Bread-baking Ethanolic (alcoholic) fermentation by Saccharomyces cerevisiae glucose → alcogol	Bread

In ethanol fermentation, one glucose molecule is converted into two ethanol molecules and two carbon dioxide molecules. It is used to make bread dough rise: the carbon dioxide forms bubbles, expanding the dough into a foam. Less than 2% ethanol remains after baking.

Ethanol fermentation, also called alcoholic fermentation, is a biological process which converts sugars such as glucose, fructose, and sucrose into cellular energy, producing ethanol and carbon dioxide as by-products. Ethanol fermentation has many uses, including the production of alcoholic beverages, the production of ethanol fuel, and bread cooking.

Winemaking

C	T	P
Grapes	Winemaking Ethanolic (alcoholic) fermentation by *Saccharomyces cerevisiae, Saccharomyces bayanus, Brettanomyce, Kloeckera, Candida genera, Aspergillus oryzae. Baijiu* glucose → alcogol	Wine

The ethanol is the intoxicating agent in alcoholic beverages such as wine, beer and liquor. Yeast is normally already present on the grapes, often visible as a powdery appearance of the grapes. The alcoholic fermentation can be done with this natural yeast, but since this can give unpredictable results depending on the exact types of yeast that are present, cultured yeast is often added.

Pickling (sour, salting)

C	T	P
Cabbage pickles	Pickling Lactic acid fermentation Lactobacillus is lactic acid-fermenting bacteria: *Leuconostoc., Pediococcus Klebsiella, Enterobacter, Leuconostoc mesenteroides, various Lactobacillus species, including L. brevis and L. plantarum,* glucose → acid	Sauerkraut, pickled cucumbers 

Leuconostoc spp., along with other lactic acid bacteria such as *Pediococcus* and *Lactobacillus*, are responsible for the fermentation of cabbage, making it sauerkraut. In this process, fresh cabbage is fermented in a light brine, where the sugars in the cabbage are transformed by lactofermentation to lactic acid which gives the cabbage a sour flavour and good keeping qualities. Leuconostoc spp. are similarly part of the symbiotic colonies of bacteria and yeast or SCOBY involved in the fermentation of kefir, a fermented milk beverage. (A SCOBY is symbiotic culture of bacteria and yeast (or mixed culture), generally associated with kombucha (tea mushroom) production wherein anaerobic ethanol fermentation (by yeast), anaerobic organic acid fermentation (by bacteria), and aerobic ethanol oxidation to acetate (by bacteria) all take place concurrently along an oxygen gradient).

Yogurtmaking

C	T	P
Milk	Yogurtmaking Lactic acid fermentation by lactic acid-fermenting bacteria: Lactobacillus sach as *Lactobacillus bulgaricus, Streptococcus thermophilus, Lactobacillus acidophilus* Lactose → lactic acid Lactose is a disaccharide. It is a sugar composed of galactose and glucose. Lactose makes up around 2–8% of milk is.	 Yogurt

There are many other types of fermentation processes: butyric acid fermentation, caproate fermentation, butanol fermentation, glyoxylate fermentation and so on.

Applications of Biotechnology in terms of history

Time	Area of application
From ancient time	<u>Agriculture</u>: domestication of animals, cultivation of the plants, and "improvements": selective breeding to improve production of crops.Through early biotechnology, the earliest farmers selected and bred the best suited crops, having the highest yields, to produce enough food to support a growing population. As crops and fields became increasingly large and difficult to maintain, it was discovered that specific organisms and their by-products could effectively fertilize, restore nitrogen, and control pests. Throughout the history of agriculture, farmers have inadvertently altered the genetics of their crops through introducing them to new environments and breeding them with other plants — one of the first forms of biotechnology <u>Food production</u>: Fermentation was used to produce leavened bread, beer, other preserved foods
The early 20th cent.	Scientists gained a greater understanding of microbiology and explored ways of manufacturing specific products
1917	Chaim Weizmann first used a pure microbiological culture in an industrial process, that of manufacturing corn starch using Clostridium acetobutylicum, to produce acetone, which the United Kingdom desperately needed to

	manufacture explosives during World War I
1928	Alexander Fleming discovered the mold Penicillium. His work led to the purification of the antibiotic compound formed by the mold by Howard Florey, Ernst Boris Chain and Norman Heatley – to form what we today know as penicillin. In 1940, penicillin became available for medicinal use to treat bacterial infections in humans.
1971	The field of modern biotechnology is generally thought of as having been born when Paul Berg's (Stanford) experiments in gene splicing had early success. Herbert W. Boyer (Univ. Calif. at San Francisco) and Stanley N. Cohen (Stanford) significantly advanced the new technology in 1972 by transferring genetic material into a bacterium, such that the imported material would be reproduced. The commercial viability of a biotechnology industry was significantly expanded on June 16, 1980, when the United States Supreme Court ruled that a genetically modified microorganism could be patented in the case of Diamond v. Chakrabarty.
The late 20th and early 21st centuries	Biotechnology has expanded to include new and diverse sciences such as genomics, recombinant gene techniques, applied immunology, and development of pharmaceutical therapies and diagnostic tests. Modern usage also includes genetic engineering as well as cell and tissue culture technologies.

Biotechnology: Definitions

There are two concepts of "biotech" or "biotechnology":

- wide "biotech" or "biotechnology" (it overlaps often with the (related) fields of biomanufacturing)
- modern "biotech" or "biotechnology" – new, innovating technologies based on modern biological sciences.

The term "biotechnology" is largely believed to have been coined in 1919 by Hungarian engineer Károly Ereky. Today there are a lot of definition to biotechnology.

UN Convention on Biological Diversity, Art.	**Biotechnology is** the broad area of science involving living systems and organisms to develop or make products, or "any technological application that uses biological systems, living organisms, or derivatives

2	thereof, to make or modify products or processes for specific use"
The American Chemical Society	**Biotechnology** as the application of biological organisms, systems, or processes by various industries to learning about the science of life and the improvement of the value of materials and organisms such as pharmaceuticals, crops, and livestock
European Federation of Biotechnology	**Biotechnology is** the integration of natural science and organisms, cells, parts thereof, and molecular analogues for products and services
	Biotechnology is the research and development in the laboratory using bioinformatics for exploration, extraction, exploitation and production from any living organisms and any source of biomass by means of biochemical engineering where high value-added products could be planned (reproduced by biosynthesis, for example), forecasted, formulated, developed, manufactured, and marketed for the purpose of sustainable operations (for the return from bottomless initial investment) and gaining durable patents rights (for exclusives rights for sales, and prior to this to receive national and international approval from the results on animal experiment and human experiment)

Color classification of biotechnologies

There is color classification of biotechnologies according to there application areas. There are approximately ten branches, with green, yellow, white and blue biotechnology the most significant. Biotechnology has applications in different areas, including health care/medical pharmaceutical industries (red color), crop production and agriculture (green color), non food industrial uses of crops and other products, e.g. biodegradable plastics, vegetable oil, biofuels (white color), environmental uses (grey color), war uses (dark color).

For example, one application of biotechnology is the directed use of organisms for the manufacture of organic products (examples include beer and milk products). Another example is using naturally present bacteria by the mining industry in bioleaching. Biotechnology is also used to recycle, treat waste, clean up sites contaminated by industrial activities (bioremediation), and also to produce biological weapons.

Red biotechnology is related to the medical and pharmaceutical industries, and health preservation. This branch involves the production of vaccines and antibiotics, regenerative therapies, creation of artificial organs and new diagnostics of diseases. As well as the development of hormones, stem cells, antibodies, siRNA and diagnostic tests Red biotechnology is applied to medical processes. Some examples are the designing of organisms to produce antibiotics, and the engineering of genetic cures through genetic manipulation. In medicine, modern biotechnology finds many applications in areas such as pharmaceutical drug discoveries and production, pharmacogenomics, and genetic testing (or genetic screening). Pharmacogenomics (a combination of pharmacology and genomics) is the technology that analyses how genetic makeup affects an individual's response to drugs. It deals with the influence of genetic variation on drug responses in patients by correlating gene expression or single-nucleotide polymorphisms with a drug's efficacy or toxicity. By doing so, pharmacogenomics aims to develop rational means to optimize drug therapy, with respect to the patients' genotype, to ensure maximum efficacy with minimal adverse effects. Such approaches promise the advent of "personalized medicine"; in which drugs and drug combinations are optimized for each individual's unique genetic makeup.

Biotechnology has contributed to the discovery and manufacturing of traditional small molecule pharmaceutical drugs as well as drugs that are the product of biotechnology – biopharmaceutics. Modern biotechnology can be used to manufacture existing medicines relatively easily and cheaply. The first genetically engineered products were medicines designed to treat human diseases. To cite one example, in 1978 Genentech developed synthetic humanized insulin by joining its gene with a plasmid vector inserted into the bacterium Escherichia coli. Insulin, widely used for the treatment of diabetes, was previously extracted from the pancreas of abattoir animals (cattle or pigs). The resulting genetically engineered bacterium enabled the production of vast quantities of synthetic human insulin at relatively low cost. Biotechnology has also enabled emerging therapeutics like gene therapy. The application of biotechnology to basic science (for example through the Human Genome Project) has also dramatically improved our understanding of biology and as our scientific knowledge of normal and disease biology has increased, our ability to develop new medicines to treat previously untreatable diseases has increased as well.

Genetic testing allows the genetic diagnosis of vulnerabilities to inherited diseases, and can also be used to determine a child's parentage (genetic mother and father) or in general a person's ancestry. In addition to studying chromosomes to the level of individual genes, genetic testing in a broader sense includes biochemical tests for the possible presence of genetic diseases, or mutant forms of genes associated with increased risk of developing genetic disorders. Genetic testing identifies changes in chromosomes, genes, or proteins. Most of the time, testing is used to find changes that are associated with inherited disorders. The results of a genetic test can confirm or rule out a suspected genetic condition or help determine a person's chance of developing or passing on a genetic disorder. As of 2011 several hundred genetic tests were in use. Since genetic testing may open up ethical or psychological problems, genetic testing is often accompanied by genetic counseling.

Green biotechnology is biotechnology applied to agricultural processes. An example would be the selection and domestication of plants via micropropagation. Another example is the designing of transgenic plants to grow under specific environments in the presence (or absence) of chemicals. One hope is that green biotechnology might produce more environmentally friendly solutions than traditional industrial agriculture. An example of this is the engineering of a plant to express a pesticide, thereby ending the need of external application of pesticides. An example of this would be Bt corn. Whether or not green biotechnology products such as this are ultimately more environmentally friendly is a topic of considerable debate.Green biotechnology involves the creation of more fertile and resistant seeds, plants and resources by using specialized techniques. It appeared with the exponential growth of global population and the concerns around it. It is commonly considered as the next phase of green revolution, which can be seen as a platform to eradicate world hunger by using technologies which enable the production of more fertile and resistant, towards biotic and abiotic stress, plants and ensures application of environmentally friendly fertilizers and the use of biopesticides, it is mainly focused on the development of agriculture. Green biotechnology is controversial because of its applications in life, such as genetically modified organisms (enhanced organisms). On the other hand, some of the uses of green biotechnology involve microorganisms to clean and reduce waste. Genetically modified crops ("GM crops", or "biotech crops") are plants used in agriculture, the DNA of which has been modified with genetic engineering techniques. In most cases, the main aim is to introduce a new trait that does not occur naturally in the species.

Examples in food crops include resistance to certain pests, diseases, stressful environmental conditions, resistance to chemical treatments (e.g. resistance to a herbicide), reduction of spoilage, or improving the nutrient profile of the crop. Examples in non-food crops include production of pharmaceutical agents, biofuels, and other industrially useful goods, as well as for bioremediation.

Farmers have widely adopted GM technology. Between 1996 and 2011, the total surface area of land cultivated with GM crops had increased by a factor of 94, from 17,000 square kilometers (4,200,000 acres) to 1,600,000 km^2 (395 million acres). 10% of the world's crop lands were planted with GM crops in 2010. As of 2011, 11 different transgenic crops were grown commercially on 395 million acres (160 million hectares) in 29 countries such as the USA, Brazil, Argentina, India, Canada, China, Paraguay, Pakistan, South Africa, Uruguay, Bolivia, Australia, Philippines, Myanmar, Burkina Faso, Mexico and Spain.

Genetically modified foods are foods produced from organisms that have had specific changes introduced into their DNA with the methods of genetic engineering. These techniques have allowed for the introduction of new crop traits as well as a far greater control over a food's genetic structure than previously afforded by methods such as selective breeding and mutation breeding. Commercial sale of genetically modified foods began in 1994, when Calgene first marketed its Flavr Savr delayed ripening tomato. To date most genetic modification of foods have primarily focused on cash crops in high demand by farmers such as soybean, corn, canola, and cotton seed oil. These have been engineered for resistance to pathogens and herbicides and better nutrient profiles. GM livestock have also been experimentally developed, although as of November 2013 none are currently on the market.

There is a scientific consensus that currently available food derived from GM crops poses no greater risk to human health than conventional food, but that each GM food must be tested on a case-by-case basis before introduction. Nonetheless, members of the public are much less likely than scientists to perceive GM foods as safe. The legal and regulatory status of GM foods varies by country, with some nations banning or restricting them, and others permitting them with widely differing degrees of regulation.

GM crops also provide a number of ecological benefits, if not used in excess. However, opponents have objected to GM crops per se on several grounds, including environmental concerns, whether food produced from GM crops is safe, whether GM crops are needed to address the world's food needs, and economic concerns raised by the fact these organisms are subject to intellectual property law.

Yellow biotechnology has been used in food production, for example in making wine, cheese, and beer by fermentation. It has also been used to refer to biotechnology applied to insects. This includes biotechnology-based approaches for the control of harmful insects, the characterisation and utilisation of active ingredients or genes of insects for research or application in agriculture and medicine and various other approaches.

White biotechnology, also known as industrial biotechnology, is mostly based on the application of bio-catalysis in industrial processes. It uses living cells from yeast, molds, bacteria, plants, and enzymes to synthesize products that are easily degradable, require less energy and create less waste. An example is the designing of an organism to produce a useful chemical. Another example is the using of enzymes as industrial catalysts to either produce valuable chemicals or destroy hazardous/polluting chemicals. White biotechnology tends to consume less in resources than traditional processes used to produce industrial goods Industrial biotechnology includes the practice of using cells such as micro-organisms, or components of cells like enzymes, to generate industrially useful products in sectors such as chemicals, food and feed, detergents, paper and pulp, textiles and biofuels. In doing so, biotechnology uses renewable raw materials and may contribute to lowering greenhouse gas emissions and moving away from a petrochemical-based economy.

Blue biotechnology is based on the exploitation of sea resources to create products and industrial applications. This branch of biotechnology is the most used for the industries of refining and combustion principally on the production of bio-oils with photosynthetic micro-algae. Blue biotechnology is a term that has been used to describe the marine and aquatic applications of biotechnology, but its use is relatively rare.

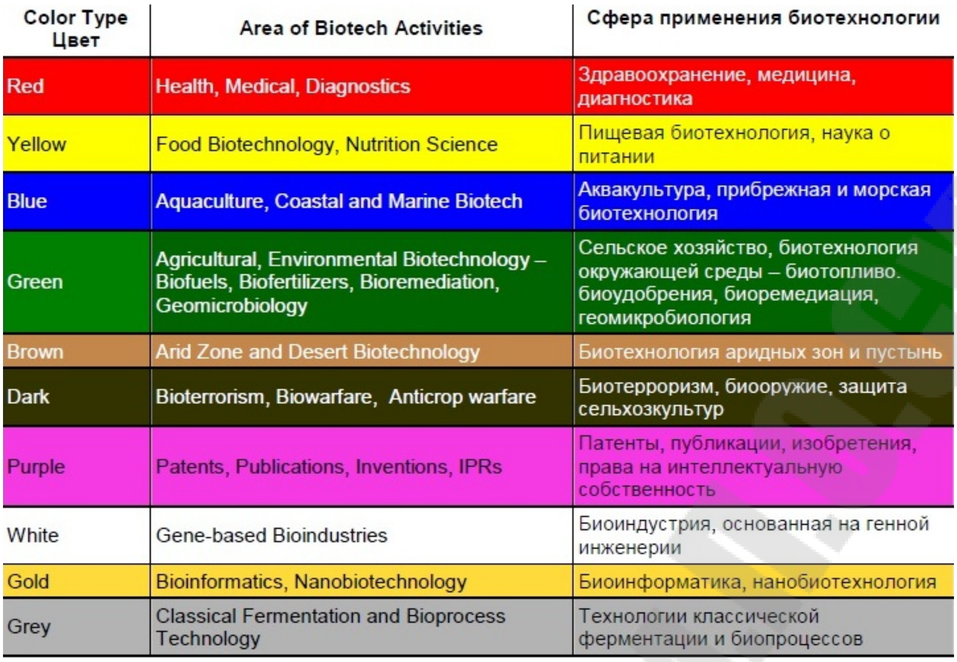
Gray biotechnology is dedicated to environmental applications, and focused on the maintenance of biodiversity and the remotion of pollutants. The environment can be affected by biotechnologies, both positively and adversely. Vallero and others have argued that the difference between beneficial biotechnology (e.g.bioremediation is to clean up an oil spill or hazard chemical leak) versus the adverse effects stemming from biotechnological enterprises (e.g. flow of genetic material from transgenic organisms into wild strains) can be seen as applications and implications, respectively. Cleaning up environmental wastes is an example of an application of environmental biotechnology; whereas loss of biodiversity or loss of containment of a harmful microbe are examples of environmental implications of biotechnology.

Brown biotechnology is related to the management of arid lands and deserts. One application is the creation of enhanced seeds that resist extreme environmental conditions of arid regions, which is related to the innovation, creation of agriculture techniques and management of resources.

Gold biotechnology is related to bioinformatics, nanobiotechnology and computer science categories. Bioinformatics is an interdisciplinary field that addresses biological problems using computational techniques, and makes the rapid organization as well as analysis of biological data possible. The field may also be referred to as computational biology, and can be defined as, "conceptualizing biology in terms of molecules and then applying informatics techniques to understand and organize the information associated with these molecules, on a large scale." Bioinformatics plays a key role in various areas, such as functional genomics, structural genomics, and proteomics, and forms a key component in the biotechnology and pharmaceutical sector

Violet biotechnology is related to law, ethical and philosophical issues around biotechnology.

Dark biotechnology is the color associated with bioterrorism or biological weapons and biowarfare which uses microorganisms, and toxins to cause diseases and death in humans, livestock and crops.



Color Type Цвет	Area of Biotech Activities	Сфера применения биотехнологии
Red	Health, Medical, Diagnostics	Здравоохранение, медицина, диагностика
Yellow	Food Biotechnology, Nutrition Science	Пищевая биотехнология, наука о питании
Blue	Aquaculture, Coastal and Marine Biotech	Аквакультура, прибрежная и морская биотехнология
Green	Agricultural, Environmental Biotechnology – Biofuels, Biofertilizers, Bioremediation, Geomicrobiology	Сельское хозяйство, биотехнология окружающей среды – биотопливо. биоудобрения, биоремедиация, геомикробиология
Brown	Arid Zone and Desert Biotechnology	Биотехнология аридных зон и пустынь
Dark	Bioterrorism, Biowarfare, Anticrop warfare	Биотерроризм, биооружие, защита сельхозкультур
Purple	Patents, Publications, Inventions, IPRs	Патенты, публикации, изобретения, права на интеллектуальную собственность
White	Gene-based Bioindustries	Биоиндустрия, основанная на генной инженерии
Gold	Bioinformatics, Nanobiotechnology	Биоинформатика, нанобиотехнология
Grey	Classical Fermentation and Bioprocess Technology	Технологии классической ферментации и биопроцессов

Topic 2. Natural resources of Belarus

Key questions

1. Main fuel mineral resources of Belarus
2. What do you know about peat?
3. What do you know about potash salt?
4. What do you know about rock salts?
5. Construction materials and raw materials for their production in Belurus
6. Water in Belarus
7. Wood in Belarus

At the moment, about 5 thousand deposits representing about 30 types of minerals were identified and explored in the depths of Belarus. In terms of the economy, the strategically important resources include potash and rock salts, oil, peat, construction materials and raw materials for their production, underground fresh and mineral water. Thus the Republic of Belarus does not have a massive mineral resource base, and in this regard, the country imports a large number of fuels and raw materials required for its facilities.

1. Fossil fuels (Fuel mineral resources)

Fuel mineral resources of Belarus include oil, oil gas, peat, brown coal and combustible shale. Deposits of coal and combustible shale are not operated.

1.1. Oil and oil gas

A total of 52 oil fields are registered, of which about 30 are operated, and the rest belongs to the category of canned or explored. Despite the reserve of oil, associated gas, peat, brown coal, Belarus is unable to meet the demand for fuel resources from its own raw materials. The volume of oil production in the country amounts to only 12-13% of the demand, and in the future this ratio will not change.

1.2. Peat

Peat is produced in Belarus by a number of small plants located all over the country. In order to increase production of peat, a government program was initiated. Its aim was to increase peat production from 2.4 Mt in 2010 to 4.4 Mt/yr by 2020. Peat resources are considerably depleted due to intensive use at the previous stages of economic development of Belarus. If the total anticipated resources of peat are estimated at 3.0 billion tons, only 240 million tons are suitable for industrial production. The remaining reserves are within the protected areas or are part of the land fund.

Peat, the country's most valuable mineral resource, is used for fuel and fertilizer and in the chemical industry.

Peat (also called **turf** (/tɜːrf/), is an accumulation of partially decayed vegetation or organic matter that is unique to natural areas called peatlands, bogs, mires, moors, or muskegs. The peatland ecosystem is the most efficient carbon sink on the planet, because peatland plants capture CO_2 naturally released from the peat, maintaining an equilibrium. In natural peatlands, the "annual rate of biomass production is greater than the rate of decomposition", but it takes "thousands of years for peatlands to develop the deposits of 1.5 to 2.3m, which is the average depth of the boreal peatlands". Sphagnum moss, also called peat moss, is one of the most common components in peat, although many other plants can contribute. Soils consisting primarily of peat are known as histosols. Peat forms in wetland conditions, where flooding obstructs the flow of oxygen from the atmosphere, slowing the rate of decomposition.

Peatlands, particularly bogs, are the primary source of peat, although less-common wetlands including fens, pocosins, and peat swamp forests also deposit peat. Landscapes covered in peat are home to specific kinds of plants including Sphagnum moss, ericaceous shrubs, and sedges. Because organic matter accumulates over thousands of years, peat deposits provide records of past vegetation and climate by preserving plant remains, such as pollen. This allows humans to reconstruct past environments and study changes in human land use.

Peat is harvested as an important source of fuel in certain parts of the world. By volume, there are about 4 trillion cubic metres of peat in the world, covering a total of around 2% of the global land area (about 3 million square kilometres), containing about 8 billion terajoules of energy. Over time, the formation of peat is often the first step in the geological formation of other fossil fuels such as coal, particularly low-grade coal such as lignite.

Depending on the agency, peat is not generally regarded as a renewable source of energy, due to its extraction rate in industrialized countries far exceeding its slow regrowth rate of 1mm per year, and as it is also reported that peat regrowth takes place only in 30-40% of peatlands. Because of this, the UNFCCC, and another organization affiliated with the United Nations classified peat as a fossil fuel. However, the Intergovernmental Panel on Climate Change (IPCC) has begun to classify peat as a "slow-renewable" fuel. This is also the classification used by many in the peat industry.

Peat application for agriculture

In Sweden, farmers use dried peat to absorb excrement from cattle that are wintered indoors. The most important property of peat is retaining moisture in container soil when it is dry while preventing the excess of water from killing roots when it is wet. Peat can store nutrients although it is not fertile itself– it is polyelectrolytic with a high ion-exchange capacity due to its oxidized lignin. Peat is discouraged as a soil amendment by the Royal Botanic Gardens, Kew, England, since 2003. While bark-based peat-free potting soil mixes are on the rise, particularly in the U.K., peat remains an important raw material for horticulture in Canada, as well as parts of the United States. However, it is recommended to treat peat thermally, e.g., through soil steaming in order to kill pests and reactivate nutrients.

Peat application at freshwater aquaria

Peat is sometimes used in freshwater aquaria. It is seen most commonly in soft water or blackwater river systems such as those mimicking the Amazon River basin. In addition to being soft in texture and therefore suitable for demersal (bottom-dwelling) species such as Corydoras catfish, peat is reported to have a number of other beneficial functions in freshwater aquaria. It softens water by acting as an ion exchanger; it also contains substances that are beneficial for plants, and for the reproductive health of fishes. Peat can prevent algae growth and kill microorganisms. Peat often stains the water yellow or brown due to the leaching of tannins.

Peat application peat for water filtration

Peat is used in water filtration, such as for the treatment of septic tank effluent and as for urban runoff.

Peat application for balneotherapy

Peat is widely used in balneotherapy (the use of bathing to treat disease). Many traditional spa treatments include peat as part of peloids. Such health treatments have an enduring tradition in European countries including

Poland, the Czech Republic, Germany, and Austria. Some of these old spas date back to the 18th century and are still active today. The most common types of peat application in balneotherapy are peat muds, poultices, and suspension baths.

1.3. Combustible shale

Deposits of combustible shale in the south of Belarus form a large shale pool with an area of more than 20,000 km2. Combustible shale is considered as a potential resource base for the development of energy, chemical industry and the production of construction materials.

2. Salts and phosphorites

Mining chemical feedstock is represented by potash and rock salts, phosphorites

2.1. Potash (potassium) salts

Potash salts are one of the most valuable natural resources of the depths of Belarus, in the amount of reserves of which the country occupies one of the first places in Europe. Extraction and processing of potash fertilizers into high-quality mineral fertilizers not only provides the country with an increase in crop yields, but is also a source of foreign exchange earnings through export of products. Potash is the leading export product for Belarus. RUE “PA “Belaruskali” annually produces 28-32 million tons of potash ore, from which it produces about 4 million tons of potash fertilizers. The enterprise fully meets the needs of the internal market in manufactured products, and in considerable volume exports to countries to the former Soviet Union and other foreign countries.

Potash is a general term referring to any potassium fertilisers used in agriculture. Potassium is a naturally occurring element which cannot be manufactured synthetically. As one of the most important plant nutrients (besides nitrogen and phosphate), it is indispensable for productive and healthy plant growth. Potassium fertilisers therefore make a decisive contribution to better providing the growing world population with food, in terms of both quantity and quality. A number of intermediate products are also produced from potassium. These are used in the production of industrial and pharmaceutical goods which would be inconceivable without potash. Potassium is the seventh most common element occurring in the Earth’s crust, accounting for 2.4% of its mass. Potash deposits, i.e. natural concentrations of raw potash, consist of potassium salt rock, predominantly made up of the potassium minerals sylvite (KCl), carnallite ($KMgCl_{3*}6$ H_2O), kainite ($KMg[Cl|SO_4]*2.75\ H_2O$) and langbeinite ($K_2Mg_2(SO_4)_3$), or potassium-bearing salt solutions either underground or in salt lakes.

2.2. Rock salts

Rock salt reserves are estimated as practically inexhaustible. They exceed 22 billion tons at three known deposits alone.

Mozyr rock salt deposit is a source of raw materials. The prospected reserves number hundreds of millions of tons.The deposit, which laid the foundation of the enterprise, is a dome-shaped elevation consisting of interstratified riders of insoluble rocks and further salt. Depth of salt occurrence varies from 600 to 1250 metres. Salt is obtained shaft free by underground dissolution of salt strata with water. The salt is obtained from 13 wells located 3 kilometres away from the main production area. Wells are used for supplying water, which washes out solid salt. Saturated brine comes up, and is supplied to the main area through pipes. The saturated brine is clarified from mechanical admixtures, calcium and magnesium salts, and is further supplied for evaporation. Then salt pulp is condensed and centrifuged. As the result there is obtained salt with residual moisture content of 3%. Then free flowing agent (potassium ferrocyanide) is added, and finally drying machines turn this semi-product into dry extra salt "Polesie" with approximate residual moisture content of 0.1%. High-scale clarification of the brine and special production techniques let obtain a product with the content of the basic substance $NaCl$ above 99.7%.

3. Metals ore

The territory of Belarus is prospective in ferrous and non-ferrous metals. Two iron ore deposits with a total reserve of category A+B+C1 amounting to 340 million tons, and probable reserves of 1.5 billion tons are open, their use will largely depend on the resolution of the fuel and energy problem in the country.

4. Construction materials and raw materials for their production

Belarus has a rich mineral base for construction materials production. Belarus has deposits of clay, sand, chalk, dolomite, building and decorative stone, and other materials. However, there is a shortage in glass sands, clays for high-quality ceramics production.

5. Water (underground fresh and mineral water)

58 mineral water springs with a total reserve of 14,320.8 m3 per day have been explored, 50 springs are being developed. Mineral water is used for health resort treatment, as well as sold through the trading network as mineral medicinal and table water.

6. Wood

Wood is not mineral resource, but very important natural resource of Belarus. Forests cover about a third of the land, and lumbering is an important sector of Belarus economy.

Topic 3. Manufacturing structure of Belarus

Key questions

1 What are the key industries of Belarus?
2 What do you know about mechanical engineering of Belarus?
3 What are the largest enterprises of mechanical engineering of Belarus?
4 What do you know about metallurgical industry of Belarus?
5 What are the largest enterprises of metallurgical industry of Belarus?
6 What do you know about chemical and petrochemical industry of Belurus?
7 What do you know about industry of building materials in Belarus?
8 Food industry of Belarus
9 Light industry of Belarus
10 Woodworking industry of Belarus
11 Paper industry of Belarus
12 Belarusian pharmaceutical industry

The economic potential of Belarus is based on a number of industries, which account for almost 40% of the basic production assets. Over 2,300 different plants which produce about 30% of the gross domestic product function in the country. The key industries are:

- mechanical engineering, (including metallurgy and metalworking),
- chemical and petrochemical industry,
- light and food industries,
- forest, woodworking and paper industries,
- production of construction materials,
- pharmaceutics and microbiology.

1. Mechanical engineering

Mechanical engineering is the most important sector of Belarus economy with the active development of the agricultural and transport aspects. The republic produces over 59,000 tractors, 2,000 combine harvesters, 22,000 trucks, 2,000 buses per year. Over 60% of Belarusian mechanical engineering products are sold abroad. Experts predict the medium-term growth of the demand for Belarusian mechanical engineering products in

Russia and Kazakhstan, which collectively account for about 73% of the Belarusian mechanical engineering export.

Largest enterprises of mechanical engineering

The Belarusian enterprises in mechanical engineering are widely known abroad thanks to such national brands as dump trucks “BelAZ”, tractors “Belarus”, trucks “MAZ”. Special equipment “Amkodor” and agricultural equipment “Gomselmash” also found their sales markets, constantly expanding the geography of export.
The key enterprise of the republic in the transport sector is the holding “BelavtoMAZ” which is engaged in the production of tractor units, vehicle-borne, medium-duty trucks, dump trucks, timber trucks, car chassis fit for all kind of special equipment. Today BelAZ produces every third dump truck on the world market. The “portfolio” of the plant includes over 500 models and modifications, which are produced at OJSC “MAZ” — the managing company of the holding. “MAZ” also carries out the customized production of small buses, commuter coaches of level Euro 4 and 5, city buses of level Euro-4 and Euro-5.

“Minsk Tractor Works” has a share of more than 7% in its segment on the world market, selling products in over 120 countries of the world. “MTZ” produces a wide range of tractors from 80 to 200 h. p. in accordance with the environmental requirements Stage-3A. The main consumers of tractors “Belarus” is Russia, Kazakhstan, Ukraine. In 2012, the list of exporting countries of MTZ tractors was joined by Equatorial Guinea, Costa Rica, Malaysia, Myanmar, Cambodia, Iraq.

PA “Gomselmash” is the leading company of Belarus in the sphere of agricultural mechanical engineering – it produces lines of grain and forage harvesters, mowers, shredders and other equipment. The export supplies of “Gomselmash” are carried out to CIS countries, Europe. The Latin American market has been tapped recently – the first batches of equipment went to Brazil.


Belarusian brand – MAZ

2. The metallurgical industry of Belarus

The metallurgical industry of Belarus is represented by enterprises of ferrous metallurgy, organizations on preparation and secondary processing of metal scrap, as well as enterprises working in the sphere of powder metallurgy and casting of non-ferrous metals. The feature of the metallurgical industry of the country is that it manufactures products based on imported raw materials and uses metal waste of the economy.

The metallurgical complex of Belarus includes 8 enterprises which produce steel electric round and shaped tubes, steel cast blanks, rolled steel, various kinds of wires, metal cords, bolts, screws, nuts, nails, molding materials, heating equipment.

The iron industry of Belarus specializes in manufacture of steel, iron casting, production of steel and cast iron pipes, metal cords, metal ware and other metal products. The production is mainly focused at the Belarusian Metallurgical Plant in the city of Žlobin of the Homel region. About 80% of the total production of the industry is concentrated at this enterprise.

Powder metallurgy is represented by enterprises of the Belarusian State Research and Production Concern of Powder Metallurgy.

The concern includes: the Powder Metallurgy Research Institute, the Pulse Processes Research Institute, the Technological Institute of Welding and Protective Coatings, the Maladzečna Powder Metallurgy Plant. The non-ferrous metallurgy of the republic is represented by foundry production in Minsk, Homel’, Mazyr.

Largest enterprises of the industry

OJSC “Belarusian Metallurgical Plant” is one of the five largest companies in the country. By 2016, the plant, the original design capacity of which amounted to 700 thousand tons of steel per year, plans to reach the level of production of 3 million tons of steel. BMP plans to increase the production of Belarusian metal cord.

OJSC “Mogilev Metallurgical Plant” produces steel, electric round and shaped tubes.

RUE “Gomel Foundry Plant “Centrolit” is engaged in the production of iron casting for machine tool building and mechanical engineering, inlets, grates, artistic and casting furnace.

“Rechitsa Hardware Plant” is the leader in Europe in the supply of construction and special nails. OJSC “Minsk Heating Equipment Plant” manufactures boilers, radiators, fittings.

3. Chemical and Petrochemical industry

Belarus produces over 500 kinds of petrochemical and chemical products. The petrochemical complex of Belarus includes the organisation of mining, as well as the processing and transportation of oil and oil products. It covers chemistry and petro-chemistry, scientific, design, construction, repair and commissioning organisations. Most are united under Belneftekhim Concern, which is among the largest and most strategically important of the country’s industrial complexes.

Industry organizations provide about 30 percent of all industrial output in Belarus and half of exports, which go to over 120 countries worldwide. More than 70 percent of petrochemical products are sold abroad, with a wide distribution network operating abroad, to facilitate these sales.

Belorusneft

Production Association Belorusneft RUE performs a complete cycle of works relating to oil exploration and production, in Belarus and abroad: in Russia, Venezuela, Ecuador and in other countries. Every year, 1.645 million tonnes of oil are mined in Belarus. Since 2013, stabilisation of oil production has been achieved through the use of modern methods of exploration and extraction, including the introduction of new techniques and technologies. The largest network of fuelling stations, under the brand of Belorusneft, provides almost 70 percent of sales of motor fuel within Belarus, and a range of services to consumers, at the most advanced level.

Belarusian refineries (Mozyr Oil Refinery JSC and Naftan JSC) are characterised by a high technological level. As regards the quality and environmental performance of motor fuel, the Republic of Belarus leads among CIS countries.

Since 2016, the annual volume of oil refining at refineries has stood at 24 million tonnes. Production includes automobile gasoline, diesel fuel (including for engines in arctic and cold winter climates), fuel for subsonic PT and Jet-1 jet engines, aromatic hydrocarbons and automotive oils.

Mozyr Oil Refinery

Owing to major investment projects, refineries fully provide motor fuels meeting 5th ecological grade, in accordance with European environmental standards and the technical regulations of the Customs Union. Refineries process crude oil supplied by the Russian Federation via the export trunking oil pipelines of Russia’s Transneft JSC.


Naftan JSC

Belarusian oil transportation companies Gomeltransneft Druzhba JSC and Polotsktransneft Druzhba JSC service these pipelines, ensuring the supply of oil to refineries and transportation of transit flows to Poland and Ukraine.

Belshina JSC produces over five million tyres of over 300 types annually, for passenger cars and heavy trucks, road construction, lifting-transporting, agricultural machinery and tractors. Babrujsk is especially proud of its super-large sized tyres, as used on giant BelAZ vehicles. As part of its technical re-equipment, Belshina JSC has mastered production of modern tubeless full-steel cord tyres of regulated pressure, with enhanced cross-country capacity, able to carry twenty-one tonnes (including for use on MZKT dump trucks). Modernisation of passenger car production has expanded the range of passenger car tyres meeting international quality standards, alongside the technical re-equipment of full-steel cord tyres for trucks.


Products of Belshina JSC

Few organisations specialise in production mineral fertilisers of various types: nitrogen (Grodno Azot JSC), and phosphorus and complex (Gomel Chemical Plant JSC) and potassium (Belaruskali – one of the world's largest manufacturers and suppliers of potash fertilizers).

Production of industry-made fibres is being developed at SvetlogorskKhimvolokno JSC and at Mogilevkhimvolokno JSC.

Meanwhile, Khimvolokno Plant (of Grodno Azot JSC) produces polyamide fibres and yarns and cord fabrics, as well as primary polyamide-6 and composite materials.

Polymir Plant (of Naftan JSC) specializes in production of high density polyethylene, of both basic grades and compositions. It also produces a wide range of acrylic fibres. Also in production areglass fibre and glass fibre products, at Polotsk-Steklovolokno JSC, and paraffin, at Mineral Wax Plant JSC. Paints and lacquers are made at Lakokraska JSC, in addition to other items.

4. Industry of construction materials

The building materials industry in Belarus is represented by about 1,500 enterprises of different form of ownership, that specialize in the production of cement, wall, coating and finish materials, precast concrete and concrete structures, roofing materials, etc. In total, the country produces over 130 kinds of building materials and products. The enterprises of Belarus export about 50 types of building materials, products and constructions. Moreover, 80% of export volume accounts for ceramic tiles, polished glass, roll roofing materials, building constructions, ceramic and silicate bricks, cement, break stone. According to the Ministry of Architecture and Construction, in 2012 the construction industry of the republic increased the export by 1.4 times compared to 2011 up to 520 million US dollars.

In the past few years, the construction complex of Belarus has been going through a period of modernization of the production of building materials, on which it is planned to spend BYR 12.5 trillion by 2015. Build-up of the capacity of domestic enterprises, as well as harmonization of building regulations with European regulations is taking place.

Major segments of the industry and the largest enterprises

4.1 Production of cement

Future demand of the republic in cement taking into account the production export in 2015 is projected to amount to 4 million tons per year. Cement export from Belarus is carried out mainly to Poland, Lithuania and

Latvia. It is planned to increase the volume of export to 25% of total production. The Belarusian flagships in cement production are RUE "Belarusian Cement Plant" located in the city of Kasciukovičy with a capacity of 1.2 million tons per year, as well as "Krichevcementnoshifer" (Kryčaū) and OJSC "Krasnoselskstroymaterialy" which has the largest and most modernized production of cement in Belarus. In 2012, due to the high demand for cement, the capacity of the two following cement plants was increased by 3.6 million tons of cement per year – "Krasnoselskstroymaterialy" and "Belarusian Cement Plant".

4.2 Finish materials

Among Belarusian finish materials, ceramic tile occupies perhaps the leading role in terms of export volume. The flagship in the production of this material is OJSC "Keramin" (Minsk), where, in particular, the production of ceramic granite is also developing. The enterprise works in collaboration with Italian companies. Moreover, tile is produced by enterprises "Brest KSM" (Brest) and "Berezastroymaterialy" (Biaroza).

4.3 Wall materials

One of the main wall materials — construction brick – is produced at a whole range of Belarusian enterprises. These are the Minsk plant of building materials and the Minsk plant of silicate products, OJSC "Keramika" in Vitebsk, the Radaškovičy ceramic plant which also mastered the production of porous ceramic blocks, and many others.

Over the last few years, Belarus has created working capacity for the production of cellular lime concrete which became one of the most used building materials in the country. OJSC "Smorgonsilikatobeton" in Smarhon' and OJSC "Zabudova" in the village of Čysc' of the Minsk region are engaged in the production of cellular building blocks.

4.4 Paint segment

There are about 100 manufacturers of paint products in Belarus, but the basis of this segment are 7-8 companies. The leaders of the sphere are OJSC "Lakokraska" (Lida), OJSC "Minsk Paint Plant", LLC "Esgit", PUE "MAV". Belarusian paint materials are exported to Russia, Ukraine, Moldova, Uzbekistan, Kazakhstan, Austria, Bulgaria, Hungary, India. In 2013, the project on the production of anti-corrosion coatings will be further developed at the Lida OJSC "Lakokraska" together with the Norwegian company Jotun Paints. The plant installed units which will allow producing enamel for painting pre-primed metal surfaces. The capacity of the line will amount to 250- 300 liters of enamel per hour.

4.5 Dry building mixes

In the last 3 years, the market of dry building mixes of Belarus has been growing by 17% on average per year in real terms. About 35 companies work in the segment of dry building mixes in the country, but 2/3 of the market account for five leaders: Taifun, Henkel Bautechnic, ILmax, Krasnoselskstroymaterialy and Sarmat. The main production trends of Belarusian DBM: cement (55%), polymer (30%) and gypsum (15%). Today the DBM segment is working on increasing the competitiveness of local brands, introducing energy-efficient building technologies for the rational use of fuel and energy resources.

4.6 Production of roofing materials

Over the past few years, Belarus has considerably increased the number of enterprises which offer various roofing materials. There is active interest in the production and sale of these goods both on behalf of Belarusian companies, as well as foreign investors. Among the largest joint ventures in the roofing segment is OJSC "Krovlya". This is a Belarusian-British project, producing rolled roofing and waterproof materials. The company is part of the corporation TekhnoNIKOL – European manufacturer of building materials.

Another major enterprise in the segment of roofing is OJSC "Gidrostekloizol" in the Brest region. The company produces synthetic materials and glass basics with bitumen-polymer coating, as well as bitumen-polymer roofing materials on the basis of fiberglass.

5. Food industry

Belarusian products are known abroad thanks largely to the food industry: dairy, meat, confectionery brands, which have won consumer preferences due to their naturality, taste and competitive price. Over the recent years, Belarus has received the status of one of the leading exporters of food products. The food industry includes more than two dozen spheres with numerous specialized productions. The largest are meat, dairy, confectionery, sugar, brewery and soft drinks productions.

5.1 Meat industry

The meat processing sphere in Belarus belongs to the category of active in regard to the introduction of new technologies and equipment upgrades. 1

trillion 163 billion Belarusian rubles were spent in order to improve the competitiveness of Belarusian meat products in 2011 – the first quarter of 2013. In the consumer market saturation of the republic, priorities are given to domestic producers. The share of domestic products in the sales volume exceeds 99%: meat and poultry – 99.7%, meat products – 99.8%, canned meat – 99.1%. Today there are over 100 companies which carry out the processing of meat in Belarus, among them are: “Agrocombine Snov”, OJSC “Baranovichi Meat-Packing Plant”, OJSC “Berezovsky Meat-Packing Plant”, OJSC “Grodno Meat Plant”, OJSC “Slonim Meat Plant”, OJSC “Bobruisk Meat Plant”, OJSC “Borisov Meat Plant”, OJSC “Brest Meat Plant”, OJSC “Orsha Meat-Packing Plant”, UE “Minsk Meat Plant” and others.

5.2 Dairy industry

The Belarusian dairy industry is the trademark of the food industry of the republic which specializes in the production of milk, butter, cheese, ice cream, canned milk and other products. In the recent years, Belarus is consistently ranked among the top five countries-exporters of dairy products in the world. Following the results of 2010, its share in the total world export of dairy products amounted to 4%. The main importers of Belarusian dairy products are the CIS countries – Russia and Kazakhstan. In the past several years, the dairy industry mastered regular state investments within the framework of a special support program. In 2015, it is planned to increase the volume of milk production in the country up to 10-10.5 million tons per year. At the same time, the sale of such volume of dairy products also requires investments in the development of the dairy industry, the attraction of foreign investors to the country. The largest enterprises of the sphere are OJSC “Savushkin produkt” (Brest), “Babushkina krynka” (Mogilev), milk plants №1 and №2 (Minsk) and others.

5.3 Sugar industry

The sugar industry of Belarus is represented by four companies: OJSC “Slutsk Sugar Refinery”, Republic of Belarus, OJSC “Zhabinka Sugar Plant”, Republic of Belarus, OJSC “Gorodeya Sugar Combine”, OJSC " Skidel Sugar Combine” The main amount of sugar is produced from sugar beets. Part of the products are obtained from the processing of raw cane sugar which is imported to the republic mainly from Cuba and Brazil.

5.4 Confectionery industry

The confectionery industry of Belarus produces about 700 various confectionery products: candy, chocolate, cakes, cookies, halva, marshmallows and more. The largest confectionery enterprises in Belarus are OJSC “Kommunarka”, JV OJSC “Spartak”, OJSC “Krasny pischevik”. An active period of technical renovation is taking place at OJSC “Kommunarka” which is implementing a modernization program that will run until 2015.

5.5 Beer and soft drinks industry

The beer segment in Belarus is represented by several major enterprises, some of which are owned by foreign concerns. Following the results of the first half of 2013, the share of the major players of the beer market in total production was distributed as follows: OJSC “Krinitsa” – 31.5%, Heineken Belarus – 24,5% (belongs to the Heineken concern), OJSC “Brewery “Olivariya” – 20.3% (belongs to the Carlsberg concern), OJSC “Lidskoe pivo” – 19% (belongs to the OLVi concern), OJSC “Brestskoe pivo” – 3.8%, other companies – 0.9%. In the previous years, all the major breweries went through a stage of modernization: following its results, enterprises upgraded their lines, increased the production volumes and developed new types of packaging. Apart from beer, the brewers of Belarus also produce kvass, cider, alcoholic cocktails, soft drinks, water. The beer industry is characterized by high export performance. Thus, in the first months of 2013, 15 million liters of Belarusian beer worth 6.9 million US dollars were exported. Of this amount, 9.2 million liters were exported to CIS countries, namely — 8.8 million liters to Russia; 5.8 million – to CIS countries

6. Light industry

The share of the light industry in Belarus amounts to about 4% in the structure of the industrial production Textile and clothing industry is the basis of Belarusian light industry and accounts for 3% of total industrial production in Belarus The largest enterprises of the industry are part of the “Bellegprom” concern and produce about 80% of the total industry volume. In general, there are about 500 light industry enterprises in the republic, producing over 5,000 product names. The light industry of Belarus has a high level of export orientation. Over a number of years, the main drivers of export remain RUPTE “Orsha Flax Combine”, OJSC

“Kamvol”, Grodno RUPE “Groniteks”, OJSC “Milavitsa”, OJSC “Komintern” and other enterprises.

Major segments of the industry and largest enterprises
6.1. The textile industry is estimated as the largest in production volume in light industry. The segment combines the production of all kinds of fabrics, knitwear, felting and other products. The largest enterprises in the textile industry are UE “Baranovichi Cotton Production Association”, OJSC “Lenta” (Magilev), OJSC “Kamvol”, OJSC “Sukno” (Minsk), RUPTE “Orsha Flax Combine”, OJSC “Mogoteks” (Magilev), OJSC “Svitanak” (Salihorsk), OJSC “Vitebsk Carpets”, OJSC “Kim” (Vitebsk) and others.The main products of these companies are fabrics, yarn, curtains, etc.

6.2. The knitting industry focuses on the production of knitwear, knitted fabric, hosiery and other products. Specialized enterprises in this segment, OJSC “Brest Stocking Combine”, RUPE “Baranovichi Knitting Factory”, OJSC “Soligorsk Knitting Enterprise “Kupalinka”. Belarusian knitwear of such brands as “Polesie”, “Alesya”, “8 Marta”, “Svitanak” is widely known.

6.3. The sewing sphere of the light industry includes about 170 plants. Among the biggest are the sewing factories: OJSC “Komintern” in Gomel, “Znamya industrializacii” in Vitebsk, JV CJSC “Milavitsa” and OJSC “Progress” in Minsk, CJSC “Vesnyanka” in Magilev.
The main activity of these enterprises is sewing suits and outerwear, children’s clothing, underwear, hats and fur items. The largest sewing factories in Belarus have a “portfolio” of export brands which are exported not only within the CIS, but also to Great Britain, Denmark, Poland, USA, the Netherlands, the Czech Republic.

6.4. The shoe sphere of the light industry includes about 20 enterprises. The most famous Belarusian shoe brands are:“Belwest”,“Marko”,“Sivelga”,“Le Grand”,“Neman”. The main producers of children’s shoes are: OJSC “Lida Shoe Factory”, OJSC “Obuv” in Minsk, OJSC “Krasnyi Oktyabr”. Today the Belarusian shoe industry resolves a whole range of problems, the most important of which is the competitive ability against the backdrop of import. In this regard, enterprises aim to improve the quality of raw materials and reduce the level of import capacity. The Belarusian shoe market requires new approaches: the development of local brands, the expansion of the model lineup, the activation of the marketing policy.

7. Woodworking industry

The share of the woodworking industry in Belarus amounts to about 2% in the structure of the industrial production and includes a number of segments: production of sawmill materials, plywood, furniture, fabricated houses and wood construction details, production of matches. Enterprises of the woodworking industry are united by the “Bellesbumprom” concern which is a monopolist in timber harvesting and production of some products from it. The concern “Bellesbumprom” includes 60 enterprises, which account for about 70% of the processing of wood and approximately 45% of furniture production in the Republic of Belarus. At the moment, almost all woodworking enterprises within the concern “Bellesbumprom” are joint stock companies. Moreover, the share of the state in their statutory funds range from 16% to 60%. The largest woodworking enterprises of the Republic of Belarus are “Gomeldrev”, “Mostodrev”, “Ivatsevichidrev”, “Vitebskdrev”, “Pinskdrev”, “FanDok” and others.

8. Paper industry

The paper industry of Belarus produces about 250 million tons of paper and about 60 million tons of cardboard annually, part of the products are exported. The key representatives of the pulp and paper segment are OJSC “Svetlogorsk Pulp and Paper Combine”, OJSC “Belarusian Wallpaper”, OJSC “Gomeloboi”, OJSC “Dobrush Paper Factory “Geroi Truda”, OJSC “Slonim Cardboard and Paper Plant “Albertin”, OJSC “Paper Plant “Krasnaya Zvezda”, UE “Paper Plant” Gosznaka of the Republic of Belarus”, OJSC “Paper Plant “Spartak”, OJSC “Molodechno Cardboard Factory “Raevka”, OJSC “Cardboard Factory “Olkhovka”, OJSC “Krovlya” and others. Imported pulp and waste paper is used as raw material. The authority coordinating the work of the enterprises of the sphere is the concern “Bellesbumprom”.

Despite the growing production volumes of the Belarusian enterprises, the level of import of paper remains high in the republic. In this regard, as well as due to the fact that there is a significant proportion of low-value softwood timber and thinners which are unclaimed on the domestic market, it is planned to accelerate the development of the production of pulp and paper. As of today, the largest projects in the industry include the putting into operation of the unbleached pulp factory in Svetlahorsk and the start-up of the plant on the production of newsprint with an annual capacity of 100 thousand tons in Shkloū. Moreover, the technical re-equipment and reconstruction of the paper plant “Spartak”, where the modernization of the paper machine was finished, has been carried out. The production of office paper in packs on an automated production line was organized at the Dobrush Paper Factory “Geroi Truda”.

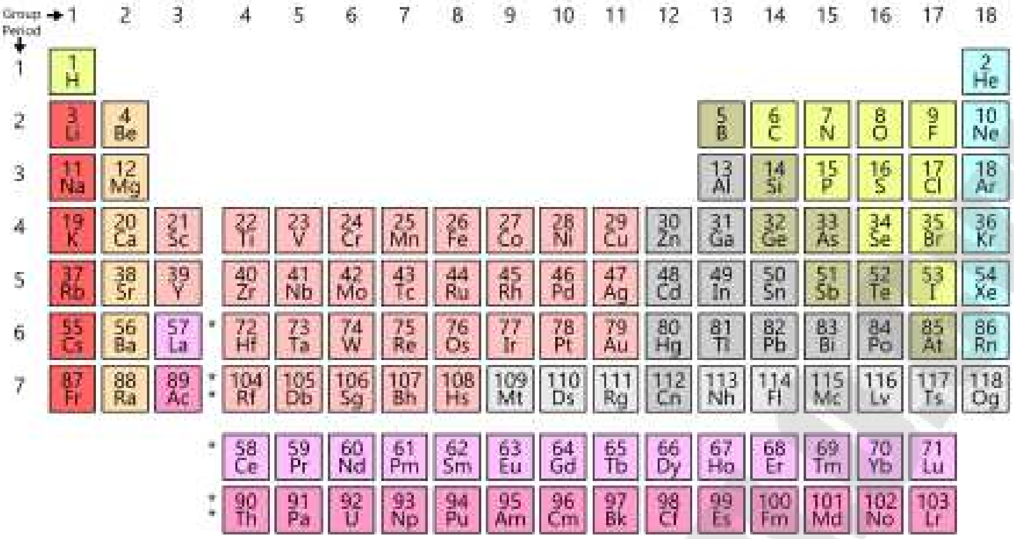
9. Pharmaceuticai industry

The Belarusian pharmaceutical sector is classified as an actively developing segment of economy. Over 30 companies are engaged in the production of medicinal products in the country. Herewith, about 90% of drugs made in the country are produced by enterprises which are part of the concern “Belbiopharm”. The organization unites 18 institutions, the largest of which are RUE “Belmedpreparaty”, OJSC “Borisov Plant of Medical Preparations” and JV LLC “Pharmland”.

Topic 4. Metals. 1. Definitions. Major groups

Key questions
What is the metal from the common used point of view?
What is the metal from the astrophysical point of view?
Hypotheses of metal creation
Definition to ferrous metals
Definition to non-ferrous metals
Definition to alkali metals
Definition to alkaline earth metals
Definition to actinides
Definition to light metals
Definition to heavy metals
Definition to transition metals
Definition to post-transition metals
Definition to precious metals
Definition to noble metals
Definition to exotic or rare metals
Definition to base metals
Definition to minor metals
Definition to most expensive metals
Definition to refractory metals
Definition to metalloids
Definition to toxic heavy metals
Definition to radioactive metals
Definition to artificial/synthetic metals
What metals are refered to as major industrial metals?

Around 90 of the 118 elements in the periodic table are metals; the others are nonmetals or metalloids.



Group → Period ↓	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 La *	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 Ac **	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
			*	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
			**	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	

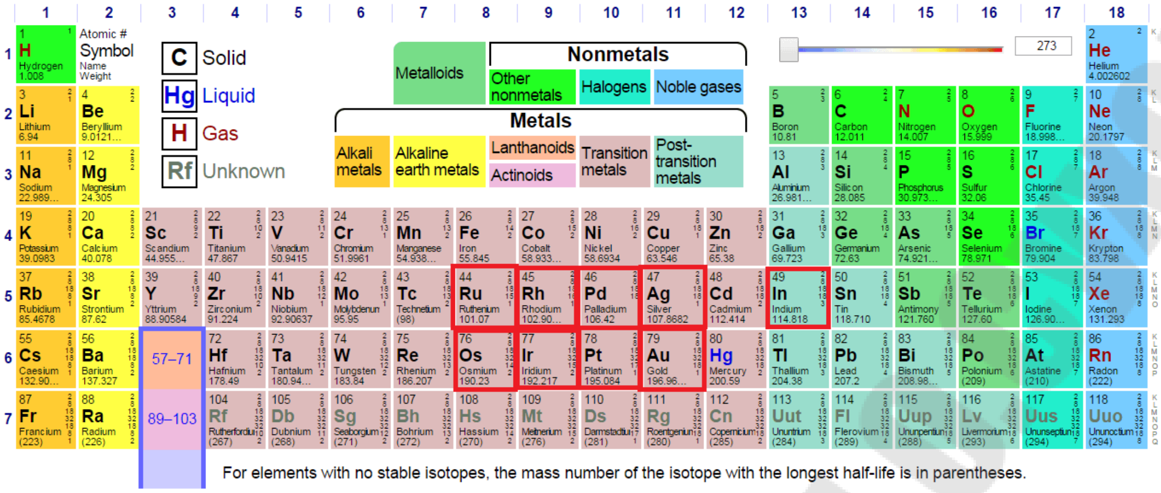
Metal is a material (an element, compound, or alloy) with metallic properties: (1) high electrical conductivity; (2) high thermal conductivity; (3) high density (most metals have higher densities than most nonmetals, but there is wide variation in their densities); (4) gloss; (5) atoms of metallic substances are typically arranged in crystal structure.

Astrophysicists use the term "metal" to all elements that are heavier than the lightest two, hydrogen and helium. There are two hypotheses of metal creation:
(1) Metals were created simultaneously as a result of Big Bang.
(2) Metals were created as a result of star activities: A star fuses lighter atoms, mostly hydrogen and helium, to make heavier atoms over its lifetime.

Major metal groups:

Ferrous metals are the iron (Fe) and its alloys: cast iron, gray iron, white iron, ductile iron, malleable iron, wrought iron and steel.

Non-ferrous metals are all other metals except iron, including alloys which does not contain iron (ferrite) in appreciable amounts.



For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

<u>Alkali metals</u> are six chemical elements in group 1 of the periodic table. They are lithium (Li), sodium (Na), potassium(K), rubidium (Rb), caesium (Cs), and francium (Fr).

<u>Alkaline earth metals</u> are six chemical elements in group 2 of the periodic table. They are beryllium (Be), magnesium (Mg), calcium(Ca), strontium (Sr), barium (Ba), and radium (Ra).

<u>Rare earth metals (REM)</u> are seventeen chemical elements of the periodic table They are scandium (Sc), yttrium (Y), and the fifteen lanthanides: the chemical elements with atomic numbers from 57 lanthanum (Ln) to 71 lutetium (Lu).

<u>Actinides</u> are the 15 metallic chemical elements with atomic numbers from 89 actinium (Ac) to 103 lawrencium (Lr).

<u>Light metals</u> are metals of relatively low density. Magnesium, aluminium and titanium are light metals of significant commercial importance. Their densities of 1.7, 2.7 and 4.5 g/cm^3 (for comparison: iron density of 7.9, copper density of 8.9). The lightest or least dense metal is a lithium, which has a density of 0.534 g/cm^3. This makes lithium nearly half as dense as water, so if lithium was not so reactive, a chunk of the metal would float on water. Two other metallic elements are less dense than water. Potassium has a density of 0.862 g/cm^3 while sodium has a density of 0.971 g/cm^3. All of the other metals on the periodic table are denser than water. While lithium, potassium, and sodium are all light enough to float on water, they are also highly reactive. When placed in water, they burn or explode. Hydrogen is the lightest element because it consists simply of a single proton and sometimes a neutron (deuterium). Under certain conditions, it forms a solid metal, which has a density of 0.0763 g/cm^3. This makes hydrogen the least dense metal, but it isn't generally considered a contender for "lightest" because it doesn't exist as a metal naturally on Earth.

Heavy metals are metals of relatively high density. But in general there is no widely agreed criterion-based definition of a heavy metal. Different meanings may be attached to the term, depending on the context. In metallurgy, for example, a heavy metal may be defined on the basis of density, whereas in physics the distinguishing criterion might be atomic number, and a chemist would likely be more concerned with chemical behaviour. A density of more than 5 g/cm^3 is sometimes mentioned as a common heavy metal defining factor. Mostly densest metals are Os (22.61 g/cm^3), Ir (22.56 g/cm^3), Pt (21.46 g/cm^3), Rh (21.02 g/cm^3), Np (20.45 g/cm^3), Pu (19.84 g/cm^3), Au (19.28 g/cm^3), W (19.25 g/cm^3), U (18.95 g/cm^3), Ta (16.65 g/cm^3). Some uses of heavy metals, including in sport, mechanical engineering, military ordnance, and nuclear science, take advantage of their relatively high densities. In underwater diving, lead is used as a ballast; in handicap horse racing each horse must carry a specified lead weight, based on factors including past performance, so as to equalize the chances of the various competitors. In golf, tungsten, brass, or copper inserts in fairway clubs and irons lower the centre of gravity of the club making it easier to get the ball into the air; and golf balls with tungsten cores are claimed to have better flight characteristics. In fly fishing, sinking fly lines have a PVC coating embedded with tungsten powder, so that they sink at the required rate. I track and field sport, steel balls used in the hammer throwand shot put events are filled with lead in order to attain the minimum weight required under international rules. Tungsten was used in hammer throw balls at least up to 1980; the minimum size of the ball was increased in 1981 to eliminate the need for what was, at that time, an expensive metal (triple the cost of other hammers) not generally available in all countries. Tungsten hammers were so dense that they penetrated too deeply into the turf.

In mechanical engineering, heavy metals are used for ballast in boats, aeroplanes, and motor vehicles; or in balance weights on wheels and crankshafts, gyroscopes, and propellers, and centrifugal clutches, in situations requiring maximum weight in minimum space (for example in watch movements).

In military ordnance, tungsten or uranium is used in armour plating and armour piercing projectiles, as well as in nuclear weaponsto increase

efficiency (by reflecting neutrons and momentarily delaying the expansion of reacting materials). In the 1970s, tantalumwas found to be more effective than copper in shaped charge and explosively formed anti-armour weapons on account of its higher density, allowing greater force concentration, and better deformability. Less-toxic heavy metals, such as copper, tin, tungsten, and bismuth, and probably manganese (as well as boron, a metalloid), have replaced lead and antimony in the green bullets used by some armies and in some recreational shooting munitions. Doubts have been raised about the safety (or green credentials) of tungsten
Because denser materials absorb more radioactive emissions than lighter ones, heavy metals are useful for radiation shielding and tofocus radiation beams in linear accelerators and radiotherapy applications.

Transition metals are metals of groups 4-11. These elements are now known as the d-block.

Post-transition metals (or poor metals) are metals of groups 13-15 on the periodic table. It is to the right of thetransition metals: aluminium (Al), gallium (Ga), lead (Pb, from the latin plumbum,свинец), tin (Sn, from latin stannum, олово), thallium (Tl), indium (In), bismuth (Bi). The elements of group 12 (zinc (Zn), cadmium (Cd), mercury (Hg)) are sometimes included. Sometimes germanium, antimony, and polonium are included, although they are normally considered metalloids.

Exotic or rare metals is a group of metals which includes cobalt (Co), mercury (Hg), tungsten (W), beryllium (Be), bismuth (Bi), cerium (Ce), cadmium (Cd), niobium (Nb), indium (In), gallium (Ga), germanium (Ge), lithium (Li), selenium (Se), tantalum (Ta), tellurium (Te), vanadium (V), and zirconium (Zr).

Noble metals are metals that are resistant to corrosion and oxidation in moist air (unlike most base metals). The short list of chemically noble metals (those elements upon which almost all chemists agree) comprises ruthenium (Ru), rhodium (Rh), palladium (Pd), silver (Ag), osmium (Os), iridium (Ir), platinum (Pt), and gold (Au). More inclusive lists include mercury (Hg), rhenium (Re) and copper (Cu) as noble metals. On the other hand, titanium (Ti), niobium (Nb), and tantalum (Ta) are not included as noble metals although they are very resistant to corrosion.

Precious metals are rare, naturally occurring metallic chemical elements of high economic value. Chemically, the precious metals tend to be less reactive than most elements (like noble metals). They are usually ductile and have a high lustre. Historically, precious metals were important as currency but are now regarded mainly as investment and industrial commodities. Gold, silver, platinum, and palladium each have an ISO 4217 currency code. The best known precious metals are the coinage metals, which are gold and silver. Although both have industrial uses, they are better known for their uses in art, jewelry, and coinage. Other precious metals include the platinum group metals: ruthenium, rhodium, palladium, osmium, iridium, and platinum, of which platinum is the most widely traded. The demand for precious metals is driven not only by their practical use but also by their role as investments and a store of value. Historically, precious metals have commanded much higher prices than common industrial metals.

Most expensive metals are metals of highest price. The cost of Californium 252 is US$ 27 million per gram. The cost of osmium-187 (Os) is US$ 200 thousand per gram

Base metals are a common and inexpensive metals, as opposed to a precious metal such as gold or silver In mining and economics, the term base metals refers to industrial non-ferrous metals excluding precious metals. These include copper, lead, nickel and zinc. The U.S. Customs and Border Protection is more inclusive in its definition. It includes, in addition to the four above, iron and steel, aluminium, tin, tungsten, molybdenum, tantalum, cobalt, bismuth, cadmium, titanium, zirconium, antimony, manganese, beryllium, chromium, germanium, vanadium, gallium, hafnium, indium, niobium, rhenium and thallium, and their alloys.

Minor metals are by-products of base metals smelting. Minor metals do not have a real exchange, and are not traded on the London Metal Exchange (LME). They include: Antimony (Sb), Arsenic (As), Beryllium (Be), Bismuth (Bi), Cadmium (Cd), Cerium (Ce), Chromium (Cr), Cobalt (Co), Gadolinium (Gd), Gallium (Ga), Germanium (Ge), Hafnium (Hf), Indium (In), Lithium (Li), Magnesium (Mg), Manganese (Mn), Mercury (Hg), Molybdenum (Mo), Neodymium (Nd), Niobium (Nb),Iridium (Ir), Osmium (Os), Praseodymium (Pr), Rhenium (Re), Rhodium (Rh), Ruthenium (Ru), Samarium (Sm), Selenium (Se), Silicon (Si), Tantalum (Ta), Tellurium (Te), Titanium(Ti), Tungsten (W), Vanadium (V), Zirconium (Zr).

Refractory metals are a class of metals that are extraordinarily resistant to heat and wear. Most definitions of the term 'refractory metals' list the extraordinarily high melting point as a key requirement for inclusion. By one definition, a melting point above 4,000°F (2,200 C) is necessary to qualify. The five elements niobium (Nb), molybdenum (Mo), tantalum (Ta), tungsten (W) and rhenium (Re) are included in all definitions, while the wider definition, including all elements with a melting point above 2,123 K (1,850 C), includes a varying number of nine additional elements: titanium (Ti), vanadium (V), chromium (Cr), zirconium (Zr), hafnium (Hf), ruthenium (Ru), rhodium (Rh), osmium (Os) and iridium (Ir). The artificial elements, being radioactive, are never considered to be part of the refractory metals, although technetium has a melting point of 2430 K or 2157 °C and rutherfordium is predicted to have melting point of 2400 K or 2100 °C.

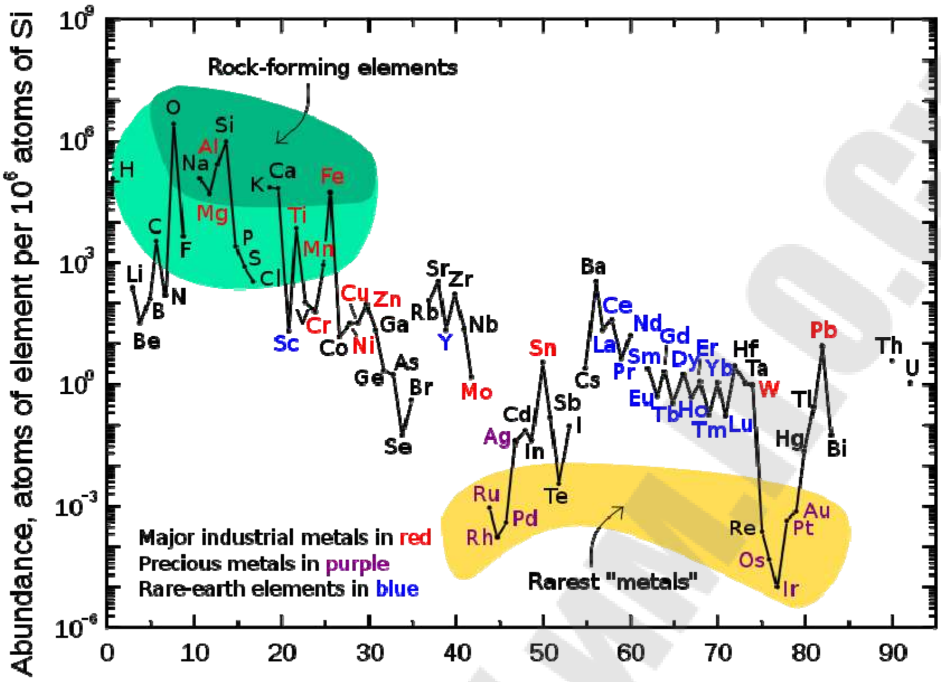
Radioactive metals either have no stable naturally occurring isotope, or else are entirely artificial (all artificial elements have no stable isotopes).

Metalloids are chemical elements which have properties in between those of metals and nonmetals, or that have a mixture of them. The six commonly recognised metalloids are boron (B), silicon (Si), germanium (Ge), arsenic (As), antimony (Sb), and tellurium (Te). Five elements are less frequently so classified: carbon (C), aluminium (Al), selenium (Se), polonium (Po), and astatine (At).

Toxic heavy metals are relatively dense metals or metalloids that are noted for its potential toxicity, especially in environmental contexts. The term has particular application to cadmium (Cd), mercury (Hg), lead (Pb), and arsenic (As), all of which appear in the World Health Organisation's list of 10 chemicals of major public concern. Other examples include manganese (Mn), chromium (Cr), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), selenium (Se), silver (Ag), antimony (Sb) and thallium (Tl).

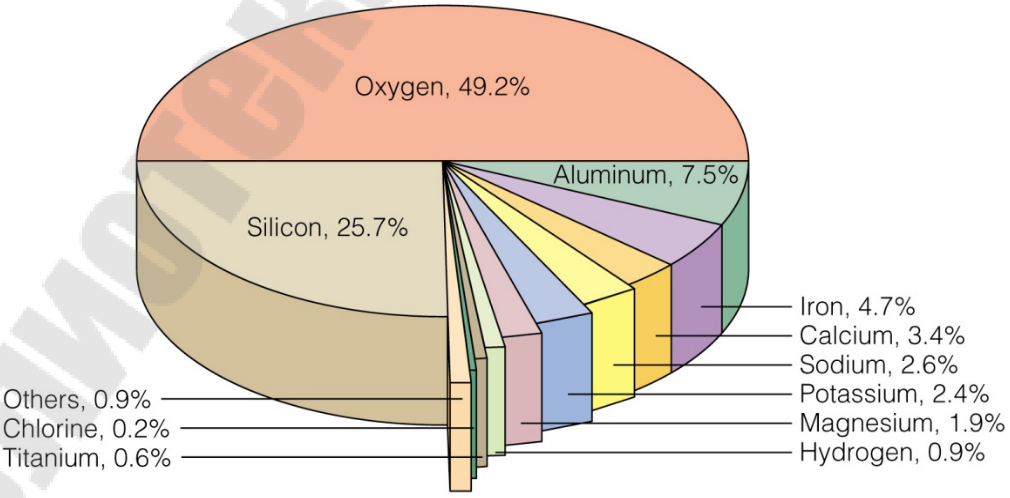
Artificial metals (or **synthetic elements**) are chemical elements that do not occur naturally on Earth, and can only be created artificially. So far, 24 synthetic elements have been created (those with atomic numbers 95–118). All are unstable, decaying with half-lives ranging from 15.6 million years to a few hundred microseconds.

<u>Major industrial metals</u> are Fe, Al, Cu, Mg, Ti, Mn, Cr, Zn, Ni, Mo, Pb, Sn, W, Co.



Abundance (atom fraction) of the chemical elements in Earth's upper continental crust as a function of atomic number.

The rarest elements in the crust (shown in yellow) are not the heaviest, but are rather the siderophile (iron-loving) elements in the Goldschmidt classification of elements. These have been depleted by being relocated deeper into the Earth's core.



Most abundant chemical elements in Earth's upper continental crust

Topic 4. Metals: 2. Ferrous metals

Key questions

1 What ferrous metals do you know?
2 What Fe-C alloys do you know?
3 What cast irons do you know?
4 What do you know about Fe? (abundance, major minerals, major properties, industrial applications, and so on?
5 Carbon influence at Fe-alloys properties
6 Steel. Definition. Properties
7 Two types of additives presented in any alloy
8 What major impurities are contained in steel?
9 What types of steel do you know?
10 Carbon steel Definition. Types.
11 Alloy steel Definition. Types.
12 Principal effects of major alloying elements for steel
13 Cast iron. Definition. Properties. Major types
14 Steel/cast iron comparison
15 What do you know about grey cast iron?
16 What do you know about white cast iron?
17 What do you know about malleable cast iron?
18 What do you know about ductile cast iron?
19 What do you know about wrought iron?
20 What do you know about pig iron?
21 What iron-metal alloys do you know? (name, composition, properties, application)

Ferrous metals are the iron (Fe) and its alloys: Fe-C alloys (steels, cast irons (gray iron, white iron, ductile iron, malleable iron), pig iron, wrought iron) and Fe-metal alloys.

1. Iron (Fe)

- Iron is a chemical element with symbol Fe (from Latin: *ferrum*) and atomic number 26.

- Iron is a metal in the first transition series.

- Iron is the most common element on Earth as a whole, because of the Earth's core (35% of the Earth mass) are believed to consist largely of an iron or an iron-based alloy (Fe+Ni). The mass of the Earth is composed mostly of iron (32.1%), oxygen (30.1%), silicon (15.1%), magnesium (13.9%), sulfur (2.9%), nickel (1.8%), calcium (1.5%), and aluminium (1.4%); with the remaining 1.2% consisting of trace amounts of other elements.

- Iron is the fourth most abundant element in the Earth's crust, after oxygen, silicon, and aluminum. Native iron is rarely found on the surface of the Earth because it tends to oxidize. Most of the iron in the crust is found combined with oxygen as iron oxide minerals such as hematite (Fe_2O_3), magnetite (Fe_3O_4), siderite ($FeCO_3$), limonite ($FeO(OH)\cdot nH_2O$). Hematite's popularity in jewelry was at its highest in Europe during the Victorian era.

- Pure iron is too soft to be used as a construction material and has a very limited application. Soft iron, as it is also called is used in electromagnets, electric motors and magnetic assemblies.

- Small amounts of other elements can improve iron properties

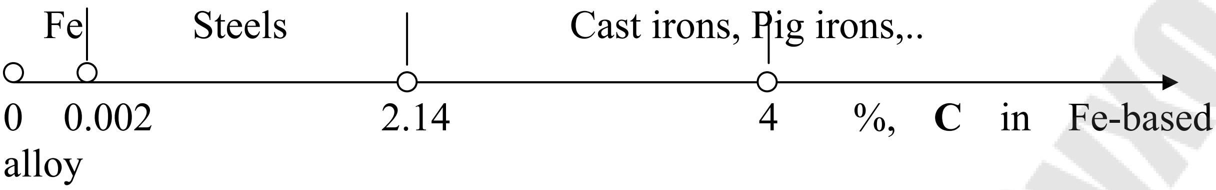
- The most common industrial metals are alloys on base of iron and carbon. Properties of alloys are influenced by the amount of carbon and other alloying elements.


magnetite


limonite


hematite

2. Fe-C alloys



2.1. Steels

- Steel is an iron-carbon alloy which has a certain amount of carbon: from 0.002% to 2.14% and small amount of impurities. As the carbon percentage content rises, steel has the ability to become harder and stronger and less ductile. A higher carbon content reduces weldability. The higher carbon content lowers the melting point. Even small amount of carbon increases hardness up to 1000 times than pure iron.

- Because of its high tensile strength and low cost, it is a major industrial metal in construction and mechanical engineering.

- Any alloy contains two types of additives: (1) alloying elements which give material demanded properties; (2) impurities which give negative effect.

Common alloying elements in steel include: manganese, nickel, chromium, molybdenum, boron, titanium, vanadium, tungsten, cobalt, and niobium.

Major impurities in steel: phosphorus, sulfur, silicon, and traces of oxygen, nitrogen, and are most frequently harmful and undesirable.

There are many different types of steel, depending on the other elements mixed with the iron.

1. Carbon steel, or plain-carbon steel is a steel containing two elements iron and carbon. Other elements are present in small quantities. The only other elements allowed in plain-carbon steel are: Mn (1.65% max), Si (0.60% max), and Cu (0.60% max). Steel with a very low carbon content has almost the same properties as iron, soft but easily formed. With more carbon the metal gains hardness and strength but becomes less ductile and more difficult to weld. Higher carbon content lowers steel's melting point and its temperature resistance in general.

There are next types of carbon steels:

- Low carbon steel (Mild steel): approximately 0.05% to 0.25% carbon content with up to 0.4% manganese content. Less strong but cheap and easy to shape; surface hardness can be increased through carburizing.
- Medium carbon steel: approximately 0.29% to 0.54% carbon content with 0.60 to 1.65% manganese content. Balances ductility and strength and has good wear resistance; used for large parts, forging and car parts.
- High carbon steel: approximately 0.55% to 0.95% carbon content with 0.30 to 0.90% manganese content. Very strong, used for springs and high-strength wires.
- Very high carbon steel: approximately 0.96% to 2.1% carbon content, specially processed to produce specific atomic and molecular microstructures.

2. Alloy steel is steel with *other* alloying elements (alloyants) in total amounts between 1.0% and 50% by weight which added to improve steel's properties. (Strictly speaking, every steel is an alloy, but not all steels are called "alloy steels"). However, the term "alloy steel" is the standard term referring to steels with alloyants. Common alloyants include Mn (the most common one), Ni, Cr, Mo, V, Si, and B. Less common alloyants include Al, Co ,Cu, Ce, Nb, Ti, W, Sn, Zn, Pb, and Zr. The following is a range of improved properties in alloy steels (as compared to carbon steels): strength, hardness, toughness, wear resistance, corrosion resistance, hardenability, and hot hardness.

There are a few types of alloy steels:

- Low alloy steels contain alloying elements (Mo, Mn, Cr, Ni) in amounts of up to 8% by weight
- High alloy steels contain alloying elements in amounts of more than 10% by weight

A summary of the properties of some different steels

Type of steel		**Alloying elements**	**Properties**	**Typical use**
Carbon steels (plain-carbon steels)		C + less than 0.5% alloying elements (+P, S impurities) can contain up to 1.2%	C is hardening, strengthening element in steel, (increased hardness, strength and	Accounts for 90% of steel production. Car body panels

	Low carbon steels (Mild steel - trade terms)	Mn and 0.8% Si Up to 0.25 % C Up to 0.4%Mn	decreased weldability and ductility) easily shaped	
	Medium-carbon steels	C (0.29–0.54%), Mn (0.60-1.65%)	Balances ductility and strength and has good wear resistance	Large parts, forging and car parts
	High carbon steels	C (0.55–0.95%) Mn (0.3–0.9%)	Very strong, hard	Cutting tools, springs and high-strength wires
	Very high carbon steels: Silver steels (The name comes from the highly polished appearance of the rods)	C (0.96–2.1%) C (0.96–1.25%), Cr 0.4%, Mn 0.35%, Si 0.3%	Very hard hardness of 27 –64 HRC	Punches, engravers, screwdrivers Blade steel for straight razors, knives
	Cast carbon steels are specified by grades A,B,C Grade A Grade B Grade C	up to 0.3% C+up to 0.8%Si+up to 1.2%Mn up to 0.25% C,up to 0.7% Mn up to 0.3% C,up to 1% Mn up to 0.25% C,up to 1.2% Mn	High casting properties	Cast steel products

	Carbon-manganese steels		1.2% C + up to 1.8% Mn	Increasing depth of hardening and improving strength and toughness.	Hot rolled bars, semi-finished products
	High-tensile steels		C (0.18%–0.64%) + Cr (0.4–1.1%), Mo (0.08–0.35%), Si (0.15-0.35%), Mn (0.7–1.2%), Ni, V	Strength, wear resistance, tensile strength.	Gears, piston pins, crankshafts tubes for transportation of pressurized gases
Alloy steels	Low alloy steels		Alloying elements (Mo, Mn, Cr, Ni) in amounts of up to 8% by weight	improvement of thick sections hardenability	
		High strength low alloy steesl (HSLA)	1.5% Mn	High strength	Mechanical engineering applications
		High-tensile low alloy steels	C (0.3%-0.5%) + Cr (0.4–1.7%), Mo (0.2–0.5%), Si (0.15–0.35%), Mn (0.7–1.2%), Ni (1.65-2.5%), V	High yield, tensile and fatigue strengths, as well as excellent toughness	Shafts, discs, rotors, connecting rods for the aircraft, automotive and mechanical engineering applications.

		Reynolds 531 (brand name)	Mn, Mo	High strength	race car chassis, aircraft components, bicycle frame tubing
		Weathering steels (Cor-ten steel)	C (less than 0.2 wt. %), Cu, Cr, Ni, Mn (no more than 3–5 wt. %)	Corrosion resistance and tensile strength were developed to eliminate the need for painting, and form a stable rust-like appearance after several years exposure to weather	Building adornments and monuments
		Spring steels	C (0.08–1.0 %), Mn (0.2–2%), Si(0.1–2%)	Very high yield strength.	Springs
		Eglin steels (ES-1)	Over a dozen different elements in varying amounts	Highstrength, high-performance, low-alloy, low-cost	Bunker buster type bombs
		Chromoly steel (CR-MOLY)	C (0.18–0.64%) Cr (0.4–1.1%), Mo (0.1–0.35%),	Excellent strength, but not easily welded	Aircraft parts, structural tubing, bicycle frames, tubes

			Si (0.15–0.35%), Mn (0.7–1.0%)		for transportation of pressurized gases
		Silicon steel (Electrical steel, Lamination steel, Relay steel, Transformer steel)	C (less than 0.005%), Si (up to 6.5%), Mn (up to 0.5%), Al up to 0.5% ()	Electrical resistivity, specific magnetic properties	Stator and rotor of electric motors
	High alloy steels		Alloying elements in amounts of more than 10% by weight		
		Stainless steels	Cr and Ni (more than 11%)	Resistant to corrosion	Cutlery and sinks
		Staballoy	Mn (20.00%), Cr (17.00%), Si (0.30%), C (0.03%), N (0.50%), Mo (6-7%)		Drilling rods.
		AL-6XN	Cr (20-22%), Ni (24–26%), C (0.03%),	Good resistance to chloride stress-corrosion cracking	Food processing equipment, Heat exchangers

			N (0.25%), Mo (0.05%)		
		Tool steels	W (1.5–18%), Co (5–8%), Cr(3.8–4.3%) Mo (5–9%), V (1-2%)	Precipitation hardening, temperature resistance	Cutting tools
		Manganese steels (or Hadfield steel)	12–14% Mn	Form an incredibly hard skin which resists wearing. High impact strength and resistance to abrasion	Tank tracks, bulldozer blade edges and cutting blades
		Maraging steels	C (0.03%) + Ni(17–19%), Mo(3–5.2%) Co(7–12%) Ti(0.2–1.6%) Al(0.05–1.15%)	Superior strength and toughness without losing malleability	Scalpel blades, bicycle frames, gas centrifuges for uranium enrichment

Principal effects of major alloying elements for steel

Element	Percentage	Primary function
Aluminium	0.95–1.30	Alloying element in nitriding steels
Bismuth	–	Improves machinability
Boron	0.001–0.003	A powerful hardenability agent
Chromium	0.5–2	Increases hardenability

	4–18	Increases corrosion resistance
Copper	0.1–0.4	Corrosion resistance
Lead		-Improved machinability
Manganese	0.25–0.40	Combines with sulphur and with phosphorus to reduce the brittleness. Also helps to remove excess oxygen from molten steel
	.>1	Increases hardenability by lowering transformation points and causing transformations to be sluggish
Molybdenum	0.2–5	Stable carbides; inhibits grain growth. Increases the toughness of steel, thus making molybdenum a very valuable alloy metal for making the cutting parts of machine tools and also the turbine blades of turbojet engines. Also used in rocket motors
Nickel	. 2–5	Toughener
	12–20	Increases corrosion resistance
Silicon	0.2–0.7	Increases strength
	2.0	Spring steels
	Higher percentages	Improves magnetic properties
Titanium		Fixes carbon in inert particles; reduces martensitic hardness in chromium steels
Tungsten		Also increases the melting point
Vanadium	. 0.15	Stable carbides; increases strength while retaining ductility; promotes fine grain structure. Increases the toughness at high temperatures

2.2. Cast irons

- Cast iron is an alloy of iron that contains 2 to 4 percent carbon, along with varying amounts of silicon and manganese and traces of impurities such as sulfur and phosphorus. In comparison with steel cast iron has more carbon and more harmful impurities.
- Carbon is hardening, strengthening element for iron-based alloys. Carbon increases hardness, but simultaneously decreases alloy's plasticity and material becomes brittle after 2 % C concentration.

Steel/cast iron comparison

Criterion for comparison		Steel	Cast iron
Composition	Common	Fe+C	
	Distinction	C (0.002–2.14%)	C (2.14–4%), more impurities
Properties	Common	Good mechanical properties	
	Distinction	More strength Plasticity Treated by hammer	Less strength Friability Treated only by casting Cannot be worked by pressure: forged, rolled etc.

-Because of comparatively high mechanical properties, good fluidity, castability, excellent machinability, resistance to deformation and wear resistance, cast irons have become an engineering material with a wide range of applications. But because cast iron is comparatively brittle, it is not suitable for purposes where a sharp edge or flexibility is required. It is strong under compression, but not under tension.

- Cast iron's properties are changed by adding various alloying elements, or alloyants. Next to carbon, silicon is the most important alloyant. Other alloying agents, Mn, , Cr, Mo, Ti, V, Ni, Cu, Zr.

There are next types of cast irons: Grey cast iron, White cast iron, Malleable cast iron, Ductile cast iron.

Grey cast iron (Gray iron), is named after the gray color of the fracture it forms, which is due to the presence of graphite. A typical chemical composition to obtain a graphite is 2.5 to 4.0% carbon and 1 to 3% silicon by weight. Silicon is important for making grey iron as opposed to white cast iron, because silicon is a graphite stabilizing element in cast iron, which means it helps the alloy produce graphite instead of iron carbides; at 3% silicon almost no carbon is held in chemical form as iron carbide.

Grey cast iron is the most common cast iron and the most widely used cast material based on weight. It is used for housings where the stiffness of the component is more important than its tensile strength, such as internal combustion engine, cylinder blocks, pump housings, valve bodies, electrical boxes, and decorative castings.

White cast iron displays white fractured surfaces due to the presence of an iron carbide Fe_3C called cementite. Because of lower silicon content the carbon interacts with iron with Fe_3C formation. White cast iron has high hardness but low toughness. So, white iron is too brittle for wide use but with good hardness and abrasion resistance and relatively low cost, it finds use in such applications as the wear surfaces (impeller and volute) of slurry pumps, shell liners and lifter bars in ball mills and autogenous grinding mills, balls and rings in coal pulverisers, and the teeth of a backhoe's digging bucket (although cast medium-carbon martensitic steel is more common for this application). High-chromium white iron alloys allow massive castings (for example, a 10-tonne impeller) to be cast. These high-chromium alloys have super hardness 1500-1800HV.

Malleable cast iron is heat treated white iron. After heat treatment (two days at temperature 950 C, then two days of cooling) the brittle structure as first cast is transformed into the malleable form. Malleable cast iron has not very wide application because of its properties are more like those of mild steel. It is used for small castings requiring good tensile strength and the ability to flex without breaking (ductility). Uses include electrical fittings, hand tools, pipe fittings, washers, brackets, fence fittings, power line hardware, farm equipment, mining hardware, and machine parts. These items can be made from cast steel. The use of cast steel has rapidly declined in most application due to its poor castability, and hence high-quality cast vises (as opposed to forged ones), among other tools and machine elements, are now almost exclusively made of malleable cast iron.

Ductile cast iron (also known as nodular cast iron, spheroidal graphite iron, spheroidal graphite cast iron and SG iron) has its graphite in the form of very tiny nodules due to effects of tiny amounts of 0.02 to 0.1% magnesium and only 0.02 to 0.04% cerium added. The properties are similar to malleable iron, but parts can be cast with larger sections. Due to nodular graphite inclusions ductile iron has much more impact and fatigue resistance. Much of the annual production of ductile iron is in the form of ductile iron pipe, used for water and sewer lines. It competes with polymeric materials such as PVC, HDPE, LDPE and polypropylene, which are all much lighter than steel or ductile iron; being softer and weaker, these require protection from physical damage. Ductile iron is specifically useful in many automotive components, where strength must surpass that of aluminum but do not necessarily require steel. Other major industrial applications include off-highway diesel trucks, agricultural tractors.

Nodular cast iron is suitable for large and complex shapes and high (fatigue) loads.

Table of comparative qualities of cast irons

Name	**Nominal composition [% by weight]**	**Tensile strength [ksi]**	**Hardness [Brinell scale]**	**Uses**
Grey cast iron (ASTM A48)	C 3.4, Si 1.8, Mn 0.5	50	260	Engine cylinder blocks, flywheels, gearbox cases, machine-tool bases
White cast iron	C 3.4, Si 0.7, Mn 0.6	25	450	Bearing surfaces
Malleable iron (ASTM A47)	C 2.5, Si 1.0, Mn 0.55	52	130	Axle bearings, track wheels, automotive crankshafts
Ductile or nodular iron	C 3.4, P 0.1, Mn 0.4, Ni 1.0, Mg 0.06	70	170	Gears, camshafts, crankshafts

2.3. Wrought iron

Wrought iron (кованное железо) is a semi-fused mass of iron alloy (alloy Fe and very low carbon) with fibrous slag inclusions (up to 2% by weight). In contrast to cast irons carbon content is very low (less than 0.08%). In contrast to steel slag inclusions are present. Wrought iron is tough, malleable, ductile, corrosion-resistant and easily welded. Wrought iron was the most common form of malleable iron before the development of effective methods of steelmaking and the availability of large quantities of steel. It was given the name ‘*wrought’* because it was hammered, rolled or otherwise worked while hot enough to expel molten slag. Today wrought iron is no longer produced on a commercial scale. The modern functional equivalent of wrought iron is mild or low carbon steel.

2.4. Pig iron

Pig iron is an iron-carbon alloy which contains at least 92% Fe, has a very high carbon content, (typically 3.5 - 4.5%), contains varying amounts of contaminants such as sulfur, silicon and phosphorus. In contrast to cast irons and steel pig iron has more carbon and impurities content. It gets its name from the shape of ingot (resembling a pig) in which it used to be cast in the 19th century. Due to it is very brittle pig iron can not be used as a material for goods production. Pig iron is used as a feedstock in iron industry for steel and cast iron production. Pig iron is the product of smelting iron ore with a high-carbon fuel and reductant such as coke, usually with limestone as a flux.. The vast majority of pig iron is produced and consumed within integrated steel mill complexes. In this context the term “pig iron” is something of a misnomer: within integrated steel mills, blast furnace iron is transferred directly to the steel plant in liquid form, better known as "hot metal" or "blast furnace iron."

The term “pig iron” dates back to the time when hot metal was cast into ingots before being charged to the steel plant. The moulds were laid out in sand beds such that they could be fed from a common runner. The group of moulds resembled a litter of sucking pigs, the ingots being called “pigs” and the runner the “sow.”

Merchant pig iron is cold pig iron, cast into ingots and sold to third parties as feedstock for the steel and ferrous casting industries. Pig iron is supplied in a variety of ingot sizes and weights, ranging from 3 kg up to more than 50 kg. Merchant pig iron comprises three main types:

1. basic pig iron: used mainly in electric arc steelmaking
2. foundry pig iron (also known as haematite pig iron): used in mainly in the manufacture of grey iron castings in cupola furnaces
3. high purity pig iron (also known as nodular pig iron): used in the manufacture of ductile (also known as nodular or spheroidal graphite – SG) iron castings.

There are also various sub-types, for example low manganese basic pig iron, semi-nodular pig iron etc.

Pig iron composition (% by weight)

Pig iron type	C	Si	Mn	S	P
Basic	3.5–4.5	≤1.25	≤1.0	≤0.05	0.08–0.15
Foundry	3.5–4.1	2.5–3.5	0.5–1.2	≤0.04	≤0.12
High Purity/Nodular	3.7–4.7	0.05–1.5	≤0.05	≤0.025	≤0.035

3. Iron-metal alloys

3.1. Invar (FeNi36 or 64FeNi in the US), is a Fe – Ni alloy notable for its uniquely low coefficient of thermal expansion (CTE or α). The name *Invar* comes from the word *invariable*, referring to its relative lack of expansion or contraction with temperature changes. In 1920 for discovery of this material Swiss physicist Charles Édouard Guillaume received the Nobel Prize in Physics. Invar is used where high dimensional stability is required, such as precision instruments, clocks, seismic creep gauges, television shadow-mask frames, valves in engines, antimagnetic watches, and large aerostructure molds. There are variations of the original Invar material that have slightly different coefficient of thermal expansion such as: Inovco (Fe–33Ni–4.5Co), FeNi42, FeNiCo (Kovar or Dilver P).

3.2. Elinvar is a Fe – Ni – Cr alloy notable for having a modulus of elasticity which does not change much with temperature changes. Elinvar originally consisted of 52% iron, 36% nickel, and 12% chromium. It is almost non-magnetic, and corrosion resistant. There are other variations of the elinvar alloy: Fe- Co -based ferromagnetic elinvar alloy, Mn – Cr -based anti-ferromagnetic elinvar alloy, Pd-based non-magnetic elinvar alloy.

The largest use of elinvar was in balance springs for mechanical watches and chronometers. A major cause of inaccuracy in watches and clocks was that ordinary steels used in springs lost elasticity slightly as the temperature increased, so the balance wheel would oscillate more slowly back and forth, and the clock would lose time. Chronometers and precision watches required complex temperature-compensated balance wheels for accurate timekeeping.

3.3. Fernico describe a family of metal alloys made primarily of Fe, Ni, Co. The family includes **Kovar, FerNiCo I, FerNiCo II**, and **Dumet**. The name is made up of the chemical symbols of its constituent three elements. "Dumet" is a portmanteau of "dual" and "metal," because it is a heterogeneous alloy, usually fabricated in the form of a wire with an alloy core and a copper cladding. These alloys possess the properties of electrical conductivity, minimal oxidation and formation of porous surfaces at working temperatures of glass and thermal coefficients of expansion which match glass closely. These requirements allow the alloys to be used in glass seals, such that the seal does not crack, fracture or leak with changes in temperature. **Dumet** is most commonly used in seals where lead-in wires pass through the glass bulb wall of standard household electric lamps (light bulbs) among other things. The two **Fernico** alloys both consist of Fe, Ni, and Co. Fernico is used at high temperatures (20 to 800°C) and is identical to Kovar. Fernico II is used at cryogenic temperatures in the -80 .. -180°C range. Both are used to create electrically conductive paths through the walls of sealed borosilicate glass containers. Dumet is used for a similar purpose, but is tailored for seals through soda lime and lead alkali silicate glasses. Other metals, including copper, molybdenum, nickel, and steel can be spot-welded to the FerNiCo alloys forming low resistance electrical connections.

3.4. Kanthal is the trademark for a family of Fe-Cr-Al alloys used in a wide range of resistance and high-temperature applications. Kanthal FeCrAl alloys consist of mainly iron, chromium (20–30%) and aluminium (4–7.5 %). This material is used in heating elements, including e-cigarettes.

3.5. Ferroalloy refers to various alloys of Fe with other elements used in the production of steels and alloys. These alloys provide distinctive qualities to steel and cast iron or serve important functions during production and are, therefore, closely associated with the iron and steel industry. The main ferroalloys are: ferroaluminum (FeAl), ferroboron (FeB), ferrocerium (FeCe), ferrochromium (FeCr), ferromagnesium (FeMg) ferromanganese (FeMn) and spiegeleisen (MnCSi), ferromolybdenum (FeMo), ferroniobium (FeNb), ferronickel (FeNi), ferrophosphorus (FeP), ferrosilicon (FeSi), ferrosilicon magnesium (FeSiMg), ferrotitanium (FeTi), ferrouranium (FeU), ferrovanadium (FeV), ferrotungsten (FeW).

Topic 4. Metals 3. Non-ferrous metals

Key questions

1 Defenition of non-ferrous metal
2 Advantages of non-ferrous metals
3 Disadvantages of non-ferrous metals
4 Groups of non-ferrous metals
5 What metals where used by humans for metallurgy the first?
6 Most commonly-used industrial non-ferrous metals
7 Abundance of Al
8 Properties of Aluminium
9 Application of Aluminium
10 What aluminium alloys do you know
11 What do you know about duralumin?(composition,application)
12 What do you know about silumin?(composition, application)
13 Abundance of Cu
14 Properties of Cu
15 Application of Cu
16 What Cu alloys do you know?
17 What do you know about brass ? (composition, application)
18 What do you know about bronze? (composition, application)
19 Abundance of Au
20 Properties of Au
21 Application of Au
22 What types of Au alloys do you know?

Defenition Non-ferrous metal is a metal, including alloys, that does not contain iron (ferrite) in appreciable amounts.

Advantages and disadvantages: Generally more costly than ferrous metals, non-ferrous metals are used because of desirable properties such as low weight (e.g. Al), higher conductivity (e.g. Cu), resistance to corrosion (e.g Zn).

Groups of non-ferrous metals. Almost all metal groups which have been studied (topic 4.1) consist of non-ferrous metals: alkali, alkaline earth, actinides post-transition, light, heavy, precious, noble, exotic or rare, refractory, radioactive are the main groups of non-ferrous metals.

History of non-ferrous metals. Non-ferrous metals were the first metals used by humans for metallurgy. Gold, silver and copper existed in their native metallic form although most of other metals are susceptible to oxygen, sulfur and exists in form of oxides, sulfides, carbonates, and silicates. Due to their rarity, these gold, silver and copper artifacts were treated as luxury items and handled with great care. Copper was the first metal to be forged; because it is soft enough to be formed into various objects by cold forging and could be melted in a crucible. The use of copper announced the transition from the Stone Age to the Copper Age. The Bronze Age, which succeeded the Copper Age, was again heralded by the invention of bronze, an alloy of copper with the non-ferrous metal tin.

Most important (commonly-used) industrial non-ferrous metals include Al and Al-based alloys, Cu and Cu-based alloys, Mg, Ti, Mn, Cr, Zn, Ni, Mo, Pb, Sn, W, Co.

Aluminium and Aluminium alloys

Aluminium or aluminum is a chemical element with symbol Al and atomic number 13.

Abundance. By mass, aluminium makes up about 8% of the Earth's crust, and about 1.4% of the Earth as a whole. It is the third most abundant element after oxygen and silicon and the most abundant metal in the crust. There are more than 270 different aluminum-containing minerals. The chief ore of aluminium is bauxite.

Aluminium is remarkable for its low density and its ability to resist corrosion through the phenomenon of passivation. Aluminium and its alloys are vital to the aerospace industry and important in transportation and building industries, such as building facades and window frames.

Properties. Aluminium metal, when in quantity, is very shiny and resembles silver. It is light metal: density is 2.70 g/cm^3. Aluminium is a relatively soft, durable, lightweight, ductile, and malleable with appearance ranging from silvery to dull gray, depending on the surface roughness. It is nonmagnetic. A fresh film of aluminium serves as a good reflector (approximately 92%) of visible light and a n excellent reflector (as much as 98%) of medium and far infrared radiation. Pure aluminium has low strength: The yield strength of pure aluminium is 7–11 MPa, while aluminium alloys have yield strengths ranging from 200 MPa to 600 MPa. Aluminium has about one-third the density and stiffness of steel. It is easily machined, cast, drawn and extruded. Aluminium is a good thermal and electrical conductor, having 59% the conductivity of copper, both thermal and electrical, while having only 30% of copper's density. Aluminium is capable of superconductivity. Aluminium is the most common material for the fabrication of superconductin qubits. Corrosion resistance can be excellent because a thin surface layer of aluminium oxide forms when the bare metal is exposed to air, effectively preventing further oxidation. The strongest aluminium alloys are less corrosion resistant due to galvanic reactions with alloyed copper.

Application. Aluminium is the most widely used non-ferrous metal. The global production of aluminium in 2016 was 58.8 million metric tons. It exceeded that of any other metal except iron (1,231 million metric tons).

The major uses for aluminium metal are in:

- transportation (automobiles, aircraft, trucks, railway cars, marine vessels, bicycles, spacecraft, etc.). Aluminium is used because of its low density;
- Packaging (cans, foil, frame etc.). Aluminium is used because it is non-toxic, non-adsorptive, and splinter-proof;
- Building and construction (windows, doors, siding, building wire, sheathing, roofing, etc.). Since steel is cheaper, aluminium is used when lightness, corrosion resistance, or engineering features are important;
- Electricity-related uses (conductor alloys, motors and generators, transformers, capacitors, etc.). Aluminium is used because it is relatively cheap, highly conductive, has adequate mechanical strength and low density, and resists corrosion;
- A wide range of household items from spoon to furniture. Low density, good appearance, ease of fabrication, and durability are the key factors of aluminium usage;
- Machinery and equipment (processing equipment, pipes, tools). Aluminium is used because of its corrosion resistance, non-pyrophoricity, and mechanical strength.

Despite its widespread occurrence in the Earth crust, aluminium has no known function in biology. Aluminium salts are remarkably nontoxic

Aluminium alloys

Pure aluminium is not used as an engineering material due to low strength. Aluminium is almost always alloyed, which markedly improves its mechanical properties. For example, the common aluminium foils and beverage cans are alloys of 92% to 99% aluminium. The main alloying agents are copper, zinc, magnesium, manganese, and silicon with the levels of other metals in a few percent by weight. The most commonly used aluminium alloys are:

- Duralumin (3.5–4.5% copper, 0.7% magnesium, and 0.7% manganese 0.7 % iron, silicon). Used for: sheet for auto body panels, aircraft structures, rivets, hardware, truck wheels, screw machine products, and other structural applications, sheet and plate in structural components for aerospace application and military equipment, aircraft fittings, wheels, and major structural components, space booster tankage and structure, truck frame and suspension components. Applications requiring high strength and hardness including service at elevated temperatures.
- Silumin (3–25% silicon) used in high-wear applications such as pistons, cylinder liners and internal combustion engine blocks.
- Hiduminium or R.R. alloys (2% copper, iron, nickel): used in aircraft pistons
- Hydronalium (up to 12% magnesium, 1% manganese): used in shipbuilding, resists seawater corrosion
- Alnico (nickel, cobalt): used for permanent magnets
- Birmabright (magnesium, manganese): used in car bodies, mainly used by Land Rover cars.
- Al–Li (2.45% lithium): aerospace applications, including the Space Shuttle
- AA-8000: used for electrical building wire in the U.S. per the National Electrical Code, replacing AA-1350.
- Italma (3.5% magnesium, 0.3% manganese): formerly used to make coinage of the Italian lira
- Magnalium (5–50% magnesium): used in airplane bodies, ladders, pyrotechnics, etc.
- Sc-Al (scandium)
- Y alloy (4% copper, nickel, magnesium)

Copper and Copper alloys

Copper is a chemical element with symbol **Cu** (from Latin: cuprum) and atomic number 29. In the Roman era, copper was principally mined on Cyprus and the origin name of the metal was cyprium (metal of Cyprus), from which the words copper.

Abundance. By mass, copper takes 16th place among metals of the Earth's crust. In nature, copper occurs in a variety of minerals, including native copper, copper sulfides such as chalcopyrite, bornite, digenite, covellite, and chalcocite, copper sulfosalts such as tetrahedite-tennantite, and enargite. Most copper deposits contain only 0.4 to 1.0% copper. Copper is one of the few metals that occur in nature in directly usable metallic form (native metals) as opposed to needing extraction from an ore. This led to very early human use, from c. 8000 BC. It was the first metal to be smelted from its ore, c. 5000 BC, the first metal to be cast into a shape in a mold, c. 4000 BC and the first metal to be purposefully alloyed with another metal, tin, to create bronze, c. 3500 BC.

Propertie. Copper is one of a few metallic elements with a natural color other than gray or silver. Pure copper is orange-red. It is a soft, malleable, and ductile metal with very high thermal and electrical conductivity, tensile strength, creep (deformation) resistance, corrosion resistance, low thermal expansion. Machining of copper is possible, although alloys are preferred for good machinability. Copper is biostatic, meaning bacteria and many other forms of life will not grow on it.

Application. Copper is used as a conductor of heat and electricity for electrical wire (60%), as a building material for roofing and plumbing (20%), as a material for industrial machinery (15%). Copper is used mostly as a pure metal, but when greater hardness is required, it is put into such alloys as brass and bronze or alloys for jewelry (5% of total use). For more than two centuries, copper paint has been used on boat body to control the growth of plants and shellfish. A small part of the copper supply is used for nutritional supplements and fungicides in agriculture.

- Copper wire is used in power generation, power transmission, power distribution, telecommunications, electronics circuitry, and countless types of electrical equipment.
- Electromagnets, vacuum tubes, cathode ray tubes, and magnetrons in microwave ovens use copper
- Electric motors use copper
- Copper has been used since ancient times as a durable, corrosion resistant, and weatherproof architectural material. Roofs, flashings, rain gutters, downspouts, domes, spires, vaults, and doors have been made from copper for hundreds or thousands of years.
- Copper has long been used to line parts of ships to protect against barnacles and mussels due to biostatic property
- Copper alloys as antimicrobial materials with public health benefits
- Copper minerals as azurite, malachite, and turquoise which often impart blue or green colors due to copper (II) salts have been used widely and historically as pigments.

- Copper compounds are used as bacteriostatic agents, fungicides, and wood preservatives.

Copper is essential to all living organisms as a trace dietary mineral because it is a key constituent of the respiratory enzyme complex. The adult body contains between 1.4 and 2.1 mg of copper per kilogram of body weight

Copper alloys:

- Arsenical copper
- Beryllium copper (beryllium)
- Billon (silver)
- Brass (zinc)
  - Calamine brass (zinc)
  - Chinese silver (zinc)
  - Dutch metal (zinc)
  - Gilding metal (zinc)
  - Muntz metal (zinc)
  - Pinchbeck (zinc)
  - Prince's metal (zinc)
  - Tombac (zinc)
- Bronze (tin, aluminium or other element)
  - Aluminium bronze (aluminium)
  - Arsenical bronze
  - Bell metal (tin)
  - Florentine bronze (aluminium or tin)
  - Glucydur (beryllium, iron)
  - Guanín
  - Gunmetal (tin, zinc)
  - Phosphor bronze (tin and phosphorus)
  - Ormolu (Gilt Bronze) (zinc)
  - Silicon bronze
  - Speculum metal (tin)
- Constantan (nickel)
- Copper hydride (hydrogen)
- Copper–tungsten (tungsten)
- Corinthian bronze (gold, silver)
- Cunife (nickel, iron)
- Cupronickel (nickel)
- CuSil (silver)
- Cymbal alloys (Bell metal) (tin)

- Devarda's alloy (aluminium, zinc)
- Electrum (gold, silver)
- Hepatizon (gold, silver)
- Manganin (manganese, nickel)
- Melchior (nickel); high corrosion resistance, used in marine applications in condenser tubes
- Molybdochalkos (lead)
- Nickel silver (nickel)
- Nordic gold (aluminium, zinc, tin)
- Shakudo (gold)
- Tumbaga (gold)

Most commonly-used copper alloys are brass (copper and zinc) and bronze (usually copper-tin alloys, but can refer to any alloy of copper such as aluminium bronze). Copper is one of the most important constituents of silver and gold used in the jewelry industry, modifying the color, hardness and melting point of the resulting alloys. The alloy of copper and nickel, called cupronickel, is used in low-denomination coins. The US five-cent coin (currently called a *nickel*) consists of 75% copper and 25% nickel in homogeneous composition. The alloy of 90% copper and 10% nickel, remarkable for its resistance to corrosion, is used for various objects exposed to seawater. Alloys of copper with aluminium (about 7%) have a golden color and are used in decorations. *Shakudō* is a Japanese decorative alloy of copper containing a low percentage of gold, typically 4–10%.

Gold and Gold alloys

Gold is a chemical element with symbol **Au** (from Latin: *aurum*) and atomic number 79.

Abundance. Gold is a relatively rare element but it often occurs in free elemental (native) form, typically as a metal solid solution with silver (i.e. as a gold silver alloy). Such alloys usually have a silver content of 8–10%. Electrum is alloy of elemental gold with more than 20% silver Gold sometimes occurs combined with tellurium as the minerals calaverite, krennerite, nagyagite, petzite and sylvanite (telluride minerals), and as the rare bismuthide maldonite (Au_2Bi) and antimonide aurostibite ($AuSb_2$). Gold also occurs in rare alloys with copper, lead, and mercury: the minerals auricupride (Cu_3Au), novodneprite ($AuPb_3$) and weishanite ($(Au, Ag)_3Hg_2$).

Properties. It is a bright, slightly reddish yellow, dense, soft, resistant to corrosion and most other chemical reactions, malleable, and ductile metal.

Chemically, gold is a transition metal and belongs to Noble and Precious metals groups. It is one of the least reactive metals. Gold is the most malleable of all metals; a single gram can be beaten into a sheet of 1 square meter. Gold sheet can be beaten thin enough to become semi-transparent. Gold has a density of 19.3 g/cm^3. Gold is a good conductor of heat and electricity. Pure 100% (in practice, 99.9% or better) gold is 24 karat by definition, so all colored golds are less than this, with the common being 18K (75%), 14K (58.5%), 10K (41.6%), and 9K (37.5%).

Application. The world consumption of new gold produced is about 50% in jewelry, 40% in investments, and 10% in industry (electrical connectors in all types of devices). Certain gold salts are still used as anti-inflammatories in medicine.

Types of colored gold: Gold alloys with different other metals (usually with silver or copper in various proportions) produce white, yellow, green and red golds.

White gold is an alloy of gold and at least one white metal (usually nickel, manganese, or palladium). A common white gold formulation consists of 90 wt.% gold and 10 wt.% nickel.

Yellow gold is an alloy of gold, copper and silver. A common yellow gold formulation consists of 75 wt.% gold, 15% copper, 10% silver.

Rose gold is a gold-copper alloy widely used for specialized jewelry. Rose gold, also known as pink gold and red gold, was popular in Russia at the beginning of the nineteenth century, and was also known as Russian gold, and is commonly used for wedding rings, bracelets, and other jewelry). A common red gold formulation consists of 50 wt.% gold and 50 wt.% copper (12K red gold).

Green gold is an alloy of gold, silver, copper and cadmium. Cadmium creates a green color, but there are health concerns regarding its use, as cadmium is highly toxic. The alloy of 75% gold, 15% silver, 6% copper, and 4% cadmium yields a dark-green alloy.

Grey gold is an alloy of gold and palladium. A cheaper alternative which does not use palladium

Topic 5. Metallurgy: 1. Metal production technologies

Key questions

1 Aim of metallurgy
2 Two major steps of metal production
3 What technologies includes extractive metallurgy?
4 What do you know about mineral processing?
5 What major physical and chemical methods mineral processing includes?
6 Definition to metal ore
7 Most commonly used extraction methods
8 What do you know about pyrometallurgy?
9 What do you know about electrometallurgy?
10 What do you know about hydrometallurgy?
11 What major types of thermal reduction techniques do you know?
12 Advantages and disadvantages of carbothermic reduction
13 Advantages and disadvantages of metallothermic reduction
14 How to choose method for metal reduction?

Aim of metallurgy is to receive metal or alloy with demanded properties.

Metallurgy is distinguished from the metalworking: metalworking is the next stage in metal good production process, products of metallurgy are the *commodity* for metalworking production, thus metalworking relies on metallurgy.

Commodity	Technology	Product	Technology	Product
Raw material (ore)	Metallurgy	Metall	metalworking	Metal good

Metallurgy is subdivided into ferrous metallurgy (also known as *black metallurgy*) and non-ferrous metallurgy (also known as *colored metallurgy*). Ferrous metallurgy involves processes and alloys based on iron while non-ferrous metallurgy involves processes and alloys based on other metals. The production of ferrous metals accounts for 95 percent of world metal production.

In a general case, metal production involves two major steps: (1) extractive metallurgy – the processing of ores to extract the metal they contain; (2) alloying metallurgy – the mixture of metals, sometimes with other elements, to produce alloys.

1. Extractive metallurgy

Extractive metallurgy also includes two types of technologies: (1) technologies for mineral processing and (2) metal extraction – technologies for separation of metal from mineral.

Commodity	Technology 1	Product	Technology 2	Product
Raw material (ore)	mineral processing	ore concentrate	extraction	Metal

1.1. Mineral processing begins with beneficiation, consisting of initially breaking down the ore to required sizes depending on the concentration process to be followed, by crushing, grinding, sieving etc. Thereafter, the ore is physically separated from any unwanted impurity, depending on the form of occurrence and/or further process involved. Separation processes take advantage of physical properties of the materials. These physical properties can include density, particle size and shape, electrical and magnetic properties, and surface properties.

Major physical and chemical methods include:

- magnetic separation,
- froth flotation,
- leaching etc.,

whereby the impurities and unwanted materials are removed from the ore and the base ore of the metal is concentrated, meaning the percentage of metal in the ore is increased. This concentrate is then either processed to remove moisture or else used as is for extraction of the metal or made into shapes and forms that can undergo further processing, with ease of handling.

Ore bodies often contain more than one valuable metal. Tailings of a previous process may be used as a feed in another process to extract a secondary product from the original ore. Additionally, a concentrate may contain more than one valuable metal. That concentrate would then be processed to separate the valuable metals into individual constituents.

1.2. Metal extraction (technologies for separation of metal from mineral). The Earth's crust contains almost all known metals (except artificial metals). But only few of them may be found in free elemental (native) form. Majority of metals occurs in nature in form of chemical compounds which forms metal ores. (A **metal ore** is a rock containing a metal, or a metal compound, in a high enough concentration to make it economic to extract the metal.)

There are several methods to extract metal from metal ore and in accordance with them there are several types of extraction metallurgies. Most commonly used extraction methods are: thermal reduction (pyrometallurgy uses this technologies), electrochemical or electrolytic reduction of metals (electrometallurgy uses this technologies) and aqueous reduction (hydrometallurgy uses this technologies). The method used to extract metals from the ore in which they are found depends on their properties (melting temperature, reactivity). For example, majority of non-ferrous metals (aluminium, magnesium, calcium, sodium) are extracted by electrolysis, while a ferrous metals (such as iron) are extracted by thermal reduction. In the extractive metallurgy industry Ellingham Diagrams helps to select the best reducing agent for various ores in the extraction process.

In accordance with the process adopted to extract there are 3 types of separation technologies or 3 types of metallurgies: pyrometallurgy, electrometallurgy and hydrometallurgy.

1.2.1. Pyrometallurgy (Thermal reduction) involves high temperature processes where chemical reactions take place among gases, solids, and molten materials. So, pyrometallurgical technologies extract metal from ore using thermal treatment. Processes that produce molten products are collectively referred to as smelting operations. This group of processes bases on the reduction of metal compounds (oxides, halides, and other compounds) by more active elements (aluminum, magnesium or silicon) with heat evolution. There are several varieties of thermal reduction. The out-of-furnace process is used in cases in which the quantity of heat evolved during the reduction reactions is sufficiently large to yield the reaction products in liquid form and to allow their satisfactory separation (1750–2300°C) – for example, in aluminothermy. The electric-furnace method is used in cases where the heat evolution is inadequate for the melting and necessary superheating of the fusion products. The additional heat is supplied by means of electric heating. This process is very widespread. Vacuum thermal reduction makes possible separation of highly volatile metals, such as magnesium, during reduction under vacuum (at 800–1400°C) or the production of metals with a low gas content.

Thermal reduction techniques are classified according to the reducing agent. There are:

1.2.1.1. Carbothermic reduction involves the reduction of substances, (often metal oxides), using carbon as the reducing agent. These chemical reactions are usually conducted at temperatures of several hundred degrees Celsius. Such processes are applied for production of the elemental forms of many elements. Carbothermic reactions are not useful for some metal oxides, such as those of sodium and potassium. The ability of metals to participate in carbothermic reactions can be predicted from Ellingham diagrams. Carbothermal reactions produce carbon monoxide and sometimes carbon dioxide. The facility of these conversions is attributable to the entropy of reaction: two solids, the metal oxide and carbon, are converted to a new solid (metal) and a gas (CO), the latter having high entropy. Heat is required for carbothermic reactions because diffusion of the reacting solids is otherwise slow. The most prominent example is that of iron ore smelting. Many reactions are involved, but the simplified equation is usually shown as: $2Fe_2O_3 + 3C \rightarrow 4Fe + 3CO_2$.

1.2.1.2. Metallothermic reduction, such as **Calciothermic Aluminothermic, Magnesiothermic**, and **Silicothermic reactions**, uses different metals as the reducing agent. Such processes are more costly than reduction processes using carbon; they are used in the production of high-quality carbon-free alloying components (hardeners with rare metals, carbon-free ferrochromium, and other alloys), titanium sponge, and other pure (mainly carbon-free) metals and alloys. $Fe_2O_3 + 2Al \rightarrow 2Fe + Al_2O_3$; $Fe_2O_3 + 3Mg \rightarrow 2Fe + 3MgO$.

1.2.1.3. Hydrothermic reduction uses hydrogen as the reducing agent. In principle, hydrogen can be applied as a reducing agent for the production of many metals. It has found commercial application for the synthesis of platinum group metals, some rare metals such as germanium and rhenium, and for the production of special grades of metals (e.g., fine nickel and cobalt powders) However, hydrogen is primarily applied for the synthesis of tungsten and molybdenum, with very pure metal powders resulting from the hydrogen reduction of their oxides. $MoO_3 + 3H_2 \rightarrow Mo + 3H_2O$.

1.2.2. Electrometallurgy (Electrochemical or electrolytic reduction) involves metallurgical processes that take place in some form of electrolytic cell. The most common types of electrometallurgical processes are electrowinning and electro-refining. Electrowinning is an electrolysis process used to recover metals in aqueous solution, usually as the result of an ore having undergone one or more hydrometallurgical processes. The metal of interest is plated onto the cathode, while the anode is an inert electrical conductor. Electro-refining is used to dissolve an impure metallic anode (typically from a smelting process) and produce a high purity cathode. Fused salt electrolysis is another electrometallurgical process whereby the valuable metal has been dissolved into a molten salt which acts as the electrolyte, and the valuable metal collects on the cathode of the cell. The fused salt electrolysis process is conducted at temperatures sufficient to keep both the electrolyte and the metal being produced in the molten state. The scope of electrometallurgy has significant overlap with the areas of hydrometallurgy and (in the case of fused salt electrolysis) pyrometallurgy. Additionally, electrochemicalphenomena play a considerable role in many mineral processing and hydrometallurgical processes.

Electroextraction, also called **Electrowinning**, is the electrodeposition of metals from their ores that have been put in solution via a process commonly referred to as leaching. Electrorefining uses a similar process to remove impurities from a metal. Both processes use electroplating on a large scale and are important techniques for the economical and straightforward purification of non-ferrous metals. The resulting metals are said to be electrowon.

In electrowinning, a current is passed from an inert anode through a liquid leach solution containing the metal so that the metal is extracted as it is deposited in an electroplating process onto the cathode. In electrorefining, the anodes consist of unrefined impure metal, and as the current passes through the acidic electrolyte the anodes are corroded into the solution so that the electroplating process deposits refined pure metal onto the cathodes.

The most common electrowon metals are lead, copper, gold, silver, zinc, aluminium, chromium, cobalt, manganese, and the rare-earth and alkali metals. For aluminium, this is the only production process employed. Several industrially important active metals (which react strongly with water) are produced commercially by electrolysis of their pyrochemical molten salts. Experiments using electrorefining to process spent nuclear fuel have been carried out. Electrorefining may be able to separate heavy metals such a plutonium, caesium, and strontium from the less-toxic bulk of uranium. Many electroextraction systems are also available to remove toxic (and sometimes valuable) metals from industrial waste streams.

Most metals occur in nature in their oxidized form (ores) and thus must be reduced to their metallic forms. The ore is dissolved following some preprocessing in an aqueous electrolyte or in a molten salt and the resulting solution is electrolyzed. The metal is deposited on the cathode (either in solid or in liquid form), while the anodic reaction is usually oxygen evolution. Several metals are naturally present as metal sulfides; these include copper, lead, molybdenum, cadmium, nickel, silver, cobalt, and zinc. In addition, gold and platinum group metals are associated with sulfidic base metal ores. Most metal sulfides or their salts, are electrically conductive and this allows electrochemical redox reactions to efficiently occur in the molten state or in aqueous solutions.

Some metals, such as nickel do not electrolyze out but remain in the electrolyte solution. These are then reduced by chemical reactions to refine the metal. Other metals, which during the processing of the target metal have been reduced but not deposited at the cathode, sink to the bottom of the electrolytic cell, where they form a substance referred to as anode sludgeor anode slime. The metals in this sludge can be removed by standard pyrorefining methods.

Because metal deposition rates are related to available surface area, maintaining properly working cathodes is important. Two cathode types exist, flat-plate and reticulated cathodes, each with its own advantages. Flat-plate cathodes can be cleaned and reused, and plated metals recovered. Reticulated cathodes have a much higher deposition rate compared to flat-plate cathodes. However, they are not reusable and must be sent off for recycling. Alternatively, starter cathodes of pre-refined metal can be used, which become an integral part of the finished metal ready for rolling or further processing.

1.2.3. Hydrometallurgy is concerned with processes involving aqueous solutions to extract metals from ores. So, hydrometallurgical technologies extract metal from ore through aqueous solutions. The first step in the hydrometallurgical process is leaching, which involves dissolution of the valuable metals into the aqueous solution and/or a suitable solvent. After the solution is separated from the ore solids, the extract is often subjected to various processes of purification and concentration before the valuable metal is recovered either in its metallic state or as a chemical compound. This may include precipitation, distillation, adsorption, and solvent extraction. The final recovery step may involve precipitation, cementation, or an electrometallurgical process. Sometimes, hydrometallurgical processes may be carried out directly on the ore material without any pretreatment steps. More often, the ore must be pretreated by various mineral processing steps, and sometimes by pyrometallurgical processes.

An example gold cyanidation (also known as the cyanide process or the MacArthur-Forrest process) is a hydrometallurgical technique for extracting gold from low-grade ore by converting the gold to a water-soluble coordination complex. It is the most commonly used leaching process for gold extraction. Besides today about 20% of copper produced by hydrometallurgical technique using reactions:

$$CuO + H_2SO_4 = CuSO_4 + H_2O, \quad CuSO_4 + Fe = FeSO_4 + Cu.$$

Topic 5. Metallurgy: 2. Technologies of ferrous metal manufacturing

Key questions

1 What is the first step in production of any ferrous metal?
2 What is the name of ironmaking furnace?
3 What is the name of furnace for castiron production?
4 What is the name of steelmaking furnaces?
5 What earliest furnaces for ironmaking do you know?
6 What do you know about blast furnace?
7 How long does blast furnace work?
8 What commodity is used for blast furnace?
9 Why blast furnace gets its name?
10 What chemical reactions take place inside blast furnace?
11 Explain a a countercurrent exchange process inside blast furnace
12 What function of coke in ironmaking process?
Chemical reaction with coke in blast furnace.
13 Chemical reaction with iron ore in blast furnace.
14 Chemical reaction with flux in blast furnace.
15 The end products of blast furnace
16 What is the biggest drawback of the blast furnaces and what is the way for decision of that problem?
17 What is the application of pig iron?
18 What does BOS (BOP, BOF, OSM, EAF) mean?
19 What are the major steps of basic oxygen steel-making process?
20 What is the difference between Bessemer and BOS processes?
21 What do you know about basic oxigen furnace?
22 What do you know about electric arc furnace?
23 What do you know about ladle furnace?
24 What do you know about cupola furnace?
25 Make a comparison of BOF and EAF processes
26 Steel semi-finished casting products
27 Application of iron and steel making by-products
28 What is the difference between slabs, blooms and billets?

Main ferrous metals are the iron (Fe) and its alloys, such as Fe-C alloys (steels, cast irons (gray iron, white iron, ductile iron, malleable iron), pig iron, wrought iron) and Fe-metal alloys. Major technological steps for ferrous metals production may be illustrated by next technological chain.

C	**T**	**P**	**T**	**P**	**T**	**P**
Fe-ore	Metallurgy Melting in blast furnace with carbo-thermic reduction	**Pig iron** or hot metal	Metallurgy Re-melting in cupola, electric induction furnaces or electric arc furnaces	**Cast irons**		
			Metallurgy re-melting in BOF or EAF with (1) oxidation; (2) metallo-thermic reduction	**Steels**		
				Iron (pure)	Alloying with other metals	Alloy

1. Pig iron production (ironmaking)

Ironmaking, which is the first step in production of any ferrous metal, involves the melting of raw materials, such as iron ore, coke, and lime in a blast furnace. The resulting pig iron or hot metal still contains 4 to 4.5 percent carbon and other impurities. The earliest furnaces for smelting iron are bloomery, puddling and reverberatory furnaces.

1.1. Blast furnace

A blast furnace is a type of metallurgical furnace used for smelting iron ore to produce pig iron. Blast refers to the combustion air being "forced" or supplied above atmospheric pressure.

Blast furnaces require many additional facilities to support their operations. However, in simplest terms, the furnace itself is a huge steel shell almost cylindrical in shape and lined with heat-resistant brick. Once started, or "blown-in," the furnace operates continuously until the refractory lining needs renewal or until demand for iron drops to the point where the furnace is closed down. Blast furnaces operate continuously for long periods because they are difficult to start up and shut down. When a sufficient quantity of molten iron accumulates in the hearth of the blast furnace, it is tapped off into ladles for steel-making. As slag builds up on the surface of the molten metal it is tapped off too at regular intervals through a separate taphole. Meanwhile, the raw materials continue to be charged into the top of the furnace, and heated air blasted in at the bottom. This process goes on throughout the ‘life’ of the furnace, which can be 10 years or more, before the heat-resistant brick lining begins to deteriorate. The furnace is then relined.The duration of furnace operations from start to finish is referred to as a "campaign" and may last more than 10 years.

In a blast furnace iron ore and other iron bearing materials, coke (as a fuel), and limestone (as a flux) are continuously supplied through the top of the furnace, while a hot air blast, from which the furnace gets its name, is injected through nozzles in the base of the furnace. The blast furnaces operates as a countercurrent exchange process: the downward flow of the ore and flux contacts with an upflow of hot, carbon-rich combustion gases. The blast fans the heat in the furnace, and the iron in the ore is melted so that the chemical reactions take place throughout the furnace as the material falls downward.

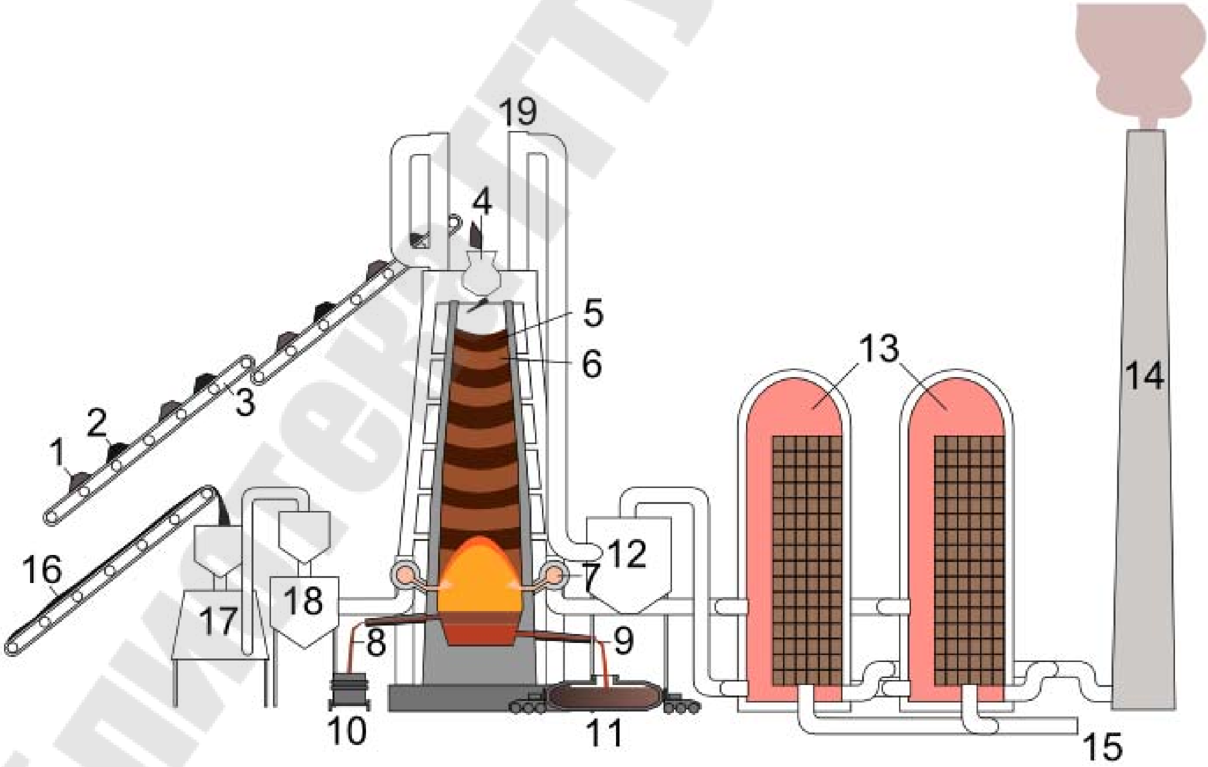
Although the efficiency of blast furnaces is constantly evolving, the chemical process inside the blast furnace remains the same. Blast furnaces operate on the principle of chemical reduction whereby carbon monoxide reduces the iron to its elemental form.
There are several chemical reactions inside of the furnace:

With coke:	Coke reacts with the preheated blast air blown into the furnace to produce carbon monoxide and heat: $2\ C_{(s)} + O_{2(g)} \rightarrow 2\ CO_{(g)}$
With ore:	The main chemical reaction producing the molten iron is reduction: Carbon monoxide reduces the iron to its elemental form $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$

With limestone:	Due to counter-current gases the limestone decomposes to calcium oxide and carbon dioxide: $CaCO_{3(s)} \rightarrow CaO_{(s)} + CO_{2(g)}$ The calcium oxide formed by decomposition reacts with various acidic impurities in the iron (notably silica), to form a slag which is essentially calcium silicate, $CaSiO_3$: $SiO_2 + CaO \rightarrow CaSiO_3$

The end products are usually molten metal and slag tapped from the bottom, and flue gases exiting from the top of the furnace.

The charging system at the top of the furnace also acts as a valve mechanism to prevent the escape of gas, which is taken off through pipes to a gas cleaning plant. One of the biggest drawbacks of the blast furnaces is the inevitable carbon dioxide production as iron is reduced from iron oxides by carbon. Steelmaking is one of the largest industrial contributors of the CO_2 emissions in the world. Several new process have been proposed to cut CO_2 emissions by at least 50%. Some rely on the capture and further storage (CCS) of CO_2, while others choose decarbonizing iron and steel production, by turning to hydrogen, electricity and biomass.



1: Iron ore + limestone sinter	1: железная руда + известняк
2: coke	2: кокс
3: conveyor belt	3: лента конвейера

4: feeding opening, with a valve that prevents direct contact with the internal parts of the furnace	4: колошник с аппаратом, предотвращающим уход доменного газа в атмосферу
5: Layer of coke	5: слой кокса
6: Layer of Iron ore +limestone	6: слой руды и известняка
7: Hot air (around 1200°C)	7: горячий воздух (ок. 1200 °C)
8: Slag	8: шлак
9: Liquid pig iron	9: жидкий передельный чугун
10: Mixers	10: шлаковый ковш
11: Tap for pig iron	11: чугуновоз
12: Dust cyclon for removing dust from exhaust gasses before burning them in 13	12: циклон для очистки доменного газа от пыли перед сжиганием его в 13
13: air heater	13: регенераторы (кауперы)
14: Smoke	14: дымовая труба
15: feed air for Cowper air heaters	15: подача воздуха в регенераторы (кауперы)
16: Powdered coal	16: порошок угля
17: cokes oven	17: коксовая печь
18: cokes bin	18: резервуар для кокса
19: pipes for blast furnace gas	19: газоотвод

Blast furnace in Sestao, Spain

Bast furnace in Port of Sagunto, Spain

2. Cast iron production (cast ironmaking)

Approximately 5% of global iron production is used for cast iron products, which are commonly used for engine blocks, machinery, fences, buildings and construction. Cast iron is produced mainly by remelting scrap of iron in cupola furnaces and pouring the molten metal into moulds

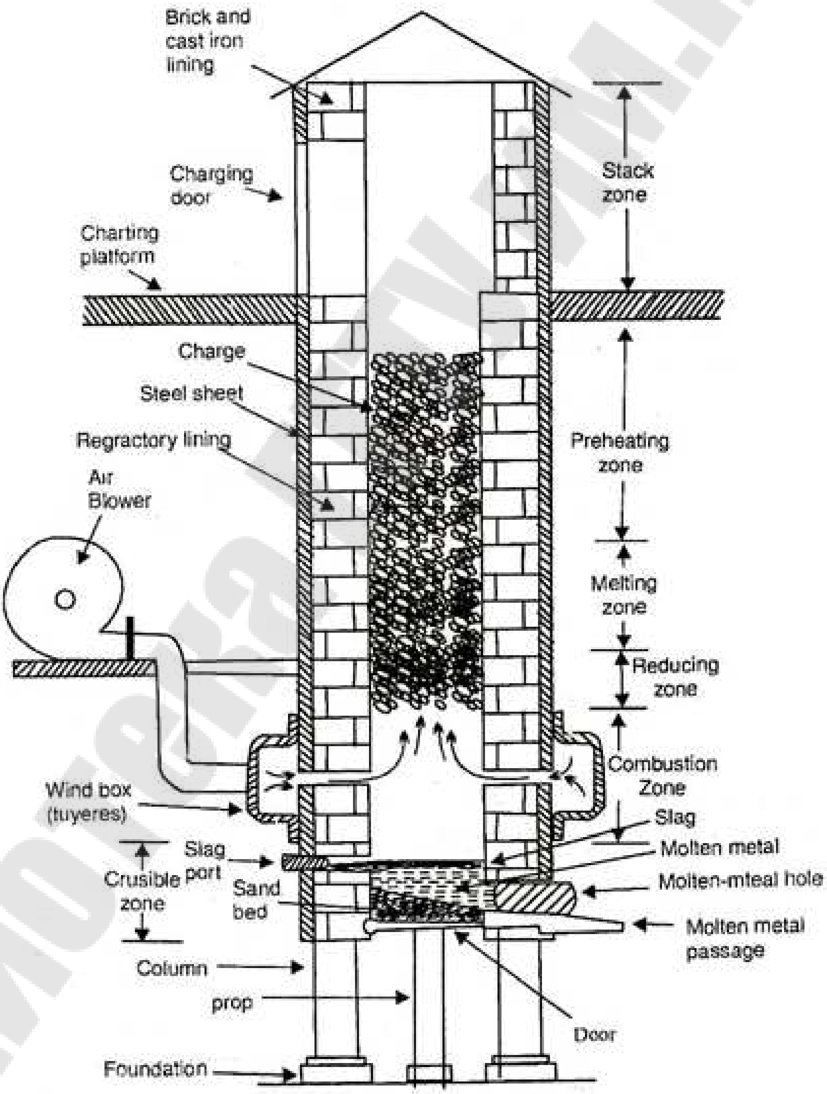
2.1. Cupola furnace

Cupola furnace is the cheapest means for converting pig iron or scrap metal into gray cast iron. Also cupola is a most widely used foundry furnace for melting ferrous metals and alloys. Sometimes, it is also used for melting non-ferrous metals and alloys. The fuel used is a good quality low sulphur coke. Anthracite coal or carbon briquettes may also be used.

The cupola can be made almost any practical size. The size of a cupola is expressed in diameters and can range from 0.5 to 4.0 m. The overall shape is cylindrical and the equipment is arranged vertically, usually supported by four legs. The overall look is similar to a large smokestack.

The bottom of the cylinder is fitted with doors which swing down and out to 'drop bottom'. The top where gases escape can be open or fitted with a cap to prevent rain from entering the cupola. To control emissions a cupola may be fitted with a cap that is designed to pull the gases into a device to cool the gases and remove particulate matter.

The shell of the cupola, being usually made of steel, has refractory brick and plastic refractory patching material lining it. The bottom is lined in a similar manner but often a clay and sand mixture ("bod") may be used, as this lining is temporary. Finely divided coal ("sea coal") can be mixed with the clay lining so when heated the coal decomposes and the bod becomes slightly friable, easing the opening up of the tap holes. The bottom lining is compressed or 'rammed' against the bottom doors. Some cupolas are fitted with cooling jackets to keep the sides cool and with oxygen injection to make the coke fire burn hotter.



To begin a production run, called a 'cupola campaign', the furnace is filled with layers of coke and ignited with torches. Some smaller cupolas may be ignited with wood to start the coke burning. When the coke is ignited, air is introduced to the coke bed through ports in the sides called tuyeres. Wood, charcoal, or biomass may also be used as fuel for the cupola’s fire. Flammable gases also can be added to air and blown through the tuyere section of the furnace to add fuel to the fire.

When the coke is very hot, solid pieces of metal are charged into the furnace through an opening in the top. The metal is alternated with additional layers of fresh coke. Limestone is added to act as a flux. As the heat rises within the stack the metal is melted. It drips down through the coke bed to collect in a pool at the bottom, just above the bottom doors. During the melting process a thermodynamic reaction takes place between the fuel and the blast air. The carbon in the coke combines with the oxygen in the air to form carbon monoxide. The carbon monoxide further burns to form carbon dioxide. Some of the carbon is picked up by the falling droplets of molten metal which raises the carbon content of the iron. Silicon carbide and ferromangan esebriquettes may also be added to the charge materials. The silicon carbide dissociates and carbon and silicon enters into the molten metal. Likewise, the ferromanganese melts and is combined into the pool of liquid iron in the 'well' at the bottom of the cupola. Additions to the molten iron such as ferromanganese, ferrosilicon, Silicon carbide and other alloying agents are used to alter the molten iron to conform to the needs of the castings at hand.

Pea-sized raw ore of metals such as iron, copper, lead, and even those containing precious metals can be melted in the the cupola or blast furnace furnace. Vannoccio Biringuccio describes how to separate metals and slag by pouring the melted ore contents from the furnace into a small pool then peeling off layers of slag or metal from the top as they cool into a solid.

The operator of the cupola is known as the "cupola tender" or "furnace master". During the operation of a tapped cupola (cupolas may vary in this regard) the tender observes the amount of iron rising in the well of the cupola. When the metal level is sufficiently high, the cupola tender opens the "tap hole" to let the metal flow into a ladle or other container to hold the molten metal. When enough metal is drawn off the "tap hole" is plugged with a refractory plug made of clay.

The cupola tender observes the furnace through the sight glass or peep sight in the tuyeres. Slag will rise to the top of the pool of iron being formed. A slag hole, located higher up on the cylinder of the furnace, and usually to the rear or side of the tap hole, is opened to let the slag flow out.

The viscosity is low (with proper fluxing) and the red hot molten slag will flow easily. Sometimes the slag which runs out the slag hole is collected in a small cup shaped tool, allowed to cool and harden. It is fractured and visually examined. With acid refractory lined cupolas a greenish colored slag means the fluxing is proper and adequate. In basic refractory lined cupolas the slag is brown.

After the cupola has produced enough metal to supply the foundry with its needs, the bottom is opened, or 'dropped' and the remaining materials fall to the floor between the legs. This material is allowed to cool and subsequently removed. The cupola can be used over and over. A 'campaign' may last a few hours, a day, weeks or even months.

When the operation is over, the blast is shut off and the prop under the bottom door is knocked down so that the bottom plates swing open. This enables the cupola remains to drop to the floor or into a bucket. They are then quenched and removed from underneath the cupola.

3. Steel production (steelmaking)

Steelmaking history knows a lot of technologies: cementation process, Bessemer process, Siemens-Martin process. Methods for steel manufacturing have evolved significantly since industrial production began in the late 19th century. Modern methods, however, are still based on the same backgraund as the original Bessemer Process, which uses oxygen to lower the carbon content in iron.

Today steelmaking industry uses two technologies: basic oxygen steelmaking (BOS) and electric arc furnaces (EAF).

3.1. Basic oxygen furnace

Basic oxygen steelmaking (BOS, BOP, BOF, or OSM), also known as Linz–Donawitz-steelmaking or the oxygen converter process is a method of primary steelmaking in which carbon-rich molten pig iron is made into steel. Blowing oxygen through molten pig iron lowers the carbon content of the alloy and changes it into low-carbon steel.

The process was developed in 1948 by Swiss engineer Robert Durrer and commercialized in 1952–1953 by the Austrian steelmaking company VOEST and ÖAMG. The LD converter, named after the Austrian towns Linz and Donawitz (a district of Leoben) is a refined version of the Bessemer converter where blowing of air is replaced with blowing oxygen. It reduced capital cost of the plants, time of smelting, and increased labor productivity. The majority of steel manufactured in the world is produced using the basic oxygen furnace. In 2000, it accounted for 60% of global steel output.

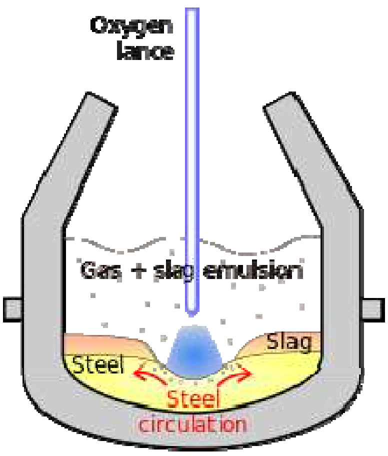
Modern furnaces will take a charge of iron of up to 400 tons and convert it into steel in less than 40 minutes, compared to 10–12 hours in an open hearth furnace.

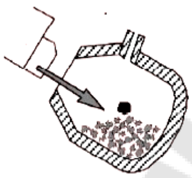
Basic oxygen steelmaking is a primary steelmaking process for converting the molten pig iron into steel by blowing oxygen through a lance over the molten pig iron inside the converter. Exothermic heat is generated by the oxidation reactions during blowing.

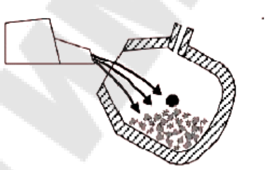
The basic oxygen steel-making process is as follows:

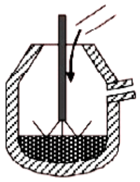
1. Molten pig iron (sometimes referred to as "hot metal") from a blast furnace is poured into a large refractory-lined container called a ladle.
2. The metal in the ladle is sent directly for basic oxygen furnace.
3. Filling the furnace with the ingredients is called *charging*. The BOS process is autogenous, i.e. the required thermal energy is produced during the oxidation process. Maintaining the proper *charge balance*, the ratio of hot metal and cold scrap is therefore very important. The BOS vessel can be tilted up to 360° and is tilted towards the deslagging side for charging scrap and hot metal. The BOS vessel is charged with steel or iron scrap (25%-30%),if required. Molten iron from the ladle is added as required for the charge balance.
4. The vessel is then set upright and a water-cooled, copper tipped lance with 3–7 nozzles is lowered down into it and high purity oxygen is delivered at supersonic speeds. The lance "blows" 99% pure oxygen over the hot metal, igniting the carbon dissolved in the steel, to form carbon monoxide and carbon dioxide, and generating the temperature to rise to about 1700°C. This melts the scrap, lowers the carbon content of the molten iron and helps remove unwanted chemical elements.

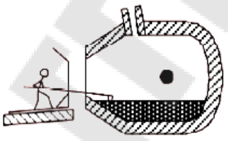
5. Fluxes (burnt lime or dolomite) are fed into the vessel to form slag, to maintain basicity above 3 and absorb impurities during the steelmaking process. Near the end of the blowing cycle, which takes about 20 minutes, the temperature is measured and samples are taken. A typical chemistry of the blown metal is 0.3–0.9% C, 0.05–0.1% Mn, 0.001–0.003% Si, 0.01–0.03% S and 0.005–0.03% P.
6. The BOF vessel is tilted towards the slagging side and the steel is poured through a tap hole into a steel ladle with basic refractory lining. This process is called *tapping* the steel. The steel is further refined in the ladle furnace, by adding alloying materials to give it special properties required by the customer. Sometimes argon or nitrogen is bubbled into the ladle to make the alloys mix correctly.
7. After the steel is poured off from the BOS vessel, the slag is poured into the slag pots through the BOS vessel mouth and dumped.

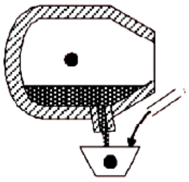


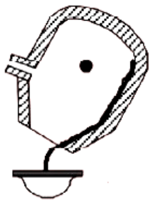

a) Charging scrap


b) Charging hot metal


c) Main blow


d) Sampling


e) Tapping


f) Slag tapping

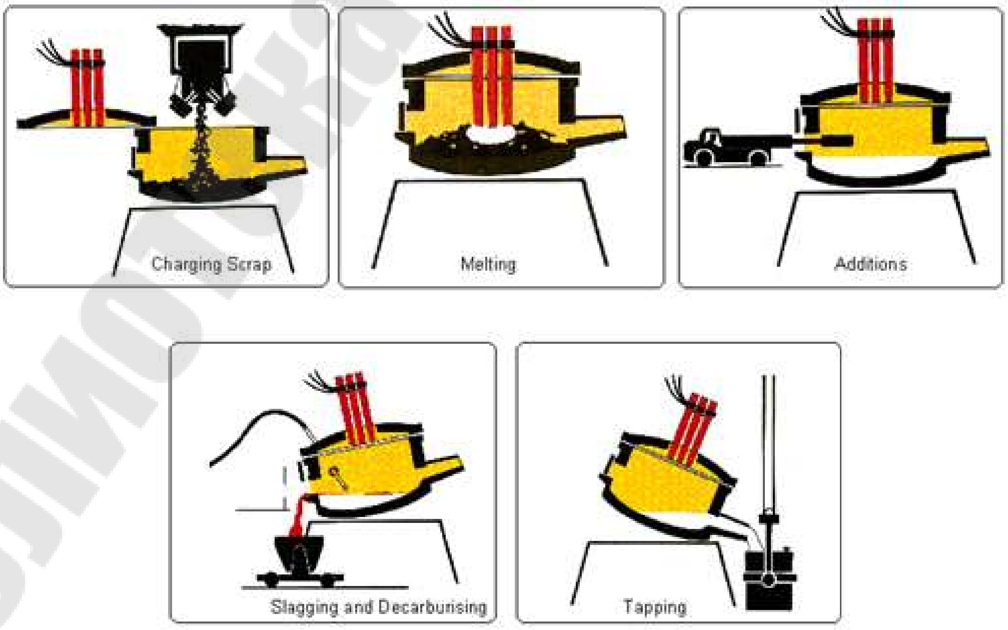
Scrap being loaded into the BOS furnace Charging hot metal to the BOS furnace

3.2. Electric arc furnace

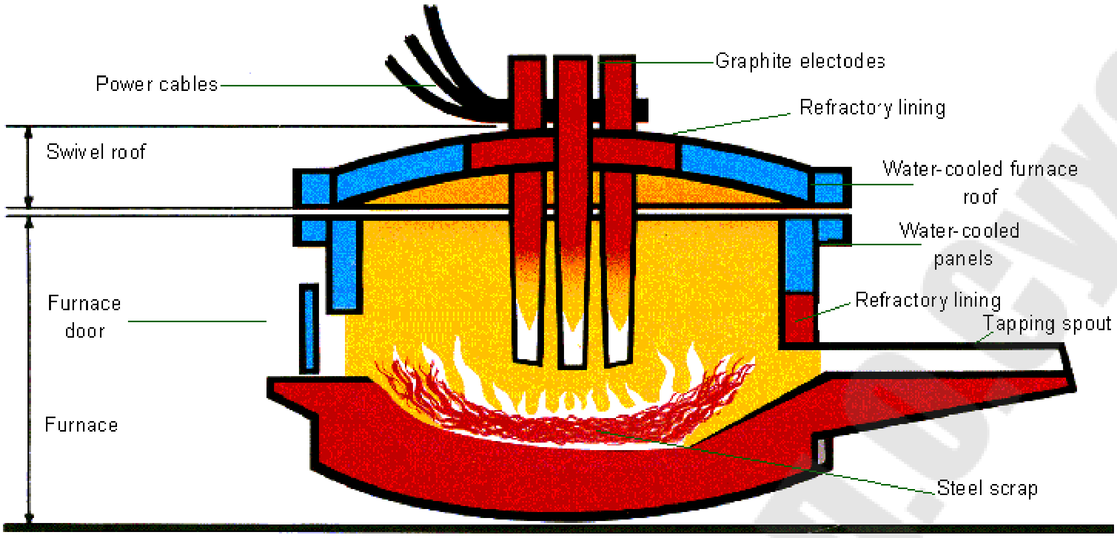
Electric arc furnace steelmaking is the manufacture of steel from scrap or direct reduced iron melted by electric arcs. In an electric arc furnace, a batch of steel may be started by loading scrap or direct reduced iron into the furnace, sometimes with a "hot heel" (molten steel from a previous heat). As in basic oxygen steelmaking, fluxes are also added to protect the lining of the vessel and help improve the removal of impurities. Electric arc furnace steelmaking typically uses furnaces of capacity around 100 tonnes that produce steel every 40 to 50 minutes for further processing.

The Electric Arc Furnace (EAF) uses only cold scrap metal. The process was originally used only for making high quality steel, such as those used for machine tools and spring steel, as it gave more precise control over the composition. Today, however, it is also employed in making more widely used steels, including alloy and stainless grades as well as some special carbon and low-alloy steels. Modern electric arc furnaces can make up to 150 tonnes of steel in a single melt.

The electric arc furnace consists of a circular bath with a movable roof, through which three graphite electrodes can be raised or lowered. At the start of the process, the electrodes are withdrawn and the roof swung clear. The steel scrap is then charged into the furnace. When charging is complete, the roof is swung back into position and the electrodes lowered into the furnace. A powerful electric current is passed through the charge, an arc is created, and the heat generated melts the scrap. Lime is added as fluxe and oxygen is blown into the melt. As a result, impurities in the metal combine to form a liquid slag.



The main steps in the EAF process



Comparison of BOF and EAF processes

N	Criterion for comparison	BOF	EAF
1	Main feed material	Hot metal	Cold scrap metal
2	Power for heating	Oxidation reaction energy	Electric power
3	Steelmaking time	15-20 min/350 tonn	40-50 min/100 tonn
4	Steel quality	Less quality steel	High quality steel

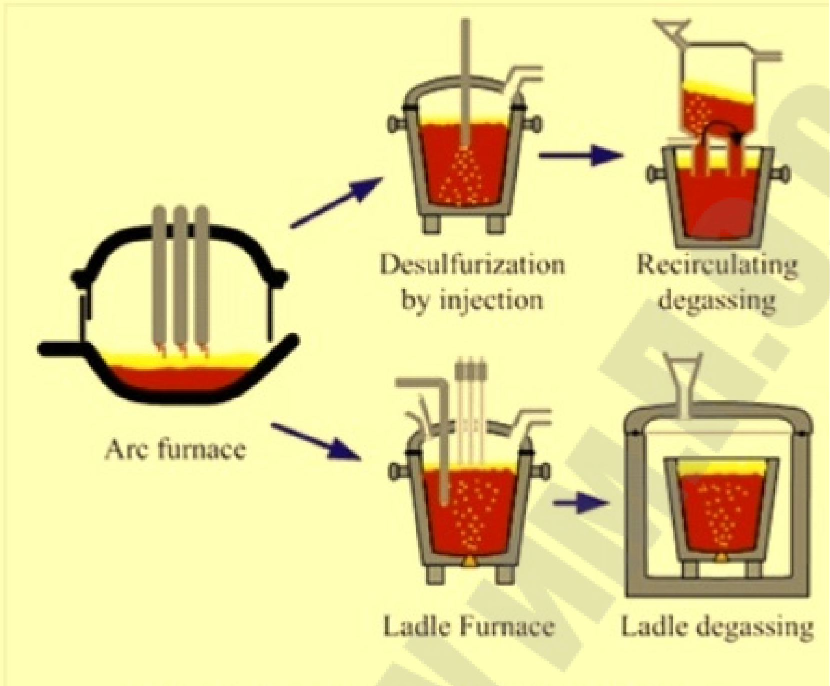
3.3. Ladle Furnace

After the molten metal is tapped into a ladle from the BOS furnace or EAF it is often given one or more extra treatment(s) depending upon the grade of steel required. These further refining stages are collectively known as secondary steelmaking and can include ladle stirring with argon, powder or wire injection, vacuum degassing and ladle arc heating. Some high-grade steels combine all of these treatments. These processes improve homogenisation of temperature and composition, allow careful trimming to precise compositions, remove harmful and unwanted gases such as hydrogen and reduce elements such as sulphur to very low levels.

Functions of a Ladle Furnace are:

- Homogenization of steel temperature and chemistry through inert gas stirring

- Alloy additions to provide demanded chemical composition
- Provide a means for deep desulphurization
- Provide a means for dephosphorization



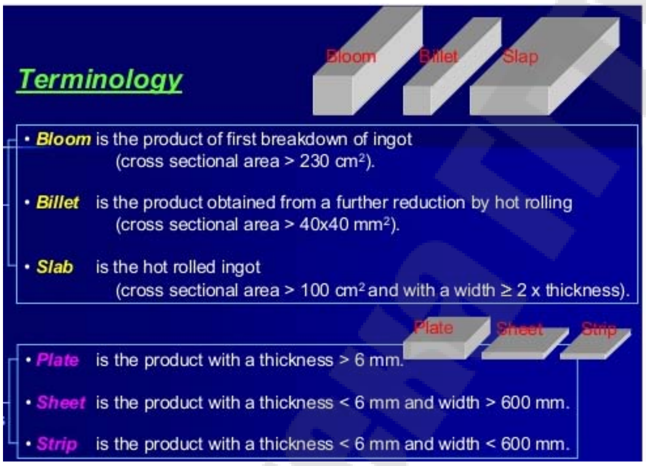
Some of the processes of ladle metallurgy

4. Steel making products

Steelworking plants (steel mills) produce steel semi-finished casting products such as ingots, blooms, slabs, billets which require a second procedure of shaping, such as cold/hot working, cutting. In principle, steel is formed into either flat products (slabs) or long products (blooms and billets).

An ingot is a piece of metal, that is cast into a shape suitable for further processing. In steelmaking it is the first step among semi-finished casting productsingots is the first step among semi-finished casting products. Ingots are large rough castings designed for storage and transportation. The shape usually resembles a rectangle or square with generous fillets. They are tapered, usually with the big-end-down.	

Blooms are long products which have a cross section with a 125 to 400 millimetres square. Common final products from blooms include structural shapes, rails, rods, and seamless pipes	
Billets are long products which have a cross section 50 to 125 millimetres square. In practice, they are not precisely distinguished by these dimensions, and there is considerable overlap in the use of the two terms (blooms and billets) Final products include bar stock and wire	
Slabs are flat products with 50 to 250 millimetres thick, 0.6 to 2.6 metres wide, and up to 12 metres long. Slabs are provided by either a continuous caster or rolled from ingots by a slabbing mill. Slabs are used for flat products rolling such as plates, strip and sheets. Common final products include sheet metal, plates, strip metal, pipes, and tubes.	



Terminology

- *Bloom* is the product of first breakdown of ingot (cross sectional area > 230 cm^2).
- *Billet* is the product obtained from a further reduction by hot rolling (cross sectional area > 40x40 mm^2).
- *Slab* is the hot rolled ingot (cross sectional area > 100 cm^2 and with a width ≥ 2 x thickness).

- *Plate* is the product with a thickness > 6 mm.
- *Sheet* is the product with a thickness < 6 mm and width > 600 mm.
- *Strip* is the product with a thickness < 6 mm and width < 600 mm.

5. Iron and steel making by-products

As with all large-scale manufacturing processes, the production or iron and steel generates by-products. On average the production of 1 tonne of steel results in 200 kg (EAF) to 400 kg (BF/BOF) of by-products.

1. The main by-product produced during iron and crude steel production is **slag** (90%). There are three main types of marketed ironmaking or BF slags, categorised by how they are cooled – air-cooled, granulated, and pelletised (or expanded).

Air-cooled slag is hard and dense and is especially suitable for use as construction aggregate. It is also used in ready-mixed concrete, concrete products, asphaltic concrete, road bases and surfaces, fill, clinker raw material, railroad ballast, roofing, mineral wool (for use as insulation) and soil conditioner.

Granulated slag forms sand-sized particles of glass and is primarily used to make cementitious material. Concretes incorporating granulated slag generally develop strength more slowly than concretes that contain only Portland cement – the most common type of cement – but can have better long-term strength, release less heat during hydration, have reduced permeability, and generally exhibit better resistance to chemical attack.

Pelletised or expanded slag has a vesicular texture (like volcanic rock) and is most commonly used as a lightweight aggregate. If finely ground, it also has cementitious properties.

Steelmaking slag (BOF and EAF) is cooled similarly to aircooled BF slag and is used for most of the same purposes. As the production process varies at this stage depending on the type of steel being made, the resulting slags also have diverse chemical properties making them more difficult to use than ironmaking slags. Some of the recovered slag is used internally in the steelmaking furnace or sinter plant, while approximately 50% of the recovered slag is used externally in construction applications, primarily roads.

2. **Gases** from iron-and steelmaking, once cleaned, are almost fully reused internally. Coke oven gas contains about 55% hydrogen and may prove an important hydrogen source in the future. It is fully reused within the steelmaking plant, and can provide up to 40% of the plant's power. The dust and sludge removed from the gases consist primarily of iron and can mostly be used again in steelmaking. Iron oxides that cannot be recycled internally can be sold to other industries for various applications, from Portland cement to electric motor cores.

Topic 5. Metallurgy: 3. Technologies of non-ferrous metals manufacturing

Key questions

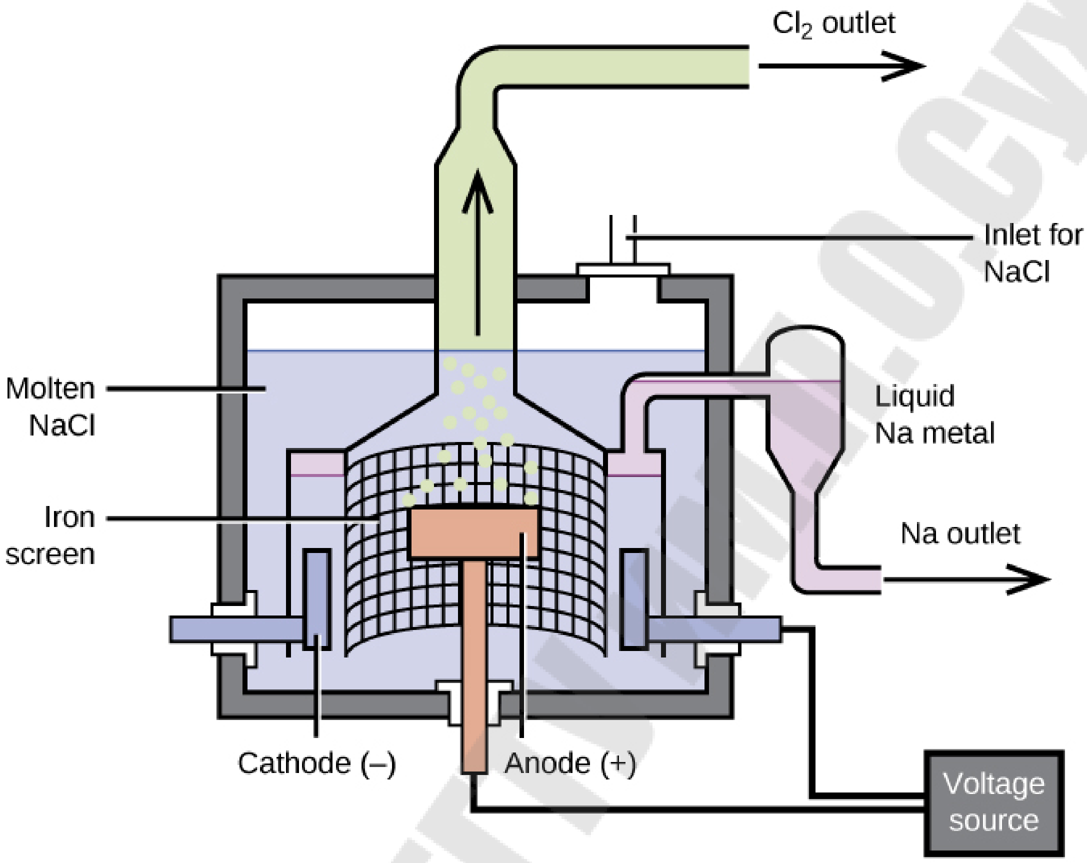
1 What is the name of technology for non-ferrous metals production?
2 What is electrometallurgy?
3 What is electrolysis?
4 Describe the electrolysis process.
5 Describe sodium production by electrolysis

Mojority of non-ferrous metals produces by electrowinning, also called electroextraction or electrometallurgy. Electrometallurgy is the process of reduction of metals from metallic compounds to obtain the pure form of metal using electrolysis. The most common electrowon metals are lead, copper, gold, silver, zinc, aluminium, chromium, cobalt, manganese, and the rare-earth an alkali metals. For aluminium, this is the only production process. Metals of the groups 1 and 2 (lithium, sodium, potassium, magnesium, calcium,..), along with aluminum, are very difficult to reduce; therefore, it is necessary to prepare these elements by electrolysis.

Electrolysis is a technique that uses a direct electric current (electrolytic cell) for elements separation. The voltage that is needed for electrolysis to occur is called the decomposition potential. Each electrode attracts ions that are of the opposite charge. Positively charged ions (cations) move towards the electron-providing (negative) cathode. Negatively charged ions (anions) move towards the electron-extracting (positive) anode.

In this process electrons are either absorbed or released. Neutral atoms gain or lose electrons and become charged ions that then pass into the electrolyte. The formation of uncharged atoms from ions is called discharging. When an ion gains or loses enough electrons to become uncharged (neutral) atoms, the newly formed atoms separate from the electrolyte. Positive metal ions like Cu^{++} deposit onto the cathode in a layer. Oxidation of ions or neutral molecules occurs at the anode. Reduction of ions or neutral molecules occurs at the cathode.

The most important method for the production of sodium is the electrolysis of molten sodium chloride. It is not possible to receive sodium by electrolysis of aqueous solutions of sodium salts because hydrogen ions are more easily reduced than are sodium ions; as a result, hydrogen gas forms at the cathode instead of the desired sodium metal. The high temperature required to melt NaCl means that liquid sodium metal forms.



The overall cell reaction: $NaCl \rightarrow Na^+ + Cl^-$. Sodium ions are reduced at the cathode to metal form.($Na^+ + e^- \rightarrow Na(s)$) Chlorine irons are oxidized at the anode and form gaseous chlorine ($2Cl^- - 2e^- \rightarrow Cl_2(g)$). The liquid sodium, which is less dense than molten sodium chloride, floats to the surface and flows into a collector. The gaseous chlorine goes to storage tanks.

Topic 6. Metalworking Technologies 1. Casting

Key questions

1. What are the general metalworking technologies?
2. Casting. Definition
3. How old casting process is?
4. Advantages of casting
5. Disadvantages of casting
6. Principle steps in casting
7. What furnaces are used for casting?
8. What does the pattern mean?
9. What do you know about pattern making?
10. What do you know about core making?
11. What is mold?
12. How molds can be classified?
13. What do you know about mold making?
14. What are the names of two parts of the mold?
15. Explain one-part molding technique.
16. Explain two-part molding technique
17. Explain two-part molding technique with patterns which loose pieces
18. Explain multiple-part molding technique
19. How metal is poured into a mold?
20. What do you know about casting removal and cleaning after metal solidification?
21. What two main branches of casting can be distinguished by the basic nature of the mold they employed?
22. Expendable Mold. Advantages and Disadvantages
23. Non-expendable Mold. Advantages and Disadvantages
24. What techniques include expendable mold casting?
25. What techniques include non-expendable mold casting?
26. Advantages and Disadvantages of sand casting
27. Sand mold composition
28. Main types of molds used in sand casting
29. Characteristics and properties of green sand molds
30. Characteristics and properties of dry sand molds
31. Characteristics and properties of skin dried molds

General metalworking technologies are casting, forming, cutting, and, joining. Each of these categories contain various processes.

Casting

Casting is a process in which a molten metal flows by gravity or other force into a mold (form for liquid metal) where it solidifies in the shape of the mold cavity.

The term “casting” also applies to the part made in the process.

Casting processes have been known for thousands of years, and have been widely used for sculpture and jewellery. Traditional techniques include lost-wax casting and sand casting.

Advantages of casting:

- All variety of metal can be cast (ductile and brittle). Especially casting is used for making goods from brittle metals part that is impossible to make by other methods.
- Casting can be used for making very complex geometry parts with internal cavities and hollow sections that would be difficult or uneconomical to make by other methods.
- Casting can be used for making any size metal parts. Especially casting is used for making big size metal part that would be impossible to make by other methods.

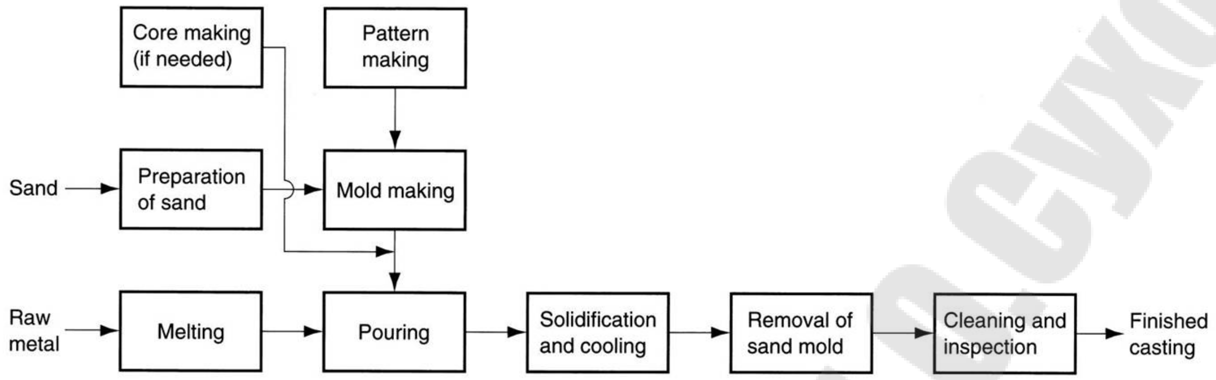
Disadvantages of casting:

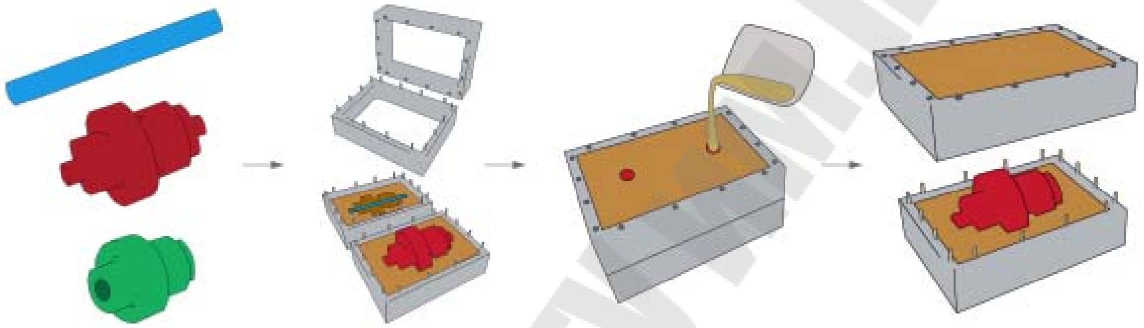
- Limitations on mechanical properties. Casting defects such as gas porosity (bubbles), shrinkage defects due to undesired irregularity in a metal casting process decrease goods quality
- Poor dimensional accuracy and surface finish for same processes, e.g. sand casting
- Safety hazards to workers due to hot molten metals
- Environmental problems

Principle steps in casting are:

1. Metal melting
2. Pattern making
3. Core making (if needed)
4. Mold making
5. Metal pouring into a mold

6. Casting removal and cleaning after metal solidification (by breaking away the mold)





Pattern's production

Mould's production, realized in foundry sand contained in metal frame

Casting

Checkout (*dismantling of mould, feedheads cutting, clening of casting surface*).

The first step. Metal melting

A furnace is used to melt the metals in initial stage of the casting process. There are different types of melting furnaces used in casting, and each furnace uses various technology. Main types of melting furnaces are cupola furnace, induction furnace and open hearth furnace (an oxygen-based furnace or an electric arc furnace). But also used another types of furnaces as propane and microwave furnaces.

Cupola Furnace

This type of high, cylindrically shaped furnace is one of the oldest melting furnaces used in casting applications. The inside of the cupola is lined up with clay, bricks, or blocks, that protect the inside of the furnace from higher levels of heat, abrasion, and even oxidation. For melting the metal, foundry operators put several layers of ferroalloys, coke and limestone in the furnace. The sedimentary rock used as a construction material will react with the metal, which makes the impurities in the furnace to float up to melting metal's surface.

Induction Furnace

As the name implies, these melting furnaces use induction technology with alternating electric currents to apply the required heat to melt the metal. The electric furnace used for melting metals makes the process energy efficient when compared to other types of melting furnaces. Most of the global foundries use induction furnace instead of the cupola to melt brass or cast iron. Besides that, induction furnaces are preferable for melting steel, iron, aluminum, and copper. The furnace can melt from less than 1 kg range to up to 100 tons

Open Hearth Furnace

Foundries use the hearth furnace to melt nonferrous metals in smaller quantities. It uses heavy oil or natural gas in order to create heat with which to melt the material. The hearth furnace is used primarily in industrial applications as an oxygen-based furnace or an electric arc furnace.

Propane Furnace

Open-flame propane furnaces are a great alternative to electric furnaces. They do not require any power and can be used on the go. Offered in a range of sizes, and they are excellent for melting gold, silver, copper, brass, aluminum, and other metals.

Microwave Furnace

A uniquely designed furnace that allows to melt material right in a standard 1200 watt microwave. Excellent for refining or purifying gold or silver.

The second step. Pattern Making

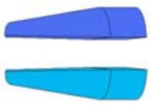
The pattern is a geometric replica of the metal casting to be produced. Patterns have to be exactly the shape of the finished item. It is made slightly oversize to compensate for the shrinkage that will occur in the metal during the casting's solidification. The material from which the pattern is made is dependent upon the type of mold and metal casting process, the casting's geometry and size, the dimensional accuracy required, and the number of metal castings to be manufactured using the pattern. Patterns can be made from wood, like pine (softwood), or mahogany (hardwood), various plastics, or metal, like aluminum, cast iron, or steel. In most manufacturing operations, patterns will be coated with a parting agent to ease their removal from the mold. Patterns can be re-used to make more moulds and, if looked after, can last for many years making thousands of moulds. Any irregularity or mistake will be reproduced in the casting.

A few different types of patterns may be used in the sand casting process.

Solid Pattern: This is a one piece pattern representing the geometry of the casting. It is an easy pattern to manufacture, but determining the parting line between cope and drag is more difficult for the foundry worker.

SOLID PATTERN

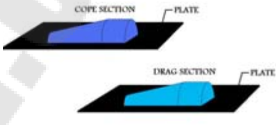
Split Pattern: The split pattern is comprised of two separate parts that when put together will represent the geometry of the casting. When placed in the mold properly the plane at which the two parts are assembled should coincide with the parting line of the mold. This makes it easier to manufacture a pattern with more complicated geometry. Also mold setup is easier since the patterns placement relative to the parting line of the mold is predetermined.



SPLIT PATTERN

MATCH PLATE PATTERN

Match Plate Pattern: The match plate pattern is typically used in high production industry runs for sand casting manufacture. A match plate pattern is a two piece pattern representing the casting, divided at the parting line, similar to the split pattern. In the match plate pattern, however, each of the parts is mounted on a plate. The plates come together to assemble the pattern for the sand casting process. The match plate pattern is more proficient and makes alignment of the pattern in the mold quick and accurate.



COPE AND DRAG PATTERN

Cope and Drag Pattern: The cope and drag pattern is also typical in sand casting processes for high production industry runs. The cope and drag pattern is the same as the match plate pattern in that it is a two piece pattern representing the casting and divided at the parting line. Each of the two halves is mounted on a plate for easy alignment of the pattern and mold. The difference between the cope and drag pattern and the match plate pattern is that in the match plate pattern the two halves are mounted together, where as in the cope and drag pattern the two halves are separate. The cope and drag pattern enables the cope section of the mold and the drag section of the mold to be created separately and latter assembled before the pouring of the sand casting.

The third step. Core making

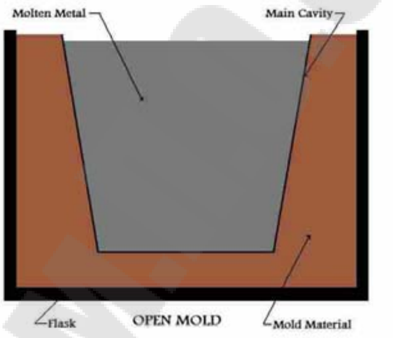
Cores form the internal geometry of the casting. Cores are placed in the mold, and remain there during the pouring phase of the sand casting process. The metal casting will solidify around the core. Core basics are covered in detail in the cores section. Cores are made of the highest quality sand and are subject to extreme conditions during the sand casting operation. Cores must be strong and permeable; also, since the metal casting will shrink onto the core, cores must have sufficient collapsibility. Sometimes a reinforcing material will be placed in a sand casting core to enhance strength. The core may be manufactured with vents to facilitate the removal of gases.

The fourth step. Mould Making

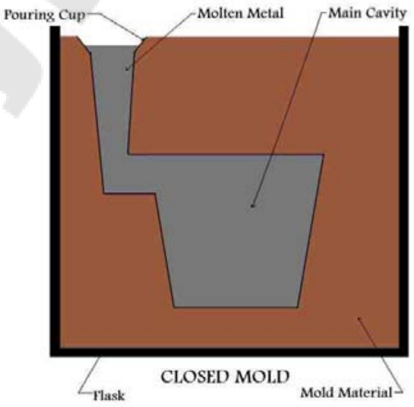
A mold or mould is a hollowed-out block that is filled with a liquid metal. A mold is the counterpart to a casting and it is formed into the geometric shape of a desired part. When molten metal is poured into the mold, the mold has to hold this liquid in shape as it solidifies. While liquid metal hardens inside the mold it adopts its shape.

Molds can be classified as either open or closed.

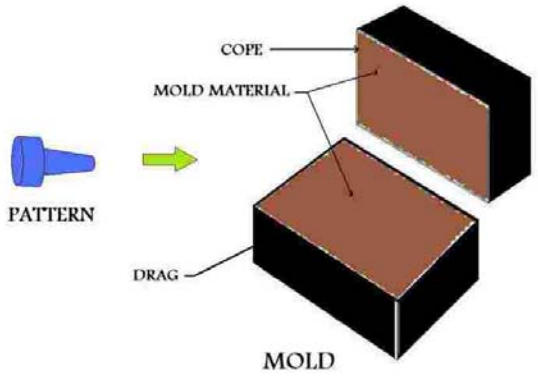
An open mold is a container, like a cup, that has only the shape of the desired part. The molten material is poured directly into the mold cavity which is exposed to the open environment. This type of mold is rarely used in manufacturing production.

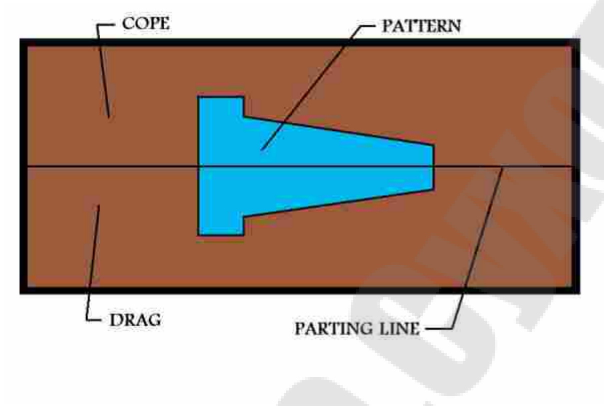


The other type of mold is a closed mold, it contains a delivery system for the molten material to reach the mold cavity, where the part will harden within the mold. Example of closed mold is shown in figure The closed mold is, by far, more important in manufacturing metal casting operations.

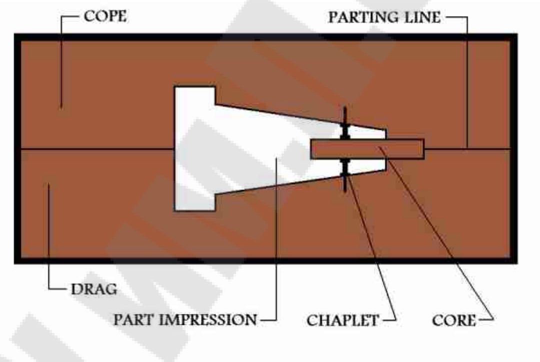


A typical mold is shown in figure. The pattern is placed in the mold and the mold material is packed around it. The mold contains two parts, the drag (bottom), and the cope (top). The parting line between the cope and drag allows for the mold to be opened and the pattern to be removed once the impression has been made.

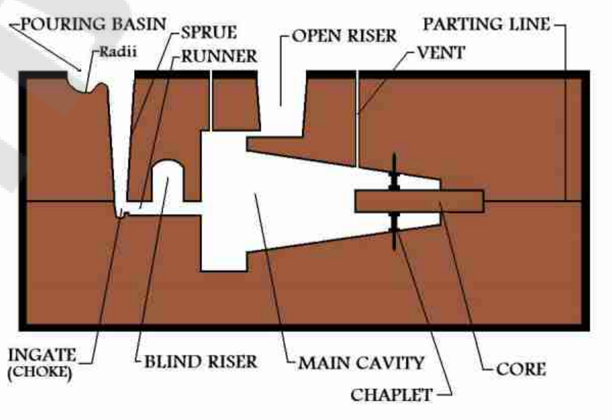




The core is placed in the metal casting after the removal of the pattern. Figure shows the pattern impression with the core in place. Now the impression in the mold contains all the geometry of the part to be cast.



In order for this mold to be functional to manufacture a casting, in addition to the impression of the part, the mold cavity will also need to include a gating system. Sometimes the gating system will be cut by hand or in more adept manufacturing procedures, the gating system will be incorporated into the pattern along with the part. Basically, a gating system functions during the metal casting operation to facilitate the flow of the molten material into the mold cavity.



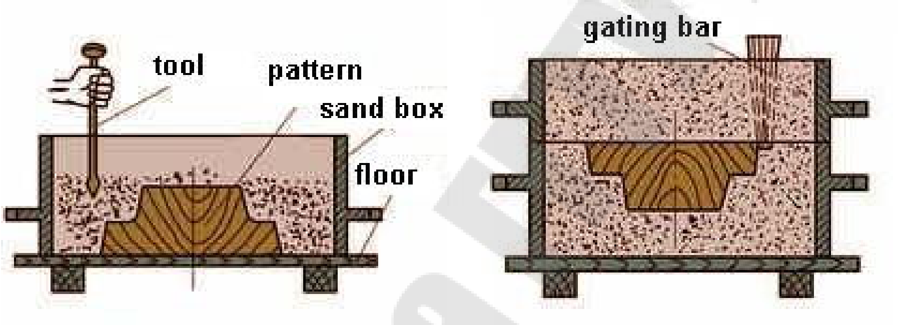
GATING SYSTEM FOR CASTING

Pouring Basin: This is where the molten metal employed to manufacture the part enters the mold. The pouring basin should have a projection with a radius around it to reduce turbulence. **Down Sprue:** From the pouring basin, the molten metal for the casting travels through the down sprue. This should be tapered so its cross-section is reduced as it goes downward. **Sprue Base:** The down sprue ends at the sprue base. It is here that the casting's inner cavity begins. **Ingate/Choke Area:** Once at the sprue base, the molten material must pass through the ingate in order to enter the inner area of the mold. The ingate is very important for flow regulation during the metal casting operation. **Runners:** Runners are passages that distribute the liquid metal to the different areas inside the mold. **Main Cavity:** The impression of the actual part to be cast is often referred to as the main cavity. **Vents:** Vents help to assist in the escape of gases that are expelled from the molten metal during the solidification phase of the metal casting process. **Risers:** Risers are reservoirs of molten material. They feed this material to sections of the mold to compensate for shrinkage as the casting solidifies.

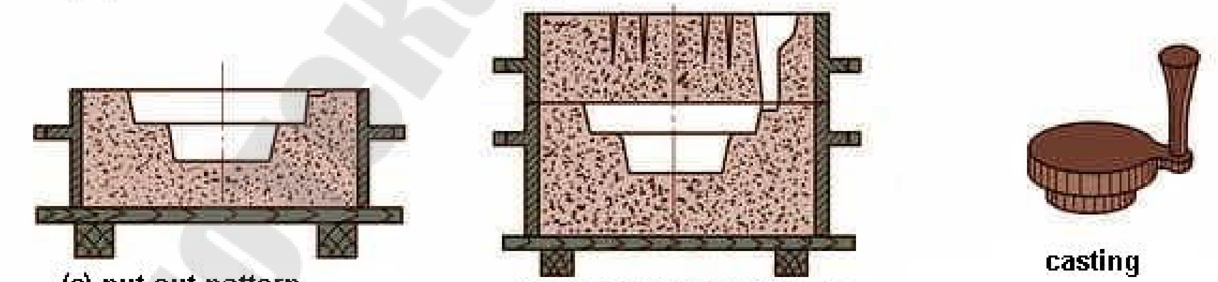
In dependence on sample geometry different molding techniques can be used.

1. <u>One-part molding</u>

When the largest cross section of casting parts is located on the top position, then this position could be used as the parting surface, and the pattern could be made as a whole part.



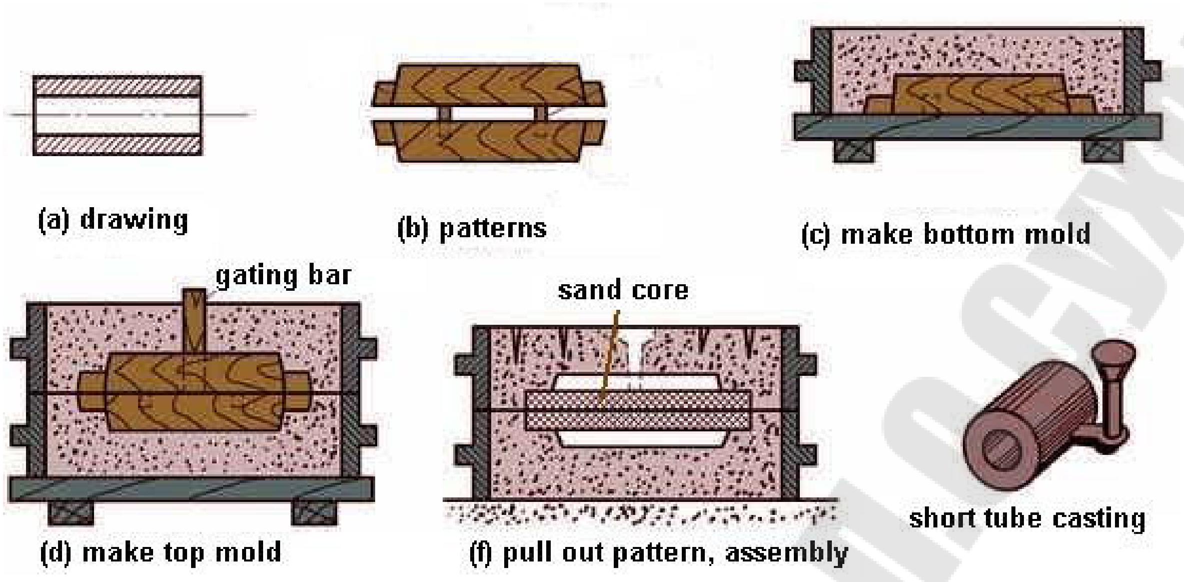
(a) make bottom mold (b) make top mold



(c) put out pattern (d) assemble sand boxes

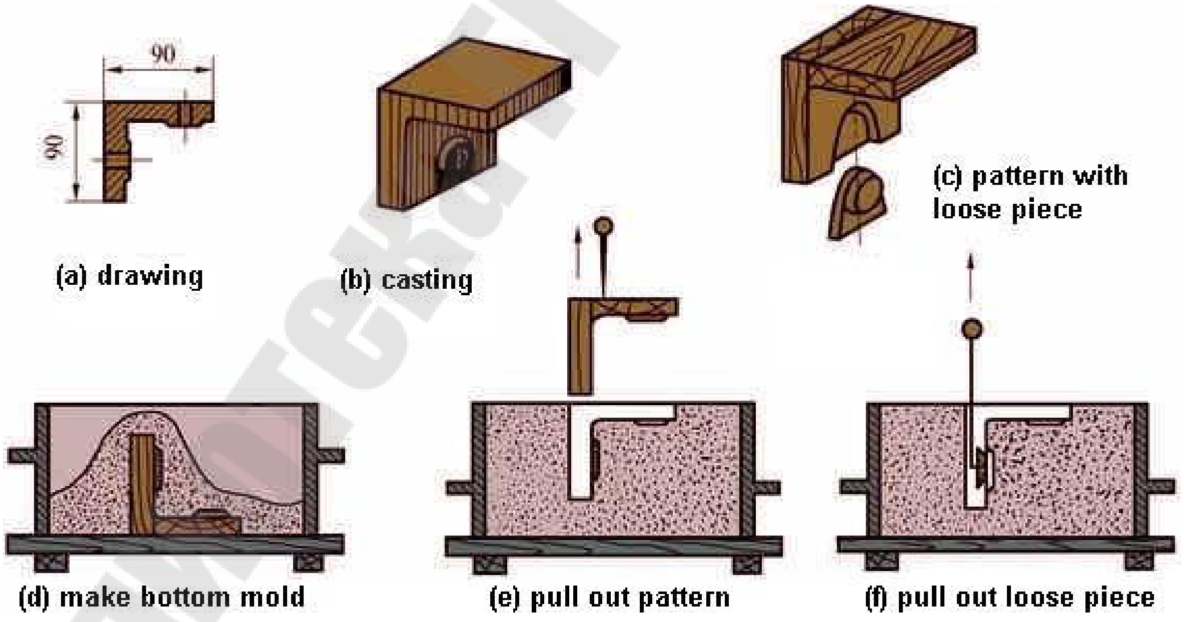
2. <u>Two-parts molding</u>

The patterns could be designed as two separated parts, and could be assembled with stop bolts as following.



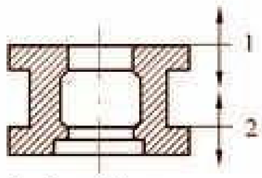
3. <u>Two-parts molding with patterns which loose pieces</u>

If the side face of casting affects the draft of patterns, then we can make some loose pieces fixed on the patterns. So, after molding, we can pull out the main part of patterns firstly, then pull out the loose pieces. This molding method requests to make the sand very tight, otherwise, when pull out the main patterns, the loose pieces may damage the nearby sand molds. This method is only suitable for producing small amount of castings.

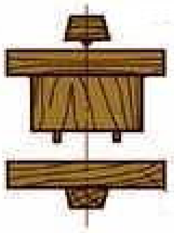


4. Multiple-part molding

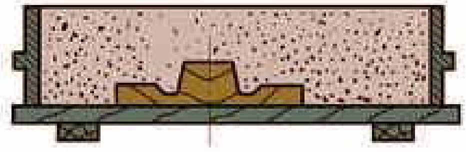
Three part molding is also called as multiple-part molding, which will use three or more sand boxes (flasks) to produce one casting. If the two ends of casting have larger cross sections than middle position, then two-part molding will not be able to produce it. The following is the molding diagram for scored pulley casting by three part molding method.



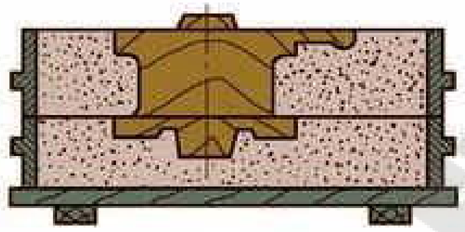
(a) casting



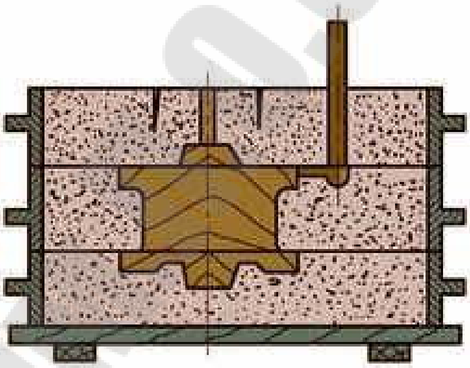
(b) patterns



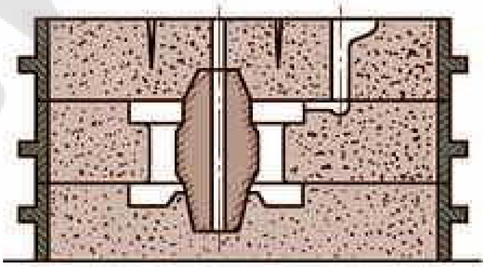
(c) make bottom mold



(d) make middle mold



(e) make top mold



(e) pull out pattern, put in sand core

<u>The fifth step. Metal pouring into a mold</u> Pouring can be accomplished with gravity, or it may be assisted with a vacuum or pressurized gas. Many modern foundries use robots or automatic pouring machines to pour molten metal. Traditionally, molds were poured by hand using ladles.

The sixth step. Casting removal and cleaning after metal solidification (by breaking away the mold)

The solidified metal component is then removed from its mold. Where the mold is sand based, this can be done by shaking or tumbling. This frees the casting from the sand, which is still attached to the metal runners and gates — which are the channels through which the molten metal traveled to reach the component itself.

Degating is the removal of the heads, runners, gates, and risers from the casting. Runners, gates, and risers may be removed using cutting torches, bandsaws, or ceramic cutoff blades. For some metal types, and with some gating system designs, the sprue, runners, and gates can be removed by breaking them away from the casting with a sledge hammer or specially designed knockout machinery. Risers must usually be removed using a cutting method (see above) but some newer methods of riser removal use knockoff machinery with special designs incorporated into the riser neck geometry that allow the riser to break off at the right place.

The gating system required to produce castings in a mold yields leftover metal — including heads, risers, and sprue (sometimes collectively called sprue) — that can exceed 50% of the metal required to pour a full mold. Since this metal must be remelted as salvage, the yield of a particular gating configuration becomes an important economic consideration when designing various gating schemes, to minimize the cost of excess sprue, and thus overall melting costs.

After degating and heat treating, sand or other molding media may remain adhered to the casting. To remove any mold remnants, the surface is cleaned using a blasting process. This means a granular media will be propelled against the surface of the casting to mechanically knock away the adhering sand. The media may be blown with compressed air, or may be hurled using a shot wheel. The cleaning media strikes the casting surface at high velocity to dislodge the mold remnants (for example, sand, slag) from the casting surface. Numerous materials may be used to clean cast surfaces, including steel, iron, other metal alloys, aluminium oxides, glass beads, walnut shells, baking powder, and many others. The blasting media is selected to develop the color and reflectance of the cast surface. Terms used to describe this process include cleaning, bead blasting, and sand blasting. Shot peening may be used to further work-harden and finish the surface.

The final step in the process of casting usually involves grinding, sanding, or machining the component in order to achieve the desired dimensional accuracies, physical shape, and surface finish.

Removing the remaining gate material, called a gate stub, is usually done using a grinder or sander. These processes are used because their material removal rates are slow enough to control the amount of material being removed. These steps are done prior to any final machining.

After grinding, any surfaces that require tight dimensional control are machined. Many castings are machined in CNC (computer numerical control) milling centers. The reason for this is that these processes have better dimensional capability and repeatability than many casting processes. However, it is not uncommon today for castings to be used without machining.

A few foundries provide other services before shipping cast products to their customers. It is common to paint castings to prevent corrosion and improve visual appeal. Some foundries assemble castings into complete machines or sub-assemblies. Other foundries weld multiple castings or wrought metals together to form a finished product.

More and more, finishing processes are being performed by robotic machines, which eliminate the need for a human to physically grind or break parting lines, gating material, or feeders. Machines can reduce risk of injury to workers and lower costs for consumables — while also increasing productivity. They also limit the potential for human error and increase repeatability in the quality of grinding.

Two main branches of casting can be distinguished by the basic nature of the mold they employ. There is expendable mold casting which includes sand, plastic, shell, plaster, and investment (lost-wax technique) moldings and permanent mold casting which includes at least four different methods: permanent, die, centrifugal, and continuous casting. As the name implies, expendable molds are used for only one metal casting while permanent molds are used for many. When considering manufacturing processes, there are advantages and disadvantages to both.

Expendable Mold

Advantages

- More cheap
- More complicated geometries are possible for casting

Disadvantages

- Can produce only one metal casting because mold that metal solidifies in must be destroyed to remove casting
- Lower production rate

Permanent Mold

Advantages

- Can produce many metal casting
- Higher production rate

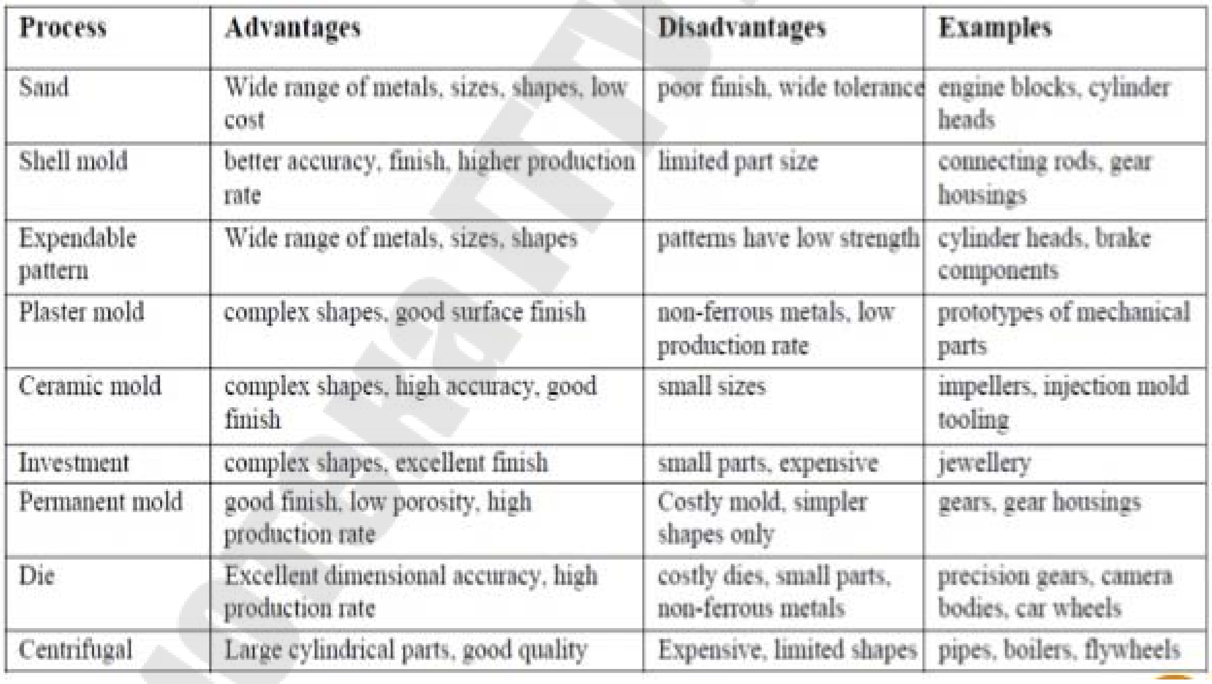
Disadvantages

- More expansive
- Can manufacture many metal castings
- Complicated geometries are not possible for casting due to mold has sections that can open or close, permitting removal of the casting. This need to open mold limits part shapes

<table>
<tr><th colspan="4">Expendable mold casting</th><th colspan="2" rowspan="2">Non-expendable mold casting (permanent mold)</th></tr>
<tr><td colspan="2">Non-expendable pattern</td><td colspan="2">Expendable pattern</td></tr>
<tr><td rowspan="6">Water and clay bond</td><td>Green sand mold</td><td rowspan="2">Evaporative pattern</td><td>Lost foam</td><td rowspan="4">Die casting</td><td>Squeeze casting</td></tr>
<tr><td>Dry sand mold</td><td>Full mold</td><td>Slush casting</td></tr>
<tr><td>Skin dry sand mold</td><td colspan="2" rowspan="4">Investment</td><td>Low pressure</td></tr>
<tr><td>Floor and pit sand mold</td><td>High pressure</td></tr>
<tr><td>Loam mold</td><td rowspan="2">Centrifugal</td><td>Centrifuging casting</td></tr>
<tr><td>High pressure mold</td><td>Semi – Centrifugal casting</td></tr>
</table>

Resin bond	Shell mold			True-Centrifugal casting
	Hot box		Vacuum casting	
	Cold box		Chill casting	
Silicate bond	Ceramic mold - Unicast process - Shaw process		Continuous casting	
	CO_2 process			
No bond	V process			

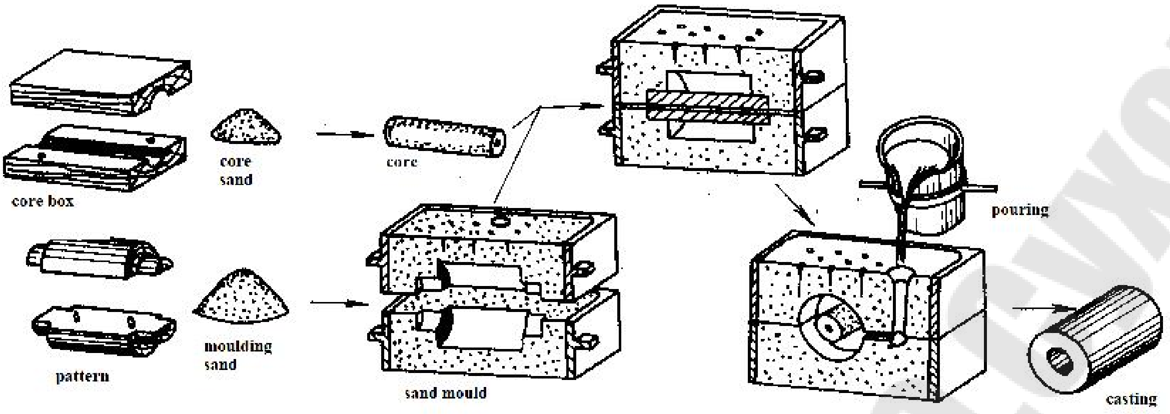
Comparison metal casting techniques



Process	Advantages	Disadvantages	Examples
Sand	Wide range of metals, sizes, shapes, low cost	poor finish, wide tolerance	engine blocks, cylinder heads
Shell mold	better accuracy, finish, higher production rate	limited part size	connecting rods, gear housings
Expendable pattern	Wide range of metals, sizes, shapes	patterns have low strength	cylinder heads, brake components
Plaster mold	complex shapes, good surface finish	non-ferrous metals, low production rate	prototypes of mechanical parts
Ceramic mold	complex shapes, high accuracy, good finish	small sizes	impellers, injection mold tooling
Investment	complex shapes, excellent finish	small parts, expensive	jewellery
Permanent mold	good finish, low porosity, high production rate	Costly mold, simpler shapes only	gears, gear housings
Die	Excellent dimensional accuracy, high production rate	costly dies, small parts, non-ferrous metals	precision gears, camera bodies, car wheels
Centrifugal	Large cylindrical parts, good quality	Expensive, limited shapes	pipes, boilers, flywheels

Sand casting

Sand casting is the most widely used metal casting process in manufacturing.



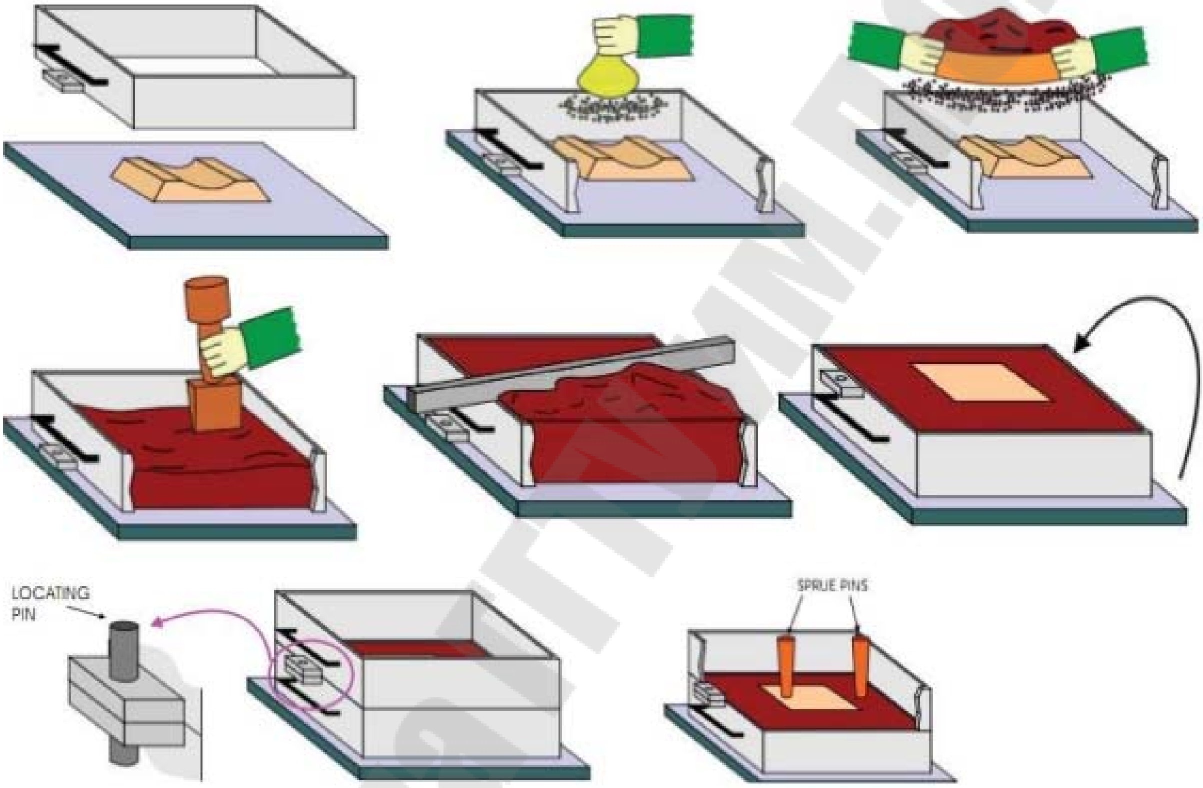
Advantages: Almost all casting metals can be sand cast. Sand castings can range in size from very small to extremely large. Some examples of items manufactured in modern industry by sand casting processes are engine blocks, machine tool bases, cylinder heads, pump housings, and valves, and many others. Most sand casting operations use silica sand (SiO_2). Silica sand usually has the ability to withstand extremely high temperature levels, and generally allows the escape of gases quite well. Due to sand is very resistant to elevated temperatures sand casting is one of the few processes that can be used for metals with high melting temperatures such as steels, nickel, and titanium. Manufacturing with sand casting allows the creation of castings with complex geometry. A great advantage of sand in manufacturing applications is that sand is inexpensive.

Sand mold composition: A mold must have the physical integrity to keep its shape throughout the casting operation. For this reason, in sand casting, the sand must contain some type of binder that acts to hold the sand particles together. Clay serves an essential purpose in the sand casting manufacturing process, as a binding agent to adhere the molding sand together. In manufacturing industry other agents may be used to bond the molding sand together in place of clay. Organic resins, (such as phenolic resins), and inorganic bonding agents, (such as phosphate and sodium silicate), may also be used to hold the sand together. In addition to sand and bonding agents, the sand mixture to create the metal casting mold will sometimes have other constituents added to it in order to improve mold properties

Main types of molds used in sand casting

Type	Characteristics	Properties
Green Sand Molds	A green sand mold is very typical in sand casting manufacture, it is simple and easy to make, a mixture of sand, clay and water. A typical mixture by volume could be 89% sand, 4% water, 7% clay. The term "*green*" refers to the fact that the mold will contain moisture during the pouring of the casting.	- Has sufficient strength for most sand casting applications - Good collapsibility - Good permeability - Good reusability - Least expensive of the molds used in sand casting manufacturing processes - Moisture in sand can cause defects in some castings, dependent upon the type of metal used in the sand casting and the geometry of the part to be cast.
Dry Sand Molds	Dry sand molds are baked in an oven, (at 300F - 650F for 8-48 hours), prior to the sand casting operation, in order to dry the mold. This drying strengthens the mold, and hardens its internal surfaces. Dry sand molds are manufactured using organic binders rather than clay.	- Better dimensional accuracy of sand cast part than green sand molds - Better surface finish of sand cast part than green sand molds - More expensive manufacturing process than green sand production - Manufacturing production rate of castings are reduced due to drying time - Distortion of the mold is greater, (during mold manufacture) - The metal casting is more susceptible to hot tearing because of the lower collapsibility of the mold - Dry sand casting is generally limited to the manufacture of medium and large castings
Skin Dried Molds	When sand casting a part by the skin dried mold process a green sand mold is employed, and its mold cavity surface is dried to a depth of .5 - 1 inch. Drying	- The cast part dimensional and surface finish advantages of dry sand molds are partially achieved - No large oven is needed - Special bonding materials must be added to the sand mixture to

	is a part of the manufacturing process and is accomplished by use of torches, heating lamps or some other means, such as drying it in air	strengthen the mold cavity surface



STEPS OF SAND CASTING

Topic 6. Metalworking Technologies. 2.1 Bulk Metal Forming

Key questions

1 What are the general metalworking technologies?
2 Metal Forming advantages
3 Metal Forming disadvantages
4 Metal Forming classification
5 What are the main bulk forming technologies?
6 Definition to rolling process
7 What flat rolling products do you know?
8 What long rolling products do you know?
9 Types of Rolling Based on work piece geometry
10 Types of Rolling Based on work temperature
11 Types of Rolling Based on Roll configurations in rolling mills
12 Types of Rolling Based on rolling processes
13 Rolling equipment
14 Definition to forging process
15 Metal Forging advantages
16 Metal Forging disadvantages
17 Types of forging based on work temperature
18 Types of forging on the basis of the deformation mechanism
19 Types of forging based on shape of the die
20 Open Die and Closed Die Forging Process in Comparison
21 Types of forging based on forging operations
22 Forging equipment
23 Definition to extrusion process
24 Metal extrusion advantages
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28 Definition to drawing process
29 Drawing, extrusion and rolling processes in comparison
30 Drawing applications
31 Metal drawing advantages
32 Metal drawing disadvantages
33 Types of drawing processes
34 Drawing equipments and tools

General metalworking technologies are casting, forming, cutting, and, joining. Each of these categories contain various processes.

Metal Forming

Metal Forming is the metalworking process of metal parts (or objects) formation through mechanical or plastic deformation. The workpiece is reshaped without adding or removing material, and its mass remains unchanged.

Plastic deformation involves using pressure (sometimes with heat) to make a workpiece more conductive to mechanical force. Historically, this and casting were done by blacksmiths, though today the process has been industrialized. In bulk metal forming, the workpiece is generally heated up.

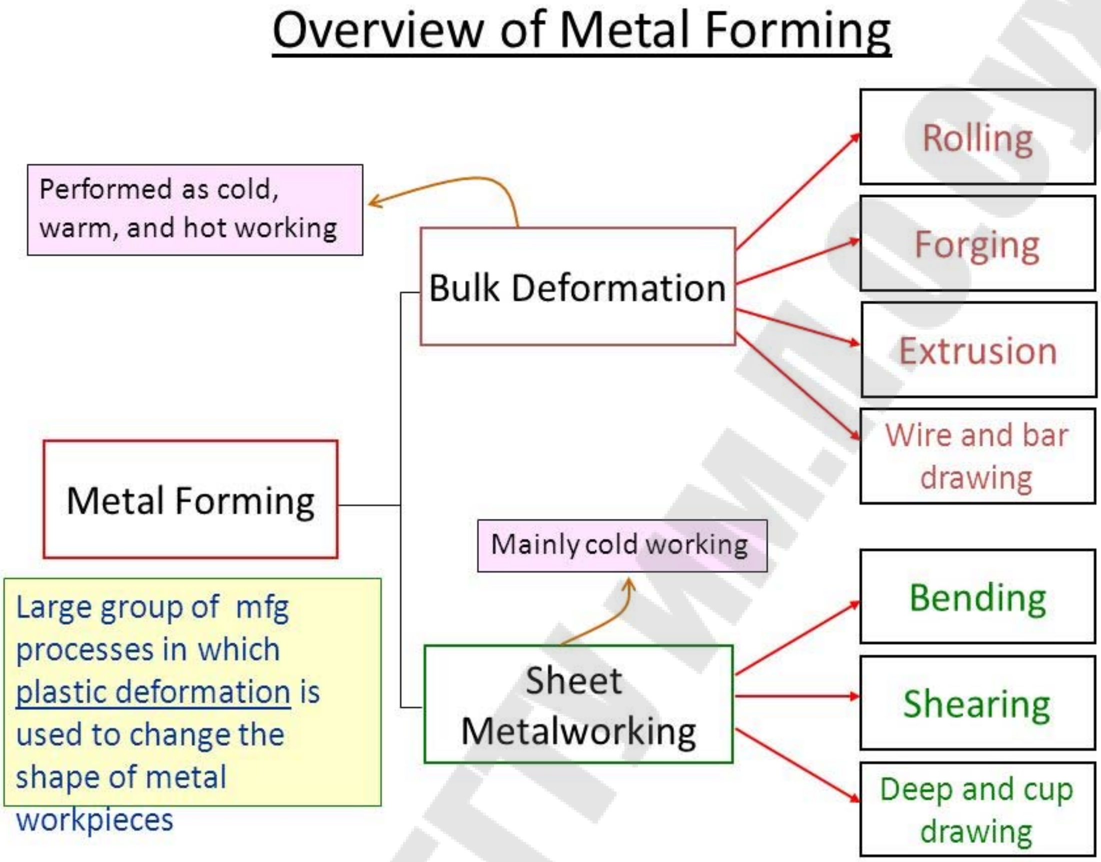
Advantages

- Forming technologies produce parts with superior mechanical properties (Superior technical end-product quality).
- High speed technologies (Higher product output per minute: up to 300 products per minute).
- Cost-effective technologies (especially when large numbers of parts have to be produced).
- Technologies with a minimum of waste or even none at all.
- Over 50% reduction of energy consumption and CO_2 emissions.

Disadvantages

- Material limitation: forming technologies are used for making goods only from ductile metals. Brittle metals part is impossible to make by metal forming methods.
- Geometrical shape limitation: forming technologies cannot be used for making very complex geometry parts with internal cavities and hollow sections
- Size limitation: forming technologies cannot be used for making big size metal parts

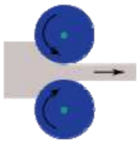
Classification. Metal Forming is a large group of technologies which is subdivided into two main categories: bulk forming process (bulk deformation) and sheet forming processes. At bulk deformation the work formed has a low surface area to volume ratio. In sheet metal working, the metal being processed will have a high surface area to volume ratio. Also metal forming technologies can be classified on the base of temperature used under cold, warm and hot technologies.



1. Bulk forming processes

At bulk deformation the work formed has a low surface area to volume ratio. Bulk forming technologies can be classified under several major groups: Rolling, Forging, Extrusion, Drawing.

1.1. Rolling



Rolling is a bulk deformation process with roll using. Rolling is a bulk deformation process in which the thickness of the work is reduced by compressive forces exerted by two opposing rolls. The rolls rotate to pull and simultaneously squeeze the work between them

1.1.1. Rolled products

1.1.1.1. Flat rolled products

Flat products include plates, hot-rolled strip and sheets, and cold-rolled strip and sheets; all have a great variety of surface conditions. They are rolled from slabs, which are considered a semifinished product and are normally not sold. Provided by either a continuous caster or rolled from ingots by a slabbing mill, slabs are 50 to 250 millimetres thick, 0.6 to 2.6 metres wide, and up to 12 metres long (that is, 2 to 10 inches thick, 24 to 104 inches wide, and up to 40 feet long).

C	T	P	T	P	T	P
Hot metal	casting	ingot	–	–	rolling	strip
			rolling	slab		sheets
	continuous casting	-	–			plates

Plates are hot-rolled either from slabs or directly from ingots. Maximum dimensions vary with available slab sizes or ingot weights and with the sizes of installed rolling mills and auxiliary equipment. Thickness can be as low as 5 millimetres, but it is usually heavier (*e.g.,* 25 millimetres) and can go as high as 200 millimetres. The width of plates is usually between 1.5 to 3.5 metres, but there are plants that can roll plates up to 5.5 metres wide. The maximum plate length that the largest mills can produce is 35 metres. Plates are usually made in small quantities and to a customer's specification, with different dimensions and tolerances for flatness, profile, straightness, and other properties. The edges can be ordered in either as-rolled condition or sheared, machined, or gas-cut. Plates are also sometimes cladded with corrosion-resistant sheets.

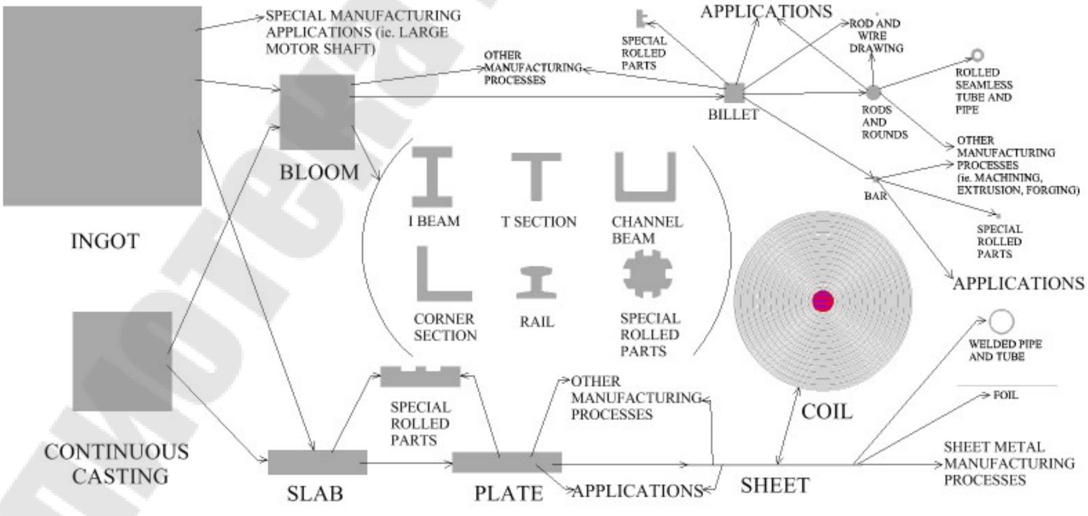
Hot-rolled strip is often shipped directly from the hot-strip mill in a large coil weighing 10 to 35 tons. Its thickness is 1.5 to 12 millimetres, and its width, depending on the available mill, is 0.7 to 2 metres. Frequently, the large coils are slit into narrower coils or edge trimmed, or they are cut to length into sheets at the finishing section of a steel plant or at a service centre. Coils and sheets are shipped either with the hot-rolled surface or with the scale removed and the surface oiled.

Cold-rolled strip, produced from hot-rolled strip, is 0.1 to 2 millimetres thick and also up to 2 metres wide, depending on a shop's facilities. Steel plants supply this product in coils or sheets, the latter being cut on special shear lines. Cold-rolled products are available in a great variety of surface conditions, often with a specific roughness, electrolytically cleaned, chemically treated, oiled, or coated with metals such as zinc, tin, chromium, and aluminum or with organic substances. They are usually produced to strict dimensional tolerances in order to assure efficient performance in the highly demanding operations of automated consumer-products industries.

1.1.1.2. Long rolled products

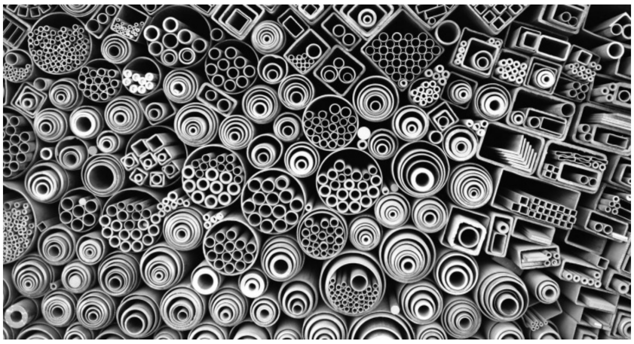
Long products are made of either blooms or billets, which are, like slabs, considered a semifinished product and are cast by a continuous caster or rolled at a blooming mill. Billets have a cross section50 to 125 millimetres square, and blooms are 125 to 400 millimetres square. In practice, they are not precisely distinguished by these dimensions, and there is considerable overlap in the use of the two terms.

C	T	P	T	P	T	P	T	P
Hot metal	casting	ingot	rolling	blooms	rolling	structural shapes (channel, angle, beam)		
						rails		
	Continuous casting	–	–			tubes		
						billets	rolling	wires
				billets	–	–		rods
								bars



METAL FORMING PROCESS HIERARCHY OF ROLLING OPERATIONS IN MODERN MANUFACTURING INDUSTRY

Long products include tubes, rods, bars, wires, structural shapes and rails.



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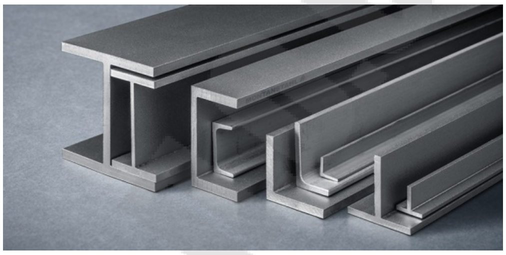
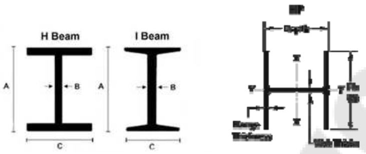


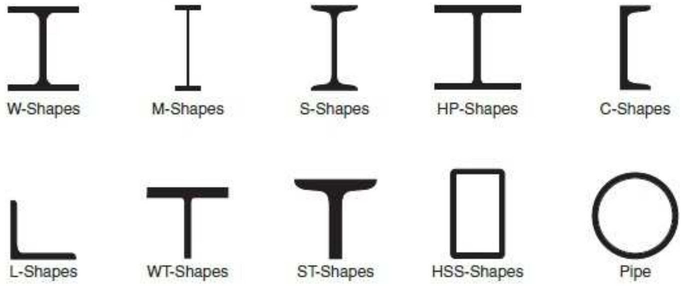
Bars are long products with square, rectangular, flat, round, hexagonal, or octagonal cross sections. The most important bar products are the rounds, which can reach a diameter of 250 millimetres. They are sometimes cold-drawn or even ground to very precise dimensions for use in machine parts. A special group of rounds are the reinforcing bars. Produced in diameters of 10 to 50 millimetres, they provide tensile strength to concrete sections subjected to a bending load. They normally have hot-rolled protrusions on their surface to improve bonding with concrete. Some bar mills also produce small channels, angles, tees, zees, and fence-post sections, with a maximum flange length of 75 millimetres, and call these products merchant bars.

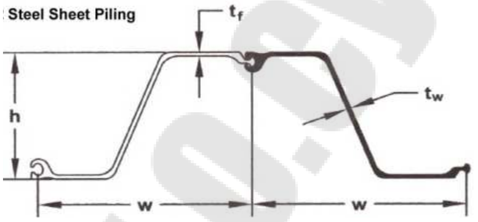
Hot-rolled wire rods are produced in diameters between 5.5 and 12.5 millimetres and are shipped in coils weighing up to two tons. A great portion of these rods are cold-drawn into wire, which is often covered afterward by a metallic coating for corrosion protection. The use of wire is extremely wide, ranging from cords for belted tires to cables for suspension bridges.

The common structural shapes are wide flange I-beams, standard I-beams, channels, angles, tees, zees, H-pilings, and sheet pilings. All these shapes are standardized, and each company has price lists showing which sections are produced and in which quality and length they can be supplied. Railroad rails are always produced to national standards. In the United States, for example, there are rails weighing 115, 132, and 140 pounds per yard and cut to lengths of 39 or 78 feet. There are also a great number of special rails—*e.g.,* for cranes and heavy transfer cars or for use in mines and construction.

H-beams call because the cross section looks like a capital H. These beams are also referred to as W-Beams because they are technically known as Wide-Flange Beams







Tubular steels are broadly grouped into welded and seamless products. Longitudinally welded tubes are normally produced up to 500 millimetres in diameter and 10 millimetres in wall thickness. Pipes produced from heavy plates are also longitudinally welded after being formed in a U-ing and O-ing operation; they can be 0.8 to 2 metres in diameter, with wall thicknesses up to 180 millimetres. Spiral-welded pipes are sometimes produced in diameters up to 1.5 metres. Seamless tubes are subjected to more demanding service; they are often rolled in diameters ranging from 120 to 400 millimetres and in wall thicknesses up to 15 millimetres, although special rolling mills can often increase the diameter to 650 millimetres. Smaller diameter tubes, both welded and seamless, can be produced by reduction mills or cold-drawing benches. Tubes are frequently machined on both ends for various coupling systems and coated with organic material.

1.1.2.Types of rolling processes

1.1.2.1. Types of Rolling Based on work piece geometry:

- Flat rolling – used to reduce thickness of a rectangular cross section.
- Shape rolling – square cross section is formed into a shape such as an I-beam.

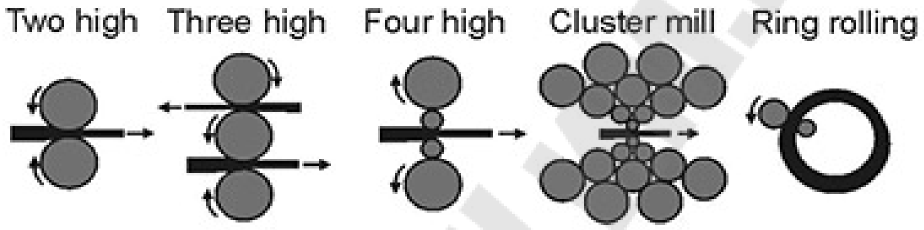
1.1.2.2.Types of Rolling Based on work temperature:

- Hot Rolling – most common due to the large amount of deformation required.
- Hot rolling is a metalworking process that occurs above the recrystallization temperature of the material. Hot rolled metals generally

have little directionality in their mechanical properties and deformation induced residual stresses. However, in certain instances non-metallic inclusions will impart some directionality. Hot rolling is used mainly to produce sheet metal or simple cross sections, such as rail tracks.

• Cold rolling – produces finished sheet and plate stock. Cold rolling occurs with the metal below its recrystallization temperature (usually at room temperature). Due to smaller size of the work pieces and their greater strength than hot rolled stock, four-high or cluster mills are used. Commonly cold-rolled products include sheets, strips and rods; products being smaller than the same products that are hot rolled.

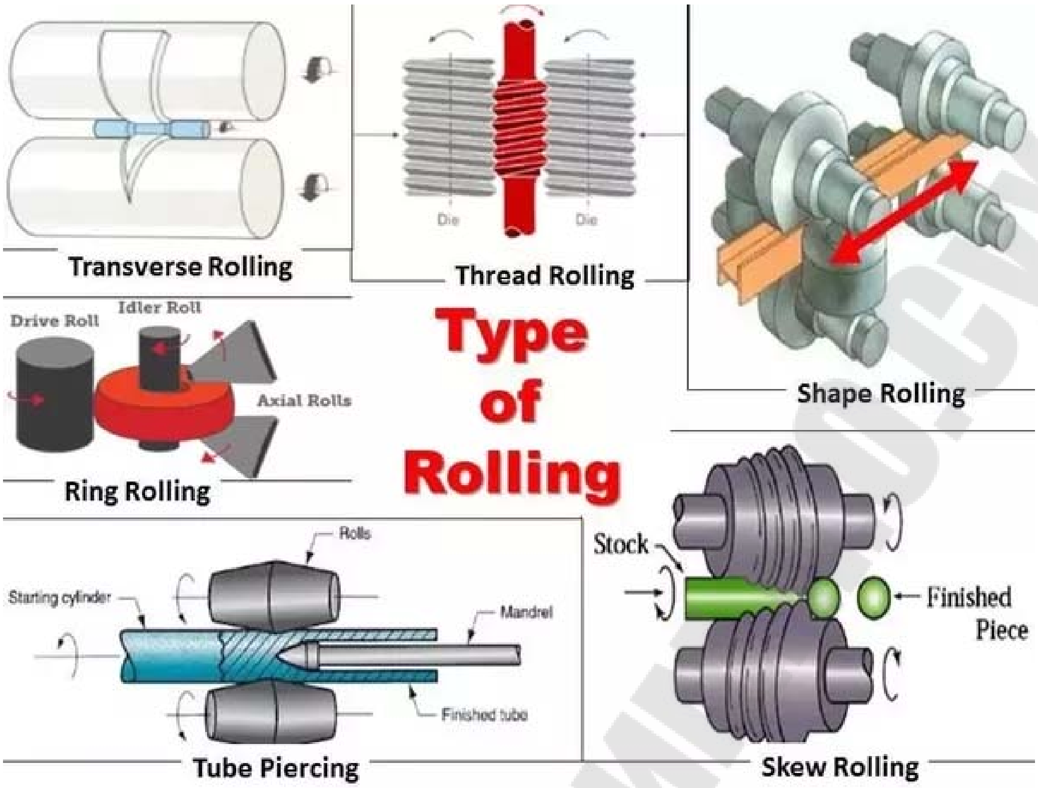
1.1.2.3. Types of Rolling Based on Roll configurations in rolling mills:



Common rolling arrangements

- Two High Rolling Mill.
- Three High Rolling Mill
- Cluster Rolling Mill.
- Ring Rolling Mill

1.1.2.4. Types of Rolling Based on rolling processes: flat rolling, shape rolling, ring rolling, thread (or gear) rolling, gear rolling, and the production of seamless tube and pipe by rotary tube piercing or roll piercing



<u>Transverse rolling</u> is characterized by using circular wedge rolls. Heated bar is cropped to length and fed in transversely between rolls. Rolls are revolved in one direction.

<u>Shape rolling</u>. Flat slap is progressively bent into complex shapes. Suitable for producing moulded sections such as irregular shaped channels and trim.

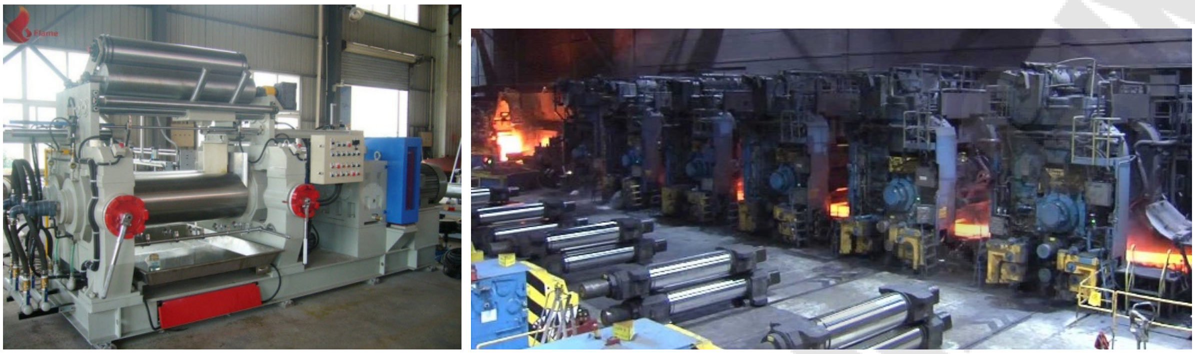
<u>Ring rolling</u> is a specialized type of hot rolling that increases the diameter of a ring. The resulting grain structure is circumferential, which gives better mechanical properties.

<u>Thread (or gear) rolling</u>. Rolled threads are produced in a single pass at speeds far in excess of those used to cut threads. Dies are pressed against the surface of cylindrical blank. As the blank rolls against the in feeding die faces, the material is displaced to form the roots of the thread, and the displaced material flows radially outward to form the thread's crest.

<u>Production of seamless tube and pipe by rotary tube piercing or roll piercing</u>. Rotary piercing is a hot working metalworking process for forming thick-walled seamless tubing. There are two types: the Mannesmann process and the Stiefel process.

1.1.3. Rolling equipment

Rolling mills: Bloomers, Continuous rolling billet mill, Universal beam mills, Rail-and-structural steel mills, Wheel-rolling and ring-rolling mills and others.



1.2. Forging

Metal forging is the oldest metal forming process which produces parts by the process of metal deformation. Forging is a bulk forming process where the material is shaped by localized compressive or impact forces

C	T	P	T	P	T	P
Hot metal	casting	ingot	–	–	forging	forging or forged piece
			rolling	slab bloom billet		
	continuous casting	–	–			
				casting		

Advantages

- Very high production rate for simple parts.
- Better microstructure control compared to some casting processes.
- Increase in strength, toughness and fatigue life due to realignment of grain structure.
- Voids, defects and porosity is quite low.

Disadvantages

- Post processing is required.
- Very limited part geometries are possible
- Production rates vary a lot depending upon the geometry and size of the product, from a single unit to several hundred units per hour.
- Lead time to produce a die set can be several weeks.
- About 25 percent of the material is wasted in a single operation, but it can often be reused.

- Labor, equipment, and tooling costs are high but finishing costs are moderate.
- The manufacture of forging die and the other high costs of setting up an operation make the production of small quantities of forged parts expensive on a price per unit basis. Manufacturing large quantities of metal forgings economically beneficial

1.2.1.Types of forging processes

1.2.1.1.Types of forging on the basis of the deformation mechanism:

- **Impact forging** (also known as **drop forging**) is a forging process where a hammer is raised and then "dropped" onto the workpiece to deform it according to the shape of the die. Thus, an impact force is applied to the work piece using a hammer.
- **Compression forging** (also known as **press forging**) works by slowly applying a continuous pressure or force, which differs from the near-instantaneous impact of drop-hammer forging. In compression forging, a constant pressure is applied to the work piece and the amount of time the dies are in contact with the workpiece is measured in seconds (as compared to the milliseconds of drop-hammer forges).

Drop and Press forging in comparison

The main advantage of press forging, as compared to drop-hammer forging, is its ability to deform the complete workpiece. Drop-hammer forging usually only deforms the surfaces of the work piece in contact with the hammer and anvil; the interior of the workpiece will stay relatively undeformed. Another advantage to the process includes the knowledge of the new part's strain rate. By controlling the compression rate of the press forging operation, the internal strain can be controlled.

There are a few disadvantages to this process, most stemming from the workpiece being in contact with the dies for such an extended period of time. The operation is a time-consuming process due to the amount and length of steps. The workpiece will cool faster because the dies are in contact with workpiece; the dies facilitate drastically more heat transfer than the surrounding atmosphere. As the workpiece cools it becomes stronger and less ductile, which may induce cracking if deformation continues. Therefore, heated dies are usually used to reduce heat loss, promote surface flow, and enable the production of finer details and closer tolerances. The workpiece may also need to be reheated.

When done in high productivity, press forging is more economical than hammer forging. The operation also creates closer tolerances. In hammer forging a lot of the work is absorbed by the machinery; when in press forging, the greater percentage of work is used in the work piece. Another advantage is that the operation can be used to create any size part because there is no limit to the size of the press forging machine. New press forging techniques have been able to create a higher degree of mechanical and orientation integrity. By the constraint of oxidation to the outer layers of the part, reduced levels of microcracking occur in the finished part.

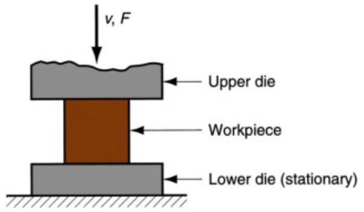
Press forging can be used to perform all types of forging, including open-die and impression-die forging. Impression-die press forging usually requires less draft than drop forging and has better dimensional accuracy. Also, press forgings can often be done in one closing of the dies, allowing for easy automation.

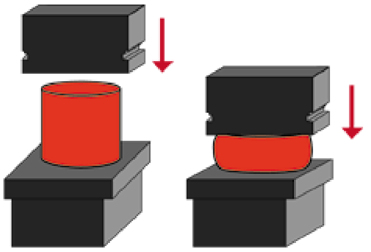
1.2.1.2.Types of forging based on work temperature

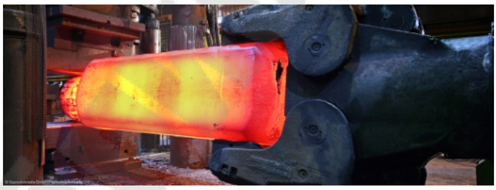
– **Hot forging** is done at the recrystallization temperature of the material.
– **Cold forging** done at room temperature.

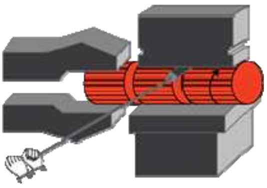
1.2.1.3.Types of forging based on shape of the die

Open die forging process is also known as **free** forging. Open die forging uses a flat die set to deform the work piece. For open die forging, enormous compressive forces are imposed by the continuous strike of a forging hammer to deform the metal billets. The piece of metal is deformed between multiple dies that do not enclose the metal entirely. The dies hammer and stamp the metal through a series of movements to alter its dimensions until the desired shape is achieved.

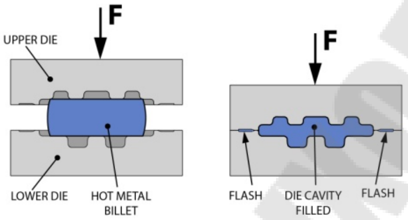








Impression (closed) die forging uses a die with a cavity and applies compression force to give the work piece the shape of the cavity. For closed die forging, the molding dies are first made. The metal bars are then placed on the dies and forged to any shapes that are desired. The closed die forging technique utilizes very less or no machining throughout the process. Also, net shape end products can be achieved.

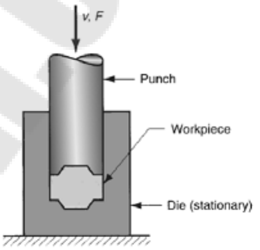


Open Die and Closed Die Forging Process in Comparison

Open Die Forging	Closed Die Forging
THE BENEFITS	
Better microstructure and mechanical properties (increased strength) Less material waste Valuable cost savings The open die metal forge parts are more suitable for large parts in a number of tons.	Economic for large runs of products high precision is obtained. Better surface Less or no machining required Closed die forging is preferred for small parts,
THE DRAWBACKS	
It is not capable of forming higher precision parts Machining is often required to achieve accuracies and the desired features A rough precision machining is further required after the open die forging process as imprecise dimensions are achieved by hammering.	It is not very economical for short runs due to the high cost of die production Closed die forging presents a dangerous working environment The set up cost is very high

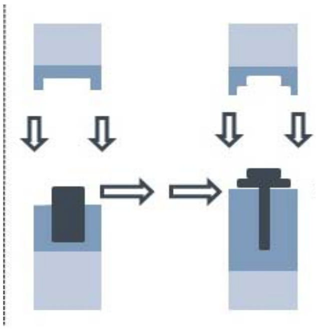
APPLICATION	
the products in this category of forging include forged long shafts, forged rollers, and forged cylinders. They are mostly utilized in the railway and the aircraft industry.	It is highly used to produce forged fittings, forged flange, forged automotive parts, etc. Oilfield, automotive, and mining are some of the industries that rely on closed die forge parts.

1.2.1.4. Types of forging based on forging operations



Flashless forging is classified as precision forging. Flashless forging uses a fixed amount of material and compresses it in a closed die. Starting working volume must equal die cavity volume to very close tolerance. Process control more demanding than impression-die forging. Flashless forging best suited for geometries that are simple and symmetrical.

Hand forging is the oldest type of metalworking. It used by blacksmiths. The work piece is heated and then shaped using hand tools like hammers and flat anvil.



Upset forging increases the diameter of the workpiece by compressing its length. Based on number of pieces produced, this is the most widely used forging process. A few examples of common parts produced using the upset forging process are bolts, screws. Upset forging (heading) is done in ehther hot or cold state. Generally an unheated workpiece in the form of thick wire or rod is fed into and fixed in a form, after which a die is pressed axially towards its end with an applied pressing force. The workpiece end deforms step by step with subsequent mandrel blows until the final shape is achieved

Roll forging is a process where round or flat bar stock is reduced in thickness and increased in length. Roll forging is performed using two cylindrical or semi-cylindrical rolls, each containing one or more shaped grooves. A heated bar is inserted into the rolls and when it hits a spot the rolls rotate and the bar is progressively shaped as it is rolled through the machine.

The piece is then transferred to the next set of grooves or turned around and reinserted into the same grooves. This continues until the desired shape and size is achieved. The advantage of this process is there is no flash and it imparts a favorable grain structure into the workpiece.

<u>1.2.2. Forging equipment:</u> hammers and presses.

<u>1.2.2.1. Forging hammer</u>

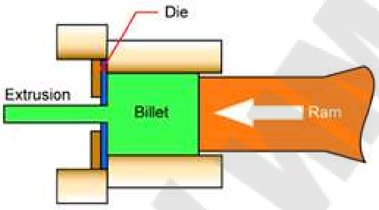
Principle behind the hammer is simple: raise the hammer and drop it or propel it into the workpiece, which rests on the anvil. The main variations between drop-hammers are in the way the hammer is powered; the most common being air and steam hammers. Drop-hammers usually operate in a vertical position.

<u>1.2.2.2. Forging press</u>

There are two main types of forging press: mechanical and hydraulic presses. Mechanical presses function by using cams, cranks and/or toggles to produce a preset (a predetermined force at a certain location in the stroke) and reproducible stroke. Due to the nature of this type of system, different forces are available at different stroke positions. Mechanical presses are faster than their hydraulic counterparts (up to 50 strokes per minute). Their capacities range from 3 to 160 MN (300 to 18,000 short tons-force). Hydraulic presses use fluid pressure and a piston to generate force. The advantages of a hydraulic press over a mechanical press are its flexibility and greater capacity. The disadvantages include a slower, larger, and costlier machine to operate.

1.3. Extrusion

Metal Extrusion is a metal forming manufacturing process in which a cylindrical billet inside a closed cavity is forced to flow through a die of a desired cross section.



Most commonly extruded materials are Al, Cu, Steel, Mg, Lead. Plastics and ceramics are also extruded extensively

These fixed cross sectional profile extruded parts are called "Extrudates" and pushed out using either a mechanical or hydraulic press. The process which was first patented by Joseph Bramah was first used to extrude lead pipes by Thomas Burr**.** Factors that affect the quality of extrusion are die design, extrusion ratio, billet temperature, lubrication, and extrusion speed. The force used to extrude the work piece is compressive in nature. Piston or plunger is used to apply compressive force at work piece. This process is similar to drawing process except drawing process uses tensile stress to extend the metal work piece. The compressive force allows large deformation compare to drawing in single pass.

C	T	P	T	P	T	P
Hot metal	casting	ingot	rolling	cylindrical billet	extrusion	Extrudates of different cross sectional profile (pipes, rods)
	continuous casting	–	–			

Advantages

- Low cost due to reduced raw material wastage and high production rate
- High mechanical properties can achieved by cold extrusion.
- Parts that are formed have excellent surface finish which minimizes post processing machining
- Metal extrusion tends to produce a favourable elongated grain structure in the direction of the material
- Able to create complex cross sections and will be uniform over the entire length of the extrudates
- This working can be done with both brittle and ductile materials Brittle material can be deformed without tear as it only exerts compressive and shear forces in the stock part
- The minimum wall thickness of ~1mm (aluminium) to ~3mm (steel) could be achieved.

Disadvantages:

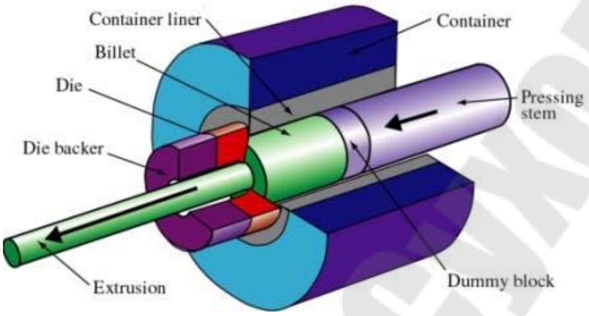
– High compressive force required (more powerful equipment required).
– High initial or setup cost.

1.3.1. Types of Extrusion Process

Similar to any other metal forming processes, metal extrusion can be performed either hot or cold, although the process generally is carried out at elevated temperatures in order to reduce the extrusion force and improve the ductility of the material. Also metal extrusion can be sub divided and grouped into the following categories depending on the direction of extrusion flow, the medium used to apply force, etc.

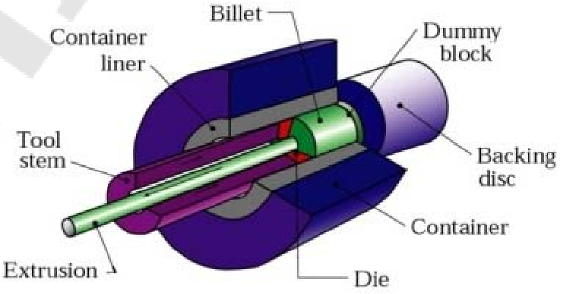
- Direct Extrusion
- Indirect Extrusion
- Hydrostatic Extrusion
- Lateral or Vertical Extrusion
- Impact Extrusion

1.3.1.1. Direct Extrusion, sometimes called Forward Extrusion is the most common type of extrusion. The process begins by loading a heated billet into a press cavity container where a dummy block is placed behind it. Then the mechanical or hydraulic ram presses on the material to push it out through the die. Then, while still hot, the part is stretched to straighten.

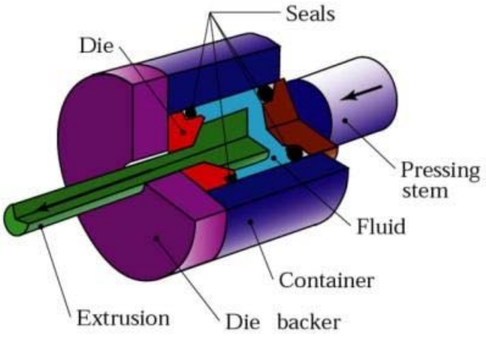


Under direct extrusion, the high friction caused by steels at higher temperatures is reduced using molten glass as a lubricant while oils with graphite powder are used for lubrication for low temperatures. The dummy block is used to protect the tip of the pressing stem (punch or ram) in hot extrusion. When the punch reaches the end of its stroke, a small portion of the billet called “butt end” cannot be pushed through the die opening

1.3.1.2. In Indirect Extrusion, the die is located at the end of the hydraulic ram and moves towards the billet inside the cavity to push the material through the die. This process consumes less power due to the static billet container causing less friction on the billet. However, supporting the extruded part is difficult when the **extrudate** exits the die.

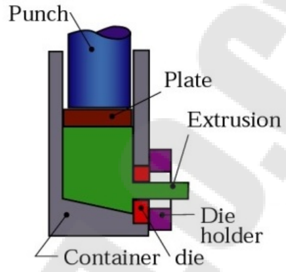


1.3.1.3. In Hydrostatic Extrusion, the chamber / cavity is made smaller than the billet and filled with hydraulic fluid which transfers the force from the ram to the billet. Although tri-axial forces are applied by the fluid, the pressure improves billet formability on the billet.



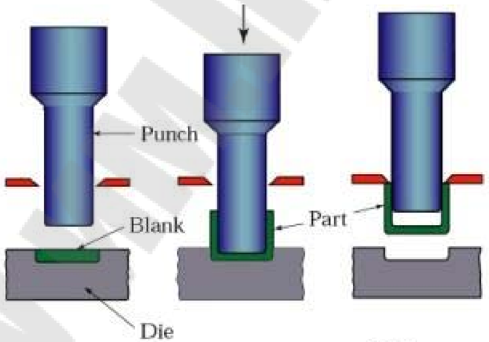
Sealing the fluid must be considered at the early stages to avoid any leaking and reduced pressure issues. Hydraulic fluid eliminates the friction between the wall and the billet by isolating them.The specialised equipment requirement, high set up time and low production rate limits its usage in the industry in comparison to other extrusion processes.

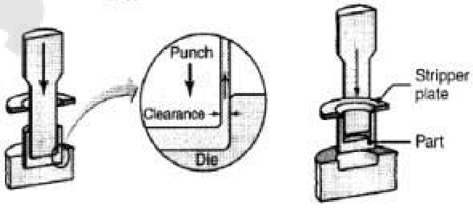
1.3.1.4. <u>In Lateral Extrusion</u> the container is in vertical position and the die is located on the side. This process is suitable for low melting point material.

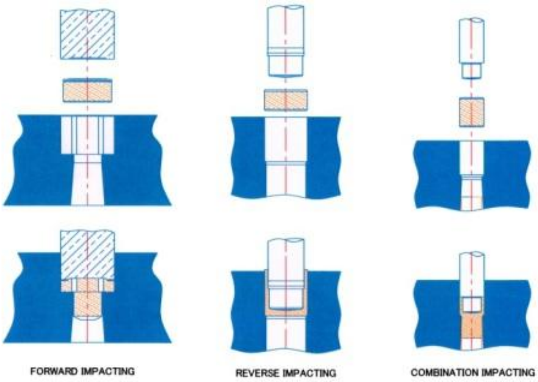


1.3.1.5. <u>Impact Extrusion</u> is very similar to In-direct extrusion and limited to softer metal such as Lead, Aluminium and Copper. The punch pushed down at high speed and extreme force on the slug to extrudes backwards. Thickness of the Extrude is a function of the clearance between the punch and the die cavity. The **Extrudates** are slide off the punch by the use of stripper plate. For impact extrusions a mechanical press is often used and the part is formed at a high speed and over a relatively short stroke.

Since the forces acting on the punch and die are extremely high, tooling must have sufficient impact resistance, fatigue resistance and strength, for extruding metal by impact.



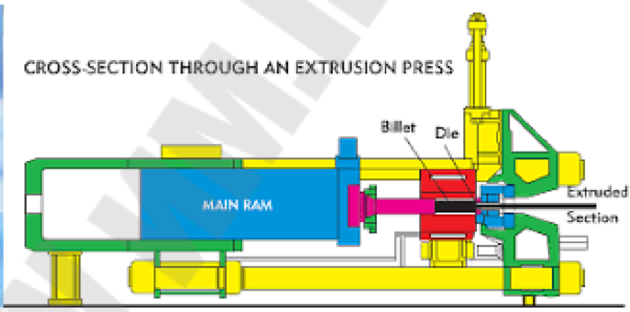




Impact extrusion can be divided into the following three types by the flow of the material. Forward, Reverse, Combination. In forward impact extrusion, metal flows in the same direction that the force is delivered while it flows in the opposite direction in reverse impact extrusion. In combination, the metal flows in both directions.

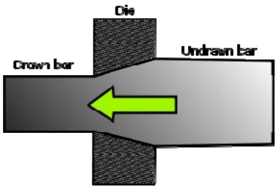
1.3.2. Extrusion equipment

The most common type of extrusion equipment is the extrusion press or extruder.



1.4. Drawing

Drawing is a metal forming process which uses tensile forces to stretch metal. As the metal is drawn (pulled), it stretches thinner, into a desired shape and thickness. In general, drawing results in reduction in area of cross-section



C	T	P	T	P	T	P	T	P	T	P
Hot metal	casting	ingot	rolling			tubes	–	–		tube
	continuous casting	–	–	blooms	rolling	billets		wires	drawing	wires
				billets	–	–	rolling	rods		rods
								bars		bars

Drawing, extrusion and rolling processes in comparison

Drawing process is very similar to metal extrusion, the difference being in the application of force. In extrusion the work is pushed through the die opening, where in drawing it is pulled through. From rolling drawing differs in that the pressure of drawing is not transmitted through the turning action of the mill but instead depends on force applied locally near the area of compression. This means the amount of possible drawing force is limited by the tensile strength of the material, a fact that is particularly evident when drawing thin wires deformation compare to drawing in single pass.

Application

- The drawing is especially good for creating cylindrical parts and components (with round cross sections), but squares and other shapes are also drawn.
- Drawn rods are used as raw materials for making bolts, nails, screws, rivets, springs etc. Wire drawing is used for producing wires e.g. electrical wires, cables, strings, welding electrodes, fencing etc. Bar drawing is used to produce metal bars for machining, forging, and other processes.
- A light reduction (sizing pass) also may be taken on rods to improve their surface finish and dimensional accuracy
- Steels, copper alloys, and aluminium alloys are common materials that are drawn.
- Metal drawing is particularly well-suited to high-volume production runs. Because it can be performed with automated machinery, it can continue for long periods with little downtime and minimal upkeep.

Advantages:

- It can use for mass product. This metal process can be an automated, is capable of producing high volumes of products in short periods of time
- The process is easy and does not require any skilled operator.
- Low manufacturing cost.
- High surface finish.
- No material wastage because it does not form any chips.
- High accuracy can obtain by this process.
- In comparison to other manufacturing processes, metal drawing much lower tool construction costs.
- It also can yield lightweight products without compromising their strength or integrity.

Disadvantages:

- It is noisy operation.
- This process is limited according to diameter of rod and die.
- This process is costly for low production rate

- Special sleeves required to assist in driving the part into the dies
- Material thickness has a large effect on processing price
- The rate at which dies may wear out due to work hardening of the material.
- Limitation of the cross-sectional area reduction

Maximum reduction in cross-sectional area per pass of drawing is restricted to 45%. Reductions of higher than 45% may lead to surface-finish deterioration. Usually, the smaller the initial cross section, the smaller the reduction per pass. Fine wires usually are drawn at 15 to 25% reduction per pass and larger sizes at 20 to 45%.

1.4.1. Types of Drawing Process

1.4.1.1.Types of drawing based on work temperature

Drawing is usually done at room temperature, thus classified a cold working process, however it may be performed at elevated temperatures to hot work large wires, rods or hollow sections in order to reduce forces.

- **Hot** drawing is done at elevated temperature.
- **Cold** drawing is done at room temperature.

1.4.1.2. Types of drawing based on lubricant used

Proper lubrication is essential in drawing, in order to improve die life, reduce drawing forces and temperature, and improve surface finish. In order to retain the lubricant of the surface, oxalate or sulfate coating is given to the rod. Soap solution or oil is used as lubricant. The following are different methods of lubrication.

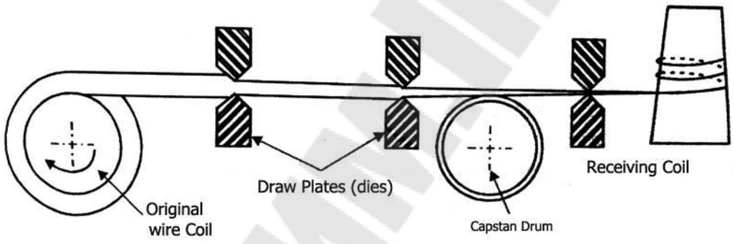
- **Wet drawing**, in which the dies and the rod are immersed completely in the lubricant.
- **Dry drawing**, in which the surface of the rod to be drawn is coated with a lubricant by passing it through a box filled with the lubricant (stuffing box). In this case the rod is lubricated before drawing. The rod is dipped into lubricant bath before fed into the die.

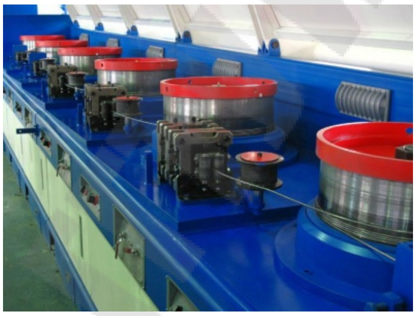
Another lubrication methods are (i) metal coating, in which the wire or rod is coated with a soft metal which acts as a solid lubricant; (ii) ultrasonic vibration, in which the dies and mandrels are vibrated, which helps to reduce forces and allow larger reductions per pass; (iii) immersion the wire in a copper sulphate solution, such that a film of copper is deposited which forms a kind of lubricant. In some classes of wire the copper is left after the final drawing to serve as a preventive of rust or to allow easy soldering.

1.4.1.3. Types of drawing based on products received

Bar, tube, and wire drawing all work upon the same principle: the starting stock drawn through a die to reduce the diameter and increase the length. Usually the die is mounted on a draw bench. The end of the workpiece is reduced or pointed to get the end through the die. The end is then placed in grips and the rest of the workpiece is pulled through the die.

Drawing can also be used to produce a cold formed shaped cross-section. Cold drawn cross-sections are more precise and have a better surface finish than hot extruded parts.





1.4.1.3.1. Wire drawing: A wire of a larger size is pulled through a drawing ring of a smaller size.
According to the machine used:
-single-draft drawing
- tandem drawing
According to the wire size used:
(1) coarse drawing: d = 16 to 4.2 mm,
(2) medium drawing: d = 4.2 to 1.6 mm, (3) fine drawing: d = 1.6 to 0.7 mm, (4) ultra-fine drawing: $d < 0.7$ mm

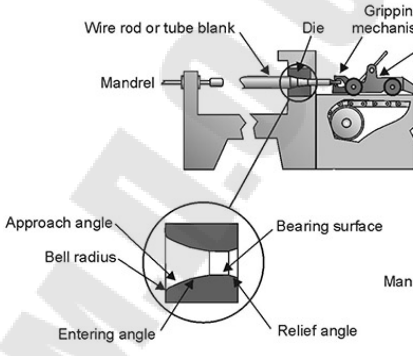
Wire drawing is usually done in multiple steps, using 4 to 12 dies. Continuous drawing of wires is done through a series of drawing dies, with intermediate winding drums. These drums are run by electric motors. They wind the drawn wire before feeding it to the next reduction stage. The drum applies mild tension on the wire, which is being drawn.

1.4.1.3.2. Bar (or rod) drawing

The work piece in the form of a bar or rod is pulled through a converging die. A bar or rod is drawn down in order to reduce its diameter.

Basic differences between bar drawing and wire drawing are

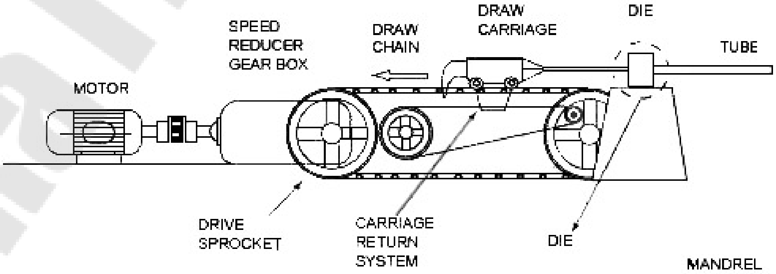
(1) the size of bar stock used for bar drawing is large, (2) bar drawing is single-draft drawing usually, (3) due to rods and bars can not be coiled bar drawing is carried out using a draw bench, (4) motor-driven carriages are used for drawing the bar through the die

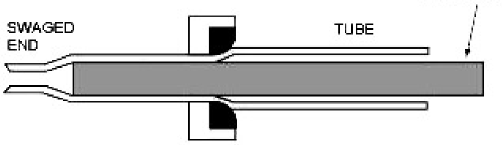


Typical die geometry for drawing rod and wire

1.4.1.3.3. Tube drawing

Drawing of hollow parts, where the outside is formed by a drawing die hole and the inside by a plug or a rod.
(1) Drawing without a mandrel (2) Drawing over a stationary mandrel (3) Drawing over a floating plug (4) Drawing over a moving mandrel (the rod and the tube are then simultaneously moved in the drawing direction)





1.4.1.3.4. Sheet drawing – one of the sheet forming processes

1.4.2. Drawing Equipment and tool

There are several types of drawing machines. These have been grouped as follows.

- Drawing frames
- Bull blocks and motor block
- Multiple drawing machines
- Fine wire machines
- Turk's head shaped wire drawing machines
- Draw benches.

Bar drawing is accomplished on a machine called a draw bench, consisting of an entry table, die stand (which contains the draw die), carriage, and exit rack. The carriage is used to pull the stock through the draw die. It is powered by hydraulic cylinders or motor-driven chains. The die stand is often designed to hold more than one die, so that several bars can be pulled simultaneously through their respective dies.The auxiliary equipments to be attached with wire drawing machines consist of pay off reels, safety stop, welders, pointer, straightening and cutting machines, rotary straighteners, and roll straighteners etc. *Drawing dies* are typically made of tool steel, tungsten carbide, or diamond, with tungsten carbide and manufactured diamond being the most common. For drawing very fine wire a single crystal diamond die is used. For steel wire drawing, a tungsten carbide die is used. Wire dies usually are used with power as to pull the wire through them. There are coils of wire on either end of the die which pull and roll up the wire with a reduced diameter.

Topic 6. Metalworking Technologies. 2.2 Sheet Metal Forming

Key questions

1. Sheet metal. Definition
2. The raw material for sheet metal manufacturing processes
3. Two categories of the sheet metalworking operations
4. Cutting (shearing) sheet metal operations
5. Forming sheet metal operations
6. Punching and blanking in comparison
7. Bending. Types of bending
8. Drawing. Types of sheet drawing
9. Embossing and coining
10. Sheet metal forming equipment

<u>Sheet metal. Definition</u>.

Sheet metal is a metal formed into thin and flat pieces. It is one of the fundamental forms used in metalworking, and can be cut and bent into a variety of different shapes. Thicknesses can vary significantly from 0.4 mm to 6 mm although extremely thin sheets (less than 0.4 mm) are considered as foil or leaf, and sheets thicker than 6 mm are considered as plate.

<u>The raw material for sheet metal</u> manufacturing processes is the output of the rolling process. If the sheets are thin and very long, they may be in the form of rolls.

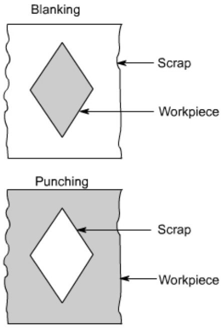
C	**T**	**P**	**T**	**P**	**T**	**P**	**T**	**P**	**T**	**P**
Hot Me	Casting	Ingot	–	–	Rolling	strip	Cutting	Working piece	Sheet metal-working operations	Goods
			Rolling	slab		sheets				
	Cont casting	–	–			plates				

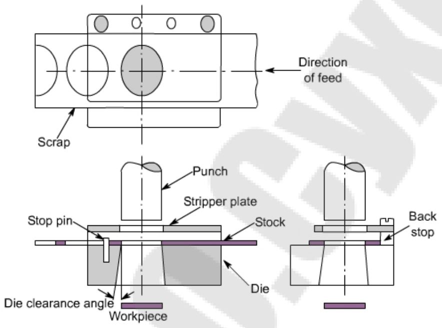
1. Types of sheet metalworking techniques

The sheet metalworking operations done on a press may be grouped into two categories <u>cutting</u> (shearing) operations and <u>forming</u> operations

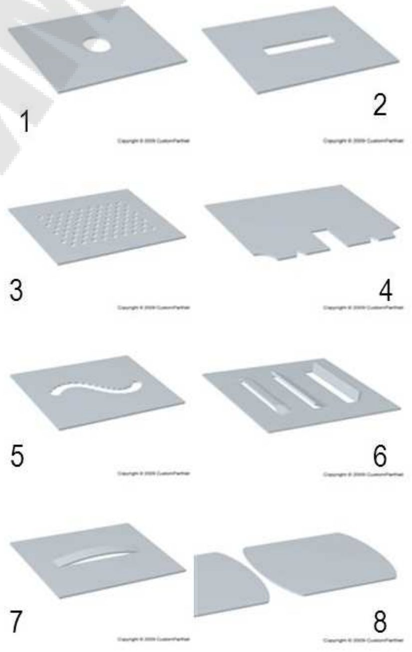
1.1. Cutting (shearing) operations

The first step in any sheet metal process is to cut the correct shape and sized blank from larger sheet. Shearing is a cutting operation used to remove a blank of required dimensions from a large sheet. The shearing operations which use of a die, include punching, blanking, piercing, notching, trimming, and nibbling.





Punching or blanking is a process in which the punch removes a portion of material from the larger piece or a strip of sheet metal. If the small removed piece is discarded, the operation is called punching, whereas if the small removed piece is the useful part and the rest is scrap, the operation is called blanking. So, in punching, the metal inside the part is removed; in blanking, the metal around the part is removed.

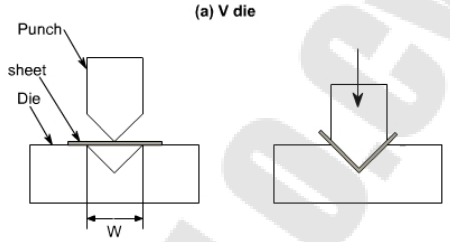


1) Piercing is a process by which a hole is cut in metal. It is different from punching in that piercing does not generate a slug. A pierced hole looks somewhat like a bullet hole in a sheet of metal. 2) Slotting is a punching operation that forms rectangular holes in the sheet. 3) Perforating is a punching a close arrangement of a large number of holes in a single operation. 4) Notching is a punching the edge of a sheet, forming a notch in the shape of a portion of the punch. 5) Nibbling is a punching a series of small overlapping slits or holes along a path to cutout a larger contoured shape. This eliminates the need for a custom punch and die but will require secondary operations to improve the accuracy and finish of the feature. 6) Lancing is a creating a partial cut in the sheet, so that no material is removed. The material is left attached to be bent and form a shape, such as a tab, vent, or louver. 7) Slitting is a cutting straight lines in the sheet. No scrap material is produced. 8) Parting is a separating a part from the remaining sheet, by punching away the material between parts.

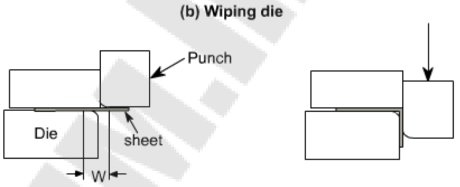
1.2. Forming operations

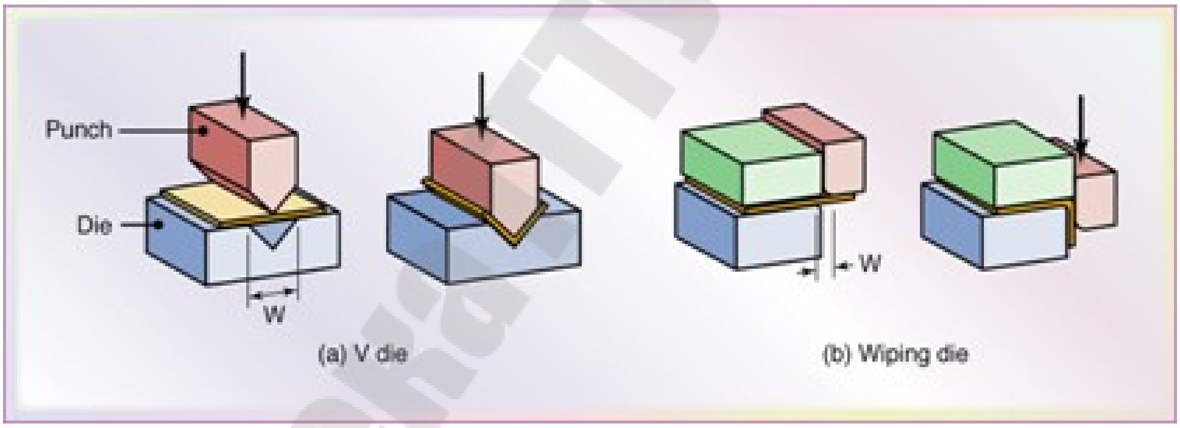
1.2.1. Bending is a metal forming process in which a force is applied to a piece of sheet metal, causing it to bend at an angle and form the desired shape. Die and punch are used for bending.

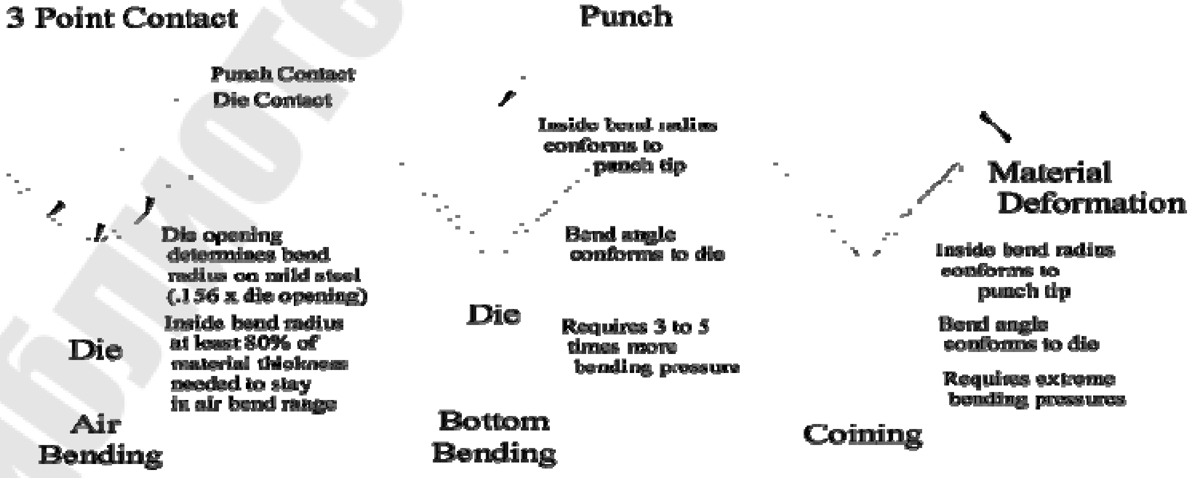
Types of Bending Based on die bending shape 1) V – die bending is bending when v shaped die and punch are used. 2) Wiping die bending is bending when the sheet is bent on the edge using a wiping die.



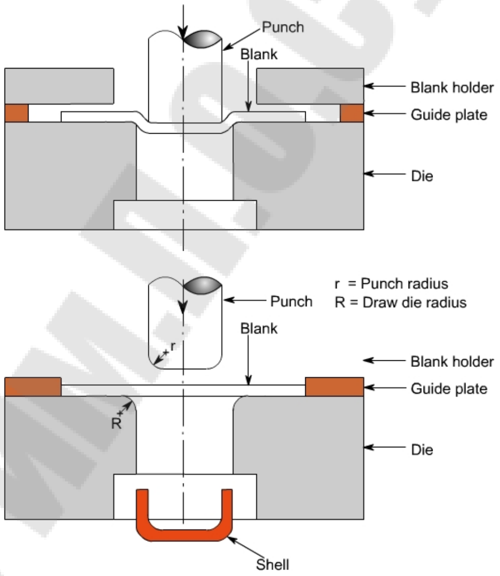
Types of Bending Based on the relationship of the end tool position to the thickness of the material: Air Bending, Bottoming and Coining. The configuration of the tools for these three types of bending are nearly identical.







1.2.2. Drawing is a process of cold forming a flat blank of sheet metal into a hollow vessel without much wrinkling, trimming, or fracturing. The process involves forcing the sheet metal blank into a die cavity with a punch. The punch exerts sufficient force and the metal is drawn over the edge of the die opening and into the die. In forming a cup, however, the metal goes completely into the die.



The metal being drawn must possess a combination of ductility and strength so that it does not rupture in the critical area (where the metal blends from the punch face to the vertical portion of the punch). The metal in this area is subjected to stress that occurs when the metal is pulled from the flat blank into the die.

- Shallow drawing is used when the height of cup formed is less than half its diameter.
- Deep drawing is used when the height of cup formed is high than half its diameter and the chances of excessive wrinkle formation at the edges of blank increases. To prevent this, a blank holder is normally provided. As the drawing process proceeds the blank holder stops the blank from increasing in thickness beyond a limit and allows the metal to flow radially. The limiting thickness is controlled by the gap between the die and the blank holder, or by the spring pressure in the case of a spring loaded blank holder.

Circular Die: Sheet metal blank is placed over a circular die opening. This die is made by either tool steel or cast irons. Sometimes carbides and plastic are also used for die material.

Blankholder: It is a part which hold the sheet metal blank at its required place. It provides necesery holding force during drawing. This force should not be as high which can cause tear of sheet metal during operation and also not too small which can cause tearing problem.

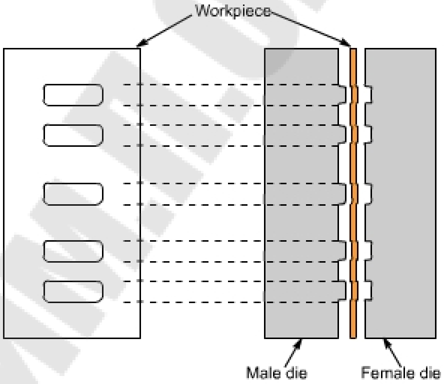
Punch: This part provides necessary downward force at the blank. It travel downward and forces the blank into the die cavity to forming a cup shape. **Blank:**The sheet metal cut piece which is used for deep drawing is known as blank. It is placed over an circular open die.

Limiting Drawing Ratio: The ratio of blank diameter to punch diameter is known as limiting drawing ratio. It plays major role in drawing operation.

Working Process:

The blank is placed over an open circular die with the help of blank holder. The blank holder provides a necessary force to hold the blank. The punch which is attached with a mechanical or hydraulic press moves downward and provide a necessary drawing force at blank. This force tends to deform metal sheet and forces it into the die cavity and convert it into a cup shape structure. If this force is high it causes elongation of cup wall to thin and if excessive, it causes tearing of sheet. So the punch force should remain a certain limit to avoid tearing during operation.

1.2.3. Embossing is an operation in which sheet metal is drawn to shallow depths with male and female matching dies. The operation is carried out mostly for the purpose of stiffening flat panels. The operation is also sometimes used for making decoration items like number plates or name plates, jewelry, etc.



1.2.4. Coining is a severe metal squeezing operation in which the flow of metal occurs only at the top layers of the material and not throughout the values.

The operation is carried out in closed dies mainly for the purpose of producing fine details such as needed in minting coins, and medal or jewelry making. The blank is kept in the die cavity and pressures as high as five to six times the strength of material are applied. Depending upon the details required to be coined on the part, more than one coining operations may be used. The difference between coining and embossing is that the same design is created on both sides of the work piece in embossing (one side depressed and the other raised), whereas in coining operation, a different design is created on each side of work piece.

2. Sheet metal forming equipment

Operations usually performed using a press as cold working. Types of presses for sheet metal working can be classified by one or a combination of characteristics, such as source of power, number of slides, type of frame and construction, type of drive, and intended applications


PTFE anti-corrosive Die Core

Topic 6. Metalworking Technologies. 3. Cutting and Joining

Key quest
1 Definition of cutting
2 Cutting process classification
3 What are the results of any mechanical cutting processes?
4 Conditions for mechanical cutting proceeding
5 What are the main mechanical cutting technologies?
6 What do you know about milling: definition,types, machine tool,cutter?
7 What do you know about turning: definition,types, machine tool,cutter?
8 What do you know about drilling: definition,types, machine tool,cutter?
9 What do you know about grinding: types, machine tool,cutter?
10 What are the main joing technologies?
11 What do you know about welding: definition, types, tool, cutter?
12 What do you know about brazing: definition, types, tool, cutter?
13 What do you know about soldering: definition, types, tool, cutter?
14 What do you know about riveting: definition, types, tool, cutter?

General metalworking technologies are casting, forming, cutting, and, joining.

1. Cutting processes

Cutting is a collection of processes wherein material is brought to a specified geometry by removing excess material using various kinds of tooling to leave a finished part.

Cutting can be produced on the base of different physical and chemical processes therefore there are many technologies available to cut metal, including:

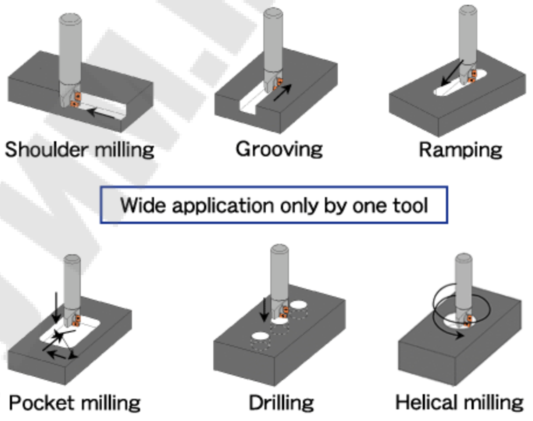
- Mechanical technologies: turning, milling, drilling, grinding.
- Welding/burning technologies: burning by laser, oxy-fuel burning, and plasma.
- Erosion technologies: by water jet, electric discharge, or abrasive flow machining.
- Chemical technologies: Photochemical machining.

1.1. <u>Mechanical cutting</u>

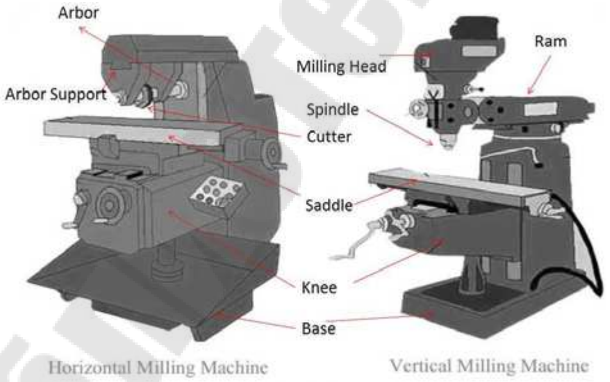
Mechanical cutting technologies are the most commonly used cutting technologies. Among them turning, milling, drilling, grinding are the more important cutting processes. The result of any mechanical cutting is two products: finished part and shavings (the waste product).

<u>Conditions for mechanical cutting proceeding</u>. Mechanical cutting is produced at room temperature in general. But cutting fluid or coolant is used where there is significant friction and heat at the cutting interface between a cutter such as a drill or an end mill and the workpiece. Coolant is generally introduced by a spray across the face of the tool and workpiece to decrease friction and temperature at the cutting tool/workpiece interface to prevent excessive tool wear. In practice there are many methods of delivering coolant.

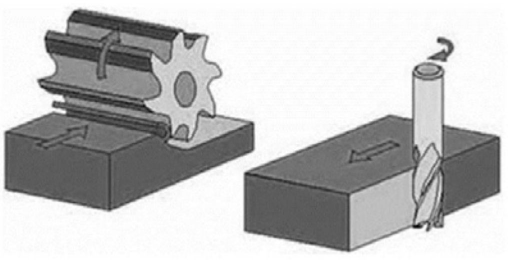
<u>1.1.1. Milling</u>



Milling is the mechanical process of using rotary cutting tool (mill cutter) to remove material from a workpiece by advancing the cutter into the workpiece at a certain direction. Milling covers a wide variety of different operations and machines, on scales from small individual parts to large, heavy-duty gang milling operations. It is one of the most commonly used processes for machining custom parts to precise tolerances. At the milling machine, milling cutter rotates about the spindle axis, and a work piece located at the worktable can move in multiple directions (usually two dimensions [x and y axis]. Milling machines may be operated manually or under computer numerical control (CNC).



Parts of Milling Machine



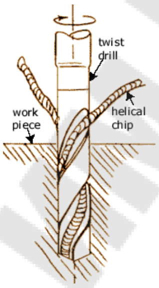
Plain Milling

Milling process at CNC machine

Mill cutters

1.1.2. Drilling

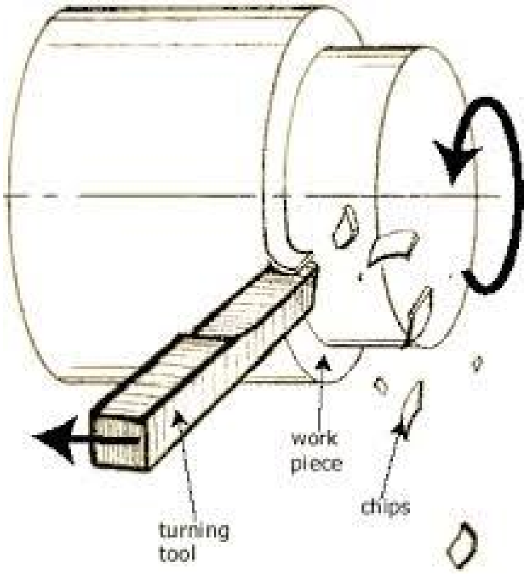
Drilling is a process of cutting holes of circular cross-section in metals by using a drilling machine and a drill. The drill bit is usually a rotarycutting tool. The bit is pressed against the work-piece and rotated at rates from hundreds to thousands of revolutions per minute.

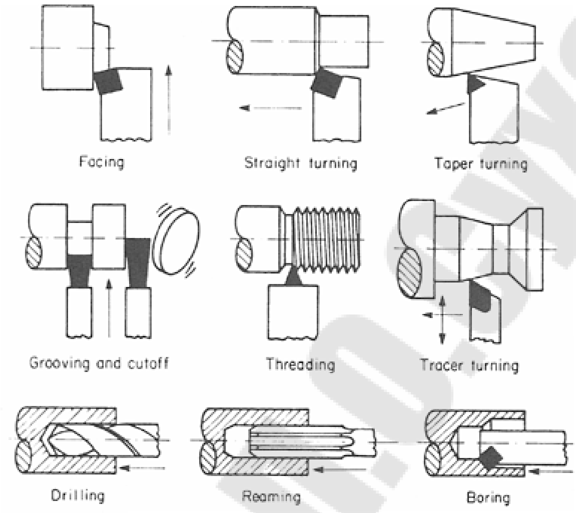


This forces the cutting edge against the work-piece, cutting off chips (swarf) from the hole as it is drilled.

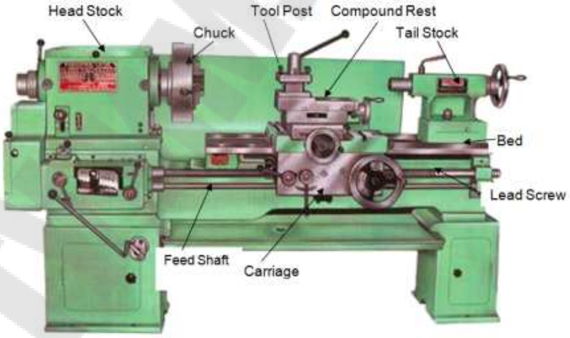
1.1.3. Turning

Turning is a metal cutting process for producing a cylindrical surface with a single point tool. The workpiece is rotated on a spindle and the cutting tool is fed into it radially, axially or both. The name of cutting tool used for turning is a lathe.





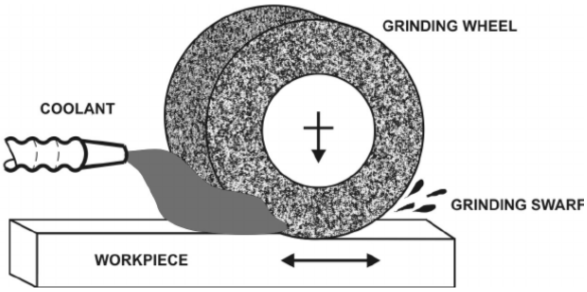
Turning process

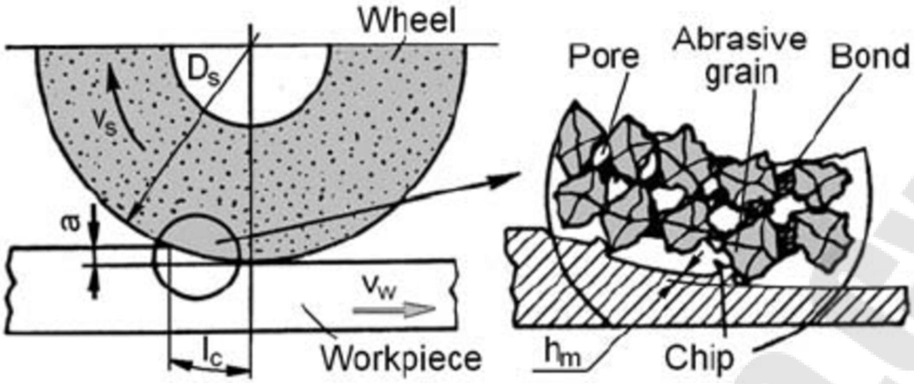


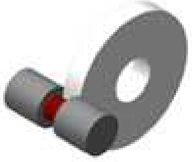
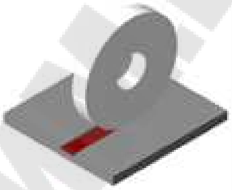
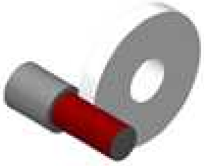
The name of machine tool for turning is lathe machine

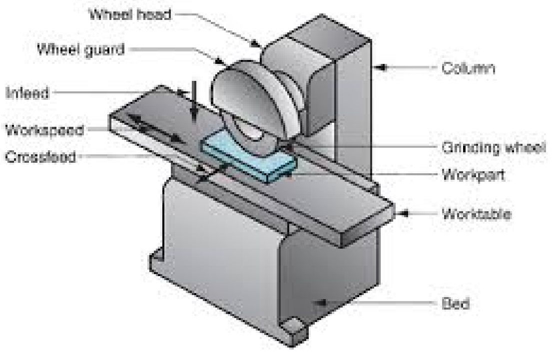
1.1.4. Grinding (abrasive cutting)

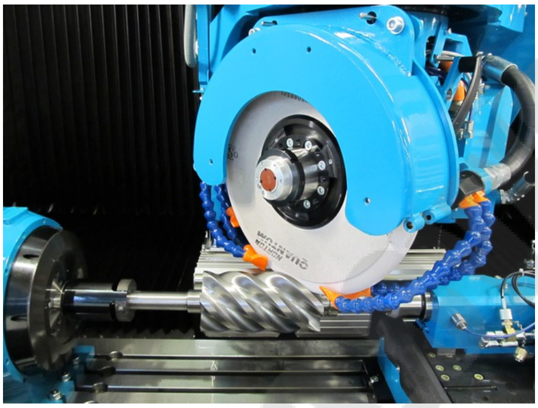
Grinding is a process of abrasive cutting used for producing very fine surfaces. Grinding uses and grinding machine making very light cuts, and a grinding wheel as the cutting tool This wheel can be made up of various sizes and types of stones, diamonds or inorganic materials.





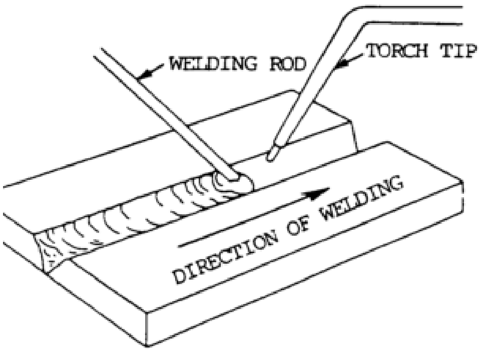
	External cylindrical	Internal cylindrical	Plan	Rotation
Peripheral plunge grinding				
Peripheral longitudinal loops				
Side plunge grinding				





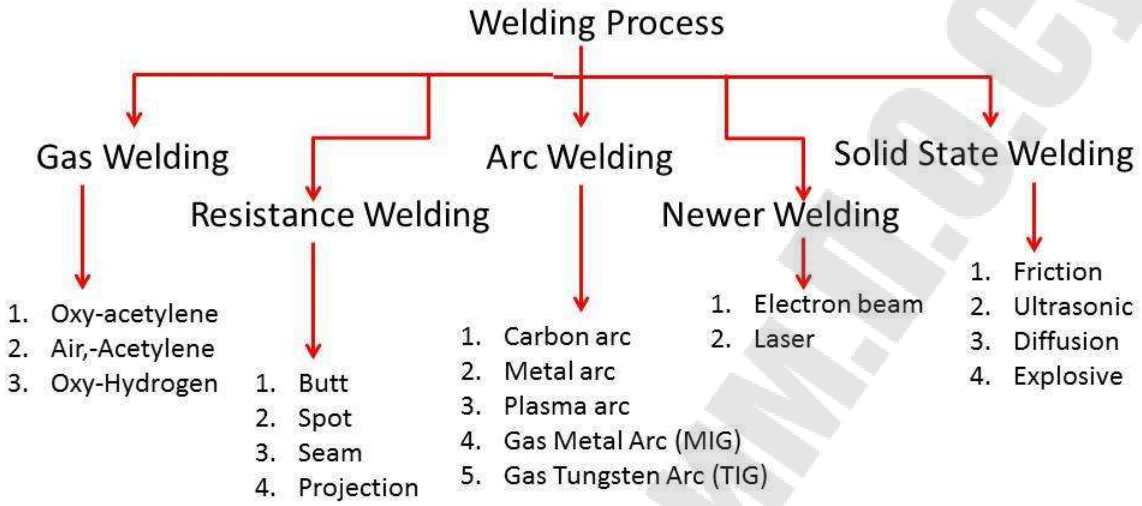
2. Joining processes

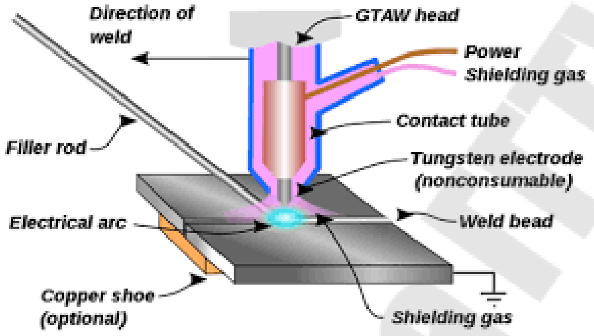
2.1. Welding

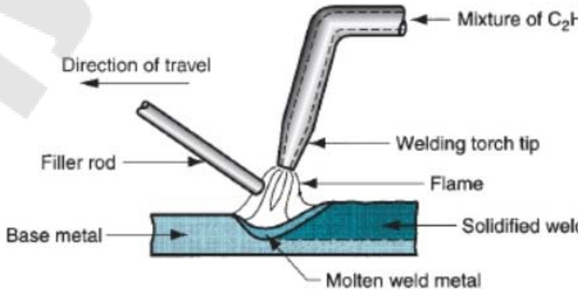


Welding is a joining process when pieces of metal are heated using electricity or a flame for melting and sticking together. There are many kinds of welding, including arc welding, resistance welding, gas welding, and so on. All types of welding require that the hot metal have protection. Dirt, rust, grease, and even the oxidation of the metal under the weld process can prevent a proper weld joint. As such all weld processes use one of two protection methods: flux, and shielding gas. During welding, the flux will melt and some of it will evaporate. This creates a small pocket of gas around the weld. This pocket of gas prevents oxidation of the metal under weld.

Shielding gas protects the weld by being a pocket of gas around the weld. The purpose of this gas is to keep normal air out, especially oxygen. It is different from flux because there is no liquid on the weld. The gases that are usually used are argon, helium, and a mixtures (3 parts argon and one part carbon dioxide, or nitrogen and hydrogen).

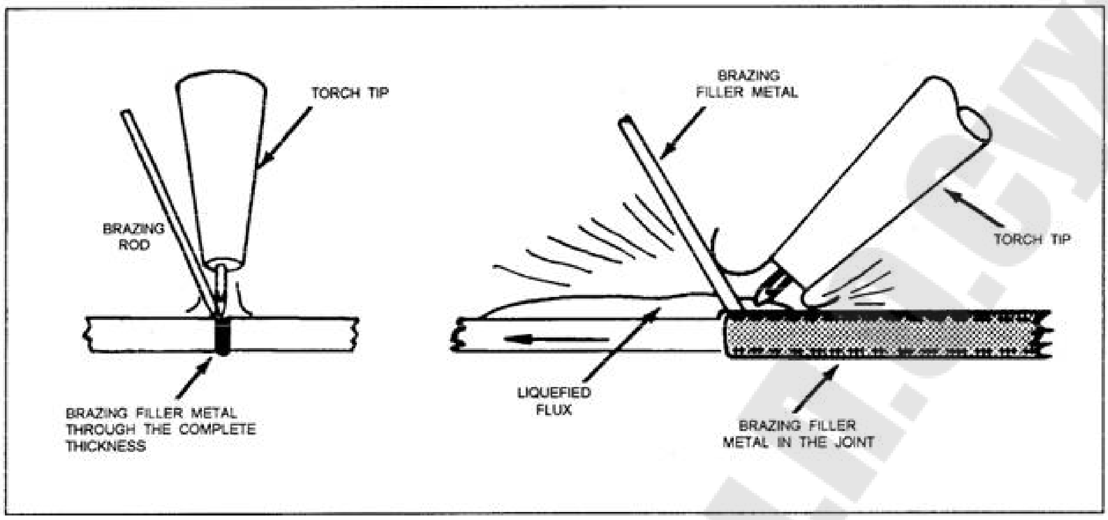






2.2. Brazing

Brazing is a metal-joining process in which two or more metal items are joined together by melting and flowing a filler metal into the joint, the filler metal having a lower melting point than the adjoining metal. Brazing differs from welding in that it does not involve melting the work pieces and from soldering in using higher temperatures for a similar process, while also requiring much more closely fitted parts than when soldering. The filler metal flows into the gap between close-fitting parts by capillary action. The filler metal is brought slightly above its melting (liquidus) temperature while protected by a suitable atmosphere, usually a flux. It then flows over the base metal (known as wetting) and is then cooled to join the work pieces together. A major advantage of brazing is the ability to join the same or different metals with considerable strength.



2.3. Soldering

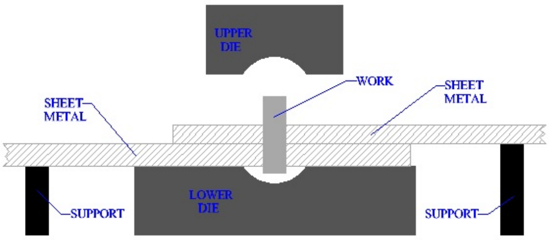
Soldering is a joining process that occurs at temperatures below 450 C. It is similar to brazing in the way that a filler is melted and drawn into a capillary to form a join, although at a lower temperature. Because of this lower temperature and different alloys used as fillers, the metallurgical reaction between filler and work piece is minimal, resulting in a weaker joint.

2.4. Riveting

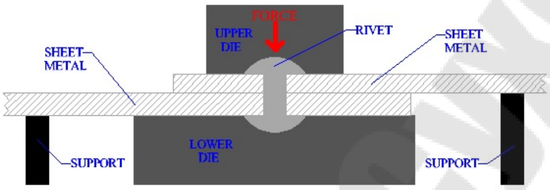
Riveting is one of the most ancient metalwork joining processes. Its use is being superseded by welding, but it still retains important uses in industry and construction.

A rivet is essentially a two-headed and unthreaded bolt which holds two other pieces of metal together. Holes are drilled or punched through the two pieces of metal to be joined. The holes being aligned, a rivet is passed through the holes and permanent heads are formed onto the ends of the rivet utilizing hammers and forming dies (by either coldworking or hotworking).

RIVETING OF SHEET METAL



WORK IS SET IN PRE MADE HOLES



ENERGY FROM DIE COMPRESSION FORMS RIVET

Topic 7. Ceramic products manufacturing. 1. Clay-based ceramics

Key quest

1 Three definitions of term “ceramic”: traditional, modern and broad
2 General comparison of ceramic material with metal and polymer
3 Major properties of ceramic
4 Distinctive features of ceramics
5 Application (before and today)
6 Composition base classification of ceramic materials
7 Microstructure base classification with examples
8 Application base classification of ceramic materials with examples
9 Clay. Definition and types
10 Types of clay-based ceramic
11 Density (porosity) base classification with examples
12 Steps of Production process
13 Material preparation techniques
14 Types of molding (forming)
15 Green Machining
16 Drying and Presinter Thermal Processing
17 Glazing
18 Firing
19 Final Processing
20 Brickmaking Features (differences)
21 Porcelainmaking Features (differences):

There are three definitions of term “ceramic”: traditional, modern and broad.

(**1**) The term *ceramic* comes from the Greek word for pottery and traditionally was defined as a material produced from clays by sintering.

(**2**) But modern ceramic materials are produced not only from clays. The modern ceramic materials, which are classified as advanced ceramics, include silicon carbide, tungsten carbide and others inorganic compounds. So, today ceramics are defined as a class of inorganic, nonmetallic solids that are subjected to high temperature in manufacture. The most common ceramics are composed of oxides, carbides, and nitrides. Silicides, borides, phosphides, tellurides, and selenides also are used to produce ceramics.

(**3**) The term *ceramic* is used to describe a broad range of materials that include glass, concrete, cement, pottery, brick, porcelain, and chinaware.

This class of materials is so broad that it is often easier to define ceramics as all solid materials except metals and their alloys that are made by the high-temperature processing of inorganic raw materials.

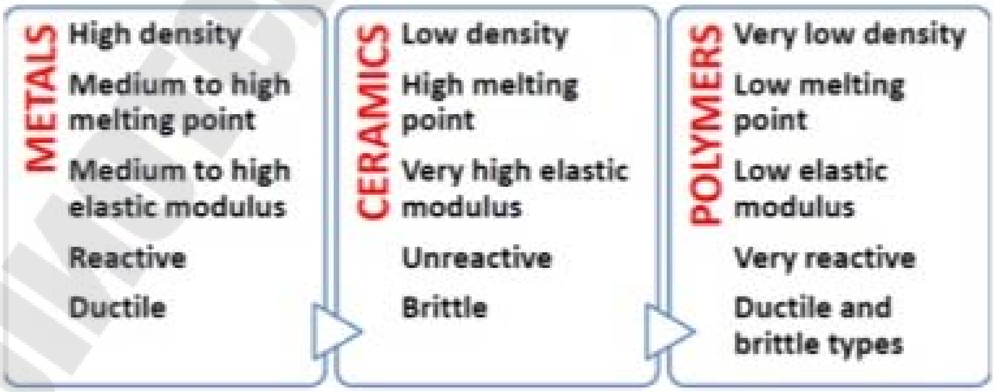
Materials		
Inorganic		Organic
Metals and alloys	**Ceramics**	Polymers

Major properties of ceramic

- High melting point
- High hardness
- Brittleness
- Good chemical resistance, high corrosion resistance
- Good electrical and thermal insulation properties (low temperature and electrical conductivity)
- High stiffness (elastic modulus) of fine ceramics

General comparison of materials

Property	***Ceramic***	***Metal***	***Polymer***
Hardness	Very High	Low	Very Low
Elastic modulus	Very High	High	Low
Thermal expansion	High	Low	Very Low
Wear resistance	High	Low	Low
Corrosion resistance	High	Low	Low



METALS	CERAMICS	POLYMERS
High density	Low density	Very low density
Medium to high melting point	High melting point	Low melting point
Medium to high elastic modulus	Very high elastic modulus	Low elastic modulus
Reactive	Unreactive	Very reactive
Ductile	Brittle	Ductile and brittle types

Distinctive features of ceramics

One of the most distinctive features of ceramics is their resistance to being worked or shaped after they are fired. With certain exceptions, such as glass tubing or plate glass, they can't be sold by the foot or cut to fit on the job. Their size and shape must be decided on before they are fired and they must be replaced, rather than repaired, when they break.

The primary difference between ceramics and other materials is the chemical bonds that hold these materials together. Although they can contain covalent bonds, such as the Si – O – Si linkages in glass, they are often characterized by ionic bonds between positive and negative ions. When they form crystals, the strong force of attraction between ions of opposite charge in the planes of ions make it difficult for one plane to slip past another. Ceramics are therefore brittle. They resist compression, but they are much weaker to stress applied in the form of bending.

Application (before and today)

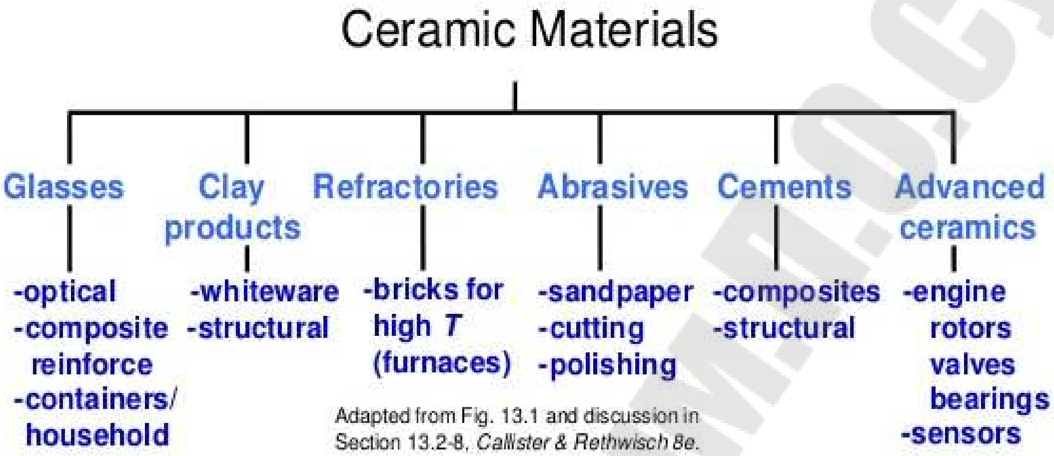
The use of ceramics traces back to Neolithic times, when clay was first used to make bowls that were baked in campfires. Clay is formed by the weathering of rock to form shinglelike particles of alumina and silica that cling together when wet to form clay minerals, such as kaolinite, which has the formula $Al_4Si_4O_{10}(OH)_8$.

Today, ceramics play an important role in the search for materials that can resist thermal shock, act as abrasives, or have a better weight-strength ratio. Alumina ceramics are used for missile and rocket nose cones, silicon carbide (SiC) and molybdenum disilicide ($MoSi_2$) are used in rocket nozzles, and ceramic tiles are used for thermal insulation to protect the Space Shuttle on re-entry through the Earth's atmosphere. Ceramics made from uranium dioxide (UO_2) are being used as the fuel elements for nuclear power plants. Ceramics are also used as laser materials, from the chromium-doped crystals that emit a coherent monochromatic pulse of light to the optics through which the light passes. $BaTiO_3$ is used to make ceramic capacitors that have a very high capacitance. It is also used to make piezoelectric materials that develop an electric charge when subjected to a mechanical stress, which are the active elements of phonograph cartridges, sonar, and ultrasonic devices. Magnetic ceramics formed by mixing ZnO, FeO, MnO, NiO, BaO, or SrO with Fe_2O_3 are used in permanent magnets, computer memory, and telecommunications.

Ceramic classifications

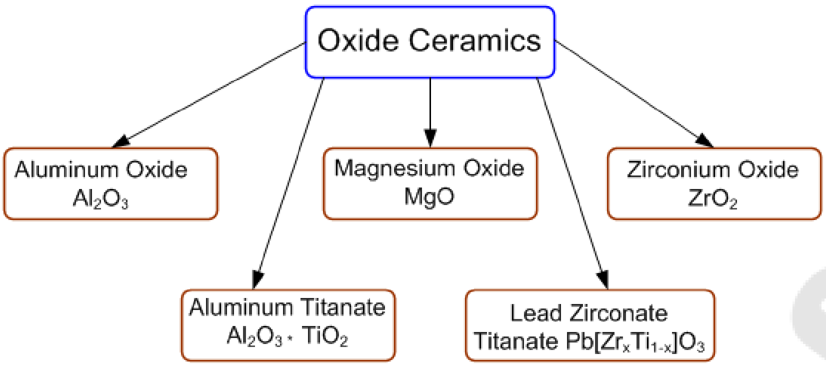
1. Microstructure base classification: crystalline (most ceramics are polycrystalline materials), semi-crystalline or semivitreous (stonewere), vitreous (porcelain) and amorphous (glass-ceramics).

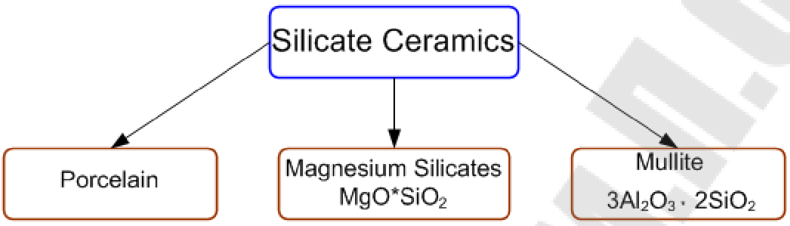
2. Application base classification of ceramic materials

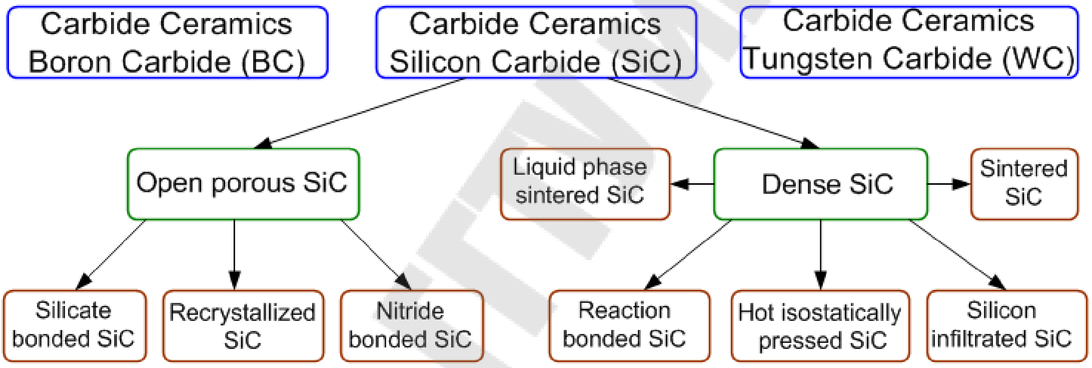


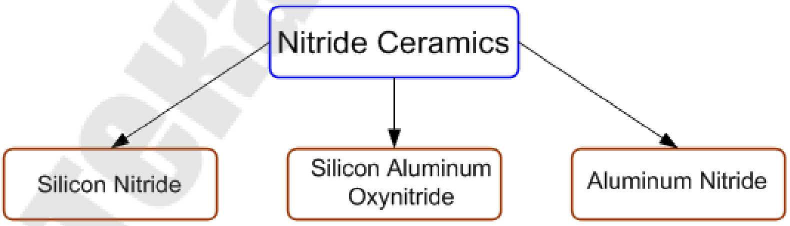
Adapted from Fig. 13.1 and discussion in Section 13.2-8, *Callister & Rethwisch 8e.*

3. Composition base classification of ceramic materials









1. Clay-based ceramics

Clay. Definition and types. Clay is a natural material that is plastic when moist but hard when fired, that is composed of fine particles of clay minerals together with varying amounts of detrital materials. The size of this rock particles is less than 0.005 millimetre. Common clays include different kinds of clays like ball clay, fireclay, stoneware clay, earthenware clay, slip clay.

Almost all clays are a mixture of several different kinds of mineral. For example, ball clay is a mixture of such minerals as kaolinite, quartz and mica. There are 12 different groups of clay minerals. The kaolin group (kaolinite, halloysite, lizardite, chrysotile), is common and might be regarded as a typical clay mineral. The hydrous micas and illites group (illite, glauconite, celadonite), chlorite group (sudoite, clinochlore, chamosite) and others. Clay minerals are composed essentially of silica, alumina or magnesia or both, and water, but iron substitutes for aluminum and magnesium in varying degrees, and appreciable quantities of potassium, sodium, and calcium are frequently present as well. Some clay minerals may be expressed using ideal chemical formulas as the following: $2SiO_2{\cdot}Al_2O_3{\cdot}2H_2O$ (kaolinite), $4SiO_2{\cdot}Al_2O_3{\cdot}H_2O$ (pyrophyllite), $4SiO_2{\cdot}3MgO{\cdot}H_2O$ (talc), and $3SiO_2{\cdot}Al_2O_3{\cdot}5FeO{\cdot}4H_2O$ (chamosite). The SiO_2 ratio in a formula is the key factor determining clay mineral types.

Types of clay-based ceramic

Clay-based ceramics					
Whiteware					**Structural and refractory**: bricks, wall, floor and roof tiles, vitrified clay pipes
Pottery				**Technical**	
Earthenware (low-fired ware)	**Stoneware** (middle-fired ware)	**Chainaware** (high-fired ware)	**Porcelain** (high-fired ware)		
			Non-technical	**Technical**	
artware, tableware	artware, tableware	artware, tableware	tableware	technicalware	

Whiteware refers to ceramic ware that is white, ivory, or light gray in color after firing. Whiteware is further classified as earthenware, stoneware, chinaware, porcelain, and technical ceramics.

Pottery is the ceramic material which makes up pottery wares, of which major types include earthenware, stoneware and porcelain. The definition of “pottery” used by the American Society for Testing and Materials (ASTM) is "all fired ceramic wares that contain clay when formed, except technical, structural, and refractory products.

Earthenware is defined as glazed or unglazed nonvitreous (porous) clay-based ceramic ware that has normally been fired below 1200 °C. Modern earthenwares are normally fired at temperatures in the range of about 1,000 °C to 1,200 C. Historically earthenware can be fired effectively as low as 600 °C, achievable in primitive pit firing, but 800 C to 1,100 °C was more typical. Applications for earthenware include artware, kitchenware, ovenware, tableware, and tile.

Stoneware is vitreous or semivitreous ceramic ware of fine texture, made primarily from nonrefractory fire clay or some combination of clays, fluxes, and silica that, when fired, has properties similar to stoneware made from fire clay. Stoneware ceramics are fired at temperatures in the range of about 1,100 °C to 1,300 C Applications for stoneware include artware, chemicalware, cookware, drainpipe, kitchenware, tableware, and tile.

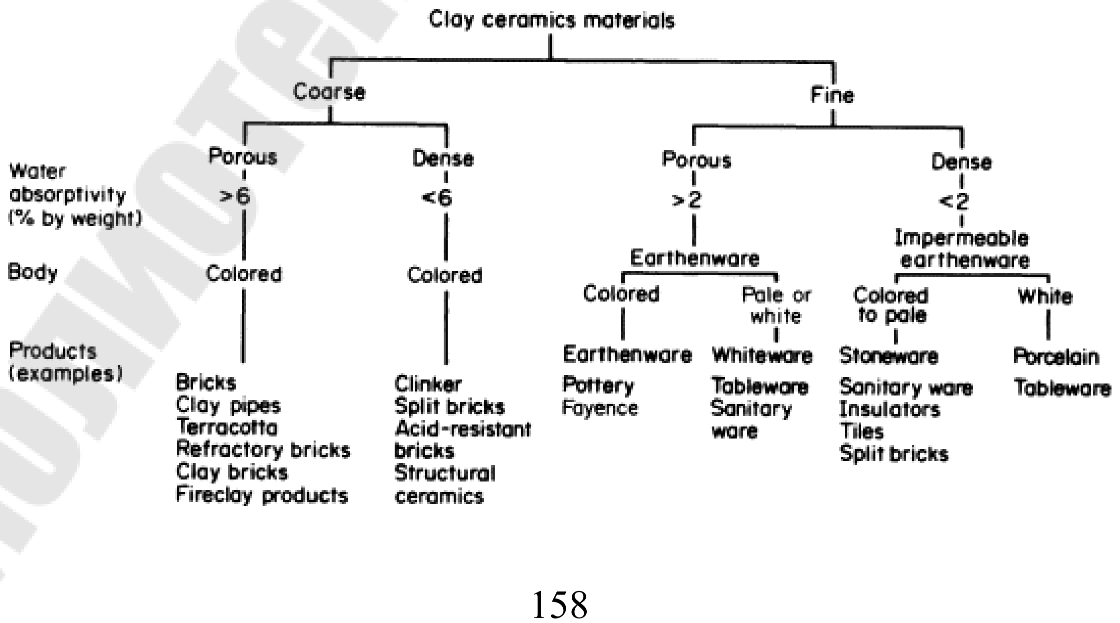
Chinaware is vitreous ceramic ware of zero or low absorption after firing that is used for nontechnical applications. Chinaware ceramics are fired at temperatures in the range of about 1,200 °C to 1,400 C. Applications for chinaware include artware, ovenware, sanitaryware, and tableware.

Porcelain is defined as glazed or unglazed vitreous ceramic ware used primarily for technical purposes. Porcelain are fired at temperatures in the range of about 1,200 °C to 1,400 C and in some English-speaking countries porcelain is also referred to as china or fine china. Applications for porcelain include ball mill balls, ball mill liners, chemicalware, insulators, and tableware.

Technical ceramics include vitreous ceramic whiteware used for such products as electrical insulation, or for chemical or thermal applications.

Structural Ceramics are served as a structural member of the device, often being under mechanical loading. These ceramics demonstrate excellent mechanical properties with good thermodynamic stability under demanding conditions such as erosive, corrosive or high temperature environments.

Density (porosity) base classification: coarse and fine ceramic.



Production process

1. Raw Materials. To begin the process, raw materials are transported and stored at the manufacturing facility. The raw materials used in the manufacture of ceramics range from relatively impure clay materials mined from natural deposits to ultrahigh purity powders prepared by chemical synthesis and are determined by final product. For example, porcelain is kaolin-based ceramic, therefore ceramic bricks are produced from broad range of clays.

2. Material preparation

2.1.There are many material preparation processes. The first step in material preparation is beneficiation. Although chemically synthesized ceramic powders also require some beneficiation, the focus of this discussion is on the processes for beneficiating naturally occurring raw materials.

The basic beneficiation processes include comminution, purification, sizing, classification, calcining, liquid dispersion, and granulation. Naturally occurring raw materials often undergo some beneficiation at the mining site or at an intermediate processing facility prior to being transported to the ceramic manufacturing facility.

Comminution entails reducing the particle size of the raw material by crushing, grinding, and milling or fine grinding. The purpose of comminution is to liberate impurities, break up aggregates, modify particle morphology and size distribution, facilitate mixing and forming, and produce a more reactive material for firing. Primary crushing generally reduces material up to 0.3 meter (m) (1 foot [ft]) in diameter down to 1 centimeter (cm) (0.40 inch [in.]) in diameter. Secondary crushing reduces particle size down to approximately 1 millimeter (mm) (0.04 in.) in diameter. Fine grinding or milling reduces the particle size down to as low as 1.0 micrometer (μm) (4 x 10-5 in.) in diameter. Ball mills are the most commonly used piece of equipment for milling. However, vibratory mills, attrition mills, and fluid energy mills also are used. Crushing and grinding typically are dry processes; milling may be a wet or dry process. In wet milling, water or alcohol commonly is used as the milling liquid.

Several procedures are used to purify the ceramic material. Water soluble impurities can be removed by washing with deionized or distilled water and filtering, and organic solvents may be used for removing water-insoluble impurities. Acid leaching sometimes is employed to remove metal contaminants. Magnetic separation is used to extract magnetic impurities from either dry powders or wet slurries. Froth flotation also is used to separate undesirable materials.

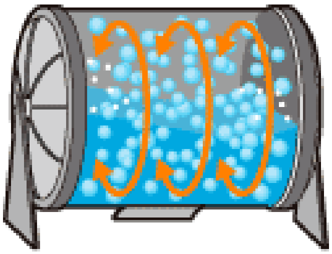
Sizing and classification separate the material into size ranges. Sizing is most often accomplished using fixed or vibrating screens. Dry screening can be used to sizes down to 44 µm (0.0017 in., 325 mesh). Dry forced-air sieving and sonic sizing can be used to size dry powders down to 37 µm (0.0015 in., 400 mesh), and wet sieving can be used for particles down to 25 µm (0.00098 in., 500 mesh). Air classifiers generally are effective in the range of 420 µm to 37 µm. However, special air classifiers are available for isolating particles down to 10 µm (0.00039 in.).

Calcining consists of heating a ceramic material to a temperature well below its melting point to liberate undesirable gases or other material and to bring about structural transformation to produce the desired composition and phase product. Calcining typically is carried out in rotary calciners, heated fluidized beds, or by heating a static bed of ceramic powder in a refractory crucible.

Liquid dispersion of ceramic powders sometimes is used to make slurries. Slurry processing facilitates mixing and minimizes particle agglomeration. The primary disadvantage of slurry processing is that the liquid must be removed prior to firing the ceramic. Dry powders often are granulated to improve flow, handling, packing, and compaction.

Granulation is accomplished by direct mixing, which consists of introducing a binder solution during powder mixing, or by spray drying. Spray dryers generally are gas-fired and operate at temperatures of 110 to 130 °C.

2.2. Mixing is the important step of material preparation. The purpose of mixing or blunging is to combine the constituents of a ceramic powder to produce a more chemically and physically homogenous material for forming. Pug mills often are used for mixing ceramic materials. Several processing aids may be added to the ceramic mix during the mixing stage. Binders and plasticizers are used in dry powder and plastic forming; in slurry processing, deflocculants, surfactants, and antifoaming agents are added to improve processing.

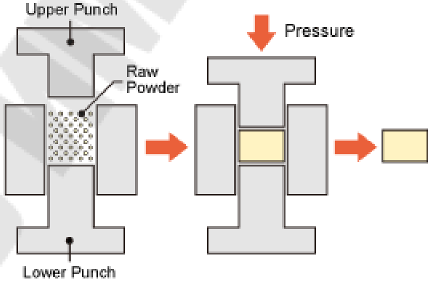

Raw Material
Milling / Mixing

Liquids also are added in plastic and slurry processing. Binders are polymers or colloids that are used to impart strength to green or unfired ceramic bodies. For dry forming and extrusion, binders amount to 3 percent by weight of the ceramic mixture. Plasticizers and lubricants are used with some types of binders. Plasticizers increase the flexibility of the ceramic mix. Lubricants lower frictional forces between particles and reduce wear on equipment. Water is the most commonly used liquid in plastic and slurry processing. Organic liquids such as alcohols may also be used in some cases. Deflocculants also are used in slurry processing to improve dispersion and dispersion stability. Surfactants are used in slurry processing to aid dispersion, and antifoams are used to remove trapped gas bubbles from the slurry.

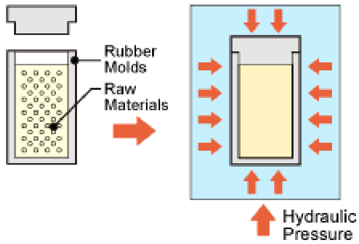
3. Molding or Forming

In the forming step, dry powders, plastic bodies, pastes, or slurries are consolidated and molded to produce a cohesive body of the desired shape and size. **Dry forming** consists of the simultaneous compacting and shaping of dry ceramic powders in a rigid die or flexible mold. Dry forming can be accomplished by dry pressing, isostatic compaction, and vibratory compaction. **Plastic molding** is accomplished by extrusion, jiggering, or powder injection molding. Extrusion is used in manufacturing structural clay products and some refractory products. Jiggering is widely used in the manufacture of small, simple, axially symmetrical whiteware ceramic such as cookware, fine china, and electrical porcelain. Powder injection molding is used for making small complex shapes. Paste forming

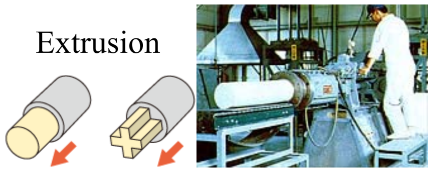
Dry pressing

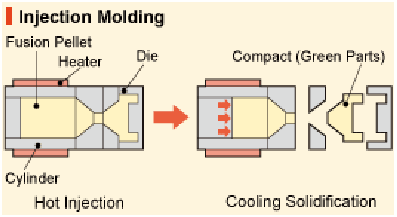


Isostatic compaction

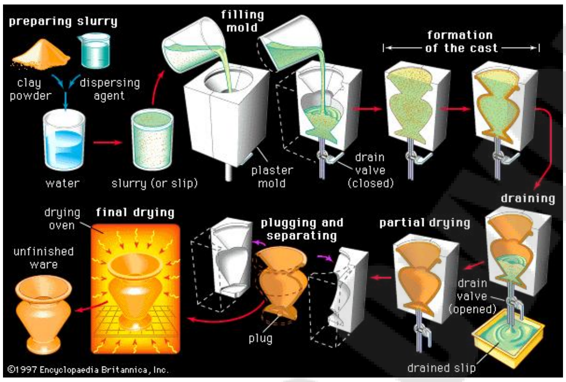


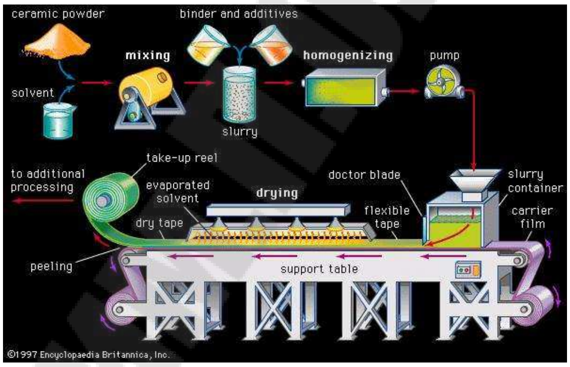
Extrusion





consists of applying a thick film of ceramic paste on a substrate. Ceramic pastes are used for decorating ceramic tableware, and forming capacitors and dielectric layers on rigid substrates for microelectronics. **Slurry forming** of ceramics generally is accomplished using slip casting, gelcasting, or tapecasting. In slip casting, a ceramic slurry, which has a moisture content of 20 to 35 percent, is poured into a porous mold. Capillary suction of the mold draws the liquid from the mold, thereby consolidating the cast ceramic material. After a fixed time the excess slurry is drained, and the cast is dried.





Slip casting is widely used in the manufacture of sinks and other sanitaryware, figurines, porous thermal insulation, fine china, and structural ceramics with complex shapes. Gelcasting uses in situ polymerization of organic monomers to produce a gel that binds ceramic particles together into complex shapes such as turbine rotors. Tape casting consists of forming a thin film of ceramic slurry of controlled thickness onto a support surface using a knife edge. Tape casting is used to produce thin ceramic sheets or tape, which can be cut and stacked to form multilayer ceramics for capacitors and dielectric insulator substrates.

4. Green Machining

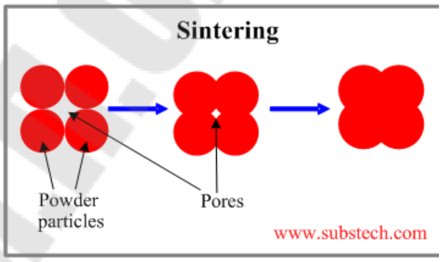
After forming, the ceramic shape often is machined to eliminate rough surfaces and seams or to modify the shape. The methods used to machine green ceramics include surface grinding to smooth surfaces, blanking and punching to cut the shape and create holes or cavities, and laminating for multilayer ceramics.

5. Drying and **Presinter Thermal Processing.** After forming, ceramics must be dried. Drying must be carefully controlled to strike a balance between minimizing drying time and avoiding differential shrinkage, warping, and distortion. The most commonly used method of drying ceramics is by convection, in which heated air is circulated around the ceramics. Air drying often is performed in tunnel kilns, which typically use heat recovered from the cooling zone of the kiln. Periodic kilns or dryers operating in batch mode also are used. Convection drying also is carried out in divided tunnel dryers which include separate sections with, independent temperature and humidity controls. An alternative to air drying is radiation drying in which microwave or infrared radiation is used to enhance drying.

6. Glazing

For traditional ceramics, glaze coatings often are applied to dried or bisque-fired ceramic ware prior to sintering. Glazes consist primarily of oxides and can be classified as raw glazes or frit glazes. In raw glazes, the oxides are in the form of minerals or compounds that melt readily and act as solvents for the other ingredients. Some of the more commonly used raw materials for glazes are quartz, feldspars, carbonates, borates, and zircon. A frit is a prereacted glass.

To prepare glazes, the raw materials are ground in a ball mill or attrition mill. Glazes generally are applied by spraying or dipping. Depending on their constituents, glazes mature at temperatures of 600° to 1500°C.



7. Firing is the process by which ceramics are thermally consolidated into a dense body. This process also is referred to as sintering or densification. With temperature increasing the clay goes from soft, totally fragile substance to one which is rock-hard, impervious to water, wind, and time. Parameters that affect firing include firing temperature (from 900 °C for porous ceramics to 1390 °C for porcelain), time, pressure, and atmosphere. Beginning at about 900 °C the clay particles begin to fuse. This cementing process is called sintering. After the pottery has sintered, it is no longer truly clay but has become a ceramic material. Different clays mature at different temperatures, depending on their composition. A red earthenware contains a large amount of iron which acts as a flux. An earthenware clay body can fire to maturity at about 1000 °C. On the other hand, a porcelain made of pure kaolin might not mature until about 1390 °C. A short firing time results in a product that is porous and has a low density; a short to intermediate firing time results in fine-grained (i. e., having particles not larger than 0.2 millimeters), high-strength products; and long firing times result in a coarse-grained products that are more creep resistant. Applying pressure decreases firing time and makes it possible to fire materials that are difficult to fire using conventional methods. Oxidizing or inert atmospheres are used to fire oxide ceramics to avoid reducing transition metals and degrading the finish of the product. In addition to conventional firing, other methods used include pressure firing, hot forging, plasma firing, microwave firing, and infrared firing. Conventional and pressure firing are the most common used methods.

Conventional firing is accomplished by heating the green ceramic to approximately two-thirds of the melting point of the material at ambient pressure and holding it for a specified time in a periodic or tunnel kiln.

Periodic kilns are heated and cooled according to prescribed schedules. The heat for periodic kilns generally is provided by electrical element or by firing with gas or oil. Tunnel kilns generally have separate zones for cooling, firing, and preheating or drying.

The most commonly used tunnel kiln design is the roller hearth (roller) kiln. In conventional firing, tunnel kilns generally are fired with gas, oil, coal, or wood. Following firing and cooling, ceramics are sometimes refired after the application of decals, paint, or ink. Advanced ceramics often are fired in electric resistance-heated furnaces with controlled atmospheres. For some products, separate furnaces may be needed to eliminate organic lubricants and binders prior to firing.Ceramic products also are manufactured by pressure firing, which is similar to the forming process of dry pressing except that the pressing is conducted at the firing temperature. Because of its higher costs, pressure firing is usually reserved for manufacturing ceramics that are difficult to fire to high density by conventional firing

8. Final Processing Following firing, some ceramic products are processed further to enhance their characteristics or to meet dimensional tolerances. Ceramics can be machined by abrasive grinding, chemical polishing, electrical discharge machining, or laser machining. Annealing at high temperature, followed by gradual cooling can relieve internal stresses within the ceramic and surface stresses due to machining. In addition, surface coatings are applied to many fired ceramics. Surface coatings are applied to traditional clay ceramics to create a stronger, impermeable surface and for decoration. Coatings also may be applied to improve strength, and resistance to abrasion and corrosion. Coatings can be applied dry, as slurries, by spraying, or by vapor deposition

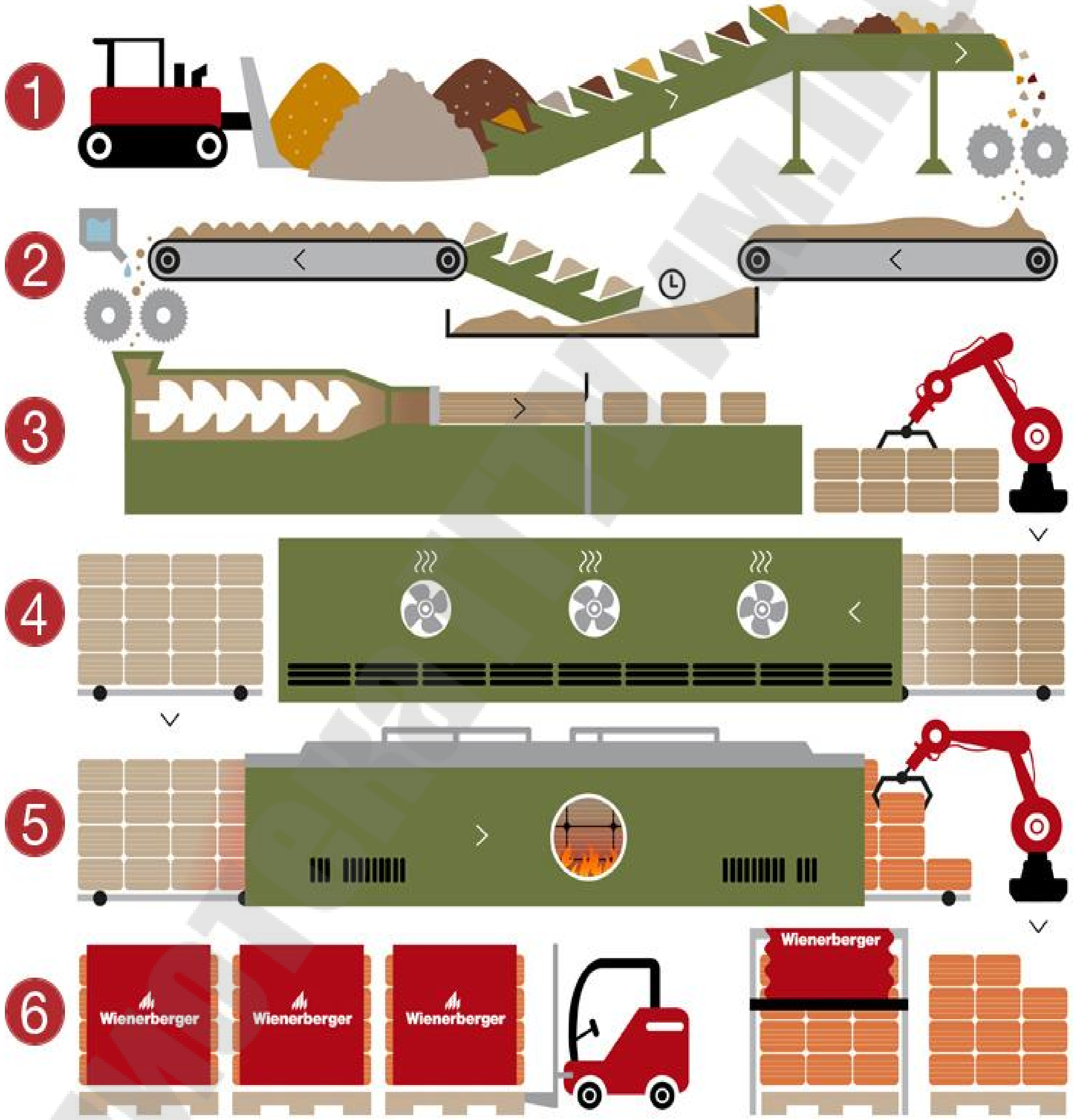
Technologies used are determined by a final product. For example, glazing is not used in process of brick production.

Porcelainmaking Features (differences):

Only kaolin clays can be used as a raw material for porcelain production. Porcelain are fired at temperatures in the range of about 1,200 to 1,400 C.

Brickmaking Features (differences):

A wide variety of raw materials may be used for brickmaking, ranging from soft sticky muds to hard shales. The fine particles in the clay fraction may consist of various mixtures of some 12 different groups of clay minerals: kaolin, hydrous mica, chlorite, illite, and others. Sintering temperature is about 900 °C.



Bricks production process

Topic 7. Ceramic manufacturing. 2. Sand-based ceramics. Glass

Key quest

1 What is glass?
2 What is the difference between crystalline and amorphous structures?
3 Under what conditions can a glass be formed?
4 Can any substances be cooled to the glass state?
5 What types of glasses do you know?
6 What do you know about silicate glasses (types, composition,application)?
7 What do you know about phosphate glasses?
8 What do you know about borate glasses?
9 What do you know about germanium oxide-based glasses?
10 Most common used additives in glassmaking
11 Properties of glass
12 Advantages of glasses
13 Disadvantages of glasses
14 Glass application in construction
15 Technologies of sheet and tube production
16 Float glass process
17 Rolling of flat plate glass
18 Glass tube drawing
19 Spinning:
20 Pressing:
21 Blowing
22 Free blowing
23 Mould Blowing
24 Blow-and-blow method
25 Press-and-blow method

What is glass?

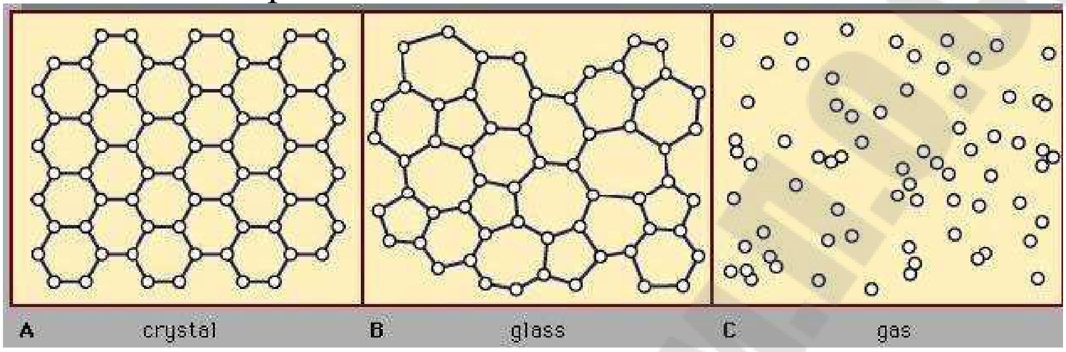
As a type of structure, “glass” refers to an amorphous (noncrystalline) structure of a solid material. The glassy state occurs in a glassy-formed material during melt cooling when cooling time is not enough for the crystalline structure formation.

As a type of material, glass is an inorganic, nonmetallic material which has cooled to solid state without crystallization.

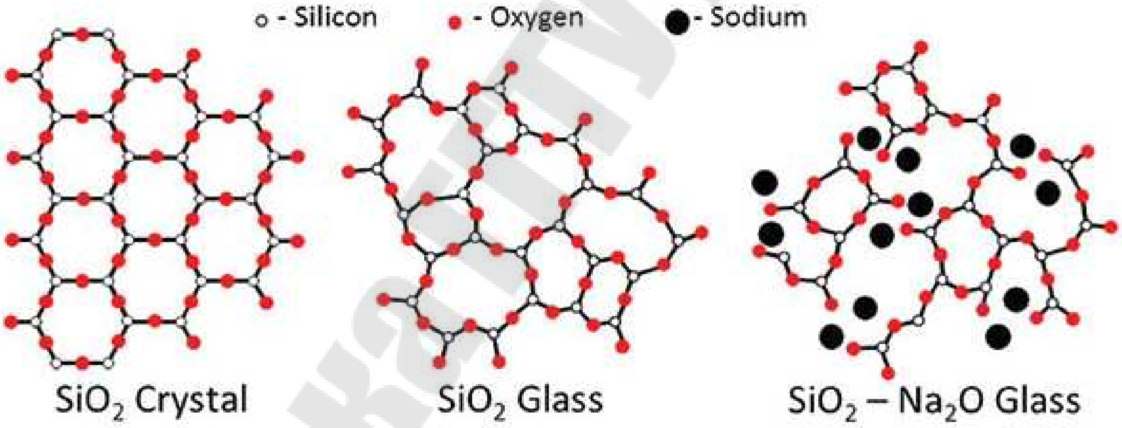
As a type of ceramic, glass is amorphous ceramic.

What is the difference between crystalline and amorphous structures?

The simplest way to understand the difference between a glass and a crystalline solid is to look at the both structure at the atomic scale. Glasses have three characteristics that make them more closely resemble "frozen liquids" than crystalline solids. First, and foremost, there is no long-range order. Second, there are numerous empty sites or vacancies. Finally, glasses don't contain planes of atoms.



The atomic arrangements in (A) a crystalline solid, (B) an amorphous solid, and (C) a gas.



Conditions for glass formation

Generally substances are more stable in a crystalline than in a glassy state. Therefore, to form a glass, crystallization must be bypassed. Under certain conditions, the melts of many substances can be cooled to the glass state. Whether or not the melt of a given material forms a glass is determined principally by a cooling rate. So, the critical point for glass formation is a rate of melt cooling: glass is formed when cooling time is not enough for the crystalline structure formation. For crystal growth melt has to cool slowly. That is why very often glass called a "frozen liquids" or a super-cooled liquid.

Can any substances be cooled to the glass state?

In terms of glass-formation ability all materials can be divided on three groups: glass network formers, intermediates, and modifiers. The network formers (oxides of silicon, boron, phosphorus, germanium) form a highly cross-linked network of oxide glass. The intermediates (oxides of titanium, aluminium, zirconium, beryllium, magnesium, zinc) can replace atoms of network formers in glass network. The modifiers (oxides of calcium, lead, lithium, sodium, potassium) alter the network structure; they are usually present as ions, compensated by nearby non-bridging oxygen atoms, bound by one covalent bond to the glass network and holding one negative charge to compensate for the positive ion nearby.

Types of glasses

Glasses can be classified based on glass network former element: silicate, borate, phosphate and so on. The most familiar, and historically the oldest, types of glass are silicate glasses based on silica (silicon dioxide), the primary constituent of sand.

1.1. Silicate glasses

1.1.1. Soda-lime-silica glass, window glass: silica (SiO_2) + sodium oxide (Na_2O) + lime (CaO) + magnesia (MgO) + alumina (Al_2O_3). Soda-lime glass, composed of approximately 75% silicon dioxide and several minor additives. It is transparent, easily formed and most suitable for window. It has a high thermal expansion and poor resistance to heat (500–600 °C). It is used for windows, some low-temperature incandescent light bulbs, and tableware. Container glass is a soda-lime glass that is a slight variation on flat glass, which uses more alumina and calcium, and less sodium and magnesium, which are more water-soluble. This makes it less susceptible to water erosion.

1.1.2. Fused silica glass, also called fused quartz, or vitreous-silica glass. Fused quartz is a glass made from chemically-pure silica. It has excellent resistance to thermal shock, being able to survive immersion in water while red hot. Fused quartz is used for high-temperature applications such as furnace tubes, lighting tubes, melting crucibles, etc. However, its high melting temperature (1723 C) and viscosity make it difficult to work with. Normally, other substances are added to simplify processing.

1.1.3. Sodium borosilicate glass: silica + boron trioxide (B_2O_3) + soda (Na_2O) + alumina (Al_2O_3). Stands heat expansion much better than window glass. Used for chemical glassware, cooking glass, car head lamps, etc. Borosilicate glasses (e.g. Pyrex, Duran) have as main constituents silica and boron trioxide. They have fairly low coefficients of thermal expansion (7740 Pyrex CTE is $3.25\times10^{-6}/°C$ as compared to about $9\times10^{-6}/°C$ for a typical soda-lime glass), making them more dimensionally stable. The lower coefficient of thermal expansion (CTE) also makes them less subject to stress caused by thermal expansion, thus less vulnerable to cracking from thermal shock. They are commonly used for reagent bottles, optical components and household cookware.

1.1.4. Lead-oxide glass, also called crystal glass, or lead glass: silica + lead oxide (PbO) + potassium oxide (K_2O) + soda (Na_2O) + zinc oxide (ZnO) + alumina. Because of its high density (resulting in a high electron density), it has a high refractive index, making the look of glassware more brilliant (called "crystal", though of course it is a glass and not a crystal). It also has a high elasticity, making glassware "ring". It is also more workable in the factory, but cannot stand heating very well. This kind of glass is also more fragile than other glasses. The most common uses of lead crystal glass are drinking glasses, ornaments, decanters, jewellery, optical lenses, enamels and lacquers, glass sealants and solders and radiation shielding from gamma and x-rays.

1.1.5. Aluminosilicate glass: silica + alumina + lime + magnesia+ barium oxide (BaO) + boric oxide (B_2O_3). Extensively used for fiberglass, used for making glass-reinforced plastics (boats, fishing rods, etc.) and for halogen bulb glass. Aluminosilicate glasses are also resistant to weathering and water erosion.

Approximate composition of silicate glasses

Fused silica	**Soda-lime-silica**	**Borosilicate**	**Aluminosilicate**	**Lead**
silica 99.9%,	silica 73%, alumina 1%, sodium oxide 17%, magnesia 4%, lime 5%	silica 81%, alumina 2%, boric oxide 13%, sodium oxide 4%	silica 62%, alumina 17%, boric oxide 5%, sodium oxide 1%, magnesia 7%, lime 8%	silica 56%, alumina 2%, sodium oxide 4%, potash 9%, lead oxide 29%

1.2. Phosphate glasses

Phosphate glasses are mainly composed of the network former P_2O_5. These glasses feature a high resistance to hydrofluoric acid, but otherwise they have a relatively low resistance to chemical corrosion. The compositions can be made more resistant to the chemicals and the environment by engineering the composition for the specific applications. Phosphate glasses are well suited for doping with various colorants, including transition metal ions and rare earth oxides. This ability results in glasses that exhibit unique and desirable transmission spectrum. These colored glasses have found their niche in various medical, military, and scientific applications. Bioactive glass, which is the material of choice to promote bone growth in the medical industry, is also a phosphate based glass composition.

1.3. Borate glasses

Borate glasses are mainly composed of the network former B_2O_3. Pure B_2O_3 is needed for the production of certain types of glasses including optical and telescope lenses, medical glasses (ampoules), electronic glasses and glass-ceramic composites. The general benefits of using B_2O_3 in glass formulations are reduction of melting temperature, increased thermal resistance and mechanical strength, and enhanced aqueous and chemical durability.

1.4. Germanium oxide-based glasses

Germanium-oxide glass: germanium dioxide (GeO_2) + alumina. Extremely clear glass, used for fiber-optic waveguides in communication networks. Light loses only 5% of its intensity through 1 km of glass fiber. The glass can be manufactured into IR windows and lenses, used for night-vision technology in the military, luxury vehicles, and thermographic cameras. GeO_2 is preferred over other IR transparent glasses because it is mechanically strong and therefore preferred for rugged military usage.

Most common used additives in glassmaking

Raw Materials	Oxides/ elements furnished	Application
Sand	SiO_2	Network former, backbone of glassy structure

Dolomite $CaO \cdot MgO \cdot 2\,CO_2$	CaO, MgO	Network modifier, gives durability to the glassy phase
Soda ash: sodium carbonate Na_2CO_3	Soda Na_2O	Fluxing agent, lowers the melting point of silica to about 1,000 °C and is therefore added to make the process more efficient. The sodium carbonate will, however, cause the finished glass to be water soluble which is not desirable in glass making. Sodium carbonate was originally found in the ash of certain plants (soda ash), but now is commonly produced from table salt.
Limestone $CaCO_3$	Lime CaO	Network modifier, gives durability to the glassy phase
Magnesia MgO	Magnesium oxide MgO	Network modifier, gives durability to the glassy phase
Aluminium oxide	Al_2O_3	Network modifier is added to some glasses to increase their durability
Lead oxide PbO	PbO	The lead has better reflective properties and therefore the glass seems to 'sparkle'. This kind of glass also lends itself to be cut to form decorative patterns on the glass. making the look of glassware more brilliant
Cromite $FeCr_2O_4$	Cr_2O_3	Green coloring agent
Cobalt oxide	CoO	Blue coloring agent
Boron oxide	B_2O_3	Boron changes the thermal and electrical properties of the glass and is used to make Pyrex glassware which can withstand extremes of heat and cold.
Lanthanum Oxide	La_2O_3	Lanthanum Oxide has excellent light reflective properties and is used to make high quality lenses in glasses.
Iron	Fe	Iron is used to absorb infrared energy in, for example, heat absorbing filters in movie projectors.

Properties of glass

1. It absorbs, refracts or transmits light. It can be made transparent or translucent.
2. It can takes excellent polish.
3. It is an excellent electrical insulator.
4. It is strong and brittle.
5. It can be blown, drawn or pressed.
6. It is not affected by atmosphere.
7. It has excellent resistance to chemicals.
8. It is available in various beautiful colors.
9. With the advancement in technology, it is possible to make glass lighter than cork or stronger than steel.
10. Glass panes can be cleaned easily.

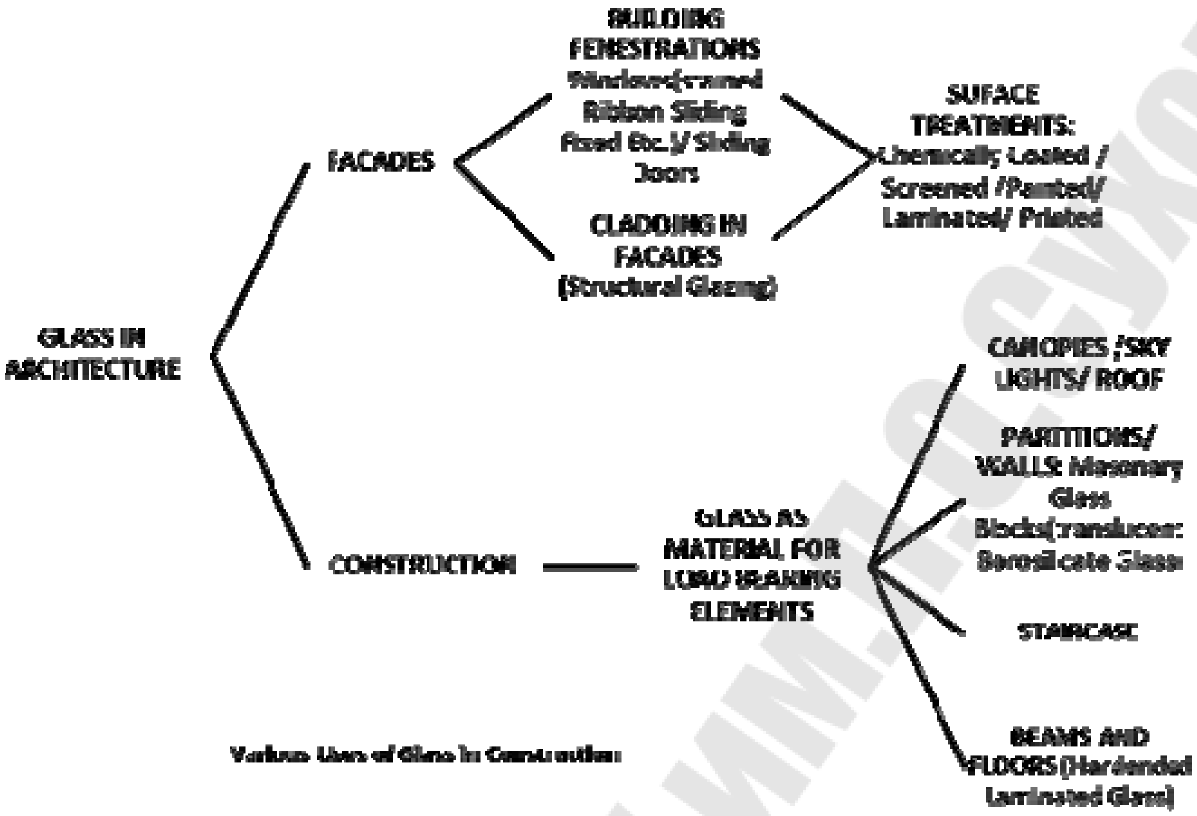
Advantages

1. Glass is an excellent material for thermal insulation, water proofing and energy conservation.
2. Glass is bad conductor of heat; it saves energy in air conditioning of building.
3. For making glass partition on upper floors, no extra design is required for slab as glass is light in weight.
4. Use of glass in construction work adds beauty to the building.
5. Its use fulfills the architectural view for external decoration.
6. By using glass in interior, it saves the space inside the building.
7. Glass cladding in building fulfill functional requirement of lighting, heat retention and energy saving.
8. Its use appear a sense of openness and harmonious.
9. As toughened glass is available, one can have good interior design with the use of glass in transparent staircase, colored shelves, ceiling etc.

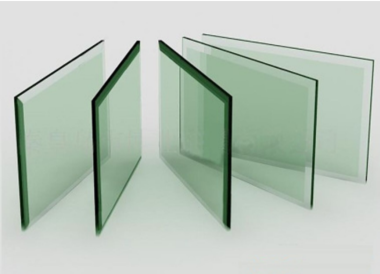
Disadvantages

1. As glass is very costly material, it may increase the budgeted cost of construction work.
2. Glass is unsafe for earthquake proven area.

Glass application in construction



Various Uses of Glass in Construction

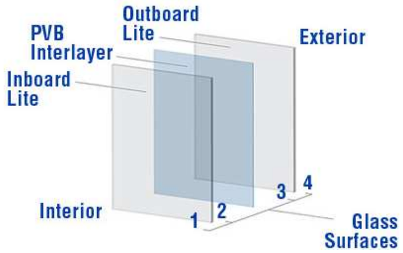


Float glass is also called soda lime glass or clear glass.

Tinted Glass
Certain additions to the glass batch mix can add color to the clear glass without compromising its strength

Toughened Glass is tempered, may have distortions and low visibility but it breaks into small dice-like pieces at modulus of rupture of 3600 psi. Hence it is used in making fire resistant doors etc

Extra clean glass
This type of glass is hydrophilic i.e. The water moves over them without leaving any marks i.e. they are covered with Nanoparticles that attack and break dirt making it easier to clean and maintain



Laminated Glass is made by sandwiching glass panels within a protective layer. It is heavier than normal glass and may cause optical distortions as well. It is tough and protects from UV radiation (99%) and insulates sound by 50%. Used in glass facades, aquariums, bridges, staircases, floor slabs, etc.

Chromatic glass can control daylight and transparency effectively. There are three forms- photochromatic (light sensitive lamination), thermochromatic (heat sensitive lamination) and electrochromatic controlled by electricity switch.)

Glass blocks Hollow glass wall blocks are manufactured as two separate halves and, while the glass is still molten, the two pieces are pressed together and annealed. The resulting glass blocks will have a partial vacuum at the hollow center. Glass bricks provide visual obscuration while admitting light

Glassmaking process

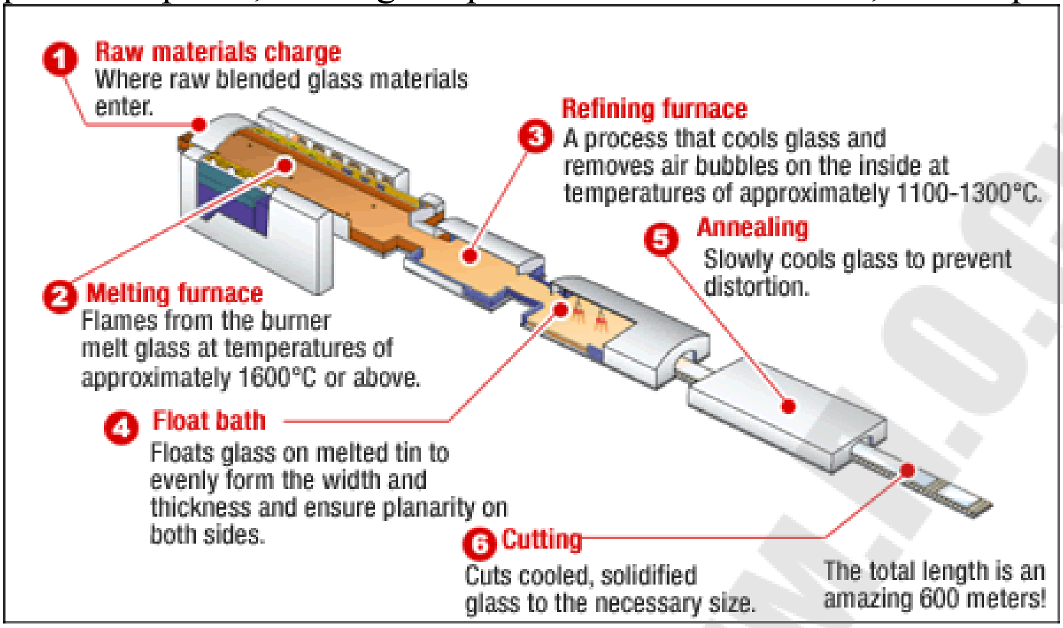
1. Sheet and tube production

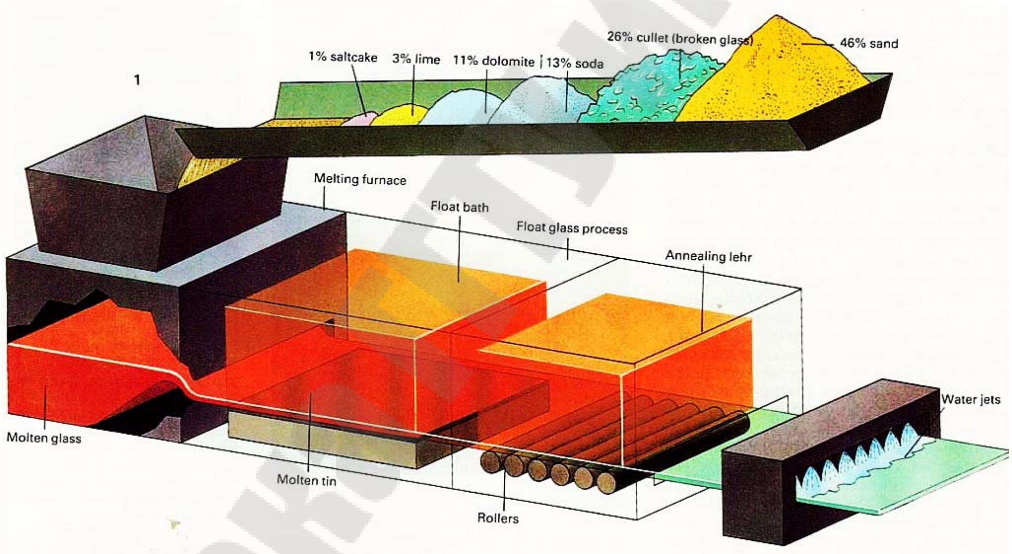
1.1. Float glass process

Float glass is a sheet of glass made by floating molten glass on a bed of molten metal, typically tin, although lead and various low melting point alloys were used in the past. This method gives the sheet uniform thickness and very flat surfaces. Modern windows are made from float glass. Most float glass is soda-lime glass, but relatively minor quantities of specialty borosilicate and flat panel display glass are also produced using the float glass process. The float glass process is also known as the Pilkington process, named after the British glass manufacturer Pilkington, who pioneered the technique (invented by Sir Alastair Pilkington) in the 1950s.

In the 1950's, Alastair Pilkington developed a new, patented system of making large, good quality sheets of flat glass for windows and glass sheets. Flat glass making had only been achieved with limited success up until then and was expensive. The new Pilkington method allowed glass to be made cheaply in bulk and to a good standard.

Molten glass is drawn on to molten metal and floats along the metal until cooled and cut – thus its name, float glass. This is achieved in a continuous process using machinery which can be up to 500m long. The machines are never switched off throughout their life span of about 10 – 15 years and produce up to 6,000 of glass per week – that's about 6,000 km per year.





1. **Batching of raw materials.** The main components, namely, soda lime glass, silica sand (73%), calcium oxide (9%), soda (13%) and magnesium (4%), are weighed and mixed into batches to which recycled glass (cullet) is added. The use of 'cullet' reduces the consumption of natural gas. The materials are tested and stored for later mixing under computerised control.

2. **Melting of raw materials in the furnace.** The batched raw materials pass from a mixing silo to a five-chambered furnace where they become molten at a temperature of approximately 1500–1600 °C.

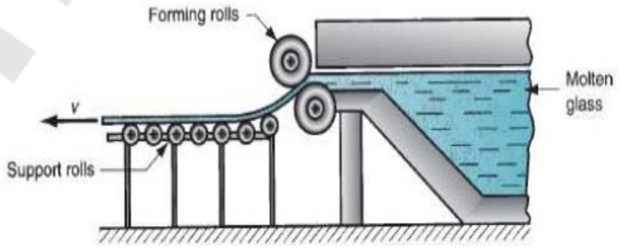
***3*. Glass melt refining.** A process that cools glass and removes air bubbles on the inside at temperatures of approximately 1100–1300 °C.

***4.* Drawing the molten glass onto the tin bath.** The **molten glass** is “floated” onto a bath of molten tin at a temperature of about 1000 °C. It forms a ribbon with a working width of 3210 mm which is normally between 3 and 25 mm thick. The glass which is highly viscous and the tin which is very fluid do not mix and the contact surface between these two materials is perfectly flat.

***5.* Cooling of the molten glass in the annealing lehr.** On leaving the bath of molten tin, the glass – now at a temperature of 600 °C – has cooled down sufficiently to pass to an annealing chamber called a lehr. The glass is now hard enough to pass over rollers and is annealed, which modifies the internal stresses enabling it to be cut and worked in a predictable way and ensuring flatness of the glass. As both surfaces are fire finished, they need no grinding or polishing.

6.* Quality checks, automatic cutting, and storage*: After cooling, the glass undergoes rigorous quality checks and is washed. It is then cut into sheets of sizes of up to 6000mm x 3210mm which are in turn stacked, stored and ready for transport.

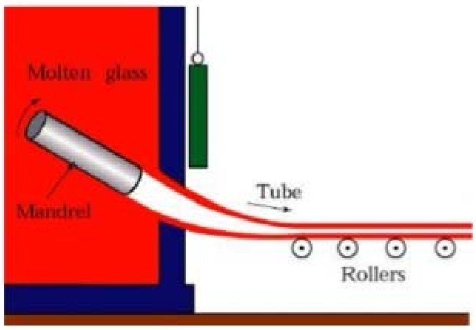
1.2. Rolling of flat plate glass



1Flat plate glass can be produced by rolling. The starting glass, in a suitably plastic condition from the furnace, is squeezed through opposing rolls whose separation determines the thickness of the sheet.

The rolled glass sheet must later be ground and polished for parallelism and smoothness.

1.3. Glass tube drawing:



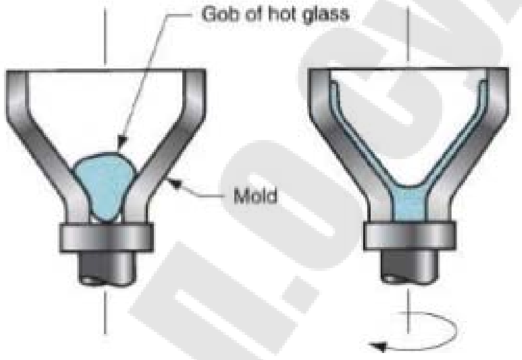
In this method molten glass is wrapped around a rotating hollow cylindrical or cone-shaped mandrel, and is drawn out by a set of rolls. Air is blown through the mandrel to prevent the glass tube from collapsing. The continuous tubing is then cut into standard lengths.

Tubular glass products include laboratory glassware, fluorescent light tubes, and thermometers.

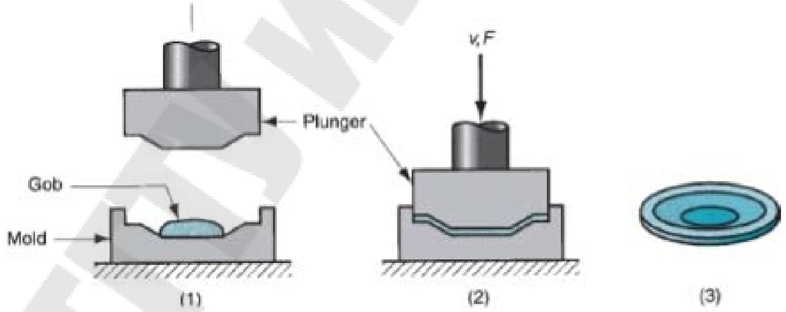
2. Glass container production

2.1. Spinning:

Glass spinning is similar to centrifugal casting of metals. It is used to produce funnel-shaped components such as the back sections of cathode ray tubes for televisions and computer monitors. gob of glass dropped into mold; rotation of mold to cause spreading of molten glass on mold surface.



2.2. Pressing: is a widely used process for relatively flat items (dishes, bake ware, headlight lenses, TV tube faceplates, and similar that)



(1) Glass gob is fed into mold from furnace; (2) glass is pressing into shape by plunger; (3) when plunger is retracted finished product is removed.

2.3. Blowing

The blowing process is used to make hollow thin-walled glass items, such as bottles and flasks.

2.3.1. Free blowing

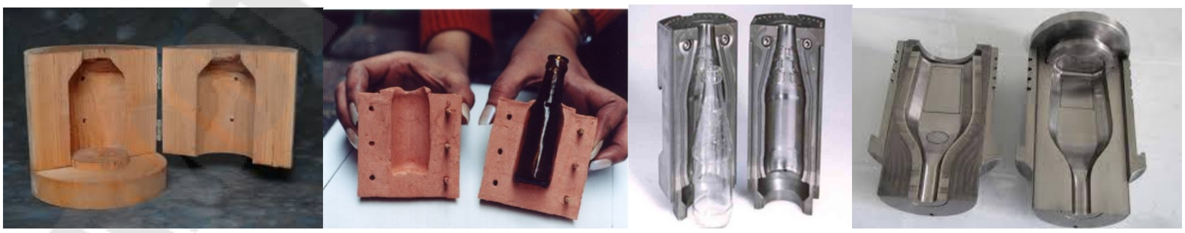
Glassblowing involves using a blowpipe_to inflate molten glass into a bubble and then manipulating it to achieve a desired shape by using wooden molds and variations in air pressure.

This involves spooling hot liquid glass onto a blowpipe and blowing short puffs of air from one end stretching the glass glob. The method dates back to the 1st Century B.C. and a skilled glassmith can make any shape he or she can imagine. This is, therefore, one of the most popular methods for artistic purposes. In addition to blowing, the glassmith can swing the pipe to cool the glass and manipulate the shape.

During blowing the thin layers of glass cool faster and become more viscous than the thicker layers, allowing the final product to have a uniformed thickness. The ancient method of glass blowing was done with clay blowpipes 30-60cms thick as this was the ideal length to be simple to handle, easy to manipulate and it was reusable several times.

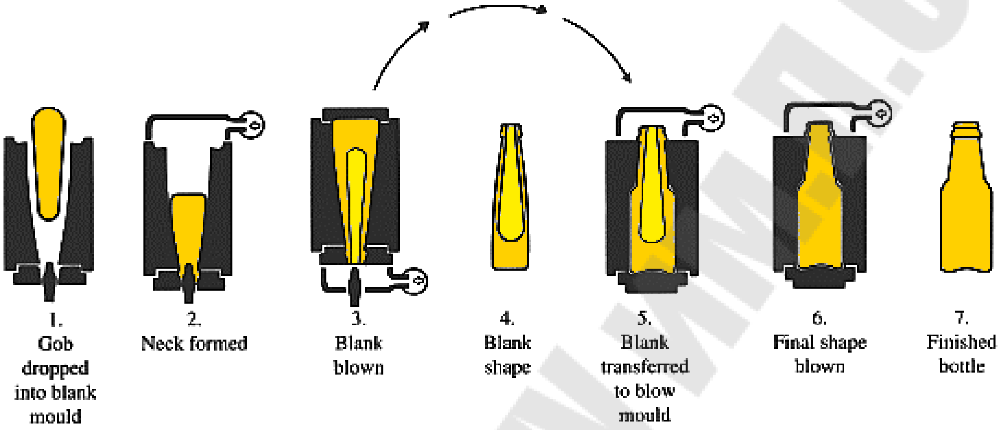
2.3.2. Mould Blowing

This method involves spooling the blowpipe with liquid glass, placing the glob in an open shut mould and blowing so that the glass takes the shape of the interior of the mould. This made it possible to mass produce glass and encourage the widespread distribution of glass products. In earlier days the mould was made using wood, however metal is now considered the best material for the mould. Single piece moulds are used for making functional vessels for storage and transportation whereas the multi piece mould is used for more sophisticated surface modelling texture and design.



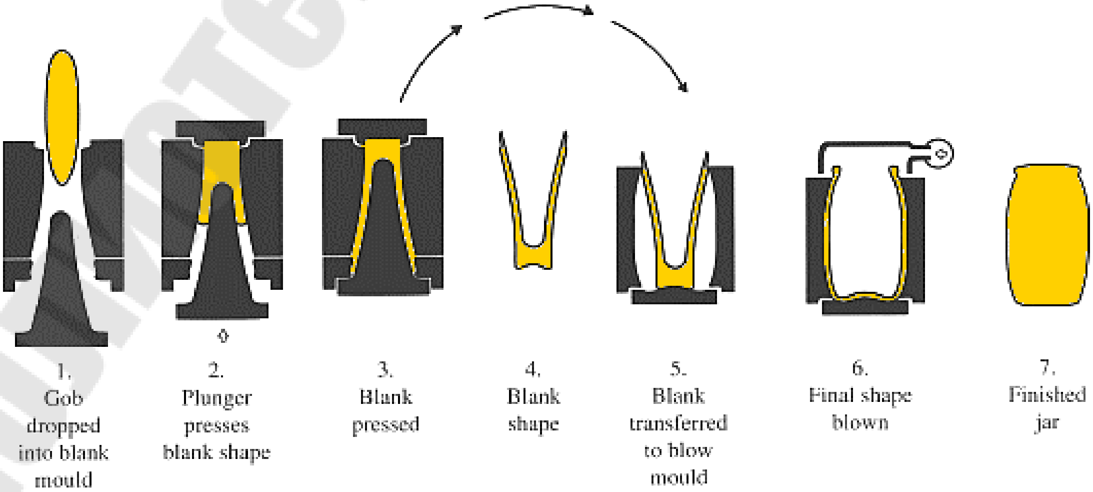
2.3.2.1. Blow-and-blow method

Heated liquid glass (gobs) are poured into a mould called the parison or the blank. A puff of air blown down into the base of the blank mould pushes the liquid glass to form the neck. A second blast of air is then applied through the already formed neck pushing the liquid into the walls of the parison mould. This mould is then transferred to the final mould where the glass is reheated to be able to take the final moulds shape. This final moulding is usually done with a combination of compressed air or vacuum. The blow-and-blow method is used to produce smaller-mouthed bottles.



3.2.1. Press-and-blow method

As the name indicates, the press-and-blow method is a pressing operation followed by a blowing operation. The process is suited to the production of wide-mouth containers. A split mold is used in the blowing operation for part removal. The gobs are delivered into the parison mould and instead of air a plunger pushes the glass to give shape. The finals stages are the same as the blow-and-blow method where the blank shape is transferred into a blow mould for the final shape.



Topic 7. Ceramic manufacturing. 3. Limestown-based ceramics.

Key questions

1 What is cement?
2 When cement starts to set?
3 Cement/binders classification based on setting condition and chemical resistance
4 What do you know about non-hydraulic cement?
5 What do you know about hydraulic cement?
6 What cements are non-hydraulic cement?
7 What cements are hydraulic cement
8 Four main components of hydraulic cements
9 Portland cement making process
10 What is clinker
11 What is concrete
12 Cement application

A **cement** is a lime-based substance used for construction as a binder (binding agent holds other materials together). Cement is seldom used on its own, but rather to bind sand and other rock formations (aggregates) together. Cement starts to set when mixed with water, which causes a series of hydration chemical reactions. The constituents slowly hydrate and the mineral hydrates solidify. The interlocking of the hydrates gives cement its strength.

Cement/binders classification based on setting condition and chemical resistance:
(1) Non-hydraulic (air-cements, magnesium oxychloride and oxysulfate cements, hydrated lime),
(2) Hydraulic (Roman cement, Portland cement, hydraulic lime),
(3) Acid-resistant (silicon fluoride cement, quartz cement),
(4) Autoclavable (harden at 170 to 300 °C i.e. 8-16 atm pressure and, e.g., comprise $CaSiO_3$ materials).

1. Non-hydraulic cement does not set in wet conditions or under water. Rather, it sets as it dries and reacts with carbon dioxide in the air. It is resistant to attack by chemicals after setting. Non-hydraulic cement, such as slaked lime (calcium oxide mixed with water), hardens by carbonation in the presence of carbon dioxide, which is naturally present in the air. First calcium oxide (lime) is produced from calcium carbonate (limestone or chalk) by calcination at temperatures above 825 °C for about 10 hours at atmospheric pressure:

$$CaCO_3 \rightarrow CaO + CO_2.$$

The calcium oxide is then spent (slaked) mixing it with water to make slaked lime (calcium hydroxide):

$$CaO + H_2O \rightarrow Ca(OH)_2.$$

Once the excess water is completely evaporated (this process is technically called setting), the carbonation starts:

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O.$$

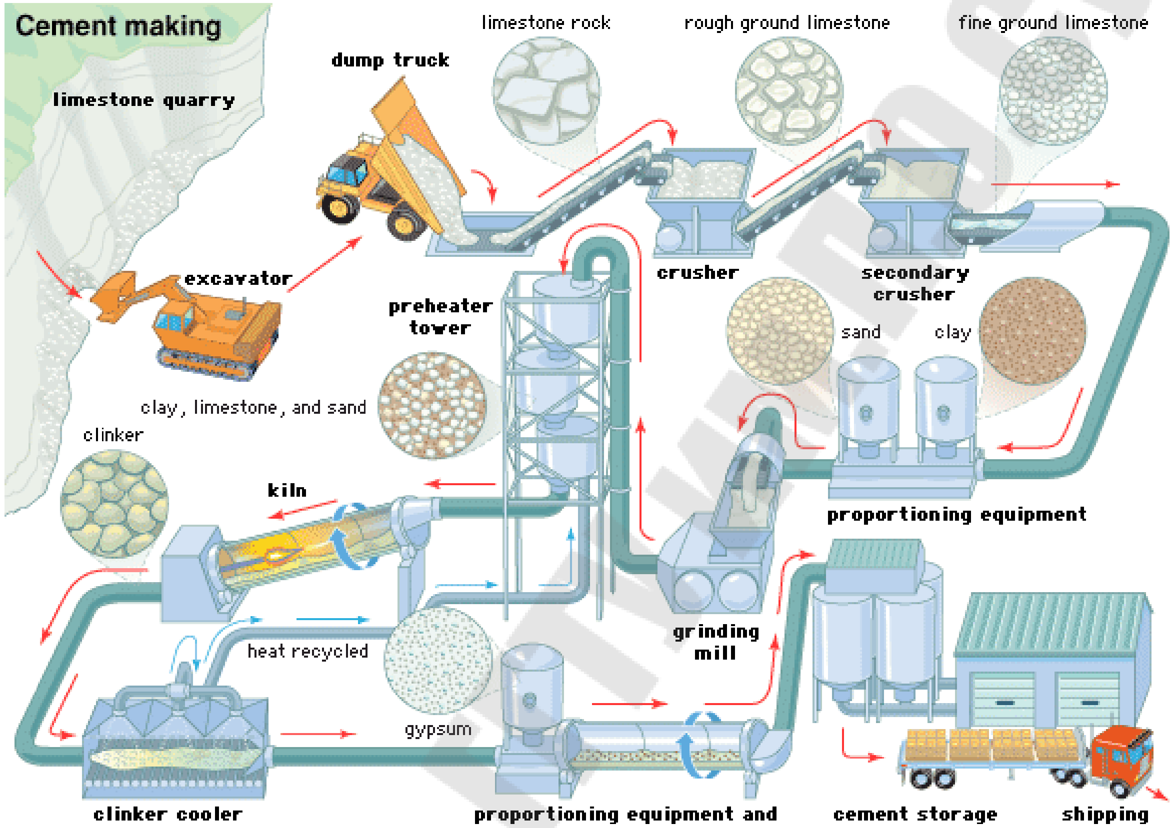
This reaction takes time, because the partial pressure of carbon dioxide in the air is low. The carbonation reaction requires that the dry cement be exposed to air, so the slaked lime is a non-hydraulic cement and cannot be used under water. This process is called the lime cycle.

2. Hydraulic cements (e.g., Portland cement) set and become adhesive due to a chemical reaction between the dry ingredients and water. The chemical reaction results in mineral hydrates that are not very water-soluble and so are quite durable in water and safe from chemical attack. This allows setting in wet conditions or under water and further protects the hardened material from chemical attack. The chemical process for hydraulic cement found by ancient Romans used volcanic ash (pozzolana) with added lime (calcium oxide).

Hydraulic cement hardens by hydration when water is added. Hydraulic cements (such as Portland cement) are made of a mixture of silicates and oxides, the four main components being: Belite ($2CaO \cdot SiO_2$); Alite ($3CaO \cdot SiO_2$); Tricalcium aluminate ($3CaO \cdot Al_2O_3$) (historically, and still occasionally, called 'celite'); Brownmillerite ($4CaO \cdot Al_2O_3 \cdot Fe_2O_3$). The silicates are responsible for the cement's mechanical properties—the tricalcium aluminate and brownmillerite are essential for formation of the liquid phase during the kiln sintering (firing). The chemistry of these reactions is not completely clear and is still the object of research.

Portland cement making process

Portland cement, the most common type of cement in general use around the world as a basic ingredient of concrete, mortar, stucco, and non-speciality grout. This cement is made by heating limestone(calcium carbonate) with other materials (such as clay) to 1450 C in a kiln, in a process known as calcination that liberates a molecule of carbon dioxide from the calcium carbonate to form calcium oxide, or quicklime—which then chemically combines with the other materials in the mix to form calcium silicates and other cementitious compounds. The resulting hard substance, called 'clinker', is then ground with a small amount of gypsum into a powder to make ordinary Portland cement, the most commonly used type of cement (often referred to as OPC). Portland cement may be grey or white.



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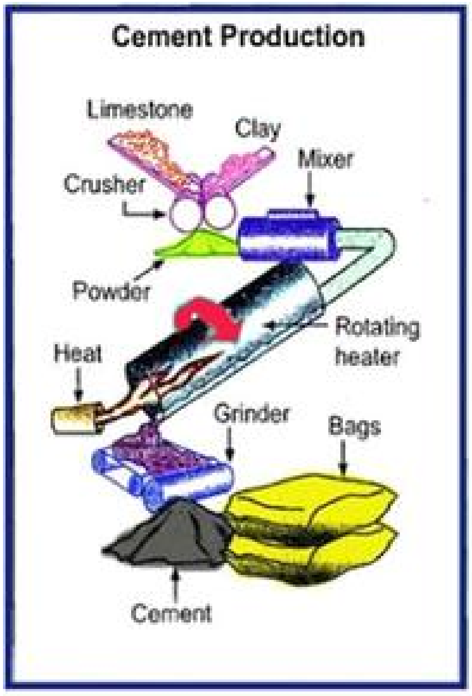
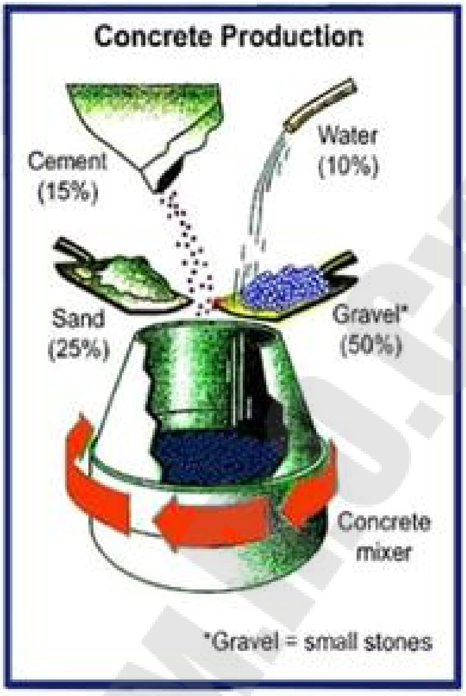
Application: Portland cement is a basic ingredient of concrete, mortar, and most non-specialty grout. The most common use for Portland cement is to make concrete. Concrete is a composite material made of aggregate (gravel and sand), cement, and water. As a construction material, concrete can be cast in almost any shape, and once it hardens, can be a structural (load bearing) element.


Cement Production
Limestone
Clay
Crusher
Mixer
Powder
Rotating heater
Heat
Grinder
Bags
Cement


Concrete Production
Cement (15%)
Water (10%)
Sand (25%)
Gravel* (50%)
Concrete mixer
*Gravel = small stones

Topic 8. Manufacturing of Basic Chemicals 1. Petroleum products

Key questions

1 Main petroleum products
2 Purification
3 Atmospheric distillation
4 Vacuum distillation
5 Reforming
6 Dehydrogenation
7 Isomerization
8 Aromatization
9 Thermal cracking
10 Catalytic cracking
11 Alkylation
12 Blending

Petroleum products

The majority of petroleum is converted to petroleum products through oil refining process

<table>
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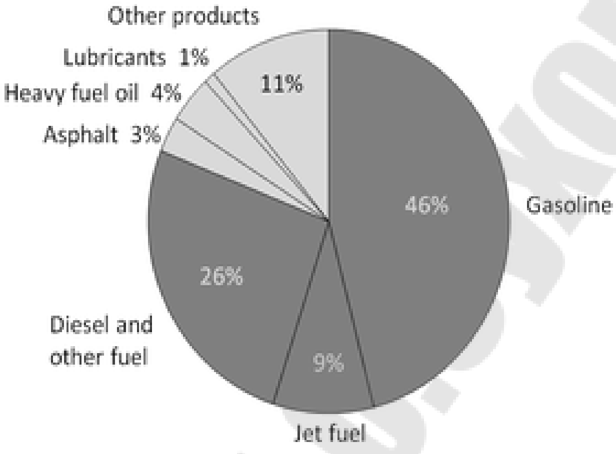
<tr><td rowspan="6">Crude Oil</td><td rowspan="6">Purification: Desaltering</td><td rowspan="6">Desal tering oil</td><td rowspan="6">Atmospheric distillation</td><td rowspan="3">Naphtha</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2">Cracking</td><td rowspan="2">Crackate</td><td></td><td>Petrochemicals</td></tr>
<tr><td rowspan="4">Blending</td><td rowspan="4">Fuels</td></tr>
<tr><td>–</td><td>–</td><td>–</td><td>–</td></tr>
<tr><td>Gaseous,
Gasoline
Kerosene
Diesel</td><td></td><td></td><td>Reforming
Alkylation</td><td>Reformate
Alkylate</td></tr>
<tr><td rowspan="2">Residue</td><td>–</td><td>–</td><td>Cracking</td><td>Crackate</td></tr>
<tr><td>Vac. distillation</td><td>Lubricant
Waxes
Bitumen
Asphalt</td><td></td><td></td><td></td><td></td></tr>
</table>

According to the composition of the crude oil and depending on the demands of the market, refineries can produce different shares of petroleum products. The largest share of oil products is used as "energy carriers", i.e. various grades of fuel oil and gasoline. These fuels include or can be blended to give gasoline, jet fuel, diesel fuel, heating oil, and heavier fuel oils.



Heavier (less volatile) fractions can also be used to produce asphalt, tar, paraffin wax, lubricating and other heavy oils. Refineries also produce other chemicals, some of which are used in chemical processes to produce plastics and other useful materials. Since petroleum often contains a few percent sulfur-containing molecules, elemental sulfur is also often produced as a petroleum product. Carbon, in the form of petroleum coke, and hydrogen may also be produced as petroleum products. The hydrogen produced is often used as an intermediate product for other oil refinery processes such as hydrocracking and hydrodes ulfurization.

Petroleum products are usually grouped into four categories: (1) light distillates (LPG, gasoline, naphtha), (2) middle distillates (kerosene, jet fuel, diesel), (3) heavy distillates and (4) residuum (heavy fuel oil, lubricating oils, wax, asphalt). This classification is based on the way crude oil is distilled and separated into fractions.

List of main petroleum products:
- Gasoline
- Naphtha
- Kerosene and related jet aircraft fuels
- Diesel fuel and Fuel oils
- Gaseous fuel such as Liquified petroleum gas and propane, stored and shipped in liquid form under pressure.

- Lubricants (produces light machine oils, motor oils, and greases, adding viscosity stabilizers as required), usually shipped in bulk to an offsite packaging plant.
- Paraffin wax, used in the packaging of frozen foods, among others. May be shipped in bulk to a site to prepare as packaged blocks. Used for wax emulsions, construction board, matches, candles, rust protection, and vapor barriers.
- Sulfur (or sulfuric acid), byproducts of sulfur removal from petroleum which may have up to a couple percent sulfur as organic sulfur-containing compounds. Sulfur and sulfuric acid are useful industrial materials. Sulfuric acid is usually prepared and shipped as the acid precursor oleum.
- Bulk tar shipping for offsite unit packaging for use in tar-and-gravel roofing.
- Asphalt used as a binder for gravel to form asphalt concrete, which is used for paving roads, lots, etc. An asphalt unit prepares bulk asphalt for shipment.
- Petroleum coke, used in specialty carbon products like electrodes or as solid fuel.
- Petrochemicals are organic compounds that are the ingredients for the chemical industry, ranging from polymers and pharmaceuticals, including ethylene and benzene-toluene-xylenes ("BTX") which are often sent to petrochemical plants for further processing in a variety of ways. The petrochemicals may be olefins or their precursors, or various types of aromatic petrochemicals.

Over 6,000 items are made from petroleum waste by-products including: fertilizer, floor coverings, perfume, insecticide, petroleum jelly, soap, vitamin capsules.

Refining processes

Major refining processes can be divided on purification, separation (e.g. distillation and stabilisation), conversion and blending processes.

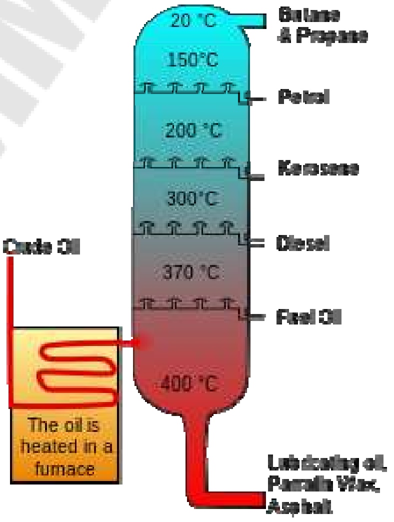
1. Purification

Gases, dirt and water are removed from the crude petroleum usually before transportation to the refinery. Crude with high salt content will typically be processed through a desalter before going to distillation, to remove salts that could cause corrosion in the distillation tower. Desalter unit washes out salt from the crude oil.

2. Separation

Crude oil is a mixture of different hydrocarbon molecules. It contains hydrocarbons of varying molecular masses, forms and lengths such as paraffins, aromatics, naphthenes (or cycloalkanes), alkenes, dienes, and alkynes. Each of them has their own boiling points. Different boiling points allow the hydrocarbons to be separated by fractional distillation. Distillation of crude oil is typically performed under atmospheric pressure and under a vacuum. Low boiling fractions usually vaporize below 400 C at atmospheric pressure without cracking the hydrocarbon compounds. Therefore, all the low boiling fractions of crude oil are separated by atmospheric distillation.

2.1. Atmospheric distillation



Crude oil is first heated to about 400°C. The heated crude is injected into the lower part of the distillation column, where much of it vaporizes. As the vapors rise through the tower, they pass through a series of perforated trays or structured packing. As the vapors cool, their components will condense back into liquid at different levels in the tower based on their boiling point. The lighter hydrocarbons will condense at higher points in the distillation tower, heavier hydrocarbons will condenser lower down.

This results in separation of the hydrocarbons based on the different temperatures at which they boil/condense. Hydrocarbons are drawn off of the tower at different heights to get a set of streams of different boiling points. These different streams are called distillation cuts or fractions. The heaviest fractions of the crude do not vaporize and are drawn off at the bottom of the tower as atmospheric bottoms. These are sent to the vacuum distillationfor further fractionation under a vacuum.

The products obtained by distillation of crude oil do not consist of single hydrocarbons, except in the case of simple gases such as ethane and propane. Each product fraction contains many hydrocarbon compounds boiling within a certain range and these can be broadly classified in order of decreasing volatility into gases (contains hydrocarbons in the range of (C1-C4)), petrol (gasoline, naphta) (contains hydrocarbons in the range of

(C4-C10)), kerosene (aviation fuels) in (C4-C19) range, diesel fuels can be found in the (C8-C21) range. Other more heavier hydrocarbons are heating oils found in range of (C15-C22), lubricants and hydraulic fluids are in the range of C20-C60.

Also fractions can be broadly classified into gases, light, middle and heavy distillates and residues. The gases consist chiefly of methane, ethane, propane and butane. The first two are utilised as fuel or petrochemical feedstocks. Propane and butane may also be liquefied by compression and marketed as liquefied petroleum gas (LPG). Butane may to some extent be added to motor gasoline.

The light distillates comprise fractions, which may be used directly in the blending of motor and aviation gasolines, or as catalytic reforming and petro-chemical feedstocks; these fractions are sometimes referred to as tops or naptha. The heavier, higher boiling-point fractions in this range (middle distillates) are the feedstocks for reforming processes lighting, heating and jet engine kerosine. Heavier distillates are used as gas oil and diesel fuel and also for blending with residual products in the preparation of furnace fuels. The residue is used for the manufacture of lubricating oils, waxes, bitumen, and feedstocks for vacuum distillation and cracking units, and as residual fuel oil.

The outputs from distillation are distillation cuts. Typically, a crude distillation unit will have the following distillation cuts:

- Refinery gas - Made up of methane and ethane. This stream remains a gas and is used as fuel for the refinery
- Light ends - Stream containing primarily propane and butane. It is sent to the sat gas plant for further separation
- Light straight run naphtha - Sold as a feedstock for petrochemicals, blended directly into gasoline or upgraded through isomerization
- Heavy naphtha - Mostly upgraded through the reformer but sometimes blended directly into gasoline
- Kerosene - Used to make jet fuel or blended into diesel
- Atmospheric gasoil - Used to make diesel or converted to gasoline through upgrading in the FCC
- Atmospheric bottoms - Contains all of the hydrocarbons that do not vaporize in the atmospheric distillation tower. It is typically fed to the vacuum distillation unit for further separation

2.2. Vacuum distillation

Vacuum distillation can also be referred as "low temperature distillation". In distilling the crude oil, it is important not to subject the crude oil to temperatures above 370 to 380 °C because the high molecular weight components in the crude oil will undergo thermal cracking and form petroleum coke at temperatures above that. Formation of coke would result in plugging the tubes in the furnace that heats the feed stream to the crude oil distillation column. In most refineries, the bottoms from the atmospheric distillation tower will be sent to the vacuum tower for further separation. The constraint imposed by limiting the column inlet crude oil to a temperature of less than 370 to 380 °C yields a residual oil from the bottom of the atmospheric distillation column consisting entirely of hydrocarbons that boil above 370 to 380 C. To further distill the residual oil from the atmospheric distillation column, the distillation must be performed at absolute pressures as low as 10 to 40 mmHg (also referred to as Torr) so as to limit the operating temperature to less than 370 to 380 C.

Atmospheric tower bottoms are injected into the vacuum tower under a pressure at about 1/20th of atmospheric pressure (typically 25 to 40 mmHg or lower). Under these low pressures, the atmospheric resid will vaporize at temperatures below those where it starts to crack. This allows separation of very heavy components without cracking. There are two key distillation cuts that result from the vacuum distillation step: vacuum gasoil (typically sent to the cracking to be upgraded into light products and vacuum resid (typically is used to make asphalt).

3. Conversion (e.g. reforming, cracking, alkylation)

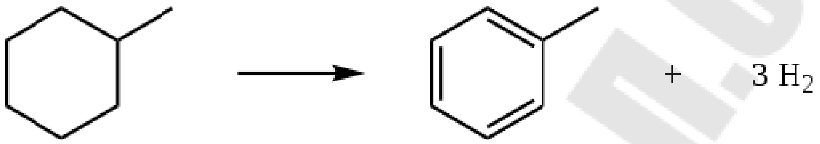
Since the lighter liquid products are in great demand for use in internal combustion engines, a modern refinery will convert heavy hydrocarbons and lighter gaseous elements into these higher value products.

3.1. Reforming

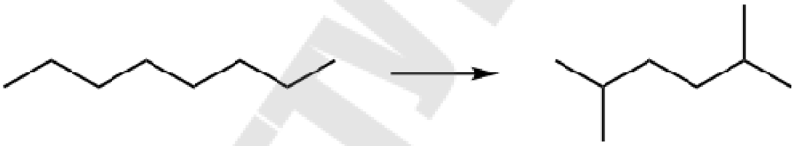
Reforming processing technique by which the molecular structure of a hydrocarbon is rearranged to alter its properties. The process is frequently applied to low-quality gasoline stocks (or petroleum refinery naphthas) to improve their combustion characteristics (octane ratings). There are thermal and catalytic reformingS. Thermal reforming alters the properties of low-grade naphthas by converting the molecules into those of higher octane number by exposing the materials to high temperatures and pressures. Catalytic reforming uses a catalyst, usually platinum, to produce a similar result. Mixed with hydrogen, naphtha is heated and passed over pellets of catalyst in a series of reactors, under high pressure, producing high-octane gasoline. Before sending to a catalytic reformer unit the naphtha must be hydrotreated. Naphtha hydrotreater unit uses hydrogen to desulfurize naphtha from atmospheric distillation.

The major catalytic reforming reactions are:

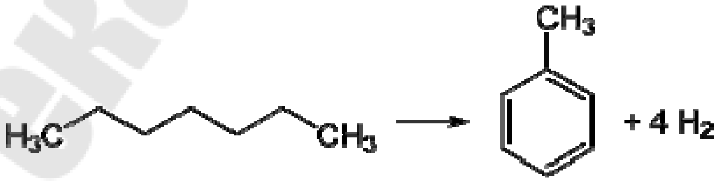
1: The dehydrogenation of naphthenes to convert them into aromatics as exemplified in the conversion methylcyclohexane (a naphthene) to toluene (an aromatic), as shown below:



2: The isomerization of normal paraffins to isoparaffins as exemplified in the conversion of normal octane to 2,5-Dimethylhexane (an isoparaffin), as shown below:



3: The dehydrogenation and aromatization of paraffins to aromatics (commonly called dehydrocyclization) as exemplified in the conversion of normal heptane to toluene, as shown below:



3.2 Cracking

Cracking, in petroleum refining, the process by which heavy hydrocarbon molecules are broken up into lighter molecules by means of heat and usually pressure and sometimes catalysts. Cracking is the most important process for the commercial production of gasoline and diesel fuel. Cracking of petroleum yields light oils (corresponding to gasoline), middle-range oils used in diesel fuel, residual heavy oils, a solid carbonaceous product known as coke, and such gases as methane, ethane, ethylene, propane, propylene, and butylene. Depending on the end product, the oils can go directly into fuel blending, or they can be routed through further cracking reactions or other refining processes until they have produced oils of the desired weight.

Cracking is the process whereby long-chain hydrocarbons are broken down into simpler molecules such as light hydrocarbons, by the breaking of carbon-carbon bonds in the precursors. The rate of cracking and the end products are strongly dependent on the temperature and presence of catalysts. Cracking is the breakdown of a large alkane into smaller, more useful alkenes.

3.2.1. **Thermal cracking**

Thermal cracking was the first category of hydrocarbon cracking to be developed. Thermal cracking is currently used to "upgrade" very heavy fractions or to produce light fractions or distillates, burner fuel and/or petroleum coke. In steam cracking, a gaseous or liquid hydrocarbon feed like naphtha, LPG or ethane is diluted with steam and briefly heated in a furnace without the presence of oxygen. Typically, the reaction temperature is very high, at around 850 C, but the reaction is only allowed to take place very briefly. In modern cracking furnaces, the residence time is reduced to milliseconds to improve yield, resulting in gas velocities up to the speed of sound. After the cracking temperature has been reached, the gas is quickly quenched to stop the reaction in a transfer line heat exchanger or inside a quenching header using quench oil. The products produced in the reaction depend on the composition of the feed, the hydrocarbon to steam ratio and on the cracking temperature and furnace residence time. Light hydrocarbon feeds such as ethane, LPGs or light naphtha give product streams rich in the lighter alkenes, including ethylene, propylene, and butadiene. Heavier hydrocarbon (full range and heavy naphthas as well as other refinery products) feeds give some of these, but also give products rich in aromatic hydrocarbons and hydrocarbons suitable for inclusion in gasoline or fuel oil. A higher cracking temperature (also referred to as severity) favors the production of ethene and benzene, whereas lower severity produces higher amounts of propene, C4-hydrocarbons and liquid products.

3.2.2. **Catalytic cracking**

Catalytic cracking process involves the presence of acid catalysts (usually solid acids such as silica-alumina and zeolites) which promote a heterolytic (asymmetric) breakage of bonds yielding pairs of ions of opposite charges, usually a carbocation and the very unstable hydride anion. Carbon-localized free radicals and cations are both highly unstable and undergo processes of chain rearrangement, C-C scission in position beta as in cracking, and intra- and intermolecular hydrogen transfer. In both types of processes, the corresponding reactive intermediates (radicals, ions) are permanently regenerated, and thus they proceed by a self-propagating chain mechanism. The chain of reactions is eventually terminated by radical or ion recombination.

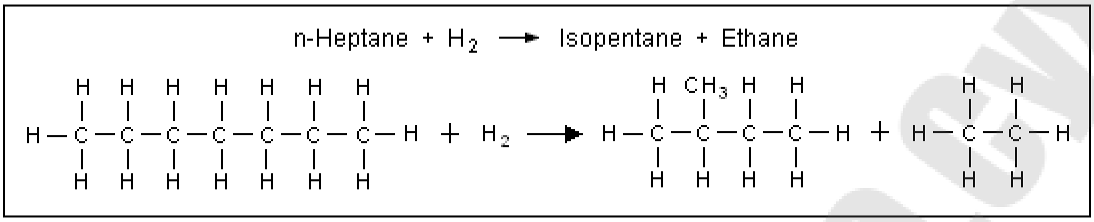
3.2.2.1. **Fluid Catalytic cracking**

Fluid catalytic cracking is a commonly used process, and a modern oil refinery will typically include a cat cracker, particularly at refineries in the US, due to the high demand for gasoline. Fluid catalytic cracking produces a high yield of petrol and LPG, while hydrocracking is a major source of jet fuel, Diesel fuel, naphtha, and again yields LPG. The gasoline produced in the FCC unit has an elevated octane rating but is less chemically stable compared to other gasoline components due to its olefinic profile. Olefins in gasoline are responsible for the formation of polymeric deposits in storage tanks, fuel ducts and injectors. The FCC LPG is an important source of C_3-C_4 olefins and isobutanethat are essential feeds for the alkylation process and the production of polymers such as polypropylene.

3.2.2.2. **Hydrocracking**

Hydrocracking is a catalytic cracking process assisted by the presence of added hydrogen gas. Unlike a hydrotreater, hydrocracking uses hydrogen to break C-C bonds (hydrotreatment is conducted prior to hydrocracking to protect the catalysts in a hydrocracking process).The products of this process are saturated hydrocarbons; depending on the reaction conditions (temperature, pressure, catalyst activity) these products range from ethane, LPG to heavier hydrocarbons consisting mostly of isoparaffins. Hydrocracking is normally facilitated by a bifunctional catalyst that is capable of rearranging and breaking hydrocarbon chains as well as adding hydrogen to aromatics and olefins to produce naphthenes and alkanes. The major products from hydrocracking are jet fuel and diesel, but low sulphur naphtha fractions and LPG are also produced. All these products have a very low content ofsulfur and other contaminants.

The hydrocracking of paraffins into smaller molecules as exemplified by the cracking of normal heptane into isopentane and ethane, as shown below:



3.3. Alkylation

Alkylation, is a chemical process in which light, gaseous hydrocarbons are combined to produce high-octane components of gasoline. The light hydrocarbons consist of olefins such as propylene and butylene and isoparaffins such as isobutane. These compounds are fed into a reactor, where, under the influence of a sulfuric-acid or hydrofluoric-acid catalyst, they combine to form a mixture of heavier hydrocarbons. The liquid fraction of this mixture, known as alkylate, consists mainly of isooctane, a compound that lends excellent antiknock characteristics to gasolines. Alkylation units were installed in petroleum refineries in the 1930s, but the process became especially important during World War II, when there was a great demand for aviation gasoline. It is now used in combination with fractional distillation, catalytic cracking, and isomerization to increase a refinery’s yield of automotive gasoline.

An alkylation unit is one of the conversion processes used in petroleum refineries. It is used to convert isobutane and low-molecular-weight alkenes (primarily a mixture of propene and butene) into alkylate, a high octane gasoline component. The process occurs in the presence of a strong acting acid such as sulfuric acid or hydrofluoric acid (HF) as catalyst. Depending on the acid used, the unit takes the name of SAAU (Sulphuric Acid Alkylation Unit) or HFAU (Hydrofluoric Acid Alkylation Unit).

Since crude oil generally contains only 10 to 40 percent of hydrocarbon constituents in the gasoline range, refineries typically use a fluid catalytic cracking unit (FCCU) process to convert high molecular weight hydrocarbons into smaller and more volatile compounds, which are then converted into liquid gasoline-size hydrocarbons. Alkylation processes transform low molecular-weight alkenes and iso-paraffin molecules into larger iso-paraffins with a high octane number. While FCCUs are a very common unit in modern oil refineries, it is not common for a refinery have an alkylation unit. Indeed, as of 2010 there are some countries in the world without any installed alkylation units.

The product of the unit, the alkylate, is composed of a mixture of high-octane, branched-chain paraffinic hydrocarbons (mostly isoheptane and isooctane). Alkylate is a premium gasoline blending stock because it has exceptional antiknock properties and is clean burning. The octane number of the alkylate depends mainly upon the kind of alkenes used and upon operating conditions. For example, isooctane results from combining butylene with isobutane and has an octane rating of 100 by definition. There are other products in the alkylate effluent, however, so the octane rating will vary accordingly.

4. Blending

The final step in gasoline production is the blending of fuels with different octane ratings, vapor pressures, and other properties to meet product specifications. Another method for reprocessing and upgrading these intermediate products (residual oils) uses a devolatilization process to separate usable oil from the waste as phaltene material.

Product blending plays a key role in preparing the refinery products for the market to satisfy the product specifications and environmental regulations. The objective of product blending is to assign all available blend components to satisfy the product demand and specifications to minimize cost and maximize overall profit. Almost all refinery products are blended for the optimal use of all of the intermediate product streams for the most efficient and profitable conversion of petroleum to marketable products. For example, typical motor gasolines may consist of straight-run naphtha from distillation, crackate (from FCC), reformate, alkylate, isomerate, and polymerate, in proportions to make the desired grades of gasoline and the specifications.

Basic intermediate streams can be blended into different finished products. For example, naphthas can be blended into gasoline, or jet fuel streams, depending on the demand. Until the 1960s, the blending was performed in batch operations. With computerization and the availability of the required equipment, online blending operations have replaced blending in batch processes. Keeping inventories of the blending stocks along with cost and physical data has increased the flexibility of and profits from online blending through optimization programs. In most cases, the components blend nonlinearly for a given property (e.g., vapor pressure, octane number, cetane number, viscosity, pour point), and correlations and programming are required for reliable predictions of the specified properties in the blends.

Gasoline blending

One of the most critical economic issues for a petroleum refiner is selecting the optimal combination of components to produce final gasoline products. Gasoline blending is much more complicated than a simple mixing of components. First, a typical refinery may have as many as 8 to 15 different hydrocarbon streams to consider as blend stocks. These may range from butane, the most volatile component, to a heavy naphtha and include several gasoline naphthas from crude distillation, catalytic cracking, and thermal processing units in addition to alkylate, polymer, and reformate. Modern gasoline may be blended to meet simultaneously 10 to 15 different quality specifications, such as vapour pressure; initial, intermediate, and final boiling points; sulfur content; colour; stability; aromatics content; olefin content; octane measurements for several different portions of the blend; and other local governmental or market restrictions. Since each of the individual components contributes uniquely in each of these quality areas and each bears a different cost of manufacture, the proper allocation of each component into its optimal disposition is of major economic importance. In order to address this problem, most refiners employ linear programming, a mathematical technique that permits the rapid selection of an optimal solution from a multiplicity of feasible alternative solutions. Each component is characterized by its specific properties and cost of manufacture, and each gasoline grade requirement is similarly defined by quality requirements and relative market value. The linear programming solution specifies the unique disposition of each component to achieve maximum operating profit. The next step is to measure carefully the rate of addition of each component to the blend and collect it in storage tanks for final inspection before delivering it for sale. Still, the problem is not fully resolved until the product is actually delivered into customers’ tanks. Frequently, last-minute changes in shipping schedules or production qualities require the reblending of finished gasolines or the substitution of a high-quality (and therefore costlier) grade for one of more immediate demand even though it may generate less income for the refinery.

Kerosene

Though its use as an illuminant has greatly diminished, kerosene is still used extensively throughout the world in cooking and space heating and is the primary fuel for modern jet engines. When burned as a domestic fuel, kerosene must produce a flame free of smoke and odour. Standard laboratory procedures test these properties by burning the oil in special lamps. All kerosene fuels must satisfy minimum flash-point specifications (49 °C, or 120 °F) to limit fire hazards in storage and handling.

Jet fuels must burn cleanly and remain fluid and free from wax particles at the low temperatures experienced in high-altitude flight. The conventional freeze-point specification for commercial jet fuel is −50 °C (−58 °F). The fuel must also be free of any suspended water particles that might cause blockage of the fuel system with ice particles. Special-purpose military jet fuels have even more stringent specifications.

Diesel oils

The principal end use of gas oil is as diesel fuel for powering automobile, truck, bus, and railway engines. In a diesel engine, combustion is induced by the heat of compression of the air in the cylinder under compression. Detonation, which leads to harmful knocking in a gasoline engine, is a necessity for the diesel engine. A good diesel fuel starts to burn at several locations within the cylinder after the fuel is injected. Once the flame has initiated, any more fuel entering the cylinder ignites at once.

Straight-chain hydrocarbons make the best diesel fuels. In order to have a standard reference scale, the oil is matched against blends of cetane (normal hexadecane) and alpha methylnaphthalene, the latter of which gives very poor engine performance. High-quality diesel fuels have cetane ratings of about 50, giving the same combustion characteristics as a 50-50 mixture of the standard fuels. The large, slower engines in ships and stationary power plants can tolerate even heavier diesel oils. The more viscous marine diesel oils are heated to permit easy pumping and to give the correct viscosity at the fuel injectors for good combustion.

Until the early 1990s, standards for diesel fuel quality were not particularly stringent. A minimum cetane number was critical for transportation uses, but sulfur levels of 5,000 parts per million (ppm) were common in most markets. With the advent of more stringent exhaust emission controls, however, diesel fuel qualities came under increased scrutiny. In the European Union and the United States, diesel fuel is now generally restricted to maximum sulfur levels of 10 to 15 ppm, and regulations have restricted aromatic content as well. The limitation of aromatic compounds requires a much more demanding scheme of processing individual gas oil components than was necessary for earlier highway diesel fuels.

Fuel oils

Furnace oil consists largely of residues from crude oil refining. These are blended with other suitable gas oil fractions in order to achieve the viscosity required for convenient handling. As a residue product, fuel oilis the only refined product of significant quantity that commands a market price lower than the cost of crude oil.

Because the sulfur contained in the crude oil is concentrated in the residue material, fuel oil sulfur levels are naturally high. The sulfur level is not critical to the combustion process as long as the flue gases do not impinge on cool surfaces (which could lead to corrosion by the condensation of acidic sulfur trioxide). However, in order to reduce air pollution, most industrialized countries now restrict the sulfur content of fuel oils. Such regulation has led to the construction of residual desulfurization units or cokers in refineries that produce these fuels.

Residual fuels may contain large quantities of heavy metals such as nickel and vanadium; these produce ash upon burning and can foul burner systems. Such contaminants are not easily removed and usually lead to lower market prices for fuel oils with high metal contents.

Topic 8. Manufacturing of Basic Chemicals 2. Polymers

Key questions

1 Basic chemicals
2 Petrochemicals
3 Common used polymers
4 PE application
5 PVC application
6 PP application
7 PS application
8 Leading man-made polymer fibers
9 Polymerization

Basic chemicals are divided into chemicals derived from oil, known as petrochemicals, polymers, basic inorganics.

Basic chemicals		
Basic organic chemicals		Basic inorganics
Petrochemicals	**Polymers** (synthetic organic polymers)	

Petrochemicals

The term ‘petrochemical’ can be misleading as the same chemicals are increasingly being derived from sources other than oil, such as coal and biomass. An example is methanol, commonly produced from oil and natural gas in the US and Europe but from coal in China. Another is ethene, derived from oil and gas in the US and Europe but increasingly from biomass in Brazil. The main use for petrochemicals is in the manufacture of a wide range of polymers.

Raw material	**T**	**P**	**T**	**P**	**T**	**P**
Oil (petroleum)	Oil refining	Petrochemicals (commo-dity chemicals)	Polymerization	Polymer materials	Forming: pressing, casting	Polymer goods

Polymers, the largest revenue segment at about 33 percent of the basic chemicals dollar value, includes all categories of plastics and man-made fibers. The major markets for plastics are packaging, followed by home construction, containers, appliances, pipe, transportation, toys, and games.

- The largest-volume polymer product, polyethylene (PE), is used mainly in packaging films and other markets such as milk bottles, containers, and pipe.
- Polyvinyl chloride (PVC), another large-volume product, is principally used to make piping for construction markets as well as siding and, to a much smaller extent, transportation and packaging materials.
- Polypropylene (PP), similar in volume to PVC, is used in markets ranging from packaging, appliances, and containers to clothing and carpeting.
- Polystyrene (PS), another large-volume plastic, is used principally for appliances and packaging as well as toys and recreation.
- The leading man-made fibers include polyester, nylon, polypropylene, and acrylics, with applications including apparel, home furnishings, and other industrial and consumer use.

The principal raw materials for polymers are bulk petrochemicals.

Chemicals in the bulk petrochemicals and intermediates are primarily made from liquefied petroleum gas (LPG), natural gas, and crude oil. Their sales volume is close to 30 percent of overall basic chemicals. Typical large-volume products include ethylene, propylene, benzene, toluene, xylenes, methanol, vinyl chloride monomer (VCM), styrene, butadiene, and ethylene oxide. These basic or commodity chemicals are the starting materials used to manufacture many polymers and other more complex organic chemicals particularly those that are made for use in the specialty chemicals category (see below).

"Polymers and plastics, especially polyethylene, polypropylene, polyvinyl chloride, polyethylene terephthalate, polystyrene and polycarbonate comprise about 80% of the industry’s output worldwide". These materials are often converted to fluoropolymer tubing products and used by the industry to transport highly corrosive materials. Chemicals are used in a lot of different consumer goods, but they are also used in a lot of different other sectors; including agriculture manufacturing, construction, and service industries. Major industrial customers include rubber and plastic products, textiles, apparel, petroleum refining, pulp and paper, and primary metals. Chemicals are nearly a $3 trillion global enterprise, and the EU and U.S. chemical companies are the world's largest producers.

Polymerization

Polymerization is the process of combining many small molecules known as monomers into a covalently bonded chain or network. During the polymerization process, some chemical groups may be lost from each monomer. This is the case, for example, in the polymerization of PET polyester. The monomers are terephthalic acid ($HOOC-C_6H_4-COOH$) and ethylene glycol ($HO-CH_2-CH_2-OH$) but the repeating unit is $-OC-C_6H_4-COO-CH_2-CH_2-O-$, which corresponds to the combination of the two monomers with the loss of two water molecules. The distinct piece of each monomer that is incorporated into the polymer is known as a repeat unit or monomer residue.

Synthetic methods are generally divided into two categories, step-growth polymerization and chain-growth polymerization. The essential difference between the two is that in chain growth polymerization, monomers are added to the chain one at a time only, such as in polyethylene, whereas in step-growth polymerization chains of monomers may combine with one another directly, such as in polyester. However, some newer methods such as plasma polymerization do not fit neatly into either category. Synthetic polymerization reactions may be carried out with or without a catalyst. Laboratory synthesis of biopolymers, especially of proteins, is an area of intensive research.

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