Communication

Identification of Mo-based Precipitates in Haynes 282 Superalloy

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Electron microscopy analyses were used to unambiguously identify the crystallographic nature of the largely speculated about Mo-based and carbon-rich intergranular precipitates in a newer γ precipitation strengthened nickel-based superalloy, Haynes 282.

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Precipitation-strengthened nickel-based superalloys are widely used for the fabrication of hot section components of aircraft and power generation gas turbine engines. The ever-increasing demand for superalloys that can operate at higher operating temperatures in gas turbines, for improved efficiency, has resulted in the development of a γ precipitation strengthened nickel-based superalloy Haynes 282. The alloy was developed with chemistry modification to enable a unique combination of excellent creep properties and thermal stability that meet and surpass those of commonly used superalloys, such as Waspaloy, Inconel 718, and Rene 41. A key factor that influences creep properties and elevated temperature microstructural stability of superalloys is the nature of second phase precipitates that form along the grain boundaries of a superalloy. Therefore, to adequately understand the influence of microstructure on high temperature performance of the new superalloy Haynes 282, proper identification of the nature of the second phase precipitates that form along its intergranular regions after standard heat treatment is imperative. Previous studies has shown that sub-micron particles including \( \text{M}_2\text{C}_3 \) and \( \text{M}_3\text{B}_4 \), which cannot be unambiguously identified by conventional scanning electron microscopy but rather requires the use of transmission electron microscopy, form the grain boundaries of Haynes 282 superalloy.[1] In the present work, along with the \( \text{M}_2\text{C}_3 \) and \( \text{M}_3\text{B}_4 \) another set of sub-micron particles of a different phase from the \( \text{M}_2\text{C}_3 \) and \( \text{M}_3\text{B}_4 \) rich in molybdenum are found along the grain boundaries of the alloy after standard heat treatment. Transmission electron microscopy identification of this phase is reported and discussed in this communication.

The Haynes 282 superalloy used in this study was provided by Haynes International Inc., Kokomo, Indiana, USA, in the form of mill bright-annealed disk samples with dimensions 610 × 120 × 11.5 mm. The nominal chemical composition of the material (wt pctl) is 1.5Al, 2Ti, 0.2Co, 20Cr, 8.5Mo, 1.5Fe, 0.3Mn, 0.15Si, 0.06C, 0.005B, and balance nickel. The as-received alloy was subjected to a recommended standard full heat treatment (SFHT) at 1390 K (1120 °C) for 2 hours and water-quenched followed by aging at 1233 K (1000 °C) for 2 hours and air-cooled + 1061 K (788 °C) for 8 hours and air-cooled.

Metallographically prepared specimens of the alloy for scanning electron microscopy examination were chemically etched with a modified Kalling's reagent—40 mL distilled water + 480 mL HCl + 48 g of CuCl₂ and electrolytically etched in 10 pct Oxalate acid at 65° for 3 to 5 seconds. Microstructural study was performed using a JEOI 5900 scanning electron microscope (SEM), a FEI Tecnai F20 (scanning) transmission electron microscopy (STEM), and a JEOL 2010F STEM. The two microscopes are equipped with Oxford energy dispersive spectrometer (EDS) and Tecnai F20 is equipped with an X-Max Silicon Drift Detector. TEM specimens were prepared by mechanical grinding 3-mm-diameter discs to ~150 um and then twin-jet electropolishing them in solution of 10 pct perchloric acid, 30 pct butanol, and 60 pct methanol at 243 K (~30 °C) and 25 V.

Microstructure of the SFHTed specimen is shown in Figure 1. The alloy contains MC carbides dispersed within the austenitic γ matrix phase. Fine sub-micron-sized precipitates were formed along the grain boundaries. The nature of the intergranular particles, which cannot be identified using the SEM because of the inherent limitation of the spatial resolution of the SEM-EDS to reliably analyze sub-micron particles, have been studied by TEM analyses by the present authors and reported elsewhere.[1] The particles were found to consist of Ti-based MC carbides, Cr-based \( \text{M}_2\text{C}_3 \) carbides, and Mo-based \( \text{M}_3\text{B}_4 \) borides.[1] Further TEM study of the superalloy Haynes 282, in the present work, revealed another type of intergranular Mo-based precipitates in the SFHT condition of the material. The Mo-based precipitates have a complex face centrosymmetrical structure in contrast to the hexagonal crystal structure of the Mo-based \( \text{M}_3\text{B}_4 \) boride particles. TEM X-ray microanalysis of the Mo-based particles, in the present work, did not reveal distinct boron peak but instead shows a distinct carbon peak (Figure 2), which suggests the particles to be likely carbides. There are two main types of secondary carbides, \( \text{M}_2\text{C}_3 \) and \( \text{M}_4\text{C} \), that can form during aging heat treatment at 1023 K to 1328 K (750 °C to 1055 °C) in nickel-based superalloys. The two carbides...