



Secondary Melting Processes for Superalloys

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For many applications, a secondary melting process needs to be applied to increase the chemical homogeneity of the superalloy material and to reduce the level of inclusions. After VIM processing, it would be normal for the cast ingot to possess a significant solidification pipe and extensive segregation. Removing the pipe reduces productivity and the segregation can lead to cracking and fissuring during subsequent thermal-mechanical working. Furthermore, VIM can leave non-metallic (ceramic) inclusions present in the material which can be harmful for fatigue properties. Application of the secondary melting practices can reduce the problems associated with these effects. Vacuum arc remelting (VAR) or electroslag remelting (ESR) are used for this purpose, sometimes in combination with each other.

For the VAR process, the electrode is a casting which will have been produced either by the VIM process or else VIM followed by ESR. During processing, the energy necessary for melting is provided by a DC arc which is struck between the electrode (the cathode) and the molten pool at the top of the solidifying ingot (the anode). The current used is typically about 10,000 A and the applied voltage is in the range 20 to 50 V. The scale of the process is impressive; finished VAR ingots are several meters in length and weigh up to 20 tons. The heat and mass transfer processes occurring during melting have a profound influence on the quality of the VAR ingot which is produced. During processing, a thin molten film is formed on the electrode which flows under gravity to form hanging protuberances. Metal transfer occurs as droplets form and short circuit the arc momentarily as they fall from the molten film. To maintain a constant arc gap, a ram arrangement is used to drive the electrode into the VAR crucible as melting proceeds. Considerable emphasis is placed on control strategies and process monitoring. For example, dynamic load cell weighing systems have been developed to enable computerized control of the melt rate which is typically in the range 2 to 6 kg/min. As the electrode is melted, a liquid pool is produced which resides on the material which has already solidified; the size and shape of the molten zone remains approximately constant during processing apart from brief transients associated with start-up and finishing, i.e. a steady-state is achieved. For a given electrode diameter, the depth of the pool increases

with the power input, i.e. the product of the current and the applied voltage; modeling work indicates that the efficiency of this process is in the range 50-75%, and that the current enters the ingot at the meniscus and at the stool at the bottom of the copper crucible on which the solidified material sits. The molten pool is subjected to complex flow patterns which are due to a combination of the buoyancy forces, electromagnetic stirring and the Marangoni effect arising from the temperature-dependence of the surface tension. The velocity of the molten material on the surface can reach 0.01 m/s; the flow pattern is radial consistent with the symmetry of the situation and outward from the centre of the pool.

The ESR process has similarities to the VAR process in that a consumable electrode is remelted, but here a molten slag pool sits between the electrode and the solidifying ingot - hence processing can be carried out in air. A major significant advantage over VAR processing then arises: molten droplets from the electrode pass through the slag, giving them a chance to react with it such that impurities such as oxides and sulphur are removed. However, unlike the VAR process, an alternating current (AC) is applied; the electrode immersion plus the slag cap must be regarded as the major resistance in the circuit; consequently the majority of the heat generation occurs in this region. Changing the weight of slag in the system alters the resistance of the circuit and thus the amperage and voltage required to maintain a given power input/melt rate. One disadvantage of the molten slag is that it acts as a heat reservoir at the top of the ingot/pool and this makes the fusion profile obtained from the ESR process somewhat different from that obtained from VAR: generally with steeper sides, larger mushy zones and decreased cooling rates for comparable power input. These factors promote levels of chemical heterogeneity which are greater in ESR than in VAR processing; hence where triple melting is employed, ESR will always precede VAR.

Secondary remelting processes which produce material which will have undergone VIM/VAR processing or even triple-melt VIM/ESR/VAR processing are necessary only for applications which require the very best fatigue properties - such that the absence of non-metallic inclusions can be assured. For many applications this is not necessary