Powder Conditioning and Heat Treatment

Only in exceptional cases can metal or ceramic powders be introduced directly into a powder metallurgy shaping operation, because they originate from various different powder production processes. Usually, additional treatments are required to make a powder suitable for further processing.

These operations are often summarized by the term 'powder conditioning'. They depend on the nature of the powder, the size and shape of the final part, and the subsequent operations to be carried out.

PRINCIPAL ASPECTS AND ALLOYING TECHNIQUES

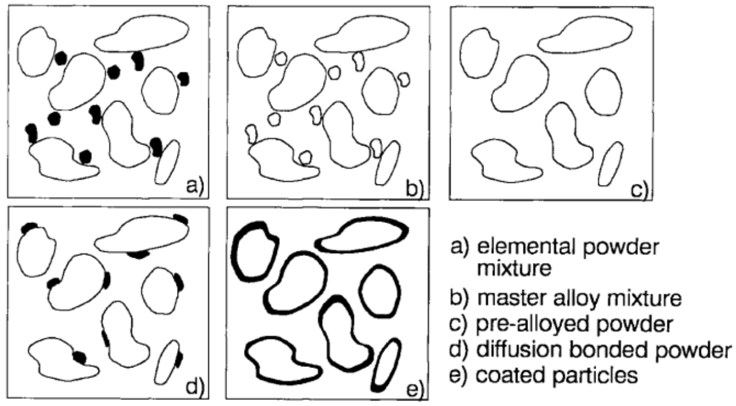
During their processing, metal powders have to be handled, conveyed and filled into dies or moulds, and usually cold or hot compacted. The powders must be suitable for such operations, their characteristics providing the basis for the desired properties of the green (compacted) and the finally sintered component.

The latter often requires additives, which are either temporarily present during some process steps and are removed in later processing, or are alloying additions, which remain in the material during the entire process. Therefore, the fundamental problems of powder conditioning are the introduction of these additives and the behaviour of the conditioned powder during its transport and compaction or forming behaviour.

Temporary additives have the function of lubrication, plasticizing and binding. Lubricants and plasticizers facilitate movement of the particles under externally applied forces by reducing interparticle and die wall friction forces.

Binders enhance the strength properties of the green compacts, which have to be sufficient to withstand the stresses arising during subsequent handling. These stresses can be quite high during ejection of a compact from an axial die press.

Alloying additions are primarily required in order to achieve the desired material properties in the final component. In powder metallurgy processing, they often have additional functions to aid sintering. They can also influence the handling and formability of the powders. Various alloying techniques can be applied to powder systems, the most important of which are shown in below Figure.



Powder mixtures of elemental or alloy constituents are the easiest way to provide the desired concentration of alloying elements. The advantages of powder mixtures are their versatility and relatively good compactability.

Master alloy powders can be used - not only elemental powders. Thus, for a particular composition of the final material, various types of starting powder mixtures can be chosen, which sometimes enable special problems related to the alloy system to be overcome. An example is the use of alloying elements of high oxygen affinity such as Cr, Ti, Al, etc., which have stable oxide films inhibit sintering. They can be used as master alloy powders, in which their activities are reduced by forming compounds or solid solutions with the base powder, or which form transient or even stable liquid phases during sintering. The disadvantages of powder mixtures are insufficient homogenization during sintering, in many cases, and the danger of segregation during powder handling.

In homogeneously alloyed (pre-alloyed) powders every individual particle consists of a homogeneous alloy of the constitutents. This is achieved mainly by melt atomization, but is also possible by mechanical alloying, coprecipitation or coreduction and by mechanical comminution of the alloy. Alloying elements exhibit their strengthening effects within each particle, reducing its ability to undergo plastic deformation at a given compaction pressure, and thus decreasing compactability.

The advantages of pre-alloyed powders are the homogeneity of the final microstructure, which is indispensable in many cases, and the elimination of segregation. When diffusional homogenization leads to problems, e.g. due to diffusion porosity, pre-alloyed powders can be a solution. Pre-alloyed powders are used, for example, in the production of stainless steels, high speed tool steels, low alloy steels for sinter forging, and in many non-ferrous alloys such as those of copper, titanium, and cobalt.

Diffusion bonded (diffusion stabilized) powder mixtures are intended to combine the advantages of powder mixtures and pre-alloyed powders. They are produced by a special heat treatment of a mixture, whereby the particles of the alloying constitutents are diffusionally bonded (sintered) to the base powder particles. Thus, the danger of powder segregation can be completely eliminated. The pre-formed particle contacts in the powder mixture reduce the time required for final homogenization by diffusion. Additionally, it becomes possible to introduce the alloying elements in the form of very fine particles or even in the form of a solution of the metal salt, which forms a film on the surface of the base powder and is reduced during heat treatment. In this way, a further reduction of homogenisation time becomes possible. Diffusion bonded powders are mainly used in the production of sintered steel structural parts.

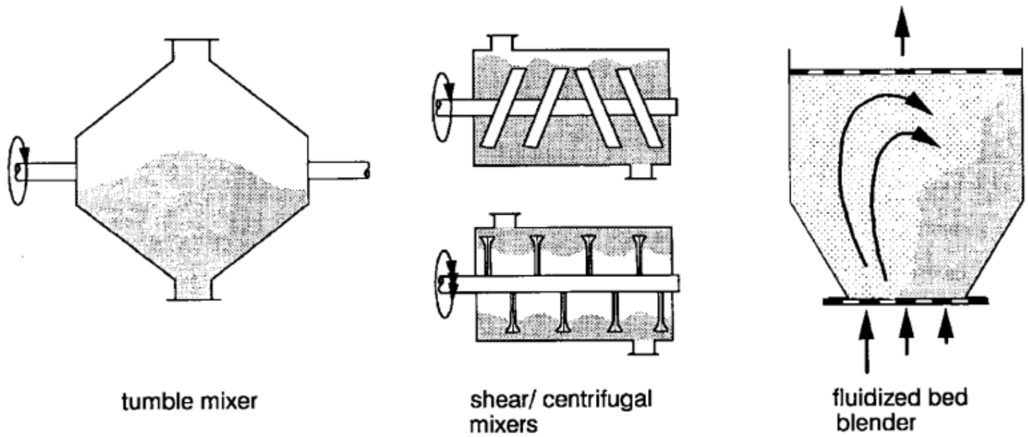
Particle coating with the alloying constituents is similar to diffusional alloying, but more effective for homogenization during sintering. It can be applied even in completely immiscible systems like metal-ceramics, where it provides the basis for ideal microstructures with a continuous skeleton of the metal phase at metal contents of only a few per cent. Coating of particles can be achieved via gas phase reactions or by precipitation from aqueous solutions.

MIXING, BLENDING, SEGREGATION

Blending is defined as the intermixing of powders of the same nominal composition. It is used to achieve a desired particle size distribution. Mixing implies intermingling powders of different chemical composition. The concentration change occurs by a convective or dispersive transport of the particles.

Many equipment are available for blending, mixing and dispersing of powders. Tumble mixers utilize gravitational forces for producing particle motion. Shear-agitated mixers use paddles or other moving components in a stationary container for shearing planes within the bulk powder. Centrifugal mixers have a similar design, but operate in the range of rotational speeds, in which particle motion is controlled mainly by centrifugal forces. In fluidized bed blenders, the powder takes the character of a liquid and the contribution of convection and diffusion to particle motion and mixing increases compared with the former methods.

The tendency to segregate in a powder or powder mixture depends on the differences in particle size and shape, and especially on particle density. Segregation increases with increasing distance travelled by a free flowing powder. Size and density differences can balance out if the finer particles are more dense than the coarse particles. With coarse particles of higher density, fine particles floating on top of the powder mass increase the problem.



AGGLOMERATION

Agglomeration (granulation) allows enlargement of very fine powders to prevent uncontrolled agglomeration and to make the powders free flowing and safe.

The bonding mechanisms for agglomeration (controlled as well as uncontrolled) can be:

- Solid bridges formed by crystallized salts or sintering contacts.
- Immobile liquid bridges formed by viscous binders, adhesives and adsorption layers.
- Mobile liquid bridges (capillary forces).
- Van der Waals and electrostatic forces.
- Mechanical interlocking of powders.

The adhesion forces decrease in the sequence given above and increase with decreasing size of the primary particles. The methods of granulation are layering agglomeration, press agglomeration and spray drying.

Agglomerate strength is an important parameter, as well as agglomerate shape, size distribution and porosity, which control flowability and tap density.

The granules must withstand handling and transportation, but have to be weak enough to be completely deformed during shaping. Otherwise, inhomogeneity's in the green compact cause agglomerate-related defects by differential sintering.

HEAT TREATMENT

Heat treatment of powders is performed for various purposes: chemical reduction, decarburization, annealing, degassing, size enlargement. Raw powders resulting from various production processes often exhibit a reduced compressibility, due to rapid cooling during atomization, work hardening from mechanical comminution, residual interstitial impurities such as oxygen, carbon or nitrogen, and to oxide layers formed during production or storage.

Annealing is therefore common for many metal powders, when a good subsequent compressibility is required. During annealing, residual stresses are relieved by recovery and recrystallization. Alloying elements in supersaturation can be precipitated in the form of relatively coarse particles, thus reducing the work hardening tendency during powder compaction. Apart from these microstructural effects, annealing can reduce the impurity levels of nitrogen, carbon and oxygen.

In many cases, decarburization is accomplished simultaneously with deoxidization by reaction of carbon and oxygen in the powder to form carbon monoxide. The additional use of reducing atmospheres such as hydrogen or dissociated ammonia further lowers the oxygen content and prevents re-oxidation.

Size enlargement by heat treatment results from sintering of powder particles. The heat treatments are therefore performed at temperatures as low as possible, to minimize sintering and to allow for a subsequent mild comminution without significant strain hardening.