POWDER METALLURGY

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The utilization of powdered metals for the production of machine parts which heretofore could only be produced by casting or forging a restricted group of alloys has made tremendous strides and has opened new vistas for the fabrication of metals and alloys. For many years tungsten lamp filaments have been produced by sintering compressed tungsten powder. The wide application of this procedure to the fabrication of parts has given rise to a new branch of metallurgy now referred to as "powder metallurgy."

In short, the procedure of making an object from powders involves two steps. The first step is the formation of a compact by the compression of individual, mixed, or alloyed metal powders in a die. The second step is the heating or sintering of the compact to coalesce, alloy, braze, or weld the particles together at a temperature below the melting point of the powder.

Powder metallurgy is divided into two divisions; first, the production of powders and, second, the production of objects from the powders. Metal powders are produced by many different methods. In some cases a powder of 200 mesh screen analysis is produced by stirring the metal as it solidifies. Such a powder is well-suited to pressing and sintering. Powders of iron, nickel, cobalt, tungsten and alloys of these elements have been produced by condensation from the vapor phase. Other methods include chemical reduction of oxides, precipitation from metallic salts and electrolytic deposition.

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While there are many methods of powder production, the methods of consolidating the powders are limited. Basically there are but two, namely, cold pressing and hot pressing. In either of these methods the pressure can be varied between atmospheric pressure and 350 tons per square inch; but the usual range employed is between 10,000 pounds per square inch and 60,000 pounds per square inch.

In the cold pressing operation the powder or powders are compacted in a cold die under pressure. In this method the powder is introduced into a die of the shape of the final product. The amount of powder is either weighed or measured volumetrically. In high production machines the powder is fed in through chutes. A plunger is inserted and the powder pressed either by hydraulic pressure as in the case of the larger products or by a toggle mechanism as in the case of small, high-speed machines. The rate rate of application of the load depends upon the equipment. Less air is trapped if the load is applied rapidly; however, in the larger presses rapid application of the load is more difficult. The time the load is maintained after application seems not to affect the compact after pressing or during or after sintering.

The die design for cold pressing is straightforward. The die must, of course, have strength sufficient to withstand the pressures applied. Sufficient clearance must be left between die and plunger to allow for escape of gases during pressing, but must not be enough to permit escape of fine powder. Dies and plungers with a slight taper are recommended for certain applications. Galling between die and plunger may occur if the powder adheres to the die wall. This may be minimized by use of a proper lubricant. Cold pressing may be readily adapted to pressing in vacuo or controlled atmosphere by suitable seals on the die; however, such control does not lend itself to mass production, upon which the success of powder metallurgy depends.

Hot pressing involves the simultaneous application of pressure and heat. The same problems of die design are encountered, coupled with choice of material which will withstand high pressure and heat without undue oxidation. The most serious problem is that of cooling the die between pressings, which is necessary to prevent gas absorption if the powder is exposed to the air when introduced into the hot die. In hot pressing, the addition of heat adds to the plasticity of the particles, permitting more intimate bonding and higher density. The higher hardness obtained might be attributed to the higher density, but cannot be correlated with the lower hardness of wrought material which has higher density. Hot pressing is usually used where higher hardness and density are desired.

Cold pressing may be used for producing either porous compacts as are required in some bearings or for high density compacts where strength and hardness are desired. The porosity can be controlled between wide limits (15 per cent to 50 per cent) by proper choice of particle size and applied pressure. Hot pressing is usually used where higher hardness and density are desired.

Pressing of powders serves several purposes. First, the shape of the piece is determined. Second, the particles are brought into more intimate contact, which in ductile materials may mean local deformation of particles to conform with neighboring particles, or in brittle materials, an interlocking of particles. Third, due to movement of particles past one another, absorbed gas films may be broken down locally, leading to a "cold welding" of particles which may be of considerable strength. Fourth, trapped gases are partially expelled.

It has been shown by several investigators that clean surfaces, whether metal or glass, when in contact exhibit a bonding. This bonding occurs with no pressure except atmospheric pressure, but increases if the surfaces are pressed together by an outside force. This phenomenon has been called "cold welding", or sintering. The external application of force probably serves to bring about better contact over a greater area, for no matter how carefully the surface is mechanically polished, surface imperfections would still be very gross when considered on an atomic scale. The simultaneous application of heat and pressure would increase this type of bonding by making more intimate contact due to increased plasticity at elevated temperature and also due to increased atomic mobility and greater diffusion which should increase the strength of the bond. Those compacts produced by cold pressing must be heated to produce a structure which has useful properties.

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Heating a previously pressed compact brings about structural changes such that equiaxed grains, as found in cast or cast and forged structures, are obtained, without reaching a temperature which would cause melting of the metal or alloy. In many cases some bonding takes place at a temperature as low as one-third the melting point of the metal or alloy.

High melting alloys of tungsten, molybdenum, tantalum and columbium cannot be processed easily by conventional casting techniques. However, these metals in the powdered state can be pressed together and heated in a controlled atmosphere at temperatures somewhat below the melting point of any component to produce alloys. Bonding will take place to such an extent that the alloys can be forged and further heated to produce a sound, strong compact. Contamination by furnace lining, losses by oxidation and undesirable atmospheric components can thus be eliminated or closely controlled.

Electric contacts can be produced exhibiting unusual properties. Silver or copper powders are mixed with tungsten, molybdenum or nickel, pressed and heated. The temperature is kept low so that bonding takes place with little diffusion between the component powders. The silver or copper thus retains its high conductivity while the alloy additions increase the hardness of the "alloy" and reduce the tendency for fusion between contacts.

Another application in which true alloying is not the objective is the production of a so-called "heavy metal." This is produced by compacting and sintering a mixture of 90 per cent tungsten powder, 5 per cent copper powder and 5 per cent nickel powder. The final product has a density 50 per cent greater than lead. It can be used for storage of radium and balancing of moving parts such as crankshafts, variable pitch propellors, vibration dampers, etc.

Cemented carbide high-speed cutting tools are produced by bonding hard, brittle tungsten carbide with tough, shock-resistant cobalt, thus yielding a product having desirable characteristics of each component. Diamond dust also has been mixed with various metals to produce a tough, well-bonded grinding or cutting tool superior in many respects to one in which the diamonds are individually set in a metal matrix.

Unusual structures can be developed by proper control of the particle size, shape and nature of component powders, pressing pressures, and heating or sintering temperatures. Porous self-lubricating bearings are one of the outstanding products in this classification. These bearings are produced by mixing proper proportions of copper, tin and graphite powders, compacting at low unit pressures and sintering so as to leave pores in the compact. These pores or intentional cavities may be interconnecting so that oil may be supplied through the bearing, or, if not completely interconnecting, of such a nature as to act as a reservoir for the oil.

Metals not miscible in either the liquid or solid state can be mixed compacted and sintered to give good dispersion of one metal in the other. Bearings and electrical collector brushes are made from copper and lead powders. Metals having very different melting points may be alloyed with less difficulty by pressing and sintering. Volatilization losses are avoided and desired analyses are more easily produced. Metal objects of high purity can be produced by sintering powders because there is no reaction between a molten metal and refractories, gases and scavengers. The chemical purity of the metal powders used is usually greater than that of metals otherwise commercially produced.

One of the best known items produced from powder metals is the filament in the electric light bulb. Tungsten has all the desired characteristics for a filament, but due to a melting point of 6098°F (3370°C) it is very difficult to melt and cast. Tungsten powder produced by chemical reduction, is pressed and then heated in a controlled atmosphere by passing a high electric current through the compact. After one heating the bond is such that the compact can be forged. By repeated forging and heating an excellent bond is effected and the compact may be rolled and then drawn into wire.

The foregoing applications of powder metals, while valuable, are limited in their extent. The extensive use of powder metals will necessitate the development of forming processes to such a degree that the products can compete on a favorable basis with those produced in the conventional manners, i. e., casting, machining, forging, etc. One advantage in producing objects from powder metals is that the products can be formed to finished dimensions with very little or no machining. Small spur gears are now being so produced, with little or no waste material. This type of application is, however, limited to smaller sizes because of limitations in the processes employed.

The few general applications given show definitely that powder metallurgy has earned a permanent place in the general field of metallurgy. However, it is not a panacea for metallurgical and production problems as there are at present several limitations on the use of the powder metals. First, there is the cost of required equipment. The dies in which the powder is compacted must be able to withstand a unit pressure of 60,000 pounds per square inch and over. This problem, however, is not as serious as that of providing a press which can exert such pressures on an appreciable area. At present there are few such presses; consequently the size of the product is limited. Since equipment costs will be high, powder metal products will fall more nearly into a class with die castings than sand castings, as mass production is necessary to warrant the high initial expense.

Another very serious limitation is the fact that metal powders do not act as perfect liquids under pressure. Due to friction between grains and on the die wall, a difference in pressure is established both parallel and perpendicular to the direction of pressing. This limits the size of pieces which can be made with a uniform structure. A larger pressure differential is obtained parallel to the direction of pressing. Such a pressure differential cannot be eliminated and hence may always limit the size and complexity of pressed powder objects. The importance of uniform pressure is due to the phenomenon of expansion and contraction of pressed compacts during heating. The compacts pressed at high pressures expand on heating, and the compacts pressed at low pressures contract on heating. Expansion or

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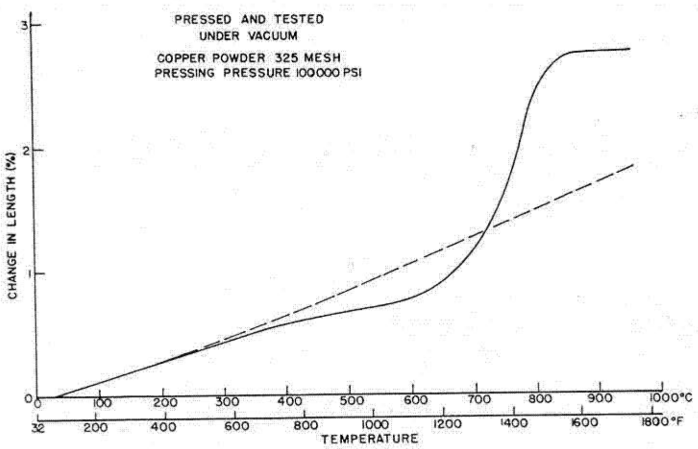

Fig. 2. Solid line indicates dilatation curves for copper powder pressed and heated in vacuo; dotted line indicates dilatation curve for solid bus bar copper.

Because dimensional changes are important, work has been conducted at the California Institute of Technology to determine the influence of pressing pressure, heating temperature, and powder particle size on the density and structure of copper powder. To obtain an accurate indication of change in length with temperature, a dilatometer was employed. Figure 2 shows the results of a test on copper powder of 325 mesh screen analysis pressed in vacuo at 100,000 pounds per square inch and then heated in vacuo. The dotted curve indicates the dilatation of forged, annealed bus bar copper. The expansion mentioned previously should be noted. Figure 3 shows the structure of the powder compact after heating. The well defined grains should be noted. Due to the voids present the specific gravity was 78 per cent that of bus bar copper.

Until these conditions are correlated and the changes in dimension can be controlled, the applications for powder metals will be restricted.

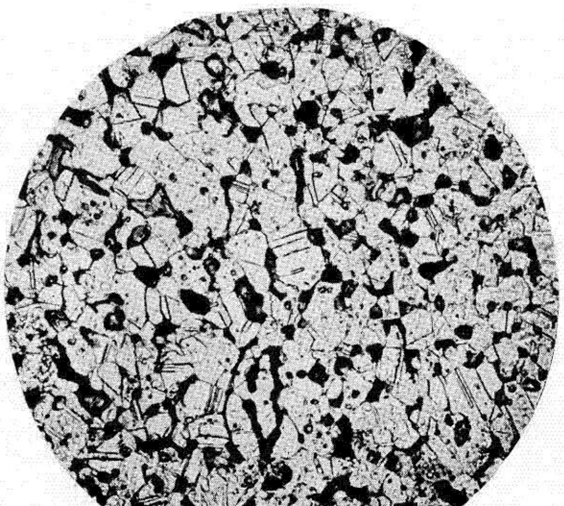

Fig. 3. Photomicrograph of copper specimen pressed at 100,000 P.S.I. in vacuo and heated to 950° C. in vacuo. 500 magnification.

JAPAN

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of baggage space. American techniques have clipped hours off peacetime airplane wing assembly schedules, months off cargo boat production and added miles to airplane bombing ranges. American technique developed the dive-bomber, the torpedo plane and the submarine, which the Japanese have found so effective. Up to now, because in peace-time inventions are shared, this inventiveness of the Americans has done the Axis more good than it has the United Nations. But from now on this will not be so.

The winning of this war depends on America's using its inventiveness in daring ways to outsmart and confuse the Japanese.