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Effect of V and Re additions on the creep properties of γ/γ' - α eutectic composites

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ABSTRACT

Alloying a ternary monovariant Ni-Al-Mo eutectic alloy with vanadium and rhenium has been investigated as a means to increase the creep strength at elevated temperature. The creep properties of directionally solidified eutectic γ/γ' - α alloys with nominal composition Ni-31Mo-6Al, Ni-32Mo-6Al-1.4V and Ni-30Mo-6Al-1.6V-1.2Re (wt.%) have been determined using strain rate change test. The tests were conducted under vacuum at temperatures between 1223 and 1323 K. Comparison of the stress-strain rate behaviour to that for directionally solidified Ni-Al-Mo eutectic alloy has revealed that the additions of vanadium and rhenium increase the steady-state stress at given creep rate and temperature by 11 to 20%. This improvement is higher at higher temperatures and lower creep rates. The steady-state stress has been found to depend strongly on creep rate and temperature. The measured power law exponents varied between 6.7 and 7.9 over the studied temperature range. The activation energies for creep were calculated to range between 471 and 517 kJmol⁻¹. The ductility of these eutectic composites was high, typically ranging from 40 to 60% reduction of area and from 15 to 38% elongation.

1. INTRODUCTION

Directionally solidified eutectic γ/γ' - α alloys are of interest as materials for high temperature use because of their excellent tensile ductility and high strength in all directions at room temperature as well as at high temperature. Much effort in previous investigations was given to an improvement of the creep strength of the fundamental ternary Ni-Mo-Al alloys. Apart from the generally accepted method of decreasing the average interfibre spacing using advanced growth techniques, Whittenberger et al [1] used for this purpose a thermomechanical processing. Henry et al. [2] made attempts to increase the rupture strength and improve the oxidation properties through alloying with multi-element additions. However, in spite of the above study, only little attention was given to the influence of alloying additions on the steady-state creep behaviour of these composites. Therefore other investigations of steady-state creep of alloyed eutectic γ/γ' - α composites are of interest.

The aim of this work is to study the influence of vanadium and rhenium additions on the high temperature steady-state creep behaviour of eutectic γ/γ' - α composites using strain rate change test.

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2. EXPERIMENTAL PROCEDURE

Master ingots of eutectic alloys with nominal composition Ni-31Mo-6Al, Ni-32Mo-6Al-1.4V and Ni-30Mo-6Al-1.6V-1.2Re (wt.%) were prepared in a vacuum induction furnace by melting high-purity metals under argon atmosphere and casting in copper chill mould. Directional solidification was accomplished in a Bridgman-type resistance furnace under dynamic argon atmosphere. The eutectic composites with fully aligned fibre structure were prepared using a constant growth rate of $2.78 \times 10^{-6} \text{ ms}^{-1}$ and a constant temperature gradient of $15 \times 10^3 \text{ K m}^{-1}$ in the liquid at the solid-liquid interface. Cylindrical creep specimens with gauge region of $35 \times 10^{-3} \text{ m}$ length and $3.8 \times 10^{-3} \text{ m}$ diameter were machined only from aligned sections of the composites.

In order to determine steady-state creep properties, strain rate change tests were undertaken on an universal Instron machine with strain rates ranging from 4.7×10^{-7} to $2.1 \times 10^{-5} \text{ s}^{-1}$. In this procedure, the tensile creep specimens were deformed at constant cross-head speeds into apparent steady-state conditions represented by a constant stress and a constant creep rate. Then the cross-head speed was abruptly changed and a new steady-state was reached. All tests were run until this apparent steady-state was reached or until the specimen failed. The creep tests were conducted at temperatures between 1223 and 1323 K in a chamber that was evacuated to a pressure of 1.5 Pa.

The microstructure of the eutectic composites was studied before creep testing and after testing. Fractography was performed with a scanning electron microscope (SEM) operated at 20 kV on fracture surfaces and on samples grounded and polished along their longitudinal axis.

3. EXPERIMENTAL RESULTS

SEM revealed that alloying of the fundamental Ni-Mo-Al alloy with V and Re had no effect on the morphology of as-grown eutectic composites. Fig. 1a shows that α -fibres retained their generally square or rectangular cross-sections. The γ' -phase surrounds the fibres and residual γ -phase appears between γ' -phase regions. Despite the oxide overlayer which had formed on the fracture surfaces in the furnace after creep rupture, analysis performed with SEM exhibited a fracture topography with dimples and secondary cracks. The microvoids that were situated within the larger dimples have usually been initiated at fibre-matrix interfaces (Fig. 1b).

True tensile strains, stresses and strain rates were calculated from recorded load time charts. Steady-state stresses σ and creep rates $\dot{\epsilon}$ were taken as the average values for the apparent steady-state conditions. Steady-state stress was found to depend strongly on creep rate according to the power law

$$\dot{\epsilon} = A\sigma^n, \quad (1)$$

where A is the constant and n is the stress exponent. The stress-creep rate-temperature data were also fitted to the Bailey-Norton power law expression

$$\dot{\epsilon} = B\sigma^n \exp(-Q/RT), \quad (2)$$

where B is the constant, Q is the activation energy for creep, R is the universal gas constant and T is the

Fig. 1. SEM micrographs of eutectic γ/γ' - α composite (Ni-30Mo-6Al-1.6V-1.2Re). (a) Transverse section of as-grown composite. (b) Fracture surface at 1273 K.

absolute temperature. Fits were accomplished by linear regression techniques and the results of these calculations for A, B, n and Q as well as the standard deviations δ_n and δ_Q for the stress exponent and activation energy for creep, respectively, and the regression coefficients r are given in Table I. The values for the activation energies for creep were higher than those for self-diffusion in the matrix (285 kJmol⁻¹) [3] or in the reinforcing phase (460 kJmol⁻¹) [4]. The ductility of these eutectic composites was high, typically ranging from 40 to 60% reduction of area and from 15 to 38% elongation.

The influence of the additions of V and Re on the steady-state stress at given creep rate and

Table I. Regression analysis of creep data for eutectic γ/γ' - α composites.

Composition (wt.%)	Temperature (K)	A	B	n	δ_n	Q (kJmol ⁻¹)	δ_Q (kJmol ⁻¹)	r
<i>(a) Power law (1)</i>								
Ni-31Mo-6Al	1223	5.65x10 ⁻²⁴		7.00	0.23			0.997
	1273	1.21x10 ⁻²²		6.77	0.15			0.997
	1323	9.22x10 ⁻²²		6.73	0.09			0.999
Ni-32Mo-6Al-1.4V	1223	2.32x10 ⁻²⁶		7.89	0.12			0.999
	1273	4.29x10 ⁻²⁵		7.67	0.11			0.999
	1323	8.06x10 ⁻²⁵		7.89	0.09			0.999
Ni-30Mo-6Al-1.6V-1.2Re	1223	2.58x10 ⁻²⁶		7.75	0.13			0.999
	1273	1.54x10 ⁻²⁴		7.35	0.16			0.999
	1298	7.08x10 ⁻²⁴		7.29	0.19			0.998
	1323	6.79x10 ⁻²⁴		7.44	0.33			0.993
<i>(b) Temperature compensated power law (2)</i>								
Ni-31Mo-6Al	1223 to 1323	9.10x10 ⁻³	6.83	0.16		487.1	10.3	0.996
Ni-32Mo-6Al-1.4V	1223 to 1323	4.97x10 ⁻⁶	7.80	0.12		471.4	8.3	0.999
Ni-30Mo-6Al-1.6V-1.2Re	1223 to 1323	1.26x10 ⁻³	7.49	0.17		516.7	11.3	0.989

temperature was calculated according to the relationship

$$\Delta\sigma = \frac{\sigma - \sigma_0}{\sigma_0} 100, \quad (3)$$

where $\Delta\sigma$ is the relative change of the steady-state stress, σ is the steady-state stress of the alloyed eutectic composite and σ_0 is the steady-state stress of the fundamental ternary eutectic composite (Ni-31Mo-6Al). The relative change of the steady-state stress $\Delta\sigma$ as a function of the creep rate and temperature with the interval of confidence is shown in Fig. 2.

Fig. 2. Dependence of the relative change of the steady-state stress $\Delta\sigma$ on the creep rate. (a) Eutectic composite Ni-32Mo-6Al-1.4V. (b) Eutectic composite Ni-30Mo-6Al-1.6V-1.2Re.

4. CONCLUSIONS

The results of the present work show that the steady-state creep stress at given creep rate and temperature of directionally solidified γ/γ' - α alloy with additions of V and Re exceeds that of the alloy with addition of V or the fundamental ternary eutectic composite. This improvement is higher at higher temperatures and lower creep rates. Discussion of these results in terms of creep mechanisms will be presented in [5].

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