IS STEEL A SUNSET INDUSTRY ?

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ABSTRACT

A brief overview of developments in steel making and processing has been done with particular emphasis on developments of various grades of steels for automobile sector. Time and again the challenges posed by alternative materials like plastics, ceramics , aluminium , magnesium etc to steel have been met and appropriate grades of steels have been produced with improved strength, toughness and corrosion resistance along with matching fabrication technologies. It has been shown that the steel industry is no more a sunset industry , it has to see many dawns.

INTRODUCTION

In the present scenario steel appears to be challenged as construction and engineering material by a host of alternative materials and perhaps there is a legitimate apprehension about its future in terms of high volume consumption. Particularly in the area of advanced materials steel has a stiff competition . Table 1 gives the major application areas along with the present technology and the future potential alternative materials . We can see that many of the conventional and improved steel based materials are being substituted by glass fibre reinforced concrete, titanium alloys, sialons, SiC ceramics , Magnesium alloys etc. When the available data of compound growth rate for steel is considered since 1900 it shows that a 4.1% growth rate in 1900-1943, 6.7% in 1945-1973 and only 0.7% in 1973-2000 . The lower growth rate in the later years is not due the threat from alternatives but due to the improvements in the technology of steel production , processing and property developments (corrosion resistance, strength etc.) so that less quantity of steel is sufficient for a particular function. In other words a given quantity of crude steel now is more useful than a decade ago.

STRENGTHENING OF STEEL

There has been considerable advance in the understanding of structure – property correlation with the availability of improved characterization and analytical facilities resulting in development of steels with manifold increase in properties by mere tailoring of microstructure. It is now possible to predict the properties as there are established equations relating various microstructural, physical and chemical parameters. For example the rule of mixers is reasonably applicable in many cases enabling the development of steels with predetermined property requirements. There are various mechanisms that are operative for strengthening in steel namely strain hardening to generate dislocation network, solid solution hardening by the introduction of a large number of solute, grain refinement by the well known Hall-Petch relationship or through precipitation hardening. For each of these mechanisms approximate equations can be written which could be used to understand the specific contribution by any of these mechanism. The equations are presented in Table 2. It is also possible to calculate ductile to brittle transition temperature which is very important in many critical applications to avoid catastrophic failures by brittle fracture. Table 3 gives the mechanical properties of various phases (ferrite, pearlite , bainite etc) and the contribution to strengthening by these phases. The usefulness of these equations can be understood if developments of strength in cold rolled steel over the years is considered as a typical example.

DEVELOPEMNTS IN COLD ROLLED STEEL

Looking into the evolution of cold rolled steel and how the strength in cold rolled steel has increased over a period of 25 years , it will be evident the structure – property relationship equations have been judiciously translated into practice. Fig 1 represents the developments of high strength cold rolled steels from 1975-2000. Whilst temper rolled steels were in use in the early periods better grades like DP and IF started appearing with improved strength through the application of physical metallurgy. For example it is known that DP steels has marensitic islands in soft ferrite matrix. By characterizing one can know how to change the strength of this particular steel . The index of solid solution strengthening for any non- interrelated element is highest in the case of phosphorus. As a result of which by rephosphorising the steel the strength of steel can be enhanced and the deleterious effect can be overcome by appropriate alloying. Similarly it is known that how the transformation induced plasticity is brought about by transformation of retained austenite during straining and how much contribution it would make to strengthening. By these so many grades of steels have been generated which can be cold rolled and which can yield very high strength. Table 4 gives control parameters for the first , second and the new generation of IF steels to indicate the fact that changing over to hot band texture control the r bar values have been improved to 3.0

PROGRESS IN STEELMAKIING

The present grades of steels have come about through not only the understanding of physical metallurgical principles but also due the parallel developments in steel making technologies. Without these corresponding technological developments in steelmaking it would have been impossible to achieve this . Historically crucible and reverberatory processes were in vogue followed by the Bessemer process and Open hearth and later by the Basic Open hearth. Later continuous casting and corex processes have come up to produce steel with better chemistry. These developments are shown in Fig.2 and Table 5. Similarly secondary refining also saw great changes. Steel was being refined in early stages in ladles and/or in the converter with additions like soda ash or by ladle deoxidation techniques or the patent process of desulphurisation. These were well known processes but subsequently it became known that vacuum can bring about a change in equilibrium and that preferential decarburisation , deoxidation etc can be achieved. Subsequently this led to a number of processes which are shown in Fig.3. Even simple argon purging can lead to great benefits in terms of removing the inclusions by allowing them to float to the surface or removing the hydrogen and nitrogen to a great extent. Also this can bring about desulphurisation.

There are yet many challenges to be met by the steel industry and therefore, there is need for continuous developments and these developments have to come about in terms of cost reduction in particular. Secondly raw materials have to be conserved and thirdly ,most importantly, the environment has to be protected . for example it is known that petrol reserves will last for only 20 years and this is the case with many raw materials. Conservation is essential for more than one reasons. Whilst the use of iron ore indiscriminately will lead to depletion of resources , coal or coke on the other hand will additionally destroy the environment. There is stringent standards of permissible emissions from various plants of the steel industry as given in Table 6. Similarly non-conservation is also another important factor. Newer technologies will have to come up with these in view. It has already been mentioned that the steel industry is in the fourth generation technology and the fifth generation is to take over shortly for improved performance , yield, quality, better environment and good working conditions. As a part of better environment Recycling of used products is essential. There are many issues like global awareness, material flow market and environmental balance which have to be understood (Table 7).

To bring about a decline in cost of production there are obviously several strategies which have been adopted in industries. One already in use is the economy of scale, i.e the larger is the unit the less will be the overhead and lower will be the cost. Whether that is appropriate or not will be discussed in the course of the lecture. The entire process route can also be made smarter to reduce the cost involved. Thus there is stress on continuous casting , continuous annealing and continuous rolling, advanced sensing and control etc. Invariably there is a reduction in labour cost associated with these technologies. The cost of production is directly related to the energy cost and it has to be brought down drastically by adopting waste heat utilization, optimizing the size of the plant , optimization of raw materials usage etc as shown in Tables 8 and 9 for the cases of sinter plant and coke making plant. Sintering has become very important to use fine ores which otherwise would have gone waste . It is known that large amount of charge that go into the blast furnace is in terms of sintered material. In this case e.g. sintered coal or gas waste heat recovery, segregation of charging in terms of various mechanical processes, combustion control all these have added to the reduction of total energy . One gratifying thing is in India also these efforts have taken a very strong route.

DEVELOPMENTS IN RECYCLING

The important step which is being taken by the steel sector is recycling with twofold purpose namely to recycle for the environment and also for the sake of conservation of raw materials. There are many stresses in this sector. One is that there is a global awareness that one cannot go on consuming raw materials indiscriminately . Secondly regarding consumption of new material there should be very strict regulations on the mining and to preserve the environmental balance. The following things are to be considered with reference to recycling steel. What is the nature of the market and what is the technology for recycling and how to collect the recycle scrap from steel industry. In this respect as far as metallurgical aspects are concerned the nature and quality of the scrap are important . Tables 10 and Fig.4 mention about the grades of steel scraps from various areas . Appropriate routes of recycling have to be followed where residual elements particularly the low melting elements like Zn and Sn are present as in the case of automobile scraps for example. First all the impurities have to be identified and characterized / categorized as mass impurities, impurities at the surface layer and alloying impurities as shown in Table 11. An example of mass impurities is scrap of electric motors which consists of windings, steel housing etc. They are distinct and can be separated easily. Surface impurities arise due to galvanizing and alloying impurities from intentionally added alloying elements. For example Cu is added for corrosion resistance, Cr, Mo and Ni in various stainless steels for different purposes. It is important , therefore , to grade the scraps before recycling. New technologies have been developed to carry this separation more quickly. The scrap undergoes various processes like cryogenic processing , simple identification and separation, and so on.

Now there is a tremendous pressure on the steel industry from the environmental standards. As one can see a coke oven plant for example cannot discharge 50mg of solid particulate matter per Nm^3. That means tremendous investment is needed in pollution control measures in the existing plants and the new plants are required to be designed according to pollution norms. Alternatively reduce the use of coke itself and try to see whether some other technologies can be developed to make iron. So there are various changes taking place with this in view. The technological developments of recent times can be organized into three different categories namely streamlining of existing facilities , new steel making and finishing routes and protection of environment as shown in Table 12. In a recent survey of 354 European steel industry projects, 41% deal with the life extension and streamlining of the existing facilities, 14% on the protection of environment , 18 % to improve efficiency /productive facility and 27% on the development of better grades of steel (Table 13). This gives a flavour of current research and development activities in countries where steel and steel technologies are well established and facilities are already existing.

There is also an overall thinking as to what would be the optimum kind of steel industry for various types of inputs . These are indicated in Fig.5. A projection is given here about how the future steel plants are likely to be . It is suggested that a conventional integrated process should normally be about 4MT per year and mini integrated production plant could of 1-2MT per year capacity. A scrap based plant essentially using electric arc furnace could be of the same magnitude and with traditional scrap the plant should not be more than 1 MT per year. These are optimized estimates about the size of the plants which will come cup. It is not expected that any one individual integrated plant will have 20 or 25MT capacity.

STEEL FOR AUTOMOTIVE/CAN INDUSTRIES

The application industries for iron and steel include most importantly the automotive/can sectors . The consumption pattern of steel sheet in automobile industry over the years is shown in Table 14.Table 15 gives the type of steel required to meet specific requirement of the vehicle. In spite of challenges from alternative materials steel continues to be a major material. .

FUTURE PROSPECTS FOR STEEL IN AUTOMOBILE INDUSTRY

Reduction in weight of the car is foremost to achieve fuel efficiency and metallurgists have a great role to play in the development of suitable grades to achieve this. Table 16 gives the properties of different grades of steel for different parts of automobile to focus the point that of requirements. What has happened over the last 25 years is a little out of date but still it is important to know. In 1975 there was 17% of plastics in a car , today there is about 37% . Use of steel has been reduced from 33% to 22% (Fig.6). Basically the automotive sector is faced with the first and foremost objective of fuel economy. This can be achieved through a number of steps like component efficiency , reducing friction at various stages , design changes etc as shown in Fig7.

It is known that 32 or 33 steel producers of the world have recently got together in order to produce all steel frame automobiles body . These attempts tell that these are reactions to the fact that steel use in the car has gone down considerably. How do they propose to spring back. The market wants stronger, super and more economical manufacture. So bake hardening grades of steel have come up in the market. For improving the aerodynamics it must be possible to press very complex shapes from sheets. IF steels have come with improved deep drawability. The vehicles will have to be more durable and hence corrosion resistance have to be enhanced . Coated steels have been developed with this in view. For acoustic comfort vibration –damp resistance steels are available. Thus newer steels have come up to meet various challenges. Whilst several examples can be cited about frontier grades of steel , the cold rolled steel can be taken as a typical example which has undergone several generations. The first generation cold rolled steels of the 1980s had r bar values less than 2 (Fig.8). Similarly stretchability as a function of tensile strength is also shown in the figure where the strain hardening component for different mechanism of strengthening is indicated. Today after so many iterations and use of so many concepts like texture control , high temperature annealing, introduction of ultra low carbon materials, addition of Nb, Nb-Ti ratio control with B addition the r bar values have gone up to 2.2. But with texture control it has been raised to even 3. To do this a large number of concepts like solid solution strengthening, precipitations and grain refining, transformation induced strength and toughness and partial annealing and cold working are employed. With this r bar values and work hardening index have been controlled to a great extent.

Another area where steel of deep drawing quality is used in significant measure is the can industry. The world wide production of various types cans runs into billions. A brief statistics of can production is shown in Table 17 and Table 18 gives the property requirements along with type of steel for cans.

CONCLSUIONS

The steel industry is no more a sunset industry it has yet to see many dawns. The industry is already meeting the pressures of cost reduction , conservation and efficient use of raw materials, adoption of new production technologies improving performance, yield, quality, environment and working conditions and adopting recycling methods to conserve to remain competitive.

Table 1 : DEVELOPMENTS TRENDS IN ADVANCED MATERIALS

Application Area	*Present Technology*	*21s' Century (?)*
Large Structures Bridges, oil-platforms	Microalloyed Steels; Q&T	Glass-fibre reinforced concrete
Ships, submarines	Microalloyed/Cu Steels	Steel, titanium alloy, CFRPs
Pipelines (Oil, Gas)	High purity steel	Steel, high grade polymers (thermoplastics)
Cables	Patented steel (0.8%C)	Carbon fibre strands
High temperature, Wear corrosion		
Machine tools	High alloy steels; WC-Co/TiN	Sialons: SiC/SiC ceramics
Chemical plant steel	Austenitic stainless	Titanium alloys, ceramics
Electrical, electronic, optical, magnetic		
Power lines	Cu, Al/steel Reinforced	Al-composites; Bi-based superconductors
Permanent magnets	Nd-Fe-B, ferrites	Polydiacetylene polymers
Transport		
Automobile bodies	Pressed steel	Aluminium, thermoplastics
Railway wagon; bodies	Steel, aluminium	GFRPs, cellular composites
Bicycles	Steel, titanium alloy	Magnesium alloy; CFRPs
Medical		
Hip joint, bone replacement	Stainless, titanium	Al_2O_3; Si_3N_4;SiO_2-bioglass

Table 2 : STRENGTHENING MECHANISMS

Strain Hardening : Other Dislocations

$$\sigma = \sigma_0 + \alpha\mu b/\rho$$

Solid Solution Hardening : Foreign Atoms in Solution

Coefficients : C&N 5000, P 500, Mn & Cu 80, Si & Cr 60, Ni 45 (Mpa/wt%)

Grain Refinement: Grain Boundaries

$$\Delta\sigma = kd^{-1/2}$$

Precipitation Hardening : Second Phase Particles

$$\Delta\sigma = (029mbf^{-1/2}/x)\ln(x/b)$$

f= vol.fraction of particles in ferrite

x = mean intercept between particles in the slip plane

Change in 50% FATT for 100 Mpa increase in YS

Ferrite grain Refinement	-60°C
Manganese in Solution	-30°C
Silicon in Solution	+45°C
Pearlite	+15°C
Precipitation Hardening	+25°C
Dislocations	+40°C

Table 3 : CONSTITUENTS OF STEELS : INTRINSIC PROPERTIES

ORDERS OF MAGNITUDE OF TENSILE PROPERTIES

Constituent	YS (Mpa)	TS(Mpa)	E(uniform)
IF Polygonal Ferrite	150	280	50%
Pearlite	900	1000	10%
Bainite (~0.1 %C)	400-800	550-1200	25% or less
Martensite (~0.1 %C)	800	1200	A few %

MECHANICAL STRENGTH OF MAJOR CONSTITUENTS

Polygonal Ferrite

$$\sigma = \sigma_0 + \alpha\mu b\rho^{-1/2} + \Sigma_i K_i\,|\,\%i\,| + kd^{-1/2} + \Delta\sigma_p$$

Pearlite

$$\sigma_{pc} = \sigma_{pe0} + kpc + \lambda^{-1/2}$$

Martensite

$$\sigma_m = k_m\,|\%C|^n$$

$$\sigma_{m0} = 290\text{Mpa} \quad k = 3000\text{ Mpa} \quad n = 0.3\text{-}0.5$$

Rule of Mixtures

$$\sigma = A(f_a)\,\sigma_a + B(f_b)\,\sigma_b$$

A and B are functions of volume fractions of constituents a and b

For Ferrite + Pearlite_Steels

$$\sigma = f^n{}_f\sigma_f + |\,1 - f^n{}_f\,| \quad n = \sim 1/3$$

Table 4 : DEVELOPMENT OF DEEP DRAWABLE COLD-ROLLED STEEL SHEET

1st GENERATION OF STEELS (before 1980's)

Grain growth stabilizing C/N
$\bar{r}<2.0$

2nd GENERATION IF STEELS (1980-1995)

- Texture control
  - By annealing temperature
  - By grain refining of hot band
- High temperature annealing
- New IF (ULC + Nb)
- Nb / Ti control, B addition
- $\bar{r}\sim 2.2$

NEW GENERATION OF STEELS (1995 onwards)

- Hot band texture control (Kawasaki)
- $\bar{r} = 3.0$

Table 5 : RATE OF IMPLEMENTATION

CONTINUOUS CASTING

Proven	1946
Acceptance	1960
Production	
5%	1970
66%	1992
>90% (Japan)	1999

FERRITIC STAINLESS STEEL
(Weldable in Thick Sections)

Proven	1980
Acceptance	1990

COREX PROCESS

Proven	1983
Acceptance	1985

REASONS FOR RAPID ACCEPTANCE

- Knowledge incorporation in design
- Less after design changes
- Computer aided simulation and validation

TECHNOLOGY UPGRADATION BECOMES A CONTINUOUS PROCESS!

Table 6 : ENVIRONMENTAL STANDARDS

Industry	Parameter	Standards
Iron & Steel (Integrated)	Particulate emission	
	Sintering Plant	150 mg/nm^3
	Steel making	
	- During normal operations	150 mg/nm^3
	- During oxygen lancing	400 mg/nm^3
	Rolling Mill	150 mg/nm^3
	Coke Oven (CO)	3 kg/t of coke produced
	I. Emissions (excl p_H)	Conc in mg/lt
(a) Coke Oven	Particulate Matter	50 mg/nm^3
(b) Refractory Material Plant	Particulate Matter	150 mg/nm^3
	II. Effluents (excl p_H)	Conc in mg/lt
(a) Coke Oven Byproduct plant	p_H	6.0-8.0
	Suspended solids	100
	Phenol	1.0
	Cyanide	0.2
	BOD (3 days at 270°C)	30
	COD	250
	Ammonical Nitrogen	50
	Oil & Greese	10
(b) Other plants such as sintering plant, BF, SMS & rolling mill	pH	6.0-9.0
	Suspended solids	100
	Oil & Greese	10
Re-heating (reverberatory furnaces)		150/450 mg/nm^3

Table 7 : RECYCLING ISSUES

GLOBAL AWARENESS
PROLIFERATION OF NEW MATERIALS
REGULATIONS

ENVIRONMENTAL BALANCE

- Materials and Energy Flows
- Distribution and Transport
- Utilisation, Reuse & Maintenance
- Manufacture
- Recycling
- Final Waste

STEEL & ENVIRONMENT

+ The Market
+ Collection

METALLURGICAL ASPECTS

- Quality of Scrap
- Melting Routes
- Residual Elements
- Zinc & Tin

Table 8 : ENERGY SAVING TECHNOLOGIES

☐ SINTER MAKING

Range : 1665-1915 MJ/t of sinter

Make up : Coke : 42-83%
Other Solid Fuels : 0-36%
Flue Dust : 0.11%
Gas : 1-06%
Electricity : 11-17%

Efforts :

- Sinter Cooler Gas Waste Heat Recovery
  Sinter Cools from 500-700°C to 100-150°C
  Coolant: Air
- Segregation Charging
  - Shift and sloping chute
  - Modify Sinter feed trajectory
  - Increase particle size at bottom for greater permeability
  Save : 8-12 MJ/t of Sinter
- Combustion Control
  - Flame length
  - Furnace pressure
  - Burner design Save: 20 MJ/t of Sinter
- Others : 110 MJ/t of Sinter

Table 9 : ENERGY SAVING TECHNOLOGIES

☐ COKE MAKING

Range : 3758-5144 MJ/t dry coke

Efforts :

- Coke Dry Quenching
  Steam Recovery — Power Generation
  Save : 1700 MJ/t dry coke
- Recovery of Sensible Heat of Coke Oven Gas (800-900°C)
  - Moisture control
  - Fuel gas preheating

  Save : 300 MJ/t dry coke
- Recovery of Sensible Heat of Waste Gas
  Save : 100 MJ/t
- Coal Moisture Control
  Normal 8-12% to 4-6%
  Save : 94-151 MG/t dry coke
  Spend 64-105 MJ/t dry coke / % Moisture
  Effective Saving : 4.5-7% increase in productivity
- Others
  Coke oven aspiration, Fuel Gas Preheating, Auxiliary Devices etc.
  Save : 200-250 MJ/t dry coke

Table 10 : MARKET SCRAP

Species	Grade	Class	Specifications
Obsolete scrap	Heavy scrap	HS	≥ 6mm Thick plate steel, Bar etc.
		H1 Bar etc.	≥ 6mm Thick plate steel,
		H2	3-6mm Thick plate steel, Round bar, heavy machine scrap
		H3	1-3 mm Thin plate and Others
	Shredded scrap	A	Car bodies
		B	Zn coated plate etc.
		C	Sn coated plate
	Processed scrap	A	Car bodies
		B	Zn coated plate etc.
		C	Sn coated plate
Process Scrap	New plate	Busheling Bundle	
	Steel turnings		Continued or fragmented

Table 11 : MODE OF EXISTENCE OF IMPURITIES

Classification	Mode of existence of impurities	Concrete examples (typical metals)
Mass impurities	Nonferrous metals each having a certain mass and coexisting with iron	Motors (iron and copper) Automotive engine blocks (iron and aluminium)
Impurities in surface layer	Impurities existing as thin nonferrous metallic phase in surface layer of iron	Galvanized sheet (iron and zinc) Tinplate (iron and tin)
Alloy impurities	Elements added to steel as alloying components to Improve performance of steel Product.	Corrosion-resisting steel (iron and copper) Stainless steel (iron, nickel, chromium, Molybdenum)

Table 12 : CATEGORIES OF TECHNOLOGICAL DEVELOPMENT

- Streamlining of existing facilities
- New steel making and finishing routes
  - o New ore reduction processes
  - o EAF steel making route
  - o Thin strip casting
  - o Thin hot rolled coil
  - o Cold rolling and finishing
- Protection of the environment
  - o Reduce emissions
  - o Use of off-gases
  - o Reduce energy consumption
  - o Improve finishing process
  - o Recover waste materials

Table 13 : R & D PROJECTS IN EUROPEAN ROAD MAP

Type	Total No.	Short	Medium	Long
Life extension/ streamlining existing facilities	145 (41%)	73	70	2
Efficient production facilities	64 (18%)	23	33	8
Protection of environment	51 (14%)	32	19	0
Steel grade development	94 (27%)	69	24	1
Total	354 (100%)	197(56%)	146 (41%)	11 (3%)

Table 14 : SHEETS FOR AUTOMOBILES

Year		1960	1970	1980	1990	2000
Changes Affecting Automobiles		Motori-Zation	Oil crisis	High grade antident	Intro duction CAFE	Crash worth iness, Restriction of CO_2, Recycling
TS Mpa	300	low YS mild steel	IF steel	BH steel		Super forming steel
	400	C-Mn steel	P-added HSS	IF HSS		
	600		PPT hardened Steel		DP steel	TRIP steel
	800					TRIP Steel
	≥1000			1000Mpa ultra HSS		1500 Mpa Ultra HSS
Process			BAF	CAPL	IF	CGL

Table 15

Market requirement trends	Steel development response
Stronger, safer, more economical automobiles	Thinner, high strength steels
Faster and more economical manufacture of stronger automobiles	"Bake hardening" steels
More aerodynamic vehicles, involving more complex shapes and components	"Interstitial-free" steel (IFS) with improved deep drawability
Greater Vehicle durability, with improved corrosion resistance	Coated Steels
Improved acoustic comfort and durability	Vibration-damping steels

Table 16

Material	Characteristics	Scope	Yield point
Conventional	Low strength High elongation High formability	Large series, outside panels	140-210 MPa
Interstitial Free Steel	Low strength High elongation	Best for deep drawing	120-160 MPa
IF High strength	High strength about 20% elongation	Body structure	240-540 MPa
Phosphorus alloy steel	High strength 28% elongation	Body structure	220-360 MPa
Bake hardening steels	Hardening while enameling Low transformation force before hardening High strength after hardening High elongation	Body structure	180-360 MPa
Dual-phase steel			230 - 350 MPa
TRIP Steel	Optimal relation between strength and elongation		230 - 460 MPa

Table 17 : CANS

WORLDWIDE PRODUCTION

Number	: 80 billion 2 billion cases
Weight	: 23 million tons
Varieties	: 1200

TYPES :

2-piece : Can body + Lid
Drawn & Ironed Cans (DI Cans) &
Thin Drawn Cans
Press formed
Coated & Printed after forming

3-piece : Can body + Top & Bottom Lids Joined by Welding or Cementing Coated & Printed in advance

Table 18 : STEELS FOR CANS

Generally tinplate or tin-free sheet

SOFT TEMPERED SHEET STEEL

- Low carbon aluminium-killed steel
- Batch annealed after cold rolling or continuous annealing after cold rolling
- Excellent deep drawability
- Non-ageing

RELATIVELY HARDER TEMPERED SHEET-STEEL

- Low carbon aluminium-killed steel
- Continuous annealing after cold rolling
- Age hardening
- Continuous annealing :
- High productivity and uniformity of properties

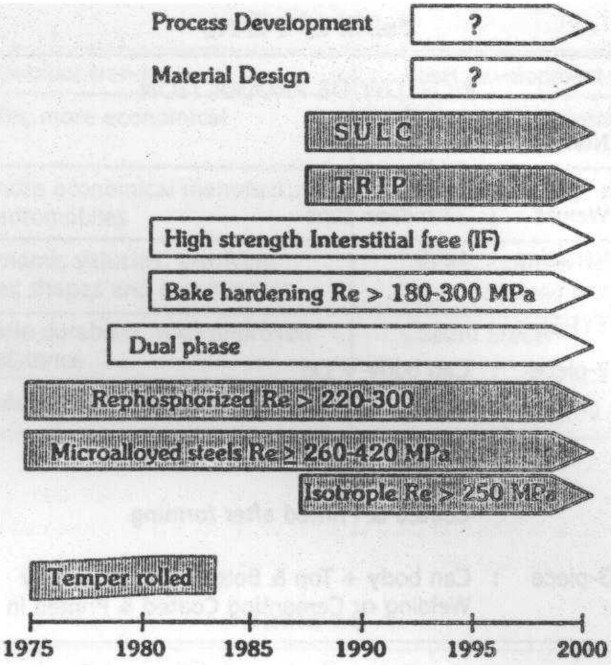


Fig. 1 : Development of high-strength cold-rolled steels

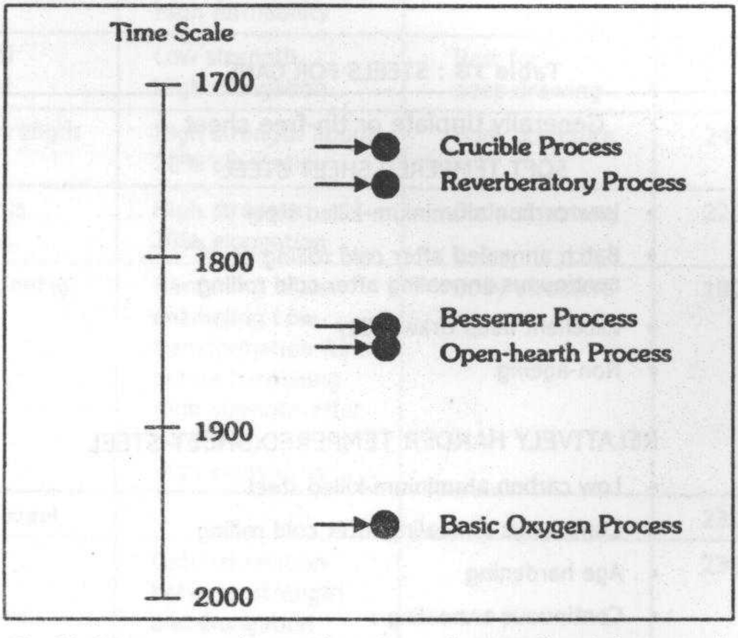


Fig. 2 : Major process innovations in carbon and stainless steel making

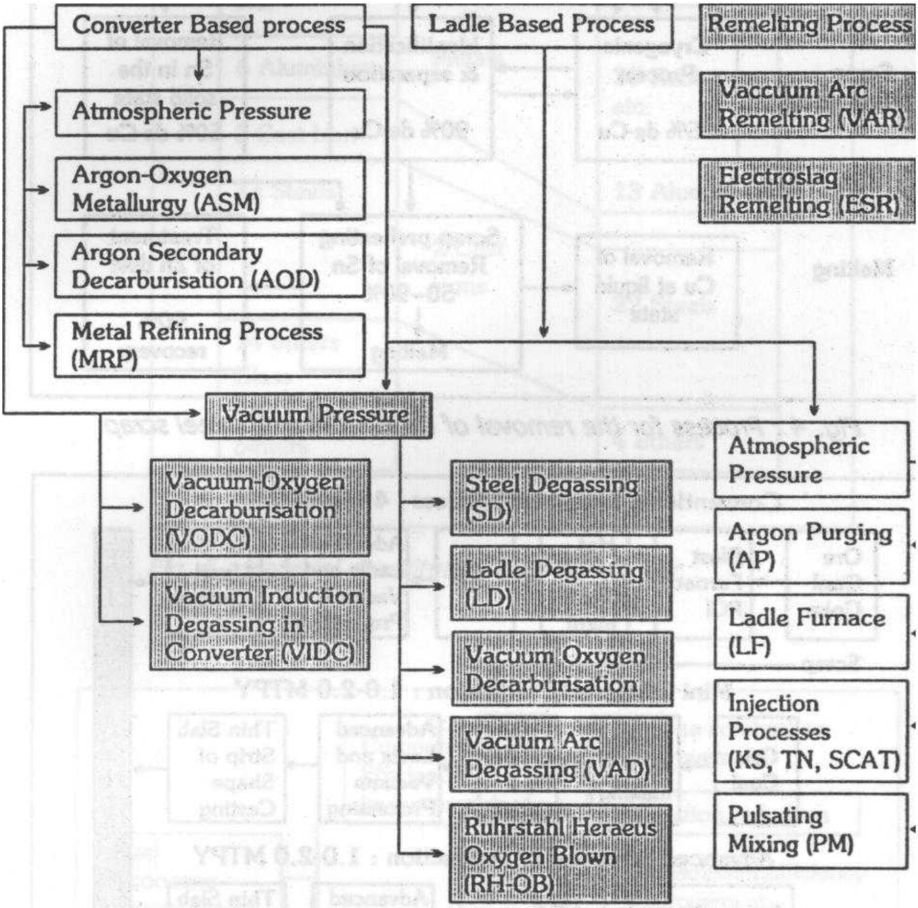


Fig. 3 : Secondary Refining Process

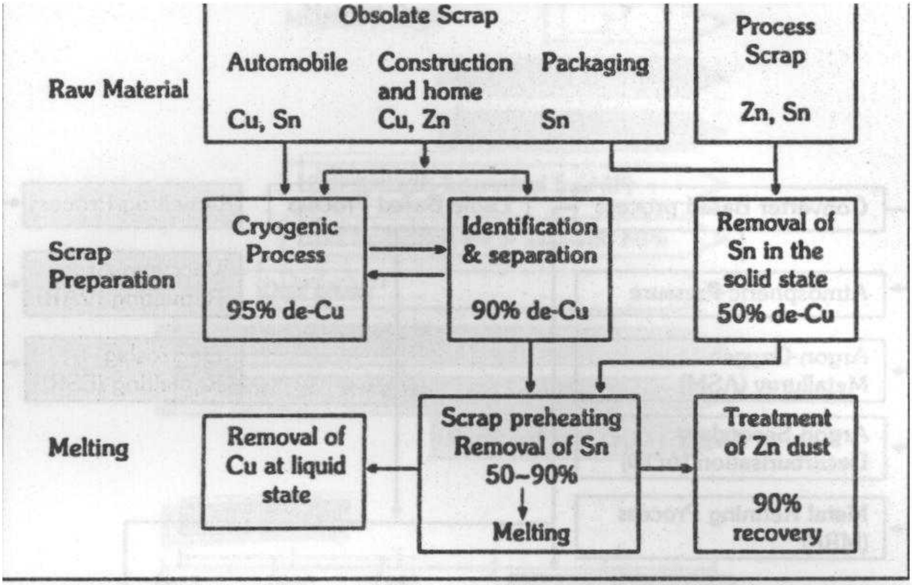


Fig. 4 : Process for the removal of Cu, Sn, Zn from steel scrap

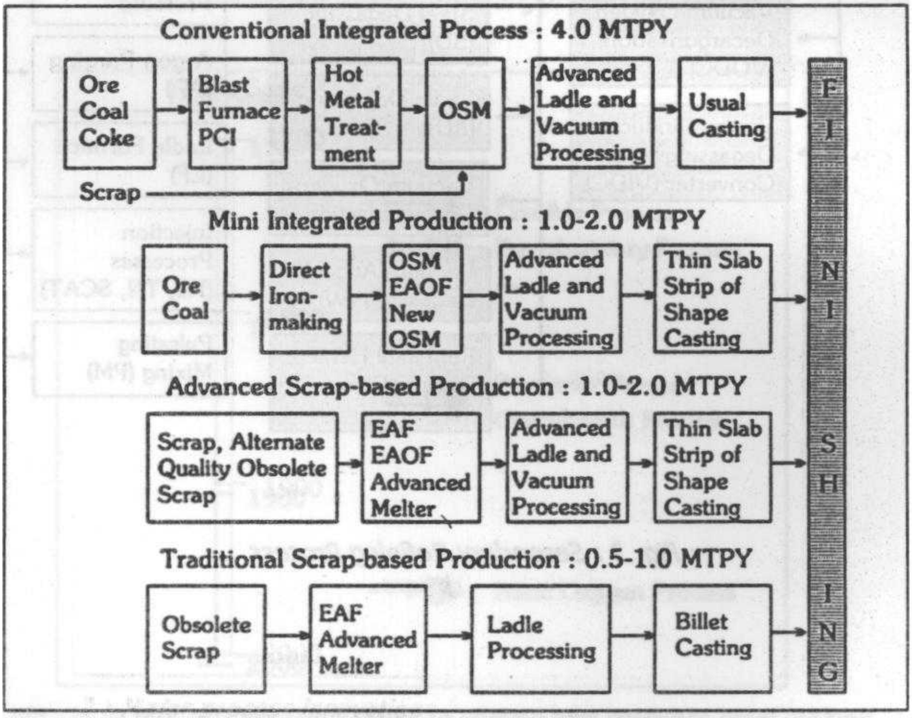


Fig. 5 : Future steel making plants

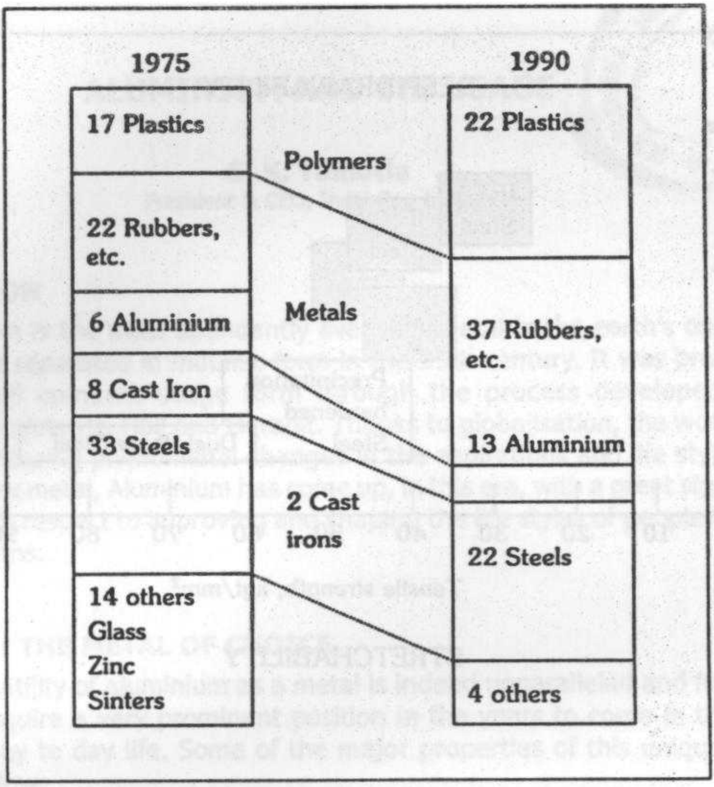


Fig. 6 : Material constitution of a typical car

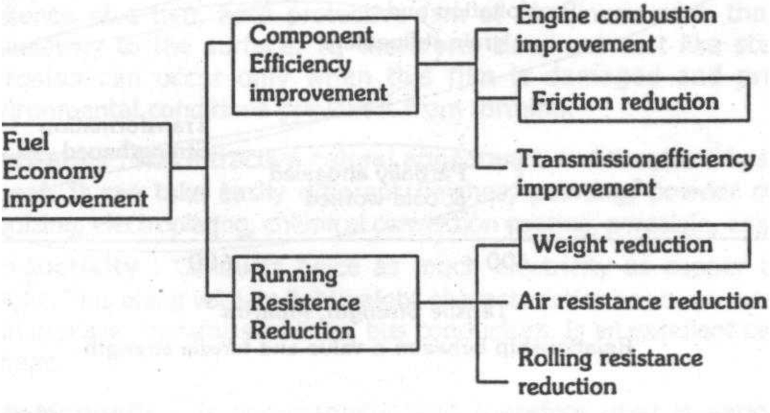
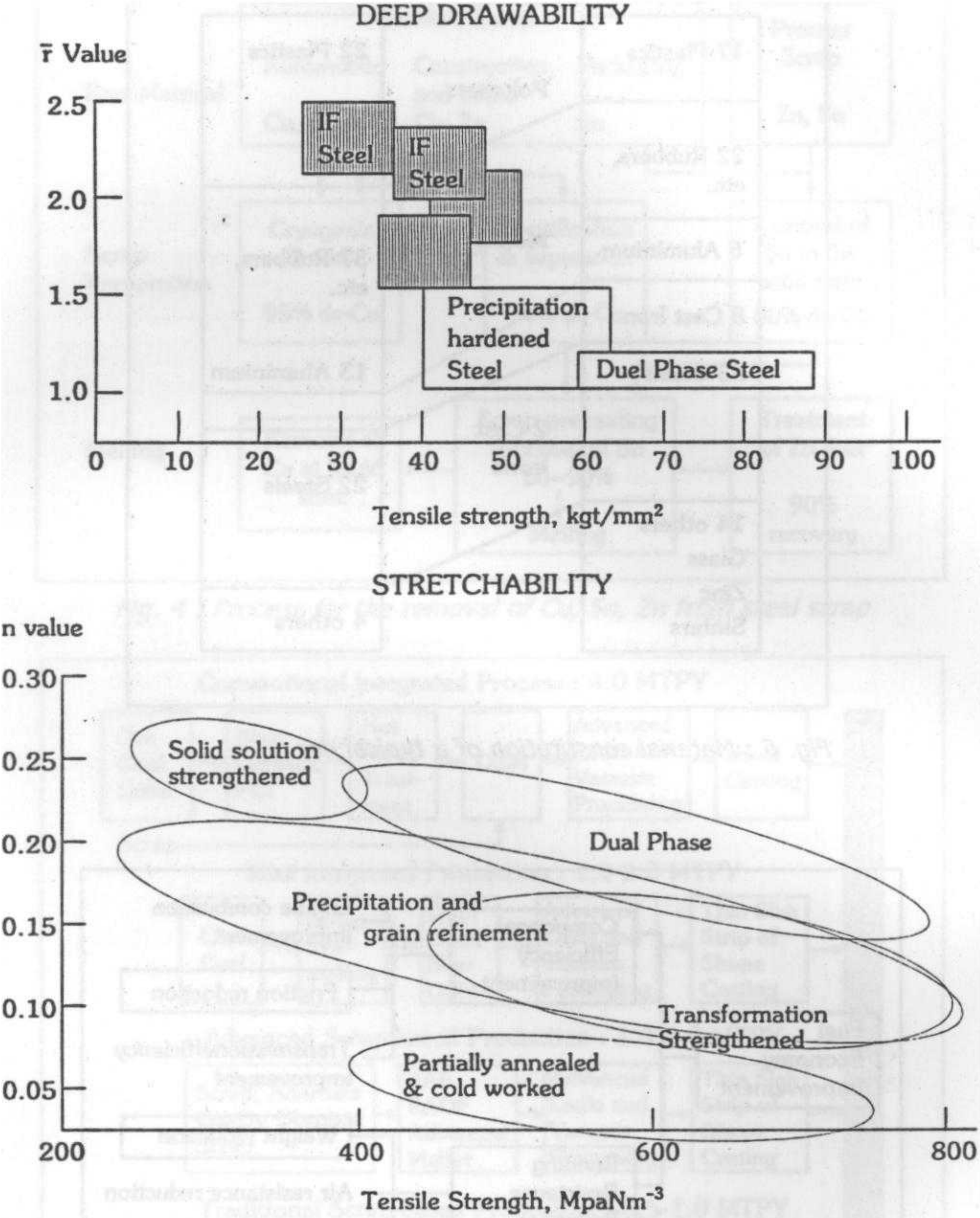


Fig. 7 : Fuel economy in automobiles



Relationship between n value and tensile strength

Fig. 8