Recent developments in powder metallurgy of non-ferrous metals

P. RAMAKRISHNAN

THE first large-scale application of powder metallurgical techniques started with the production of ductile tungsten—a non-ferrous metal, by W. D. Coolidge in 1910. This date can be considered as the renaissance of powder metallurgy, because this invention was the basis for the development of the modern incandescent lamp industry. In this context one has to forget about the prehistoric and primitive powder metallurgy as well as the production of sintered platinum by the British and Russians in the first half of the 19th century. The development of ductile tungsten led to large scale production of refractory metals such as tungsten, molybdenum; contact materials, such as tungsten-copper, tungsten-silver; porous products, such as bearings, filters and also cemented carbides. These materials could not be produced by the conventional techniques. Later developments include the high temperature high strength materials, such as cermets, dispersion hardened materials and fibre reinforced composites. The entry of powder metallurgy into the competitive field for the production of structural parts and semi-finished products by the continuous compaction of metallic powders is a remarkable one. Today powder metallurgy process can compete on equal terms with other processes. It is no longer the last resort. Among the various methods available for the processing of metals, powder metallurgy occupies a unique place. It can be used not only for making a variety of products for different applications like other methods, but also to create new materials which are either difficult or impossible by the conventional techniques.

The growing current interest in powder metallurgy is being manifested by the increased activity of research workers and industries. Considerable progress has been made in the field of refractory, rare and heavy metals, electrical contact, magnetic, friction and nuclear engineering materials, structural parts, cermets, cemented carbides and other refractory compounds. However, the scope of the paper is limited to the developments in the field of porous materials, high strength, high temperature materials and continuous compaction of metal powders.

Dr P. Ramakrishnan, Indian Institute of Technology Bombay.

SYNOPSIS

This paper presents briefly the recent developments in the technology of powder metallurgy of non-ferrous metals. Particular mention has been made of the developments of self-lubricant bearings, filters and other porous parts, high temperature materials including the dispersion strengthened materials and fibre reinforced composites. Continuous compaction of metallic powders has been discussed in detail with particular reference to powder rolling of aluminium, copper, nickel, etc. for the production of semi-finished articles. The technique is used for the production of bi-metallic and tri-metallic strips and also for nickel and aluminium-coated steels. The continuous compaction of metallic powders indicates that large scale production will become technically possible as well as economical. Since powder metallurgy is competing with the conventional manufacturing method by offering greater economy or better performance or both, the paper concludes with some suggestions to exploit the tremendous potentiality of this industry in India.

Bearings, filters and other porous parts

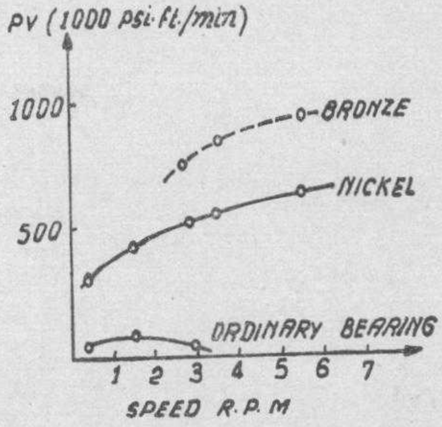
One of the unique advantages of powder metallurgy is its ability to prepare materials with controlled porosity. By varying the quantity as well as the quality of porosity a wide variety of useful articles have been made. These include self-lubricant bearings, filters, materials for distributing and restricting the flow of fluids, electrodes for batteries and fuel cells and formed structures.

Bearings are one of the most important applications of powder metallurgy parts. The interconnecting pores in these products are filled with oil or other suitable lubricants, which result in self-lubrication and reduction in wear during service conditions. Self-lubricant bearings and bushings are widely used in electric fans, home appliances, automobiles, office equipments, agricultural equipments, food and textile machinery, fractional horse power electric motors and associated devices. Substantial savings in maintenance costs have been effected by their use. The commonly used non-ferrous metals are copper, lead, tin and recently aluminium. The largest use of copper powder is in the manufacture of oil impregnated sintered 90/10 bronze bearings. The bearings are produced by the compaction of a mixture of elemental powders or less frequently the alloy powders, followed by sintering, sizing and impregnation. The fatigue strength of bearings can often be improved by bonding the shell of the bearing to a strong support. A typical example of such a bearing, which is widely used in automobile engines, is the copper-lead bonded to steel. They are produced on a continuous basis. Copper-lead powder is spread on to a steel sheet which is loose-sintered, roll-compacted and resintered. Some of the problems associated with these bearing materials, such as oil corrosion, have been solved by electro-depositing a thin layer of lead or tin-base alloy on the bearing surface. The overlay plated bearing is one of the most popular heavy-duty engine bearings.

The search for a better material, which is readily available and cheap, led to the development of aluminium-base bearing materials.[1,2] As bearing materials they have many advantages.[3] The higher co-efficient of thermal conductivity of these materials lead to a lower oil film temperature and hence a higher PV rating. With aluminium bearings PV factors more than 200 000 are permissible, whereas porous bronze bearings fail at about 150 000 PV and are not recommended normally for PV factors much above 50 000. Aluminium bearings are having a longer life—about twice that of bronze at 20 000 PV. They are having good fatigue strength, light weight and high resistance to corrosive agents in lubricants. But the difficulty lies in the manufacturing process, particularly at the sintering stage, because of the presence of refractory oxide film on the powder. Hence to get effective bonding of the particles aluminium bearings are sintered in a low pressure atmosphere of dry hydrogen obtained by the thermal decomposition of a metal hydride. The sinterability of aluminium has also been improved by changing the initial powder characteristics.[4]

An interesting development to increase the life of a porous metal bearing has been reported from France.[5] The new bearing consists of a thin (0·002 to 0·004 inch) low permeability nickel alloy lining on the bore of a conventional porous bearing. This layer is produced by spreading ultrafine powder, inside the bore of the porous bearing followed by sintering and sizing. This double layer bearing is reported to give a two-fold reduction in the co-efficient of friction at high load and hence a ten-fold increase in the allowable pressure velocity product. Fig. 1 shows the comparison of properties of bronze and double layer bearings.

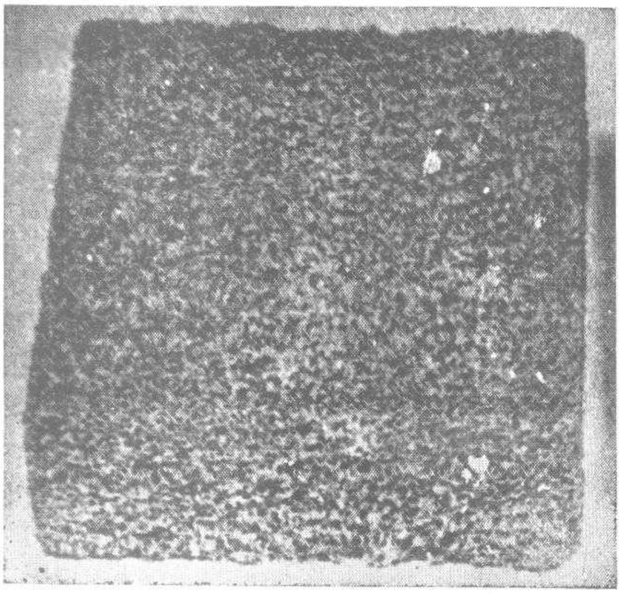
Filters are another important use of powder metallurgy parts. They are produced in different sizes and shapes. Filters are used to remove solid particles from a stream of liquid or gas or to separate two immiscible liquids or a liquid from a gas. They are generally manufactured from spherical powders and less frequently from irregular powders, fibres or a combination of these materials. Some of the manufacturing processes are gravity sintering, pressure sintering, compaction and sintering, slip casting and roll compaction and sintering.[6–8] Other methods include centrifuging a paste containing metal powder, spraying paste on to a mandrel and extrusion.[9]



1 *Product of the speed by the load psi as a function of the number of thousands of runs per minute ; upper curves are related to "double layer" bearings having fine layer in nickel-tellurium and bismuth (solid line) and bronze (dotted line)*[5]

The important factors in the selection of metallic filters are their heat and corrosion resistance and high strength. The most commonly used non-ferrous metals for making filters are bronzes (90 Cu 10 Sn), monel (30 Cu 70 Ni), German silver (65 Cu 12 Ni 23 Zn) nickel, tungsten, chromium and aluminium. Recently more and more metallic filters are being used. Notable among them are zirconium and platinum for high temperature and corrosive applications. Titanium is another newcomer which is replacing stainless steel in aircraft hydraulic systems, largely because of their weight advantage and other favourable properties. They are also used in many chemical industry applications. Titanium filter tubes, 6 inches outsides diameter, 4 feet long and half inch wall thickness, have been produced by isostatic pressing. Filters of large sizes and complicated shapes can be produced without welded joints and with uniform permeability. Metallic filters are superior to conventional paper and ceramic filters in mechanical strength and machinability and suitable for repeated use. They have been installed in the fuel systems of automobiles, aircraft and filter assemblies of chemical processes with good results.

Porous nickel electrodes are another non-ferrous powder metallurgy product, which is gaining its importance. These electrodes are used in alkaline nickel-cadmium batteries and fuel cells. One of the main reasons for the use of nickel is its resistance to corrosion by the potassium hydroxide electrolyte. The electrodes for nickel-cadmium batteries must possess a high porosity of the order of 70 to 90 per cent to hold the active mass, have low electrical resistance to minimise potential gradients and possess mechanical strength adequate to withstand the stresses encountered during manufacture and service. The thickness of the thin electrode is about 0·01 inch and of the flat plates vary from 0·03 to 0·16 inch. The electrodes for fuel cells require a narrow pore spectrum and a highly-active internal surface. Porosity range from 40 to 50 per cent appears to be satisfactory. Ideally, the pores should be of uniform size and of conical shape. The



2 *Foamed metal structure*

porous materials can be produced by the various powder metallurgy techniques, such as loose sintering, slurry techniques, roll compaction, die compaction and a combination of these methods.[10,11] Though the porosity obtainable by the roll compaction of carbonyl nickel powder alone is limited to 60 per cent, because of handling difficulties due to poor green strength, strips with porosities approaching 80 per cent have been made by blending the powder with a spacing agent such as methyl cellulose powder and by the incorporation of an electro-formed mesh in the powder feed.[12] Table I shows the properties of roll compacted strip suitable for fuel cells and alkaline batteries.

Porous structures are also used in the distribution and restriction of flow of fluids, in aircraft deicing, heat exchangers and in transpiration cooling.[13] Infiltrated tungsten is an important high temperature material currently being used for rocket nozzle and nose cone applications because of its ability to resist corrosion, erosion and thermal shock and because of its machinability and structural reliability. The use of silver-infiltrated tungsten, produced by powder metallurgy, has considerably reduced the heat transfer to and within the power plant component by transpiration cooling.[14,15] The cooling is effected by the vaporisation of silver through the porous tungsten as well as by heat absorption in the solid vapour change of the infiltrant. Tungsten ionisers with controlled porosity are used in cesium-ion engines.[16] These engines are suited for interplanetory travel because of their ability to provide continuous thrust for a long period. Tungsten is a suitable ioniser material because it has a high work function, is suitable at the critical temperature for ionisation and does not react with cesium. They are manufactured from fine spherical tungsten powder of particle size ranging from 2·4 to 6·9 microns by warm pressing at 400°C and sintering to achieve a density of about 80 per cent of the theoretical. Depending upon the particle size distribution, the surface pore density will vary from 8×10^6 to $1{\cdot}4 \times 10^6$ pores/cm². As an ioniser these materials showed a high efficiency in cesium ion engines.

Another recent metal powder application is in the foamed metal structures of high porosity. The idea of making foamed metals is not a new one. But only recently good quality materials have become available. Many metals like aluminium, lead, zinc, copper, tungsten, beryllium, etc. have been made into foamed structures. Foamed aluminium can be produced in the porosity range of 5 to 90 per cent. Foamed tungsten with a porosity of 70 per cent will show tensile and compressive strength, 4 to 5 per cent of those of solid metal. They are produced by treating metal powders with an organic compound in combination with a foaming agent. Fig. 2 shows the structure of a foamed metal. They are used to absorb impact, deaden noise and vibration or shock. The possibilities of impact absorbing systems range from auto bumpers to clamping fixtures. Other possible applications include fuel cell electrodes, filters, transpiration cooling, marine buoyancy devices and rigid light weight structures.[17]

TABLE I Properties of porous nickel electrodes[12]

Electrodes	Thickness inch (mm)	Porosity %	Bend strength kg/cm² (lb/in²)	Resistivity microm cm	Tensile strength kg/cm² (lb/in²)
Alkaline (1)	0·041 (1·04)	72	102 (1450)	123	54 (762)
Battery (2)	0·0395 (1·00)	70	150 (2133)	81	—
Fuel (3)	0·041 (1·04)	40	1255 (17850)	24	1837 (26200)
Cell (4)	0·035 (0·89)	51	880 (12510)	35	—

Nickel powder type 287, particle size 2·9/3·6 microns sintered in cracked ammonia.

1. and 2. Powders mixed with 40 per cent volume of methyl cellulose powder and in 2 wire mesh incorporated during rolling, sintering of 1 and 2 strips 12 min/700°C (1292°F)
3. 4 min/850°C (1562°F)
4. 4 min/800°C (1472°F)

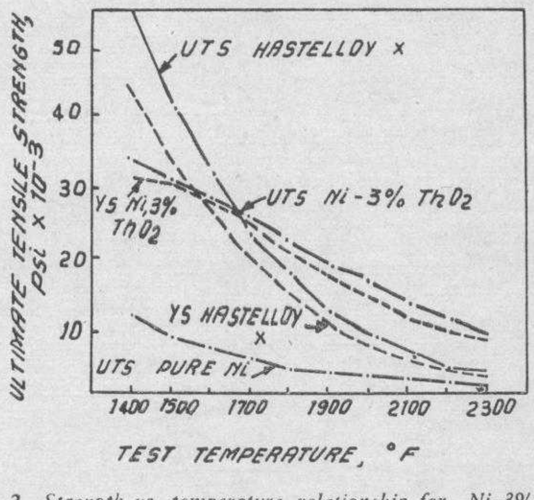
High temperature materials : dispersion-hardened and fibre-reinforced composites

One of the earliest applications of powder metallurgy is in the fabrication of refractory metals like tungsten, which is having the highest melting point of all the metals. Later the technique has been extended to molybdenum, tantalum, niobium (columbium) and other high melting point materials. Powder metallurgy technique has shown considerable economic advantages over melting procedures in terms of greater recovery of a worked product. Now-a-days these metals and alloys are widely used for a variety of applications in different sizes and shapes. Production of large tungsten crucibles and susceptors up to 36 inches in diameter and weighing up to 1700 pounds has been reported by isostatic pressing and sintering.[81] Recently much attention has been given to the outstanding properties of beryllium for nuclear engineering, aircraft, missile and spacecraft application. It possesses outstanding rigidity (Young's modulus $2{\cdot}8 \times 10^4$ kg/mm^2) density ($1{\cdot}84$ gm/cm^3), relatively high melting point (2344°F) and low capture cross section for thermal neutrons (0·009 barn). The undesirable characteristics of beryllium are its toxicity, brittleness and difficulty associated with its fabrication. To attain the required purity and adequate control of grain size the metal has to be processed by the powder metallurgy techniques. Hot pressing of beryllium is notable for the large sizes that have been produced, e.g. billets up to 75 inches dia. × 30 inches high weighing up to 9100 lb have been reported.[19]

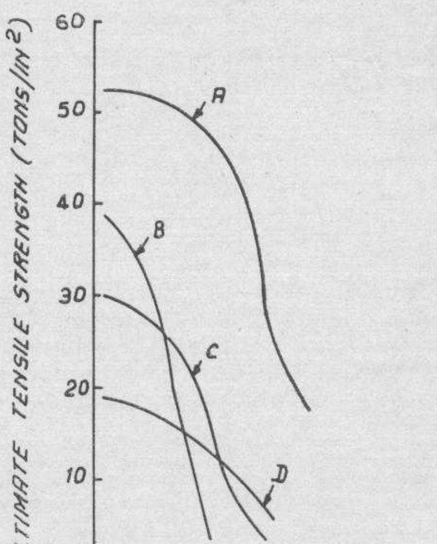
Powder metallurgy technique has also been used in the fabrication of nickel and cobalt base superalloys for gas turbine aero-engines. The marked increase in the working efficiency of a gas turbine, when the operating temperature is raised, has led to the search for better materials. An ideal material should have the homogeneity and structural stability of wrought alloys coupled with the high creep strength found in cast alloys. These alloys are difficult to forge and the casting techniques do not allow a close control of structure. To combine the best features of the two types of materials powder metallurgy techniques have been tried. It is possible to produce superalloys suitable for use in aero-gasturbines by sintering of pre-alloyed powders.[20,21]

While there is a pressing demand for better high temperature materials there appears to be a limit to the operating temperature attainable with the superalloys because of the dissolution of the precipitated phases at high temperatures. A logical solution to this problem would be to select a second phase which is insoluble and inert in the matrix at high temperature and this is what is happening in dispersion strengthening. In dispersion-strengthened materials fine particles of a stable second phase is uniformly distributed through a ductile metal matrix. Common matrix metals are aluminium, nickel, tungsten, molybdenum, magnesium, copper, cobalt, etc. and the effective dispersoids are refractory oxides, (alumina, thoria, zirconia, titania, magnesia, etc.) carbides, nitrides and borides. They are produced by the powder metallurgy compacting procedures followed by extrusion or rolling. Since the impediment of dislocation motion by the dispersoid particles has a great influence in the strengthening mechanism, these particles should be small about 0·01 to 0·1 micron and evenly distributed. Their composition vary from 2 to 20 per cent of the composite metals volume.

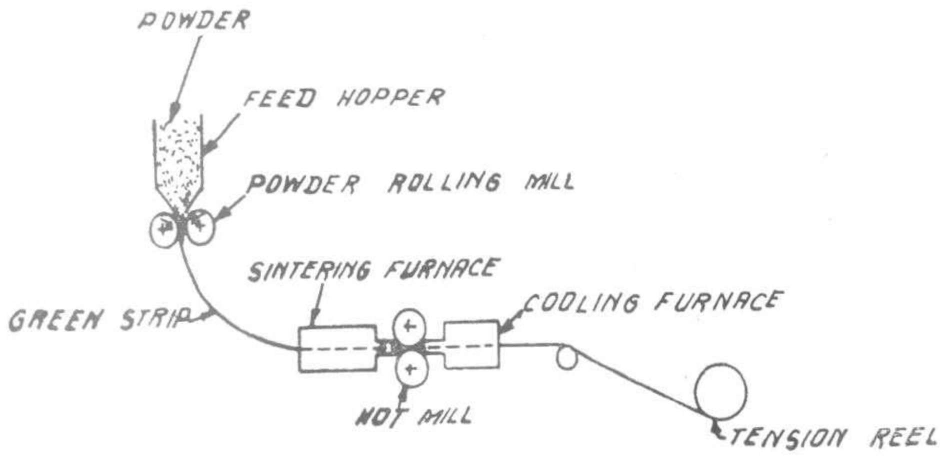
In recent years, by improving the fabrication techniques, sintered aluminium powder (SAP) of more homogeneous nature and better structural stability at elevated temperatures have been produced.[22] Probably the best known of the dispersion-strengthened metals is T D nickel (thoria dispersed nickel). This is superior to most superalloys at temperatures over 1900°F. The



3 *Strength vs. temperature relationship for Ni–3% ThO_2, pure nickel, and Hastelloy X*[24]



4 *Methods of strengthening aluminium (A) SiO_2 reinforced, (B) 7079 alloy, (C) RR58 alloy, (D) 10% SAP*[31]

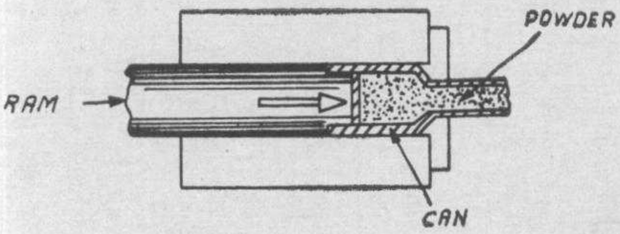


5 *Continuous roll compaction of powders*

strength vs temperature relationship for Ni-3% thoria, pure nickel and hastelloy X, is shown in Fig. 3.[24] By superimposing the effect of solid solution strengthening and dispersion-strengthening, it is possible to improve the temperature properties of these materials. In aluminium, with magnesium additions up to 5 per cent and oxide content up to 12 per cent, it is possible to achieve room temperature tensile strength value of 60 000 to 65 000 psi, while maintaining the high temperature properties of SAP.[23] Chromium-added dispersion-strengthened nickel alloys have exceeded 120 000 psi tensile strength at room temperature. Thoria-cobalt alloys have twice the strength of TD nickel at 2000°F, although welding and other joining methods have posed some problems. In the case of thoria-dispersion-hardened tungsten also it has been shown that if alloying could be combined with dispersion further improvement in properties could be achieved.[25] Dispersion-strengthened aluminium, nickel, copper, tungsten, etc. have great future in nuclear energy equipment, gas turbine engine components, chemical processing vessels, aircraft skins and high temperature fasteners. The recent developments in these materials indicate that they may soon be specified for the above mentioned applications.[26] The technique of dispersion-strengthening has recently been extended to the development of cutting tool materials. By this process it is possible to get a very fine, hard stable carbide phase in a high temperature high strength matrix. Dispersion-hardened cobalt-base cutting tool alloys, prepared by the extrusion of pre-alloyed powders, performed significantly better than the conventional tool steel alloys and the cast tool of the same composition in the machining test.[27]

The search for better materials having greater strength and stiffness at room and at elevated temperatures, coupled with low density has led to the development of a new technique for strengthening by fibre-reinforcement. It is possible to produce materials in the form of thin fibres with strengths approaching those theoretically predicted. Some whiskers are capable of withstanding tensile stresses of the order of several million psi. By incorporating strong stiff refractory fibres it should be possible to put metals into service at temperatures much nearer to their melting points than possible by conventional or by dispersion-strengthening. These materials can be conveniently prepared by the powder metallurgy technique of compaction and or by extrusion, forging or rolling.[28]

A whisker-reinforced composite consisting of Al_2O_3 whiskers in silver is 20 times stronger than pure silver at 1400°F and stronger than dispersion-strengthened silver at temperatures above 750F.[29] Remarkable improvement in the room temperature properties has also been achieved by fibre-reinforcement in copper.[30] Aluminium-silica composites with continuous fully-aligned fibres can be produced by precoating the fibre with aluminium and then hot-pressing. The coating on the fibre served the dual purpose of preserving the fibre strength by preventing mechanical damage and providing the matrix of the composite. Fibre reinforcement gives better tensile properties, when they are measured in the fibre direction, than the other modes of strengthening aluminium. Fig. 4 shows the properties of aluminium influenced by various modes of strengthening.[31] These composites can also be joined by modified pressure welding or soldering.[32] By the introduction of a high strength high temperature filament such as tungsten or molybdenum in a high temperature and oxidation-resistant matrix such as nickel or cobalt alloys, it should be possible to create a superior high temperature material. The reported tensile strengths at 2000°F of a cobalt, cobalt-alloy and nichrome containing aligned wires are approximately 6, 1·6 and 2 times greater than the unreinforced material.[33] In the fibre-reinforced composites it is generally assumed that the relatively soft and ductile matrix acts to transfer load between fibres by sheer forces at the interface. The strengthening effect is directly proportional to the fibre content, aspect ratio (ratio of fibre length to diameter) and the orientation of the fibres. Maximum strength is obtained when all the fibres are oriented in the direction of stress. Many applications require greater strength in one direction and in these applications materials with unidirectional properties would be beneficial. Further, to exploit the maximum advantage of these materials, components should be designed so that the reinfor-



6 *Canned extrusion*

cing fibres be in the direction of the principal tensile stresses. However, a better understanding of the strengthening mechanisms and fabrication parameters will certainly result in a wider application of the composite materials. In the technological development of these materials powder metallurgy techniques can be expected to contribute substantially.

Continuous compaction of metallic powders

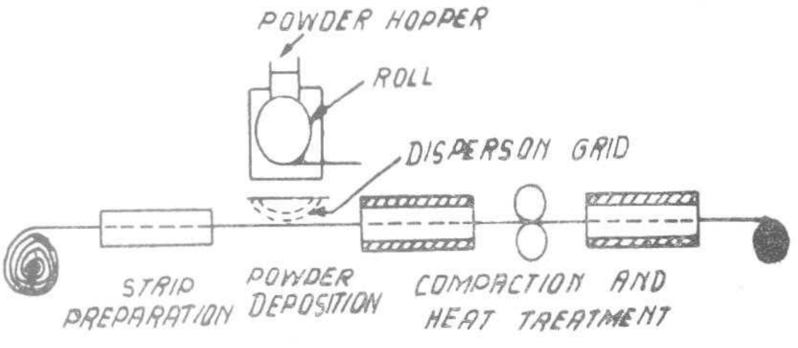
Continuous compaction of metallic powders into semi-finished products such as strips, sheets, tubes, rods and wires is a major break through in powder metallurgy. The process can be used not only for producing speciality items which are not possible by the conventional ways but also for conventional non-ferrous metals like copper, nickel, aluminium, cobalt, etc. Elemental powders of nickel, copper, aluminium and cobalt have been successfully converted into strip by roll compaction.[34,37] Alloy strips may be produced by roll-compacting either the blends consisting of the elemental powders or the pre-alloyed powders. Diagramatic view of the roll-compaction of metal powders is shown in Fig. 5. Some of the advantages of roll-compaction of metal powders are : (1) the technique is able to produce thin strips with fewer passes through the mill and fewer annealing cycles than are necessary when commencing with cast billet, (2) the yield is high compared to the ingot to finish strips, (3) superior properties of the powder rolled product in many cases and (4) high purity of the products. But the major limitation in the wide application of this process was the high cost of the metal powders. In recent years metallic powders became available at lower prices than before and there is a great interest in converting these powders directly into strip. In this context it will be interesting to note that Powdered Metals Corporation (P. M. C., U. S. A.) is in a position to produce high purity copper powder at a cost substantially lower than the published costs for electrolytic wire-bar. They are producing the copper powder from the ore through leaching and electro-winning techniques.

Full density nickel strip with better formability and purity is produced from sintered powder strip.[38] Though the cost of nickel powder is higher than that of the ingot nickel, by this process it is possible to produce superior quality nickel strip at the same cost as for the lower purity strip made by the conventional way, because powder rolling eliminates the melting, ingot castings and surface preparation stages. Sintered powder strip can be used for the production of coins, tokens and medallions. Coin blanks can also be made directly by compacting the powder.[39] Because of the high purity and ductility of the strip, the coin will take the fine coinage detail with a minimum of die wear. As per the 1967 report, Sherrittgorden has produced all the Canadian 5 cent coin blanks for the past two to three years, which amount to more than 100 000 000 pieces. There is a definite advantage in this field of applications. It is now proved that the conversion of metal powders to strip by continuous roll-compaction is both practical and economically advantageous.

Materials that are difficult to roll, extrude or shape in the cast form can be conveniently processed in the powder form. For hot working (extrusion, forging, rolling, etc.) the powders or the porous billets are heated in suitable scaled jackets. These jackets can support the powder during consolidation and can also prevent oxidation, particularly if it is evacuated before sealing. Fig. 6 shows the canned extrusion of powders.

Powder metallurgy approach may permit the production of forged shapes for those alloys normally regarded as unforgable. It has been shown that sintered inconel 713°C (68 Ni-13 Cr-4·5 Mo-2·5 Fe-2 Cb-6 Al-1 Ti) can be forged with substantial improvement in room temperature properties over the cast one.[40] Continuous compaction of powders is widely used for the production of materials that cannot be produced by using a cast billet. Typical examples are dispersion-hardened materials such as thoriated tungsten, TD nickel, SAP, etc., porous materials such as bearings, filters, nickel electrodes and fibre-reinforced composites.

Any of the bi-metallic strips can be prepared by continuous powder metallurgy. Steel-backed bearing for automobile engine bearings is a multi-metallic strip. Here copper or mixtures of copper and nickel powders are evenly spread upon steel strip and sintered. The porous sintered layer is then impregnated with babbit metal. Recently much interest has been shown for the production of aluminium and nickel-coated steel by the continuous roll-compaction technique. Pilot plant studies indicate that nickel strip can be coated, about 0·001 to 0·002 inch thickness, continuously via a nickel slurry process.[41] The powder was applied to the strip in the form of an aqueous slurry which was then dried, sintered, cold-rolled and annealed to give dense adherent coatings of uniform thickness. The coated material can be deformed and welded with no coating fracture or separation, while maintaining good corrosion resistance. Their markets range from automotive and appliances to diary and chemical applications where appearance, corrosion resistance and fabricability are essential. Aluminising steel, using aluminium powder, became a commercial reality in 1964 when Elphor Ltd., successfully operated a continuous strip aluminising line based on BISRA's 'Elphal' process. Coatings, with excellent adhesion and flexibility, were produced at a reduced cost. Further development by BISRA in the aluminising process led



7 Dry powder aluminising of steel

to the dry-powder process.[12] Fig. 7 shows the dry powder aluminising of steel strips. The new BISRA process consists of strip preparation, powder deposition, compaction and heat treatment. An electrostatic potential between the grid and strip greatly improves the powder dispersion. High quality coatings of aluminium up to 0·002 inch. thick can be produced on steel strip by this process. Thus there is an incentive to explore further in the field of continuous compaction of metal powders.

Conclusions

The above mentioned developments clearly indicate the tremendous potentiality of powder metallurgy in the fabrication of various non-ferrous metals including the semi-finished proucts. Indian non-ferrous industry can adapt the powder metallurgy techniques in many fields because it offers better economy and product performance. Because of the deficiencies of the known resources, our country will be largely dependent on the import of almost all non-ferrous metals or their ore concentrates, except aluminium. Further, to release the strains imposed on the non-ferrous metal industry in India by the emergencies, import restrictions and devaluation, it is necessary to change the growth pattern of this industry. To solve the problem of acute shortage of many non-ferrous metals, it is necessary to undertake more survey work and mining operations and to find out effective import substitutions. Other probable methods to face the situation may include : (1) secondary refining of the metal from scrap, drosses, wastes and other sources, (2) handling the material more carefully during fabrication to minimise the scrap losses and other wastes. Efforts should be made to exploit the wider utilisation of metals such as titanium, aluminium, magnesium, zirconium, beryllium, manganese and their alloys in which our country has got enough resources. More attention should be given to recover many of the non-ferrous metals in the powder form from the low grade ores, scrap and other resources. Many of the items which we are importing at present can be produced indigenously. In this context mention may be made of the porous materials such as filters and some of the high temperature materials. In order to effect economic advantage and to avoid scrap losses in many cases, it is worthwhile to consider the possibility of continuous compaction of metal powders particularly the roll-compaction. The primary factor for all these developments is the creation of a more favourable economic climate far raw materials. Enough quantity of good quality powders of a variety of metals should be available at reasonable prices. This will lead to a marked change in the economic pattern of powder metallurgy industry. Greater efforts should be made for market development and to educate the consumer of powder metallurgy products. A close co-operation between industries and academic and other research institutions is a vital necessity for the successful growth of powder metallurgy.

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