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The effect of minor elements on the hot-workability of nickel-based superalloys*

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We have investigated the effect of five minor elements, S, Ca, Mg, Y and Zr, on the hot-workability of three solid solution strengthened nickel-based superalloys, Inconel 600, Hastelloy-X and a Ni–Cr–W type prospective alloy (NSC-1) for heat exchanger pipes in high temperature gas reactors.

The hot-workability was evaluated from the reduction in area of hot tensile specimens by using a Gleeble testing machine. Round bar specimens were prepared from the near-surface portion of the alloy ingots, melted and cast by vacuum induction melting, vacuum arc remelting or electro-slag remelting.

When the S content increases, a ductility dip appears between 1050 and 1150 °C on each alloy; the greater the S content, the deeper the dip. At the same time, the fracture appearance becomes more and more intergranular.

By adding a small amount of Ca, Mg, Y or Zr, the hot-workability of the alloys changed drastically, and it was found that a controlled addition of these minor elements gave a superior hot ductility.

With ΔS defined as follows

$$\Delta S = S - 0.8Ca - 0.3Mg - 0.5Y - 0.1Zr,$$

where concentrations are percentages by mass, the hot ductility of these alloys changed systematically as follows, irrespective of the three refining processes: the ductility dip diminished and excellent ductility was achieved with $0.003 > \Delta S > -0.004$. The hot ductility decreased gradually with $\Delta S < -0.004$, and became extremely poor when ΔS was larger than 0.003.

Investigation of fractured surfaces with A.e.s. and e.p.m.a. showed that, when ΔS was greater than zero, atomically segregated sulphur was present on the intergranular fractured surfaces and when ΔS was less than zero, atomic sulphur was not detected but metallic sulphide compounds were observed, both in the grain interior and on the grain boundaries.

In conclusion, the hot-workability of nickel-based superalloys can be estimated from ΔS, and in order to improve the hot-workability of these alloys, minor elements should be added such that ΔS becomes nearly zero.

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