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INDIA'S EXPERIENCE IN POWDER METALLURGY

by

Saurin Chatterjee

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1. INTRODUCTION

Powder metallurgy (P/M) is now a well-established technology for the mass production of a large variety of structural parts and components such as bearings, gears and pinions, cams and sprockets, pulleys, piston, filters, tool bits, magnets, friction materials, electrical contact elements and components from refractory metals and a host of other components, utilising metal powders. The basic steps involved in P/M technology are production of the powder, mixing and pressing/moulding into shapes and sintering. These may be followed by other manufacturing steps such as sizing, coining, repressing and resintering, forging or metal infiltration as the case may be. The principal advantages of P/M component manufacture are:

i) Efficient use of raw materials and energy

ii) Production of parts and components with close tolerances which require minimum finishing operations and little machining

iii) Elimination of production steps

iv) Production of complex shapes without any of the additional joining techniques required in alternative production techniques

v) Flexibility which permits infinite adjustments and modifications to component making for different end-uses

vi) Production of certain components which can only be achieved through the P/M route and

vii) Efficient use of capital for the production of parts and components with high technology content.

2. EARLY BEGINNING OF P/M IN INDIA

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Though P/M technology as it is known and practised today is of recent origin in India, the art and techniques of the use of metal powders were not unknown in India. Traditionally, metal powders especially gold, silver, copper and the like have been in common use for medicinal preparations in the traditional ayurvedic system of medicine over the centuries. Metal powders, especially iron powder, must also have been used for other purposes. An early example of the use of metal powder is the famous Ashoka pillar at Delhi weighing about 6½ tons which was fabricated by consolidation of iron powder. It is said that even larger objects were produced during this period based on the traditional art and technique of powder metallurgy. Metal powders were also used extensively for manufacturing casting articles of every day use especially those made of brass.

3. GROWTH OF MODERN P/M INDUSTRY

The first known modern industrial application of P/M in India was in the hard metals sector for wire drawing dies, percussion tools etc. Today the installed capacity for P/M in the hard metals area is 750 tons per year excluding the captive capacity in the defence establishments. In the late fifties, India also started the manufacture of self-lubricating iron and bronze bushes with imported raw materials and equipment. At present however most of the raw materials required for these P/M products are being produced within the country.

With the development of the automobile domestic appliances, business machines and other industries, iron powder, especially in the form of sintered products and components, came to be widely used. Today over 62600 million sintered pieces are being produced in the organised industrial sector of the country and their production is rapidly rising. In addition, there are number of units in the small scale sector which produce a wide variety of P/M products for which the statistics are not readily available.

Subsequently, non-ferrous powder metallurgy especially copper and copper alloy powders came to be applied to the manufacture of a wide range of products including electrical contacts and brushes, friction components, filters and other porous parts. With the improvements in powder production, consolidation processes and equipment, further progress was made by the P/M industry. A large variety of non-ferrous powders such as copper, zinc, tin, lead, aluminium etc are now manufactured in the country. Today, the P/M industry has established itself as a competitive alternative process for the manufacture of structural components for automobiles, domestic appliances, business machines and the like.

Hard metals

The principal P/M products in the hard metals field are cutting tips for machine tools and ceramic coated tool tips over hard metal, tool inserts and disposable brazed tools for one-time use. Percussion tools with P/M hard metal tip are widely used in mining and quarrying operations such as coal cutting, rock drilling etc. The current production is around 400 tons per year both for domestic consumption and export. The three major units in this field are Widia India, Sandvik Asia and India Hardmetals. Unlike in the early stages, the entire manufacturing is now carried out indigenously from the raw materials to the finished product using mostly domestic and some imported raw materials. The total value of these P/M products is possibly higher than that of all other P/M products used in other areas. P/M is also extensively used for cold heading tools such as wire drawing dies, bar drawing dies and other wear applications.

Refractory metals

With the development of the industrial base in the country, the use of P/M refractory metals has extended especially for filament making in the electric lamp industry, resistance wires for furnace winding and other industrial applications where high temperatures are involved.

Ferrous P/M

Iron powder especially electrolytic iron powder has found a number of special uses in various industries. It is also extensively used in the manufacture of sintered products, especially for use in the automobile industry and in manufacture of domestic appliances. Other major applications are in the welding electrodes industry and in the ferrous foundries as well as for non-destructive testing of ferrous and non-ferrous components.

In the chemical industries iron powder is used i) as a catalyst in organic reactions, ii) as a chemical reagent, iii) for carbon estimation and iv) for textile dyes. It is also utilised as a filler in epoxy resins to increase their strength, hardness, weight and magnetic properties and also for colour matching.

In the pharmaceutical industries, iron powder is used in the manufacture of iron citrate, gluconates, fumerates, succemates, sulphates and EDTA salts. In the agricultural sector, it has found application in the magnetic cleaning of seeds, and also for enriching animal and poultry feed.

4. IRON POWDER PRODUCTION

The powder metallurgy industry in India is relatively small and of recent origin. Iron powder is produced by the electrolytic route, namely by the electrolysis of ferrous sulphate. The total installed capacity is around 1600 tons per year. Most of the units are in the small scale sector with production capacities of less than 50 to 100 tons per year. Some of these plants are not equipped with appropriate facilities for annealing, quality control etc for the production of quality iron powder. Due to the high cost of power, the production costs have risen substantially. Consequently, the operations of some units have become uneconomic, as their product is no longer competitive in terms of price and quality, leading to low utilisation of installed capacity.

Demand for iron powder

The domestic demand for iron powder is estimated at about 3000 tons per year constituting 1200 tons for consumption by welding electrodes industry, 1500 tons by sintered products and 300 tons by other applicattions. As new plants have been set up since for the manufacture of sintered components and the existing plants have expanded their capacity, there have been significant increases in the demand for iron powder in India. The current demand is around 3100 tons (1984-85) and it is expected that this would rise to about 8000 tons in 1986-87 and to 10600 tons in 1989-90 (Table 1). In view of the rising demand, India has had to resort to substantial imports of iron powder to meet the domestic recuirements (Table 2). This imbalance is sought to be remedied by the creation of additional capacity for the production of iron powder of various grades corresponding to varying bulk-density and granulometry to meet the diverse needs of the end product such as moulding grades, welding grades and other applications.

5. INDUSTRIAL APPLICATIONS OF IRON POWDER

As mentioned above, the major industrial uses of iron powder in India are at present for the production of sintered components and coated welding electrodes. In addition some small quantities are used for scarfing cutting and other applications in alloy and special steel plants, foundries etc.

<u>Sintered components industry</u>

Until recently there were only three major producers of sintered components in the country but now there are as many as 14 units (Table 3) who are engaged in the manufacture of sintered products from iron powder. Of these, five are major manufacturers of sinter products who between them consume at present 50% of the total iron powder consumption by the sintered products industry. Three new units are expected to go into production during the Seventh Plan period (1985-90). The present consumption of iron powder by the sintered components sector is estimated at about 2500 tons. It is envisaged that the demand for iron powder by this sector may rise to 6000 tons by 1986-87 and 8000 tons by 1989-90.

The bulk of the demand for sintered products come from the automobile and farm machinery industrues as well as other durable consumer industries such as refrigerators, household appliances, bicycles, typewriters, business machines etc. In fact, in the developed countries the automobile industry accounts for over 70 per cent of the consumption of iron powder. In a developing country like India, sintered parts are not yet extensively used by the aotomobile industry. However, with the injection of new technology into the automobile industry and changes in materials/component specification it is expected that sintered parts will be used to a greater extent in the manufacture of automobiles in India.

To meet the increased demand for passenger cars and jeeps, commercial vehicles, three-wheelers and motor cycles, scooters and mopeds etc, the Indian automobile industry has geared itself to raise its production capacity and to introduce modern technology which would enable the manufacture of more economical and energy efficient vehicles. Substantial new capacity us also being created for two-wheelers including motor cycles, scooters, mopeds etc. The production of agriculture machinery and tractors is likewise being stepped up. With all these developments envisaged in the automobile sector, the consumption of sintered products is bound to increase. The estimated demand for all types of motor vehicles during the 7th five-year Plan (1989-90) is estimated at 1270000 per year (Table 4) of which the passenger cars number about 150000 per year.

Welding electrodes industry

Iron powder is estensively used in the welding electrodes industry for coating high efficiency arc welding electrodes. The total licensed capacity in this sector is about 742 million running melters (MRM) of electrodes. In addition, new capacity of 200 MRM is now under implementation. Of the 20 units operating in this sector, four major producers - Advani Oerlikon, Philips Electricals and Electronics, Indian Oxygen and D&H Scheron Electrodes account for 85 per cent of the production in the country and consume at present about 1000 tons of iron powder per year. The total present consumption of iron powder by the welding electrodes industry is estimated around 1200 tons and this is expected to rise to about 2000 tons by 1989-90 (Table 5).

Other industrial users

Apart from these two major applications for sintered products and welding electrodes, iron powder is also consumed in small quantities in alloy and special steel plants (stainless steels, low alloy steels etc) for cutting and scarfing, in foundries etc as well as non-destructive testing of ferrous products and components. The total current demand for these end-uses is estimated at about 350 tons per year which is expected to rise to 600 tons by 1989-90.

6. NON-FERROUS P/M

As mentioned earlier, the metal powder industry in India commenced in the hard metals sector with the production of wire drawing dies, cutting tips for tools, tool inserters etc followed by the manufacture of self-lubricating bronze bearings and bushes. Subsequently powder metallurgy based on copper and copper alloys was employed for the manufacture of a wide range and variety of products such as electrical contacts and brushes, friction and antifriction components, filters and other porous parts, metal-bonded diamond tools and ceramic tools etc. Some of the units which produce ferrous sintered products are also engaged in the manufacture of non-ferrous sintered products.

Non-ferrous metal powders production

Simultaneously there was substantial progress in the production of non-ferrous metal powders and a number of units mostly in the small scale sector came to be established. At present there are some 18 units producing metal powders and their total installed capacity is around 2000 tons per year. If the capacities of some of the non-reporting small scale units were also taken into account, the total available capacity for non-ferrous powder production would be around 3000 tons to 3500 tons per year. However, due to wide market fluctuations the actual capacity utilisation has been much lower, at about 60% to 75%. Some quantities of powder is also produced at some of the sinter product manufacturers for their captive use.

The total estimated demand for nonferrous metal powders is over 3500 tons/year, mostly for the manufacture of bearings, bushes, metal graphite blocks and structural parts. In addition, some quantity of electrolytic and atomised powders find application as catalysts in the chemical industry and as pigments in printing inks. Precise data of the demand/consumption of metal powders by these industries are not readily available.

Today, a wide range of non-ferrous metal powders of various grades and metals are manufactured in the country. These range from the more common brass, bronze, copper, lead, aluminium and zinc powders to cadmium, cobalt, magnesium, nickel, silicon, silver, tantalum, tungsten, zirconium, uranium oxide etc.

Non-ferrous sintered products

There are at present some 15 units which are engaged in the manufacture of non-ferrous sintered products which is only four units are in the small scale sector. A large variety of non-ferrous sintered products are being produced by these units such as bimetal and trimetal bearings, bushes, diamond powder products, bronze filters, friction materials, self-lubricating bearings, silver-graphite contact materials, sintered metal parts and bushes, tantalum capacitors etc. This list is only illustrative, not exhaustive; and the product range is still growing, as new applications are being found for non-ferrous metal powders.

7. TECHNOLOGY AND ALTERNATIVE ROUTES OF POWDER MANUFACTURE

Several alternative processes have emerged for the manufacture of iron, copper and copper alloy and other metal powders, ever since P/M industrial applications. Some of these processes which have played their role in the development of P/M have now been rendered obsolete with the emergence of newer, and more competitive and satisfactory processes. Broadly speaking, the more important processes in today's context are i) electrolysis, ii) atomisation, iii) chemical reduction and iv) hydrometallurgy. Of these electrolytical and atomisation methods are at present more widely accepted and used for commercial scale manufacture of metal powders. These two process routes account for the bulk of the powders utilised for various structural and non-structural applications. Though chemical reduction is used to a lesser extent, it has a distinct role, as the powder produced by this process is well suited for the manufacture of structural parts and several other applications. Hydrometallurgical process is also well established especially for the production of copper, nickel and cobalt based powders.

Electrolytical process

The electrolytical process, because of the simplicity of its operation and excellent control of parameters, continues to occupy a dominant position in the field of powder metals production, despite the high power inputs and higher costs of production. The powder produced is of high purity. The adaptability of the process to produce a wide variety of non-ferrous metal powders has made it popular with metal powder producers, though it is extremely sensitive to rising energy costs. In India, substantial quantities of pure iron powder continue to be produced by this process.

Atomisation

Atomisation is primarily the disintegration of a molten stream of metal by high pressure gas or water jet. This is a well established process especially for the production of a wide variety of iron powders as well as copper-based powders of varying alloy compositions and powder characteristics. This is essentially a high speed production process, rendering control over the parameters difficult. These and other problems concerned with the atomisation of melting compositions as well as reactive metals and alloys have been overcome by technological developments in the melting furnaces, atomiser design, quenching process etc.

Apart from the control of the physical characteristics of the powders during the various stages of manufacture, the final control can be exercised during the annealing, crushing and grinding operations. Water jet atomisation is commonly used because of its advantages. The amenability of the process to pre-alloying with accuracy is an added advantage. This is particularly useful for the manufacture of low alloy iron and other non-ferrous powders.

Chemical reduction

Chemical reduction presents an attractive method for the utilisation of industrial waste from hot fabricating industries, especially for the production of non-ferrous powders. Copper scale and other oxide wastes are reduced by cracked ammonia or endothermic gas mixture at elevated temperatures. The reduced product which is in a semi-sintered state is further pulverised mechanically. The purity of the powder obtained is uncertain and limited by the quality of the oxide used. Moreover, inadequate control of the operations and the type of reducing agent employed may often reduce the purity level. To ensure better purity levels and more complete reduction, the use of cracked ammonia as the reducing agent is preferable. Moreover, during mechanical pulverisation, some of the desirable properties including surface activity may be destroyed. In view of these inherent shortcomings the prospects of further developments in this process appear to be limited.

Reduction of iron ore

The production of iron ore by the reduction of iron oxide, and in particular, the reduction of iron ore by carbon, is the oldest method of producing iron powder. The Swedish sponge iron process developed in Hoganas in early 1900, though originally intended for manufacturing sponge iron for steelmaking, has now become a primary source for iron powders in the world.

The Hoganas process uses pure magnetite ore after beneficiation by grinding and magnetic separation. Coke breeze or other carbon source provides the reducing agent for manufacturing sponge iron powder. Additionally, limstone is used to react with sulphur contained in the coke and to prevent its inclusion in the iron powder as impurity. The reduction of oxides to iron takes place at a lower temperature than in the conventional sponge ironmaking and the reduction is carried out in ceramic tubes which consist of silicon carbide. After reduction, the powders are sized by crushing, screening and separation. To make them suitable for use in compaction, the powders are process annealed and mixed prior to despatch to consumers. As the iron ore quality available in India is not suitable for this process, India has not opted for it.

Hydrometallurgy

The hydrometallurgical process originally developed for extracting copper from lean sulphides, oxidised or complex ores and concentrates, ore tailings and other mining wastes is now extensively employed for the production of not only copper and copper alloy powders but also of other non-ferrous metal powders especially nickel and cobalt based powders. The process consists of first leaching the metal bearing ore with a leachant and then suitably reducing the aqueous leach liquor by physico-chemical processes such as precipitation, reduction, solvent extraction, cementation, electrowinning etc. Hydrometallurgical process has the distinct advantage that it can utilise as raw material a wide variety of industrial wastes including low grade scales, heavily oxidised scrap, floor and flue dust, foundry wastes spent catalysts, spent pickling liquors effluent sludges etc.

8. FUTURE PROSPECTS

Future prospects of P/M manufacturing industries will be closely linked to the process and development of the end-use applications and the user industries including sintered products manufacture. Development of newer end-uses which is bound to take place with improved availability of powders in the market would accelerate the growth of the powder manufacturing industry. In the context of India's sustained industrial growth and development plans, there are considerable growth prospects for P/M industry in the country.

However, certain developments are necessary to meet the growing demand for larger quantities of low cost powders and some special grade powders for sophisticated and critical applications. These changes will necessarily involve modifications and innovations in powder production technology in keeping with the need for conserving energy and material resources. Also, sustained promotional efforts and continuing education will be required to popularise and extend the use of P/M, as it is still comparatively a new development and its full potential is yet to be realised.

The Indian context

In the Indian context, however, the electrolytic process may continue to maintain its prominent position in the near future. Its suitability for small scale operation with low overheads can more than compensate the higher energy requirements. Atomisation is, however, rapidly gaining ground. At present, this process is employed mostly for the production of pigment grade, gold bronze powders, prealloyed powders for sintered bearings, filter grade powders etc. Several units in the small scale sector produce other non-ferrous powders by this process. In respect of chemical reduction technology, its use is likely to be limited to certain units with an assured supply of better quality raw materials, possibly to produce special grade powders.

Hydrometallurgical process is likely to gain greater popularity as it is economically attractive in view of its ability to use low grade raw materials entailing relatively lower raw materials cost and recycling of industrial wastes.

While electrolysis will continue to be attrative for small metal powder units, prospects are equally good for medium and large scale powder plants employing atomisation technology as also hydrometallurgical processes. Future trends favour the installation of integrated units in the medium or large scale sector producing metal powders by more than one process as well as sintered products, supported by ancillary units supplying certain grades of powder which will further be processed into special grades of premixed and blended powders.

9. RESEARCH AND DEVELOPMENT

P/M research and development activities are in progress in a number of research organisations, technical institutes and universities on various aspects of manufacture, industrial uses and special applications of metal powders. Notably, specialised research institutions such as the National Metallurgical Laboratory (NML), Jamshedpur, the Defence Metallurgical Research Laboratory (DMRL), Hyderabad, the Bhabha Atomic Research Centre (BARC), Bombay, Central Electrochemical Research Institute (CECRI), Karaikudi, National Aeronautical Laboratory (NAL), Bangalore, Vikram Sarabhai Space Centre (VSSC) Trivandrum have been doing pioneer work in this field. Similarly, considerable research work, both applied and fundamentai, is being carried at the various Indian institutes of technology and a number of other institutions of higher technical education and universities such as Banaras Hindu University, Indian Institute of Technology Bombay, the Indian Institute of Science etc. Some of the major R and D activities are briefly mentioned.

Air-, nitrogen- and water-atomised non-ferrous powders

The Metal Powders Group at the National Metallurgical Laboratory has been specially active in the development of the production process for metal powders for nearly a decade. The major thrust has been in the area of air-atomised, nitrogen-atomised and water-atomised non-ferrous metal and alloy powders. The know-how developed by NML for a number of these extra-fine gas atomised non-ferrous metal powders has been successfully transferred to industry. These include aluminium and aluminium alloys, brasses and bronzes, tin, lead, copper and copper alloys and solders. Developmental work is also in progress on water-atomised iron and ferrous alloy powders. NML know-how for the production of distilled grade extra fine zinc dust has also been licenced for commercial production and technology transfer.

These R and D activities have involved a good deal of related peripheral investigations on the extraction of parent metal from leach solutions by adsorption on lignite; recovery of parent metal from metal wastes such as drosses; development of compacting/sintering grade P/M, prealloyed powders and premixes; and other related applications technology.

In the frontier area of geo-micro-bio-hydrometallurgy, exploratory work is also underway at NML for the production of high grade bimetal powders from microbeal leach liquors by cementation and dilute solution electrolysis. Work has also been initiated in some areas of application technology for metal powders.

Special materials and superalloys

At BARC, the research and development work is primarily contered round the powder metallurgy of special materials and superalloys. Some of the investigations in progress are: development of a process to fabricate a superconductor wire; large scale fabrication of carbide fuel pellets for the fast breeder test reactor; silver-nickel composites used as contacts in electrical and electronic industries; investigations on electro-ceramics based on lanthanum chromite, for use as hot electrodes in open cycle magnetohydrodynamic power generation and ultra high temperature heating elements; production of nuclear fuel elements by cold compaction and sintering of uranium oxide agglomerates; preparation of uranium monocarbide insulation pellets for fast breeder test reactor fuel pins etc.

Special metals and alloys products

At DMRL the major research and development activities relate to pilot plant studies of special metal and alloy production; research and development in various aspects of compaction and sintering of metals, ceramics and cermets, compact forging etc. CERI is carrying out research work in the area of electrometallurgy and powder production. NAL is investigating titanium base P/M alloys. At VSSC research and development work is in progress on P/M products for aerospace applications.

The production activities of the Mishra Dhatu Nigam (Superalloys Plant, Hyderabad) is closely associated with the work of these laboratories and within a short period of time, India has been able to produce the bulk of its requirements of highly specialised metals, alloys and other components for its nuclear energy programmes, defence, electronics and other needs. Some research work is also in progress at the research and development centres established by the earlier P/M manufacturers to improve their products and to develop new products and processes.

Metallic glasses and super aluminium alloys

Another fascinating development which is engaging the attention of Indian P/M metallurgists is the new technology of rapid solidification processing (RSP) of complex alloys into metallic glasses. These metallic glasses belong to a novel class of RSP alloys characterised by their unique compositions, amorphous structures and excellent mechanical, magnetic and corrosion resistance properties. Rapid solidification techniques such as melt spinning are capable of fabricating metallic glasses in large quantities as continuous ribbons and tapes. Because of the need for extremely fast cooling during processing, metallic glasses can only be fabricated as thin bodies at the present status of our knowledge. Their application in bulk shape products is not yet feasible. However, these metallic glass alloys can be fabricated into bulk shapes suitable for engineering and structural applications. Though the basic process of RSP is well known information on production technology is not readily available.

India has made a beginning in RSP technology for the production of a new generation of super aluminium alloys. Laboratory studies at the Banaras Hindu University have already demonstrated the feasibility of their production. RSP technology presents the exciting possibilities of the use of this new class of alloys for a new generation of space applications and missiles with substantial weight savings and service life.

Powder Metallurgy Association of India (PMAI)

The P/M activities in India are speaheaded by the Powder Metallurgy Association of India. This organisation with a membership of 400 actively promotes powder metallurgy in India. Through its various activities such as publications, seminars, workshops and technical meetings it successfully disseminates information on the latest developments in the field of P/M, working in close cooperation with international and Indian organisations in the field.

10. ACQUISITION, DEVELOPMENT AND TRANSFER OF P/M TECHNOLOGY

India's progress and development in P/M has followed the traditional growth route. The country made a modest start in powder metallurgy in the 1950's in the hard metals field, based on imported technology and raw materials. This was followed by its entry in the late 1950's into the production of iron and bronze bushings. With the rapid growth of industrialisation under the impetus of the five-year development plans and the consequent rising demand for P/M products and raw materials, India started with the manufacture of metal powders and sintered products with imported technology and raw materials. A number of industrial units, mostly small-scale and a few medium scale came to be established.

The progress witnessed in the earlier years was mostly in the ferrous P/M sector as the demand for sintered products increased which in turn created a rising demand for iron powder. This led to the establishment of several small units for the manufacture of electrolytic iron powder based on indigenous technology. Most of these units were established by enterprising entrepreneurs, with meagre resources and without recourse to technology inputs. The electrolytic process was well known and with the technical assistance of some university professors who had specialised in P/M, these units were able to work out the parameters and develop the requisite know-how. Today, India has achieved a good measure of self-sufficiency in the production of iron powders, though certain grades of iron powder still continue to be imported on a limited scale.

As mentioned earlier, due to the peculiar characteristics of most Indian iron ores and its unsuitability for the production of iron powder by the direct reduction process, this technique of iron powder making has not made much headway in India. Efforts are, however, under way for the production of ferrous powder by the atomisation process (which is currently used in Brazil, USSR, West Germany, Japan etc).

In the case of non-ferrous metal and alloy powders, however, India till recently was entirely dependent on foreign technology and imports of powders for various end-uses. The earlier plants set up in the late 1950's for producing non-ferrous metals and powders were either foreign collaboration ventures or were manufacturing under licence. With the NML technology now available within the country, some of the new units have acquired this technology for the production of air- and nitrogen- atomised non-ferrous and alloy powders (aluminium and aluminium alloys, brasses and bronzes, tin, lead, copper and copper alloys, zinc and zinc alloys, distilled grade zinc dust etc).

In respect of the applications of powder metallurgy, namely hard metals, sintered products and welding electrodes, most of the know-how had initially come through foreign collaboration, joint ventures and licensing arrangements. Recently, however, some new units have been set up in these sectors by professionals who had worked in the earlier units and acquired some production experience. This process of indigenisation or Indianisation also received some encouragement by the import substitution programme and the policy of technological self-reliance. Some of the facets of this development processes/experience of India in powder metallurgy are discernible though the development did not take place in any definite sequence or chronological order.

- production of sintered components with imported raw materials and technology
- production of some types of metal powders and P/M products with indigenous raw materials and imported technology (foreign collaboration/joint ventures with or without equity participation)
- production of P/M products with imported technology (under licensing arrangements)
- production of metal powders and P/M components with domestic raw materials and technology (Indian enterprises without any foreign collaboration)
- R & D activities and development of new technologies with local raw materials
- commercialisation of indigenous processes and transfer of technology to industry
- development of R & D infrastructure and consultancy services for installation of plants and export of technology/services.

India has now reached a level of development in P/M in which there is a balanced mix of imported and indigenous know-how. India is still importing know-how where required and joint ventures/licensing arrangements continue to be entered into. At the same time, however, it is stepping up its own R & D efforts not only in the conventional areas and products but in emerging technologies and frontier areas. The policy of self-reliance in technology and import substitution that the country has pursued over the years is evidently paying good dividends.

Relevance of Indian experience to other developing countries

India's varied experience in P/M has some relevance to other developing countries who are planning or developing their P/M industry. Though the course of India's development may not be uniformly applicable to all developing countries due to the diverse techno-economic environment obtaining in the individual country and its specific requirements, some broad guidelines can be drawn to indicate the lines or directions for the development of P/M sector. Some developing countries have already successfully established sizeable P/M industry over the years, starting with imported technology, production equipment and raw materials. South Korea is a good example of a country which not only rapidly absorbed and made good use of imported technology but developed its own processes for the production of copper and other non-ferrous metal powders. There are other developing countries where limited domestic markets, weak industrial and technological base and lack of resources may be the limiting factors.

Obviously developing countries newly entering the P/M field will have to rely in the initial stages on foreign know-how for establishing P/M ventures, based on their requirements. Depending on their industrial development plans and the possible demand for P/M products, they may identify the P/M products they would like to take up for immediate development. This in turn would indicate the directions which the P/M development should follow. Assuming that in the first instance the demand for P/M products will be primarily for sintered components from the automobile, agricultural machinery and domestic appliances industries and other equipment of every day use, possibly the country could start with the manufacture of various sintered components using imported raw materials. If the demand so warrants, the country may then commence manufacturing ferrous and non-ferrous metals and alloy powders on a modest scale acquiring the know-how from foreign sources or entering into foreign collaboration. The technological infrastructure also needs to be created for the effective transfer and absorption of the technology. Simultaneously the requisite R&D facilities will have to be developed for the adaptation and improvement of the product and also for developing new processes and products. These activities are aimed at bringing about a measure of self-reliance in technology. In these development tasks the technologies developed by other developing countries and their experience in P/M may be more suitable and relevant to the conditions obtaining in the recipient country. The terms and conditions of acquisition and transfer of technology may also be more favourable.

Concluding remarks

India has come a long way in the field of powder metallurgy since the modest beginnings in the 1950's. Within a short span of three decades the country has been able to achieve a measure of self-reliance in the P/M field both in terms of technology and raw materials. Though early P/M ventures in the country had been dependent on foreign technology and raw materials it had earlier relied on its own efforts in setting up P/M units and in developing suitable technology especially for the electrolytic production of iron powder and some categories of sintered products. With the development of the industrial and technological infrastructure and intensive R&D efforts India has been able to venture far ahead. It has developed its own technologies for the production of various non-ferrous metal and alloy powders and is in a position to share its experience with other developing countries. Many of the processes developed in India have been commercialised since and a number of industrial units are already in operation. India can now offer a comprehensive technology package along with the process know-how and design/engineering consultancy services for the installation of P/M units of various capacities. Developing countries establishing and developing domestic powder metallurgy industry can benefit immensely by the experience of India in this field.

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TABLES

Table 1 - PRESENT AND ESTIMATED FUTURE DEMAND FOR IRON POWDER

	Present 1984-85 tons/yr	1986-87 tons/yr	1989-90 tons/yr
Sintered components	1,500	6,065	8,310
Welding electrodes	1,250	1,500	1,900
Other applications	350	510	600
	3,100	8,075	10,810
say,	3,100	8,000	10,800

Table 2 - IMPORTS OF IRON POWDER

Year		Quantity tons
1973-74	..	334
1974-75	..	324
1975-76	..	461
1976-77	..	423
1977-78	..	915
1978-79	..	671
1979-80	..	858
1981-82	..	1,109
1982-83	..	7,800

Table 3 - ESTIMATED DEMAND FOR IRON POWDER BY SINTERED COMPONENTS MANUFACTURERS (1984-85 TO 1989-90)

Sintered product manufacturing unit		1983-84 tons/yr	1986-87 tons/yr	1969-90 tons/yr
Mahindra Sintered Products Pune	..	300	600	700
Assotex Engg Industries Bombay	..	100	750	1,500
Sundaram Fasteners Hosur	..	300	2,000	2,500
Andhra Sintered Components Gundur	..	-	700	1,100
S.S. Miranda, Ankleshwar	..	-	1,000	1,000
Akay Sintered Products Faridabad	..	200	200	200
Flexicons Ltd Udhna	..	60	120	160
Sintering Virmani Delhi	..	150	225	300
Goa Sintered Products Goa	..	50	90	150
Ashok Sinterings Pvt Ltd Delhi	..	50	65	80
National Sinterings Lucknow	..	30	45	60
Clutch Auto Faridabad	..	50	65	80
M.M. Sintered Products Wardha	..	50	60	70
Hindustan Aircraft Ltd Bangalore	..	75	85	105
Arvind Sinterings Ltd Delhi	..	30	30	30
Jhansi Sinterings Pvt Ltd Delhi	..	30	30	3
R.K. Jajoo New Delhi	..	-	-	225
		1,475	6,065	8,310

Table 4 - ANNUAL DEMAND FOR MOTOR VEHICLES IN INDIA DURING SIXTH AND SEVENTH FIVE-YEAR PLANS

		Sixth 5-year Plan (1985–85) Nos	Seventh 5-year Plan (1985–90) Nos
Passenger cars	..	60,000	150,000
Jeeps	..	30,000	45,000
Light commercial vehicles	..	40,000	75,000
Medium and heavy commercial vehicles		90,000	140,000
3-wheelers	..	50,000	150,000
Motor cycles	..	175,000	350,000
Scooters	..	400,000	800,000
Mopeds and mini motor cycles		425,000	850,000
		1,270,000	2,550,000

Table 5 - DEMAND FOR IRON POWDER BY WELDING ELECTRODES INDUSTRY

Electrode producer	Present (1983–84) tons/yr	1986–87 tons/yr	1989–90 tons/yr
Advani Oerlikon (ADOR)	550	630	730
D&H Scheron Electrodes	300	400	530
Indian Oxygen (IOL)	100	170	290
Philips India (PEICO)	70	80	90
Modi Arc Electrode	25	30	35
Others	155	190	240
	1,200	1,500	1,915
say,	1,200	1,500	1,900