J Mater Sci (2006) 41:6476–6478
DOI 10.1007/s10853-006-0684-5

LETTER

Morphological evolution of MC carbide in K465 superalloy

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Received: 13 June 2006 / Accepted: 17 July 2006 / Published online: 2 September 2006

A cast nickel-base K465 superalloy is strengthened by γ' precipitates and carbides and is intended for use as gas turbine blades and vanes operating at elevated temperature where phase alteration is prone to occur, such as carbide precipitation and degradation. Normal thermal exposure, such as experienced in processing, heat treatment or service, can alter the original structure, morphology and distribution of carbides, thereby, producing variations in the properties of the alloy [1–11]. For example, MC carbide can be decomposed into M_6C and $M_{23}C_6$ carbides, and these three types of carbides may also be precipitated during the long-term thermal exposure [1, 3, 4]. In this investigation, MC carbide is emphasized.

MC carbide has blocky and script-like morphology [3]. In addition, the chemical composition of MC carbide is very complex, including C, W, Cr, Mo, Ti, Nb and Hf. HfC is the most stable carbide compared with other types of carbides [9]. Meantime, Ti and Nb increase the stability of MC carbide, whereas W and Mo decrease the stability of MC carbide [3]. The combined effects of these elements determine the stability of MC carbide, which is illustrated in addition to the morphological alteration of MC carbide in this investigation.

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The chemical composition (wt%) of K465 alloy is given in Table 1. The tested specimens were solid solution treated at 1,210 °C for 4 h and followed by air cooling in electric resistance furnace where the temperature fluctuation is ±5 °C. Metallographic observations were carried out by optical microscopy, scanning electron microscopy (SEM), transmission electron microscopy (TEM) and selective area diffraction pattern (SADP). Quantitative analysis was performed using energy-dispersive X-ray analysis (EDS) on TEM.

As-cast MC carbide forms in interdendritic regions having script-like morphology as shown in Fig. 1, and is identified as MC by TEM image and SADP, that can be correlated with TiC data fairly well (Fig. 2a, b). In three-dimension morphology, this script-like MC carbide is either smooth platelet (Fig. 3a) or bone-like structure (Fig. 3b). The script-like MC carbide forms at the lower ratio of the temperature gradient in front of the liquid/solid interface to the growth rate which creates a favorable condition for the growth of carbide branches, resulting in script-type morphology with developed branches [8]. In addition, this MC carbide is enriched in the higher levels of Ti, Nb and W, as well as a small amount of Cr and Mo indicating that it is a mixed carbide with Ti, W and Nb (Table 2). It is reported that Ta and Nb has strengthened the binding force in MC carbide; and Mo and W has weakened the binding force in MC carbide [3, 9]. From thermodynamics, Ti is a more potent carbide forming element than W; Nb is the stabilizing MC carbide element. Cubic WC is not a stable compound and instead a hexagonal WC appears in the equilibrium C–Ti–W phase diagram, but the ternary C–Ti–W phase diagram shows that (Ti,W)C is more stable than TiC as the former has a higher melting point[10]. The present MC

Table 1 Nominal composition of K465 alloy (wt.%)

C	Cr	Al	Ti	Mo	W	Co	Nb	Zr	Ni
0.17	10	5.5	2.8	2.2	10.5	11	1.1	< 0.04	Bal.

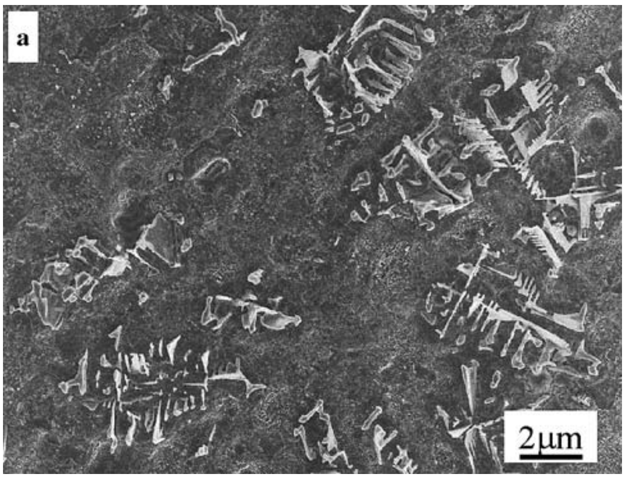

Fig. 1 As-cast script-like MC carbide

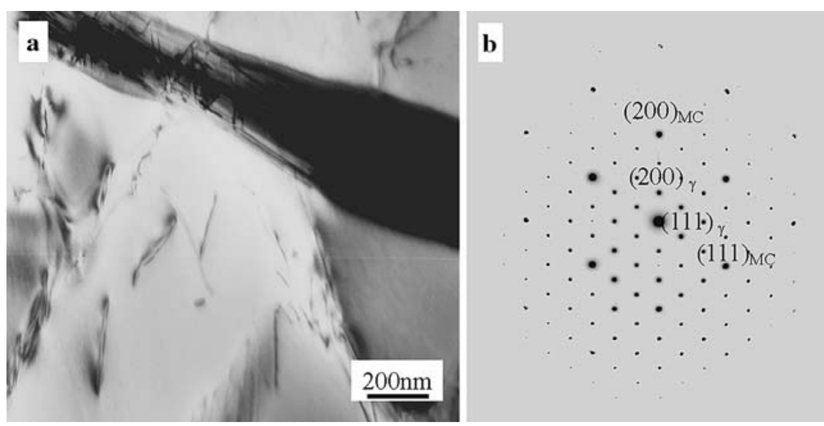

Fig. 2 Identification of script-like MC carbide: (**a**) TEM metallograph; (**b**) SADPs of MC and γ/γ'

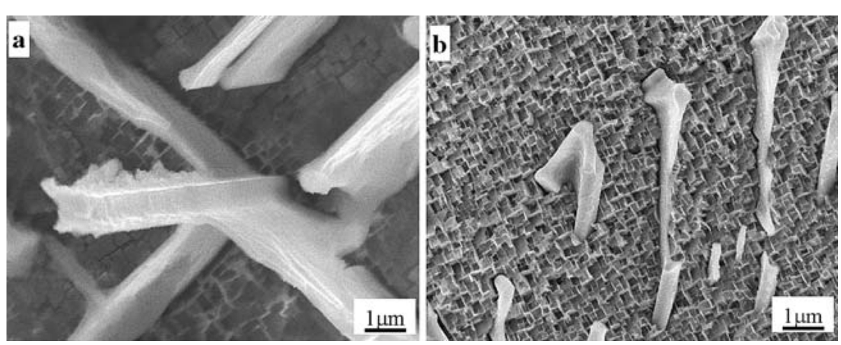

Fig. 3 Three-dimension images of as-cast MC carbide: (**a**) smooth platelet image, (**b**) a row of bone-like MC carbide

carbide having a cubic structure is a mixed carbide with the metallic atoms of the large amount of Ti, Nb and W, and a small amount of Cr and Mo. Hence, this MC carbide is stable in contrast to WC-type and TiC-type carbides according to the above analysis.

In addition, MC carbide has a NaCl structure, and its coherent planes with the matrix is (111) and (100) planes as shown in Fig. 2b showing $(111)_{MC}//(111)\ \gamma$ and $(100)_{MC}//(100)\ \gamma$. The MC carbide platelet had better conherency with the matrix than other shapes[9, 11]. As a result, the small misfit energy is produced by the good coherency between the MC carbide and matrix. Accordingly, the MC carbide platelet has a larger surfacial area than the blocky MC carbide particles, but causes smaller lattice misfit energy. Script-like MC carbide is prone to decompose at high temperature because this orientation relationship is destroyed, which is gradually lost accompanying the decomposition of MC carbide.

After solution treated condition, MC carbide is dissolved and thinned out as shown in Fig. 4a.

Because of the decomposition of MC into another new carbide, a new carbide in the form of blocky particles is formed on the surface of MC carbide (Fig. 4b, c). This new carbide is M_6C demonstrated by its chemistry in Table 2 indicating the presence of higher

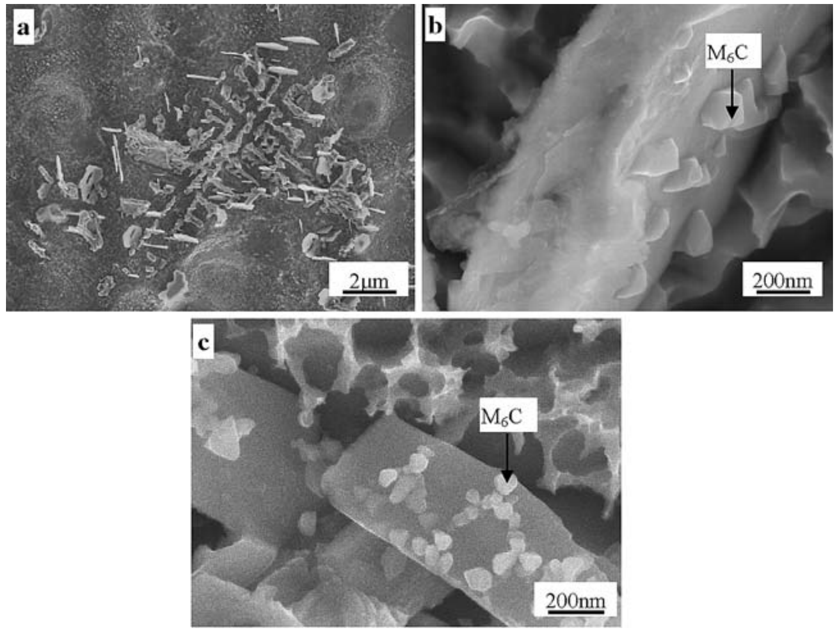

Fig. 4 Solution treated microstructure of K465 alloy: (**a**) residual script-like MC and other carbides; (**b**) MC and small M_6C particles; (**c**) small M_6C particles precipitated on the surface of MC carbide

Table 2 Compositions of carbides (at.%)

Condition	W	Nb	Ti	Cr	Mo
As-cast MC	9.8	18.9	44.9	9.1	4.3
Solution treated MC	7.9	21.1	45.9	7.0	2.1
Solution treated M_6C	42.1	1.2	2.0	10.1	7.5

levels of W, Mo. From thermodynamics consideration, MC carbide is less stable than M_6C carbide at high temperature. Hence, MC carbide is gradually degenerated into M_6C carbide during solid solution treatment, which induces the irregular morphology of MC carbide, but the residual MC carbide still remains the original script-like morphology. Meantime, MC carbide releases a large amount of alloying elements, Ti, Nb, W, Cr and Mo by the transformation into M_6C carbide. The decrease of the contents of Ti and Nb in MC carbide accelerates the decomposition of MC carbide into M_6C carbide, thus destroys the script-like shape so that MC carbide changes from smooth and regular surface to coarse and irregular configuration accompanying with the loss of the orientation relationship between the MC carbide and matrix.

The script-like MC carbide is either smooth platelet or bone-shaped structure in morphology in as-cast condition. This MC carbide is decomposed into M_6C carbide, and MC carbide platelet becomes coarse because of the decomposition of MC carbide and precipitation of M_6C carbide after solid solution treatment. The morphological stability of MC carbide is related to chemical composition and the orientation relationship between the MC carbide and matrix.

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