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Benefits of minor additions of yttrium to the oxidation and creep behaviour of a nickel-based composite*

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Metal matrix composite materials produced by the directional solidification of eutectic alloys continue to be advocated as future turbine blade materials. However, although considerable improvements in creep performance have been obtained from some eutectic alloys, relative to current superalloys, their oxidation and corrosion resistances have failed to meet the requirements for engine applications. One such alloy, designated γ-γ'-Cr_3C_2, consisting of a nickel matrix reinforced by cubic γ' precipitate particles and aligned Cr_3C_2 fibres has been shown previously to have superior creep properties to current advanced superalloys at high temperatures (over 950 °C). However, the alloy is subject to severe surface degradation in cyclic oxidation conditions by the spallation of chromium-rich oxide scales and by internal oxidation.

It is well known that small additions of rare earths and other reactive elements can lead to improvements in the oxidation resistance of nickel-, iron- and cobalt-based alloys although the effect is not always or uniformly obtained in all alloys. There also remains considerable uncertainty over the mechanism by which the additives modify the oxidation behaviour. Additions of 0.1, 0.2 and 0.5 % (by mass) of yttrium metal to the basic γ-γ'-Cr_3C_2 composition lead to large changes in both the cyclic oxidation resistance and to the nature of the oxidation products. The doped alloys all form stable protective scales of Al_2O_3 during cyclic oxidation to temperature maxima of 1373 and 1493 K; although Al_2O_3 also initially forms on the undoped alloy this spalls, leading to the subsequent formation of chromium and nickel oxides. The reduced specific mass gains of the doped alloys, which are indistinguishable, relative to the basic γ-γ'-Cr_3C_2 (5–10 and 100 g^{-2} respectively after 300 h at 1373 K) can be attributed to the stabilization of this initial oxide.

Auger electron analysis of surfaces of the basic and doped alloys at an early stage of development of the oxide before spallation occurs shows that (i) the Al_2O_3 in the doped alloy grows at about one-third of the rate of that in the undoped material at 1273 K and (ii) the yttrium concentration is enhanced in the region of the oxide–metal interface. The yttrium is thought to segregate to the metal–oxide interface leading to improved adhesion and to the oxide grain boundaries reducing grain boundary diffusivities and inhibiting oxide grain growth. The combination of these effects reduces the rate of growth of the oxide and favours the accommodation of oxide growth stresses through oxide plasticity in the doped material rather than by scale spallation as in the undoped alloy.

The creep rupture lives at 1273 K of the doped alloys are up to three times longer than for the basic γ-γ'-Cr_3C_2. Moreover, the level of improvement increases with increased yttrium content up to 0.5% yttrium (by mass). The major benefit in creep behaviour is attributed to an improved morphological stability of the Cr_3C_2 fibres, which are degraded by the formation of Cr_2O_3 on the basic alloy, rather than to an intrinsic strengthening of the alloy by the dopant.

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