PARTITIONING BEHAVIOR OF ALLOYING ELEMENTS IN PWA 1484

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In order to achieve a desired set of properties, such as high creep strength and oxidation resistance, a variety of alloying elements are typically added to commercial nickel-based superalloys. Since single crystal superalloys do not require the inclusion of alloying elements to improve the grain boundary properties, there is significant scope in optimizing the composition and heat treatment of these alloys. The effectiveness of these alloying elements depends on their level and location in the different phases present in the microstructure. Therefore, it is desirable to be able to accurately measure and theoretically predict their distribution within the microstructure.

The partitioning behavior of the alloying elements in nickel-based superalloy PWA 1484 has been determined with the atom probe field ion microscope. These results have been compared with predictions generated from the "Alloy Design Program". This computer program is based on regression analysis.[1] Of particular interest were the characterization of the partitioning behavior of hafnium between the γ' L_{12}-ordered precipitates and the γ disordered face centered cubic matrix and the clustering behavior of the rhenium atoms in the γ matrix.

The nominal composition of the single crystal PWA 1484 material used in this investigation was Ni-10.5 at. % Co, 6% Cr, 1.3% Mo, 2.0% W, 12.9% Al, 3.0% Ta, 0.04% Hf and 1.0% Re. All compositions quoted are given in atomic percent. The superalloy was examined after a standard heat treatment of 4 h at 1304°C, 4 h at 1079°C and 24 h at 704°C. Specimen temperatures of between 50 and 60K and a pulse fraction of 20% were used for the compositional determinations in the ORNL energy-compensated atom probe field ion microscope.[2]

The average compositions of the γ' precipitates and the γ matrix were experimentally determined in the atom probe and are shown in Table 1. A series of estimates of the compositions of the γ and γ' phases was also determined with the use of the model specifically for the nominal composition of this PWA 1484 alloy. The results for each of the 3 stages of the heat treatment for the γ and γ' phases are summarized in Table 2. It should be noted that the volume fraction of the γ' phase increases with decreasing temperature. In all cases, the expected partitioning of the alloying elements between the γ and γ' phases was found. In particular, the experimental atom probe and the model results both indicate that Co, Cr, Mo, W and Re partition to the γ phase and Ni, Al, Ta and Hf partition to the γ' phase. The partitioning factors (defined as the ratios of the concentrations of the elements in the γ and γ' phases) were determined from the atom probe results and the model and are summarized in Table 3. The atom probe results for Co, Mo, W, Al, Hf and Re are in reasonable agreement with the model. The results for chromium appear to be slightly over predicted and those of tantalum are slightly under predicted by the model. However, it is also possible that the equilibrium compositions had not been fully attained after 24 h at 704 °C in the real material. As in previous atom probe studies of this and other nickel-based superalloys, no solute enrichments were observed at the γ - γ' interfaces in the atom probe compositional data, Fig. 1, and no evidence of local enrichments were evident in the field ion images, Fig. 2.

The distribution of rhenium in the γ matrix was investigated by examination of the atom-by-atom data chains and by applying two statistical tests, namely the mean separation method and the Johnson and Klotz ordering parameter to the atom probe data.[2] In contrast to previous atom probe results,[3] neither method was able to detect the presence of rhenium clusters in the γ matrix and there was no evidence of clustering in the field ion images.[4]

DISCLAIMER

1. H. Harada, K. Ohno, T. Yamagata, T. Yokokawa and M. Yamazaki, *Superalloys 1988*, eds. S. Reichman, *et al.*, The Metallurgical Society, Warrendale, (1988) 733.
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3. D. Blavette, P. Caron and T. Khan, *Scripta Metall.*, **20** (1986) 1395.
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TABLE 1. Phase compositions experimentally measured in the atom probe.

γ phase	Co	Cr	Mo	W	Al	Ta	Hf	Re
Average	22.8	16.9	2.8	3.2	3.2	0.28	0	3.7
γ′ phase	Co	Cr	Mo	W	Al	Ta	Hf	Re
Average	6.1	2.1	0.9	2.6	23.5	6.2	0.08	0.27

TABLE 2. Predictions of the phase compositions by the linear regression model.

γ phase	Co	Cr	Mo	W	Al	Ta	Hf	Re
1304°C	10.6	5.98	1.30	2.03	12.9	2.99	0.03	1.00
1079°C	13.6	10.0	2.14	2.44	8.20	1.32	0.01	1.93
704°C	25.5	19.7	2.94	2.54	1.74	0.54	0	3.13
γ′ phase	Co	Cr	Mo	W	Al	Ta	Hf	Re
1304°C	8.63	2.20	0.33	1.34	15.7	7.75	0.13	0.09
1079°C	7.86	2.38	0.55	1.67	17.1	4.47	0.06	0.18
704°C	5.59	1.42	0.75	1.86	16.6	3.81	0.05	0.29

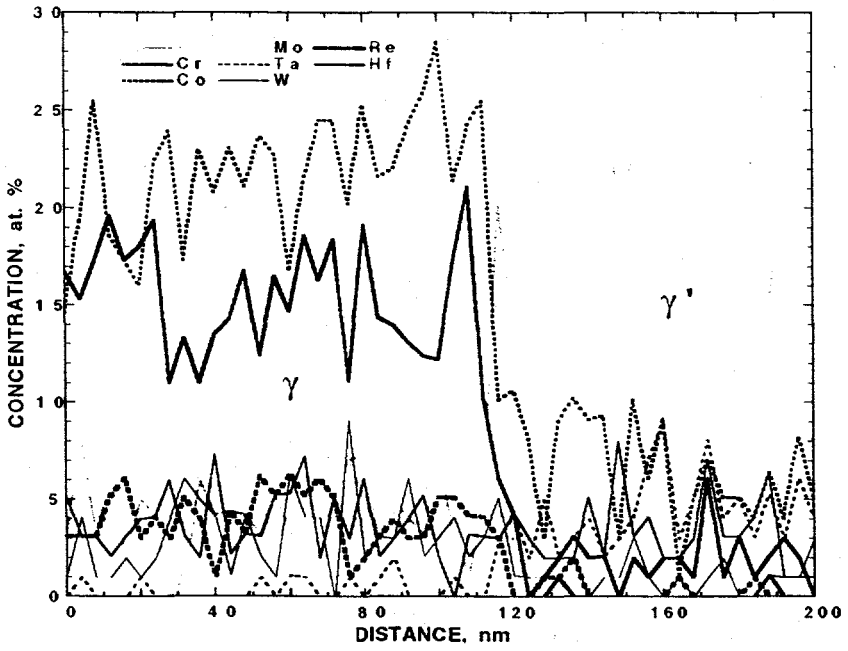

FIG. 1. Composition profile through a γ - γ′ interface.

TABLE 3. Comparison of the partitioning factors of γ : γ′ compositions determind from the atom probe experiments and the 704°C results from the linear regression model.

Preference γ	γ′	Atom Probe	Model
Co		3.7 : 1	4.6 : 1
Cr		8.0 : 1	13.8 : 1
Mo		3.1 : 1	3.9 : 1
W		1.2 : 1	1.4 : 1
	Al	1 : 7.3	1 : 9.5
	Ta	1 : 22.1	1 : 7.0
	Hf	1 : ∞	1 : ∞
Re		13.7 : 1	10.8 : 1

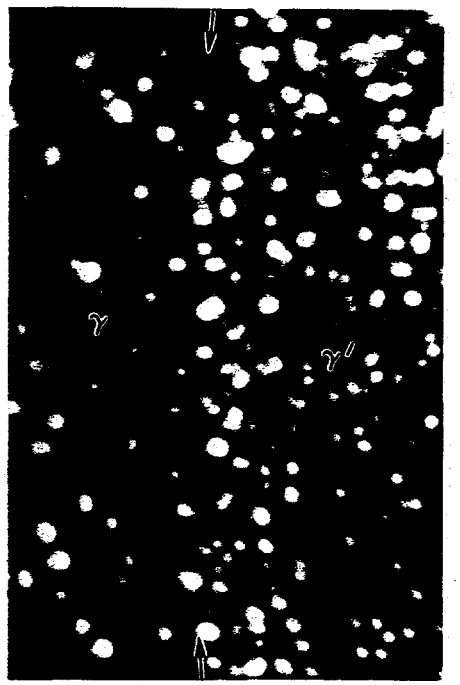

FIG. 2. Field ion micrograph of PWA 1484 after the three stage heat treatment.