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Powder Metallurgy and Superalloys

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The need for powder metallurgy (P/M) for the production of some high-integrity superalloy components such as turbine discs became apparent in the 1970's due to the development of alloys such as Rene 95, Astroloy and MERL 76 - with strength levels higher than earlier alloys such IN718 and Waspaloy - which were found to be unamenable to processing into the cast & wrought form. It is an expensive processing route but for these heavily alloyed grades, the levels of segregation arising during melt processing and the significant flow stress at temperature cause cracking during thermal mechanical working. Powder metallurgy is therefore the only viable way of producing the alloys with acceptable chemical homogeneity. Powder metallurgy is used only for alloys which will be used in fatigue-critical applications - for example turbine discs which are spinning very fast in the engine. It is important to reduce the possibility that ceramic inclusions are present to minimal levels - hence care is taken to sieve the powder before consolidation - and great care is taken with non-destructive testing (NDT) of the billet.

The first step in the production of P/M product is inert gas atomization from master melts produced by VIM processing; clearly the cleanliness of these is important since any contamination will be inherited by the powder. Molten metal is poured into a tundish which contains a carefully-designed ceramic nozzle surrounded by one or more inert gas jets; usually argon is preferred. A continuous stream of gas at high pressure is delivered to the stream of molten metal arriving at the nozzle, the action of which causes its disintegration into spherical particles of diameter 30 to 300 microns. The atomization chamber is designed to be long enough to allow solidification of the particles before they reach the outlet of the chamber. Cooling rates are typically in excess of 10^2C/s, being greater for finer particles. A number of variants of the process have been developed with varying degrees of success, e.g. soluble-gas atomization in which atomization is induced by inserting a ceramic tube into the melt, the open end of which is connected to a vacuum chamber; the dissolution of a soluble gas (usually hydrogen) over the molten metal aids the atomization process.

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Consolidation of the powder usually involves processing by extrusion. The fundamental challenge is to obtain good metallurgical bonding across the prior particle boundaries; to ensure bonding across oxide films which are inevitably present, the particles must be brought into contact at temperature and subjected to pressure and mechanical deformation. The powder is first packed into a steel container which has been cleaned carefully. This is evacuated to encourage outgassing, sealed and then compacted either by hot isostatic pressing (HIPing) or occasionally using closed die forging. A very high tonnage press with specialized tooling is then used to extrude the material to the high reduction ratios necessary for fine-grained billet; this step has been shown to disperse any non-metallic inclusions still present thus improving the defect tolerance of the material. Isothermal forging - in which the billet is deformed at the same temperature as the dies, both being held in a well-instrumented furnace - is the preferred route by which P/M superalloy product is shaped after powder consolidation. Superplastic behaviour is observed on account of the small grain size and because the deformation rates are relatively low (in the range 0.002 to 0.03 s^{-1}) and stresses high (50 to 100 MPa at $1200^{o}C$).

Several advantages then arise. Recrystallization and grain growth can be controlled; for example the considerable variations in microstructure arising during cold-die forging, due to excessive grain growth and die-chill, are avoided. Second, significant savings in material can be made since forgings can be produced of a geometry very close to the 'sonic shape' required by ultrasonic testing.

The benefits of powder processing over ingot metallurgy which produces cast & wrought product are now well established. For example, the low-cycle fatigue (LCF) properties of Rene 95 at $650^{o}C$ have been compared in the HIP, HIP + isothermally forged, extruded + isothermally forged and cast & wrought conditions. The best properties are generally displayed by extruded + forged material and the worst by the conventional cast & wrought processing, with the behaviour of the HIP material between the two; the differences were most pronounced at low total strain ranges.

For further information, try 'Powder Metallurgy of Superalloys' by G H Gessinger, Butterworths, London (1984).