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Thermal-Mechanical Working of Superalloys

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The superalloy ingots produced by the remelting processes are unsuitable for mechanical applications: they must undergo thermal-mechanical working in order to break down the as-cast structure and to reduce the grain size to acceptable levels, i.e. from a few 10's of millimeters to a few 10's of microns. This is known as ingot conversion. During this process, the diameter of the cylindrical ingot is reduced in size by a factor of approximately two, so that its length increases fourfold. The conversion is generally achieved in a series of stages, or heats. The ingot is placed in a furnace and allowed to reach an appropriate temperature for forging. Upon removal, it is manipulated between two horizontal dies which are driven hydraulically. These squeeze (or bite) the material causing it to deform both in and out of the plane of the dies. Typically the ingot is deformed twenty to thirty times at various points along its length, with the pattern repeated with the ingot rotated through 90^{o}, 45^{o} and one final turn of 90^{o}. At the end of this procedure, the ingot is returned to the furnace now with a characteristic octagonal cross-section. The deformation applied to the ingot causes substantial recrystallization to a finer grain structure. After reheating the whole process is repeated. To reduce a 60 cm diameter ingot down to the required 30 cm or so as many as seven heats may be required. In the later heats a temperature below the relevant solvus is employed to ensure that grain growth following deformation is inhibited.

After the conversion process, forging operations are often employed. The principle objective of the forge-master is to turn the forging stock into a shape as close as possible to the final component shape. A further concern at this stage is not to promote excessive grain growth. The process often comprises (i) upsetting by open-die forging, to produce an axisymmetric ingot of reduced thickness and greater cross-sectional area(ii) blocking by closed-die forging, to place thicker and thinner sections in the appropriate place, and (iii) finishing, again by closed-die forging, to produce the desired disc shape. In these three operations the temperature is typically kept very close to the appropriate solvus of the alloy being forged, thereby ensuring that any recrystallization that does occur results in a finer grain structure than that achieved in the conversion stage. At the end of processing the forged discs are either quenched into a bath of oil or water, or then sent for machining. Following this a heat treatment is then applied to encourage the appropriate strengthening phases to precipitate in sufficient quantities to give the necessary high temperature properties. A quenching operation, typically into oil, is employed following the heat treatment to optimize the precipitation structure for the best properties.

It is possible to design heat treatment processes such that a gradient in grain size is produced. So-called 'dual heat-treatment processes' are now available which make use of heat treatment furnaces in which a gradient in temperature exists. These show promise for the heat-treatment of turbine discs which require a fine grain size at the bore (to promote static strength) and a larger grain size at the rim (to promote creep resistance).