Secondary and Finishing Operations

Even though Powder Metallurgy is considered as a near-net shape technology, in many cases, PM-components require features and properties that cannot be achieved simply by sintering. For instance, supplementary operations may be used to reproduce complex shapes, achieve closer tolerances, improve mechanical properties, or protect against corrosion.

In spite of the increase in cost caused by secondary operations, often the final products are still economical compared to those from competing technologies. Some of the secondary operations described in this section are specific for PM parts (such as the steam treatment and the infiltration with metals or polymers), but most of the operations are commonly used also in non-PM parts. However, some specific requirements must be considered for PM parts because of the limitations imposed by the peculiar characteristics of the PM materials, particularly porosity.

Deburring and Cleaning

Powder Metallurgy parts are often subjected to deburring processes to remove burrs, sharp edges, or surface irregularities resulting from compaction or machining operations. It is possible to carry out deburring in bulk by tumbling or shot blasting (hitting by abrasive media in compressed air), or on a unit basis using processes such as brushing, polishing, and electrolytic deburring.

A common practice consists of tumbling PM parts in a liquid medium with abrasive particles by using rotating barrels (barreling) or vibrating tubs (vibratory deburring). As a consequence of the penetration of liquids in the surface porosity, corrosion problems may arise. Thus, corrosion inhibitors should be added to the liquid media. In some cases, the parts are resin- or oil-impregnated to minimize water absorption during the deburring process. Parts may be cleaned to remove surface contaminants from the production process (such as grease, oil, and lubricants).

Cleaning operations are diverse and depend on the specifications and the type of pollutants that the part may contain. For ultrasonic cleaning, the parts are placed in a tank and agitated with ultrasonic waves that are able to shake the contaminants trapped in the pores. Electrolytic–alkaline cleaning reduces the risks of corrosion as the parts are immersed in a strong alkaline solution. Through electrolysis, the parts are cleaned and the oxides or nonmetallic coatings are removed.

Repressing, Sizing, and Coining

Repressing is sometimes used to increase the density of a compacted and then presintered part, before the final sintering process. For ferrous components, it allows achieving a high level of density and mechanical properties, whereby using standard pressing loads. The plastic deformation imposed during repressing operations is substantial (from 5 to 20%) and the forces required are comparable to those used during the initial pressing operation.

Sizing is also a repressing process, but the aim is to improve geometrical precision. It requires only moderate forces as usually only slight deformations are needed (below 5%)—at least if the hardness of the as-sintered part is not too high (typically below 200 HV). For an as-sintered ferrous part, the accuracy in the dimensions is typically 0.004 mm per mm in parallel to the pressing direction, and 0.002 mm per mm within certain angles from the pressing direction. The tolerances and properties achievable after sizing depend on the material, and closer tolerances are attained with softer materials.

Coining is a repressing operation in which plastic deformations are intermediate between repressing and sizing. The process has a double purpose: reduce dimensional variability and increase density. The considerable strain hardening achieved with this process causes an increase in tensile strength and hardness and a decrease in elongation. This process can also be used to imprint the faces in contact with the punches.

Local Surface Densification Techniques

As the mechanical performance of components is determined to a large extent by the structure and properties of the surface, a promising method to widen the capabilities of Powder Metallurgy parts consists in developing techniques to increase the density of near-surface areas, which are frequently the mechanically loaded zones. In porous components, superficial plastic deformation brings out a density increase in surface and near-surface regions, creates residual compressive stresses, and provides work hardening in the deformed layer. Thus, a surface layer of controlled plastic deformation can dramatically improve fatigue properties in PM components.

An important method for increasing the fatigue life of PM components is shot peening, a cold working process in which small spherical media (metallic, glass, or ceramic particles) are used to impact the surface of a part with enough energy to cause plastic deformation. A compressive residual stress layer is formed in the surface, and the mechanical properties in this layer are modified by the effect of strain hardening.

In porous PM materials, it has an additional effect because plastic deformation induces surface densification by closing smaller pores and reducing the size of larger pores. Fatigue and contact fatigue resistance can be increased by up to 25%, and the resistance to surface damage is also significantly enhanced

Machining

Machining operations are often needed to incorporate geometrical features that cannot be reproduced during pressing (e.g., transversal bores or re-entrants at an angle to the pressing direction). In some cases, it is simply more economical to introduce such features with a machining operation. Machining parameters for PM parts are different from those of cast or wrought components. Machinability of PM parts is affected by their complex property profile (density, chemical composition, microstructure, additives, etc.).

The inherent porosity affects chip formation, thermal conductivity, cutting temperature, bulk strength of the workpiece, cutting forces, and the characteristics of the surface generated after machining. Typically, machining becomes more difficult with higher porosity levels and with heterogeneous microstructures. Machinability of PM parts can be improved by incorporating certain additives in the powder mix prior to compaction (lead, copper, graphite, sulfur, or a metal sulfide such as manganese sulfide). Also, infiltration with low-melting point metals or impregnation of the porosity with polymer is a common practice to improve machinability.

Joining

Some of the limitations in the geometries achievable with powder metallurgy techniques can be overcome by joining different sintered parts, or a sintered part with another part produced through a different technique. However, some factors should be considered when joining PM parts.

Porosity affects thermal conductivity and thus expansion as well as thermal conductivity and thus hardenability. As porosity may trap impurities that could seriously damage the properties of the joint (e.g., residual lubricants, machining coolants, quench oils, etc.), it is important to thoroughly clean the parts before joining. Low density Powder Metallurgy parts are preferably joined using solid-state processes such as brazing, diffusion bonding, shrink fitting or techniques as adhesive bonding. Parts with higher densities can be welded using fusion based processes.

Welding

Most of the conventional welding methods can also be used for PM parts. In general, low heating input is recommended for porous materials and, if needed, any steam treatment or heat treatment should be performed after joining.

Thermal stresses in the heat affected zone (HAZ) can result in cracks due to the porosity. Any given welding process needs to be optimized for each specific PM components considering factors such as porosity, chemical composition, impurity level, ductility and toughness, residual stresses and distortion, welding metal and HAZ cracking.

Typical welding techniques used for PM materials are arc welding, laser welding, electrobeam welding, resistance projection welding, and friction welding. Arc welding is often avoided because it can result in pore coalescence. Laser and electrobeam melting provide low heating inputs that minimize distortions. The disadvantage is the rapid thermal cycling that may result in cracking. Friction welding is a remarkable welding technique for PM material as it promotes porosity closure and oxide layers breakage in the weld interface.

Brazing

(Soldering and Brazing) consists of assembling the parts to be joined in the desired position and insert a brazing powder between them. During heating, the brazing powder melts and infiltrates the components. The most practical way of applying the brazing powder is in the form of a green compact with the required shape and weight. The brazing alloy must be conveniently designed to avoid the absorption of the brazing liquid in the adjacent pores, which would leave insufficient material in the joint.

Diffusion bonding is based on the interdiffusion between two parts in contact. Interdiffusion can be promoted by locating a bonding material that, upon heating, creates a small amount of liquid phase between the parts to be joined.

Adhesive Bonding

In some cases, PM parts can simply be joined by gluing, and the inherent porosity can be advantageously used to hold the adhesive in place providing high bond strengths. Care must be taken to avoid that the adhesive is drained by the porosity. Adhesive bonding allows joining thin and thick parts, thus complex shapes can be obtained. High temperature performing adhesives are developed to overcome poor resistance at elevated temperature in this type of joint. In any case there is virtually no thermal loading on the joining partners, with resulting good geometrical precision.

Surface Treatments

The aim of chemical modifications of the surface is usually to improve corrosion behavior or wear resistance. Steam treatment process is frequently performed on ferrous materials to improve their corrosion resistance and/or to seal the surface porosity, thus avoiding liquid or gas penetration. The part is exposed to overheated steam at temperatures in the range of 430–590°C for 1–4 h. As a consequence of the reaction with the steam a well adhering blue-gray oxide (magnetite Fe_3O_4) is formed on the surface of open porosity.

Due to the formation of the oxide, compressive stress is increased on the surface. As a general rule, apparent hardness is increased (improving abrasive and adhesive wear resistance) and tensile strength can be slightly increased or decreased depending on the thickness of the oxide formed. Steam treatment might be followed by plating, or by dipping in oil to enhance the blue-gray color and further increase corrosion resistance. Infiltration and impregnation processes are used to fill the open porosity present in a sintered part. Sealing the open porosity provides some increase in mechanical properties.

Heat and Thermochemical Treatments

In ferrous parts, properties such as hardness and strength can be improved by heat treatments. In PM materials, thermal conductivity is reduced as a consequence of the porosity and the parts may crack when quenched too rapidly. Whereas in conventional wrought steels, plain water or water and brine are used as quenching media, PM parts are normally quenched in oil or gas to avoid penetration of water, brine or salt baths in the pores that could cause severe corrosion. Besides, heating must typically be carried out in protective atmosphere.

Sinter hardening is a process that combines sintering with a gas quench treatment within one run and is therefore highly economical. At the transition between the high temperature furnace zone and the cooling zone of the furnace, a quench unit is installed in which the parts are cooled with cold N_2 gas, with typically linearized cooling rates of up to 3 K/s attained.

Induction hardening allows performing a heat treatment only in certain areas of the part surface. Before quenching, the part is heated for a few seconds in an induction coil that must be specially adapted to the shape of the component. The depth of the hardened case can be controlled by modifying the frequency of the alternating current in the coil (higher frequencies give thinner heated zones).

Case hardening treatments are relatively inexpensive and simple processes for increasing surface wear resistance and mechanical properties. The chemical composition of the surface is modified by the local diffusion of carbon (carburizing), nitrogen (nitriding), or both (carbonitriding /nitrocarburizing), and the part is subsequently quenched.

Carburizing is carried out at temperatures in the range of 820–920°C in a carburizing atmosphere (e.g., endogas, 40%N_2–40%H_2–20% CO_2). To obtain a better control of the carburized layer, especially with locally densified parts, low-pressure carburizing is employed.

Low-pressure carburizing is carried out in a vacuum furnace in which hydrocarbon gases (such as acetylene or propane) are pulsed in well-defined periods of time. The temperature, number, and length of the pulses, and the time allowed between pulses for carbon diffusion determine the case depth. The process is usually combined with high-pressure gas quenching. As quenching can be carried out in a protective atmosphere, this process is particularly suitable for materials with a high oxygen affinity. Low-pressure carburizing yields case depths that are almost independent of the porosity and therefore is well suited for surface-densified gears.

Nitriding consists of heating the part in a nitrogenous atmosphere (e.g., ammonia or nitrogen). In gas nitriding, ammonia dissociates into hydrogen and nascent (atomic) nitrogen catalyzed by the Fe surface. Low processing temperatures are used, within the ferrite range, and the parts need not be quenched. Thus, drastic volume changes can be avoided; however, there is the risk of through-nitriding. Plasma nitriding is increasingly used because it minimizes distortion and provides better control and highquality layers, with nitriding limited to the surface area.

Carbonitriding and nitrocarburizing introduce both carbon and nitrogen, giving emphasis to carburizing/nitriding, respectively. The processes differ mainly in the process temperature (lower for nitrocarburizing) and in the composition of the atmosphere. Carbonitriding makes use of the fact that nitrogen stabilizes austenite and increases steel hardenability, thus this treatment is commonly used in low alloy or unalloyed steels.