Powder Metallurgy – Powder Processes (Solid State Reduction, Electrolysis, Atomization, Mechanical Comminution and Chemical Processes)

Background

There are many ways in which metals may be produced in powder form, comminution of solid metal - precipitation from solution of a salt; - thermal decomposition of a chemical compound; reduction of a compound, usually the oxide, in the solid state, - electrodeposition, and the atomization of molten metal. Of these the last three account for the bulk of the powders used.

Solid State Reduction

This has been for long the most widely used method for the production of iron powder. Selected ore is crushed, mixed with carbon, and passed through a continuous furnace where reaction takes place leaving a cake of sponge iron which is then further treated by crushing, separation of non-metallic material, and sieving to produce powder.

Since no refining operation is involved, the purity of the powder is dependent on that of the raw materials. The irregular sponge-like particles are soft, and readily compressible, and give compacts of good green strength. Refractory metals are normally made by hydrogen reduction of oxides, and the same process can be used for copper.

Electrolysis

By choosing suitable conditions - composition and strength of the electrolyte, temperature, current density, etc., many metals can be deposited in a spongy or powdery state. Extensive further processing - washing, drying, reducing, annealing and crushing may be required.

Copper is the main metal to be produced in this way but chromium and manganese powders are also produced, by electrolysis. In these cases, however, a dense and normally brittle deposit is formed and requires to be crushed to powder. Electrolytic iron was at one time produced on a substantial scale but it has been largely superseded by powders made by less costly processes. Very high purity and high density are two distinguishing features.

Atomization

In this process molten metal is broken up into small droplets and rapidly frozen before the drops come into contact with each other or with a solid surface. The principal method is to disintegrate a thin stream of molten metal by subjecting it to the impact of high energy jets of gas or liquid. Air, nitrogen and argon are commonly used gases, and water is the liquid most widely used. A commercial scale plant was set up in Japan to produce iron powder using paraffin as the atomizing liquid the object being to keep the surface oxygen content as low as possible. The process was technically successful, but the advantages did not justify, in commercial terms, the extra cost involved. However, interest has not entirely evaporated and work is going on elsewhere.

Control of Powder Properties

By varying the several parameters: design and configurations of the jets, pressure and volume of the atomizing fluid, thickness of the stream of metal etc. - it is possible to control the particle size distribution over a wide range.

The particle shape is determined largely by the rate of solidification and varies from spherical, if a low heat capacity gas is employed, to highly irregular if water is used.

Process Suitability

In principle the technique is applicable to all metals that can be melted, and is commercially used for the production of iron, copper, including tool steels, alloy steels, brass, bronze and the low-melting-point metals, such as aluminum, tin, lead, zinc, cadmium.

The readily oxidisable metals, for example chromium-bearing alloys, are being atomized on an increasing scale by means of inert gas, especially argon.

Centrifugal Atomization Processes
In addition, there are several other processes that are finding increasing application, an important one being centrifugal atomization in which droplets of molten metal are discharged from a rotating source. There are basically two types of centrifugal atomization processes:- in one a cup of molten metal is rotated on a vertical axis at a speed sufficient to throw off droplets of molten metal, or a stream of metal is allowed to fall on a rotating disc or cone; in the other a bar of the metal is rotated at high speed and the free end is progressively melted e.g. by an electron beam or plasma arc. This latter process is called the Rotating Electrode Process (REP), and the bar may be rotated either on a horizontal or on a vertical axis. A special advantage of these processes is that they can be carried out in a sealed vessel in a controlled atmosphere - even vacuum - and thus produce 'clean' powders of highly reactive metals. With the REP process the avoidance of contact with refractory is a potent means of reducing the number of non-metallic inclusions in the powder, and in components manufactured from the powder.

Advantages of Using Atomized Powders
Atomization is particularly useful for the production of alloys in powder form, since the constituents metals are fully alloyed in the molten state. Thus each powder particle has the same chemical composition. Additionally the process is used to produce compositions such as copper-lead, in which the lead, though soluble in the liquid state, comes out of solution on solidification. If a casting of such an alloy is made, serious segregation of the lead results, but if the liquid is atomized, the end product is copper powder containing a very fine and uniform distribution of lead inclusions within each powder particle.

Mechanical Comminution
Brittle materials such as inter-metallic compounds, ferro-alloys - ferrochromium, ferrosilicon, etc. are pulverized mechanically in ball mills, and a process known as the Cold stream Process is finding increasing application for the production of very fine powders such as are required for injection molding. In this process, granular material, which may be coarsely atomized powder, is fed in a stream of gas under pressure through a Venturi and is cooled and thereby embrittled by the adiabatic expansion of the gas before impinging on a target on which the granules shatter.

Chemical Processes
Thermal decomposition of a chemical compound is used in some cases, a notable one being nickel carbonyl. This Carbonyl Process was originally developed as a means of refining nickel, crude metal being caused selectively to react with carbon monoxide under pressure to form the carbonyl which is gaseous at the reaction temperature and which decomposes on raising the temperature and lowering the pressure. The same process is used for iron, and carbonyl iron powder finds small scale application where its very high purity is useful. Recently, demand for very fine powders for the injection molding process has given a considerable impetus to the carbonyl process.

Typically the particle size of carbonyl iron powder is 1 - 5µm, but, as in the case of nickel, it can be tailored to suit particular requirements. Another case of thermal decomposition is platinum powder of which is made from sponge produced by heating salt - platinum ammonium chloride. In the Sherritt-Gordon process, nickel powder is made by hydrogen reduction of a solution of a nickel salt under pressure. Chemical precipitation of metal from a solution of a soluble salt is used in other cases - e.g. silver, powder of which is produced by adding a reducing agent to a solution of silver nitrate. This is, of course, the same basic process as is used to produce black and white photographs.