Compacting

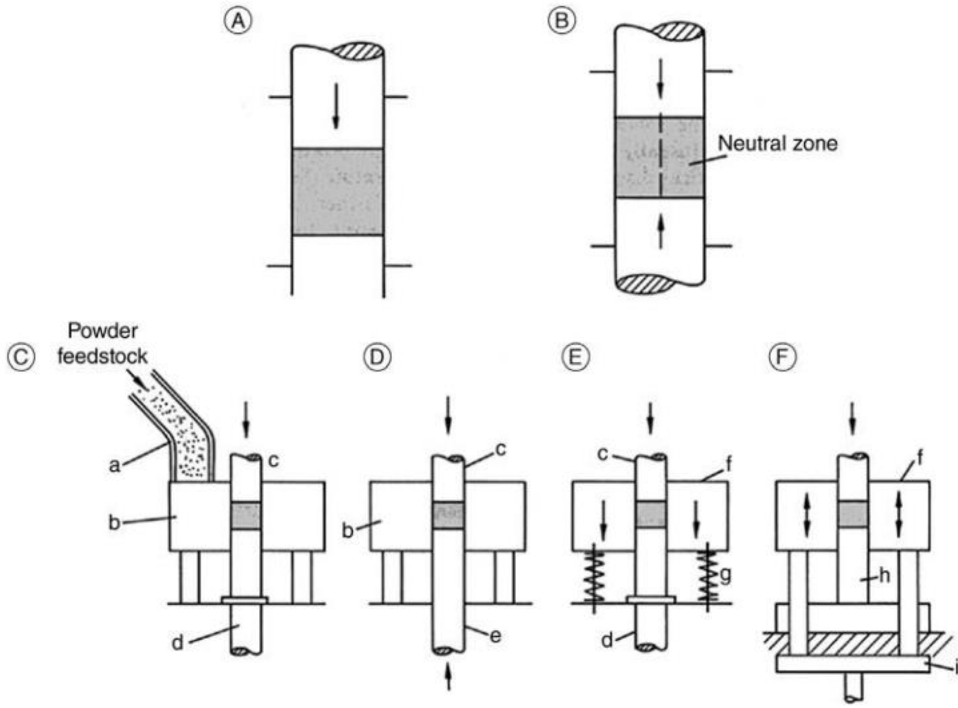
Powder metallurgy comprises several processes to consolidate powders into a desired shape with a certain density level. The most common method for shaping powder metallurgy parts is the uniaxial compaction in rigid dies (die compaction), a cost-effective technique very suitable for the production of large series. In compaction processes, densification and shaping occurs simultaneously, usually providing green compacts with locally varying density.

Densification gradients can be overcome to some extent by isostatic compaction (isostatic pressing) at ambient temperature (cold isostatic compaction, CIP) or at elevated temperatures (hot isostatic compaction, HIP). There is also the possibility to shape the powders at low pressures by mixing metallic powders with a polymer, and injecting such mix-named feedstock- into a mold (MIM).

In general, uniaxial die compaction and MIM technologies are employed for large series of small parts, and HIP more suitable for small or medium series.

Die Compaction

Uniaxial die compaction is the dominant technology for shaping metallic powders. Powder particles are consolidated by compaction in a rigid die by the application of pressure through upper and lower punches. The powder is poured in a rigid die cavity, and compaction is achieved by a vertical movement of the upper or upper and lower punches with a fixed or floating die. Afterwards, the green compact is ejected by pushing the lower punch upwards moving the die downwards.



Sufficient strength of the compact must be achieved during pressing to withstand ejection forces and handling prior to sintering. Compaction pressures are normally around 150–900 MPa (for ferrous parts usually 400–600 MPa). In some cases, pressures around 1000 MPa may be used to reach higher densities and higher levels of performance. Nevertheless, cold pressing cannot result in full density, and some porosity is always left as a consequence of work hardening.

In uniaxial die compaction, the punches move only in the vertical direction. As a consequence of the friction between powder and die walls, the axial stress (stress in the direction of compaction) is larger in the areas of contact with the moving punches than anywhere else. Thus, a density gradient occurs inevitably in the compact, with the highest density next to the moving punch face and the lowest near the fixed punch.

Double action pressing (from both sides) or the use of a floating die reduces the density gradient by moving the die to compensate the friction effect. In these cases, a neutral zone (zone of lower density) is generated in the center part of the compact. Friction effects during die compaction are reduced significantly by using lubricants either in powder form (mixed to the metal powder) or applied as a thin coating to the die walls ("die wall lubrication"). Although the amount of lubricant used in lubricated powder mixes is usually below 1 mass%, this is approximately 5% in volume, which means that the maximum density achievable after compaction would not be higher than 95% because the lubricants are virtually incompressible.

There are certain shape limitations for uniaxial pressing. Parts with re-entrant angles and with holes at an angle to the vertical direction are generally not produced by die pressing. A critical factor for attaining satisfactory densities and economical processes is the design of ingenious pressing tools.

The main advantages of die pressing are the precise dimensional control obtained by pressing in well-defined rigid die cavities, the batch to-batch consistency and the high rates of production achievable in fully automatized systems. A variant of the die compaction process is warm compaction. Usually, a polymer is used to glue the particles together. The polymer softens or melts with the application of moderate temperatures, reducing considerably the friction forces.

Hot pressing

In hot pressing processes, the powder is uniaxially pressed at high temperature, at least above the recrystallization temperature. As compaction and sintering take place simultaneously, the process is also known as pressure sintering. A combination of temperature-induced diffusion and stress at high temperatures causes a time dependent plastic deformation below the yield strength of the metal. The die is usually made of graphite, also to facilitate induction heating, and the process is often performed in vacuum to avoid contamination of the compact. Maximum temperatures and pressures are around 2200°C and 50 MPa, respectively.

Three different types of heating technologies are used: induction heating, indirect resistance heating and field-assisted sintering (FAST)/direct hot pressing. Owing to the rather low productivity and poor dimensional precision, the use of the process is limited. It is, however, widely applied in research and development to investigate innovative compositions. An important application is in the consolidation of diamond–metal cutting tools, for which the high added value compensates the extra costs.

Isostatic Pressing

Die pressing results in compacts with heterogeneous density because of the friction between powder particles and between powder and die walls. This can be avoided if the compacting pressure is evenly applied to the powder from all directions (isostatic pressure), which is achieved by placing the powder in a closed flexible mold and introducing the mold in a fluid (liquid or gas) that is afterwards pressurized.

The fluid transmits the pressure evenly in all directions through the flexible mold. As compared to die pressing, isostatic pressing requires lower pressures to achieve a certain density, and the density distribution obtained is more homogeneous. Most of the limitations on mass and dimensions are eliminated due to the homogeneous densification and the elimination of the ejection step. Besides, as no lubricants are needed, contamination is reduced, and it is possible to obtain high and uniform densities. On the other hand, geometrical precision is usually inferior to that of uniaxial die compaction.

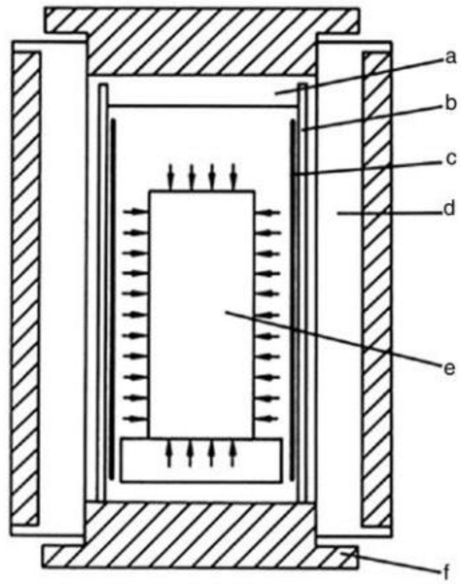
Cold Isostatic Pressing (CIP)

The powder is poured into a flexible mold commonly made of rubber that is then sealed. The filled mold is immersed in a liquid (usually water with some corrosion inhibitors), and the liquid is pumped to high pressure. Pressure is transmitted in all directions from the liquid to the powder through the flexible mold. The process is performed at room temperature, and the pressure applied can be as high as 1500 MPa, but the pressures used in practice are commonly around 200–600 MPa.

Many constraints of die pressing regarding shapes and dimensions can be overcome in CIP. CIP has become an essential process step for the production of certain PM materials: molybdenum and tungsten (e.g., in arc furnace melting electrodes), tungsten heavy alloys, hard metal parts (e.g., rollers and dies), high-speed steel semiproducts.

Hot Isostatic Pressing (HIP)

In HIP, a gas medium is used to apply isostatic pressure at high temperature to porous parts, or to a powder that is hermetically sealed in a container that deforms plastically at operation temperature (“canned”). An example of a HIP pressure vessel is shown in below Figure.



Pressure vessel for hot isostatic compaction a) Isolating lid; b) Isolating mantle; c) Furnace; d) Wire wound pressure vessel; e) Part to be pressed; f) Vessel lid.

The container in this case cannot be of polymeric material because of the high temperatures used in the process. Generally, metallic (low carbon steel, stainless steel) or even glass containers are used and are referred as “cans”. An inert gas is used to avoid reaction with the material. The gas is usually argon, but other gases such as helium or nitrogen can also be employed. Temperatures are material-dependent and can range from 480°C for aluminum to 1700°C for tungsten powders. This technology is very importantly applied to steel and nickel, with common temperatures between 1100°C and 1250°C. Pressures range from 20 to 300 MPa and are most commonly around 100 MPa. Spherical powders are normally used to achieve higher apparent densities. Avoiding contamination of the powders (e.g., oxidation) is critical for the properties of the HIP components because the contamination affects the formation of strong bonds between particles. The combination of pressure and temperature allows achieving virtually full density at lower pressure than required for CIP and a lower temperature than that required for sintering.

Injection Molding

Injection molding is a powder-shaping technology in which metallic powders are mixed with an organic binder to form a "feedstock" that is injected at moderate temperatures into a mold cavity with the required shape. Afterwards, the binder is removed through a debinding process, and the remaining powder structure is sintered. Ideally, very fine powders are used to obtain high and uniform powder loadings in the feedstock and to attain high sintering activity. The amount of binder is typically in the order of 40–50 vol%. The large specific surface area of fine powder particles activates the sintering mechanisms, thus achieving high density levels (usually above 95%). In spite of the large shrinkage, very good dimensional tolerances can be obtained if the powder load in the feedstock is uniform.

Critical aspects of this technology are: · The formulation of a suitable binder that wets the metallic powder particles and forms a uniform mass when mixed with the powder. Besides, it needs to be removable without damaging the powder structure. · The binder removal process (debinding). Different processes have been developed: heat treatments to decompose and evaporate the binder (thermal debinding), chemical decomposition in a gaseous acid environment at approximately 120°C (catalytic debinding), dissolution in a liquid (solvent debinding), etc.

The main advantages of the MIM technology are the possibility to economically produce complex parts from high performance materials in large numbers, the high-density levels and tight tolerances achievable, and the suitability for processing most materials (including special materials such as nickel superalloys, intermetallics, precious metals, refractory metals, and ceramic-fiber reinforced ceramic composites).