Scripta METALLURGICA Vol. 19, pp. 319-322, 1985
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THE DECOMPOSITION OF HEXAGONAL MARTENSITE IN A TITANIUM-COPPER ALLOY

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(Received October 25, 1984)
(Revised December 26, 1984)

Introduction

Metastable beta titanium alloys have been receiving a great deal of attention because of their excellent fabricability and ability to readily respond to heat treatment. The beta eutectoid forming alloys like Ti-Cu, Ti-Cr, Ti-Fe, Ti-Mn etc. are a class of beta alloys possessing moderate strength and are good candidate materials for structural applications. The high temperature beta phase in these alloys decomposes through a eutectoid reaction resulting in α and an intermetallic compound. However, when the quenching is rapid, the alloy undergoes a martensitic transformation. These alloys are strengthened by the precipitation of the intermetallic compound in the alpha phase [1,2]. Lutjering and Weissmann [3] have studied the mechanical behaviour of Ti-Cu alloys and reported two types of precipitates occurring while ageing in the temperature range 673-773K:(a) a metastable ordered coherent precipitate and (b) a stable equilibrium precipitate with Ti_3Cu stoichiometry and f.c.t. structure. Williams et al.[4] have observed heterogeneously nucleated Ti_2Cu precipitates at dislocations and other substructures of the martensite. Besides this they observed a thin coherent disc shaped precipitate which finally yielded the equilibrium precipitate Ti_2Cu. Decomposition of orthorhombic martensite by a spinodal mechanism in some Ti-Mo alloys has also been observed [5].

In the present paper we report certain experimental observations in the decomposition of the hexagonal martensite formed in a Ti-6.7 wt% Cu alloy.

Experimental Procedure

The alloy was melted in a vacuum arc furnace using a non-consumable tungsten electrode. The alloy was forged in the form of a cylindrical rod of 10mm diameter and 100mm length. The rod was sliced into 0.5mm thick disc specimens. All heat treatments were carried out in vacuum, better than 10^{-3} Pa. Samples were polished by the conventional method for optical and x-ray diffraction studies. Thin foils for transmission electron microscopy were prepared by jet technique using an automatic 'Tenupol' electropolishing unit. The electrolyte used was of composition: methanol - 300 ml, n-butanol - 175 ml and perchloric acid - 30 ml. Polishing was carried out at 228K and 11 volts d.c. Thin foils were observed using a Hitachi HU 11E and a Philips EM-300 transmission electron microscope at 100 kV.

Results and Discussion

Microstructure of Water Quenched Samples:

Fig.1 shows an optical micrograph of the water quenched sample. It was observed that while the grain interior shows a martensitic product, a precipitation reaction had occurred at the grain boundaries. The morphology of the precipitates at this stage is not well defined. It may be concluded from the above observation that with the present cooling rates employed it is not possible to suppress the eutectoid reaction at the grain boundaries.

Transmission electron microscopy indicated that the martensite exhibited both lath and acicular morphology. The simultaneous occurrence of lath and acicular morphology is not uncommon and has been reported in many other systems as well [6]. The sub-structure of the lath martensite was found to be heavily dislocated. Also' it was observed that a modulated structure existed within the martensite plates. Such a decomposition of metastable beta during quenching has also been observed in a Ti-Mo alloy [5].

Microstructure of the Aged Samples:

The beta quenched samples were aged at 923K for different intervals of time. Fig.2 is a transmission electron micrograph of the sample quenched from beta phase and aged at 923K for 2 minutes. It can be observed that a tweed like structure is present inside the martensite laths and upto the boundaries. The existence of this mottled contrast can be attributed to the presence of compositional fluctuations. When the alloy was aged for 30 minutes at 923K the uniformly nucleated phase present inside the martensite has grown into thin rod like particles. Figs.3(a) and (b) are the bright and dark field transmission micrographs showing the uniformly nucleated rod-like precipitates inside the martensite plate. The selected area electron diffraction pattern and the key to the pattern are shown in Figs.3(c) and (d). The precipitate phase could be indexed in terms of a b.c.c. structure. The orientation relation between the metastable b.c.c. and the matrix has been established by stereographic analysis as $(0001)_{\alpha'} \parallel (111)_{bcc}$ and $<10\bar{1}0>_{\alpha'} \parallel <1\bar{2}1>_{bcc}$. It is reasonable to postulate that the nucleation sites for these precipitates must have been the spinodal product observed in the quenched structure. When the alloy was aged for a longer interval of time, a lamellar product having the equilibrium structure resulted, Fig.4. This is similar to the product of a cellular reaction as treated by Turnbull. The reaction results because of the nonequilibrium composition existing at the advancing boundary and the solutes diffuse rapidly across the interface. The existence of a metastable b.c.c. phase has been reported in the case of a Zr-Cu alloy also [7]. The origin of the b.c.c. structure can be explained on the basis that the Ti_2Cu unit cell can be constructed as made up of three b.c.t. cells stacked one above the other.

When the alloy was aged at 923K for a very long interval a lamellar precipitate resulted. By electron diffraction studies it could be established that the lamellar precipitates are indeed the equilibrium Ti_2Cu precipitates, Fig.5. From stereographic analysis the orientation relation between the Ti_2Cu phase and the matrix was established as: $(0001)_{\alpha'} \parallel (0\bar{1}3)_{Ti_2Cu}$ and $<1\bar{2}10>_{\alpha'} \parallel <100>_{Ti_2Cu}$.

Ageing of the alloy at higher temperature (998K - 1053K) resulted in both lamellar and non-lamellar precipitates with Ti_2Cu structure. However, the intermediate stages of precipitation were not found.

Conclusions

The present study reveals that at lower temperatures of ageing the martensite in titanium-copper alloy decomposes possibly by compositional fluctuations leading to the formation of a metastable phase before attaining the equilibrium Ti_2Cu structure.

Acknowledgements

The authors would like to thank Dr D.Banerjee for his help in TEM work. They also thank Dr A.K.Singh, Head, Materials Science Division, NAL for his encouragement and their colleagues at NAL for helpful discussions. Experimental facility provided by the Defence Metallurgical Research Laboratory is gratefully acknowledged.

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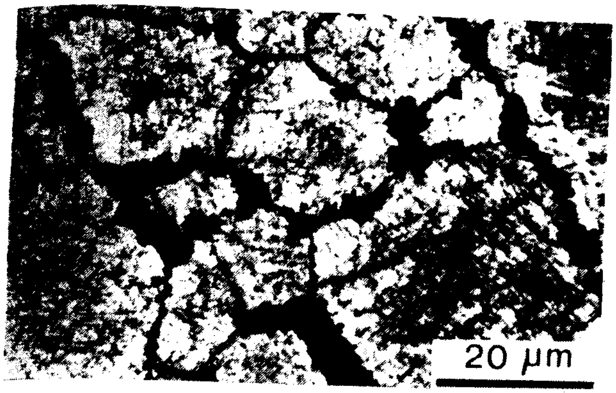

FIG.1: Optical micrograph of water quenched Ti-6.7Cu sample showing grain boundary precipitation and martensitic product in grain interior.

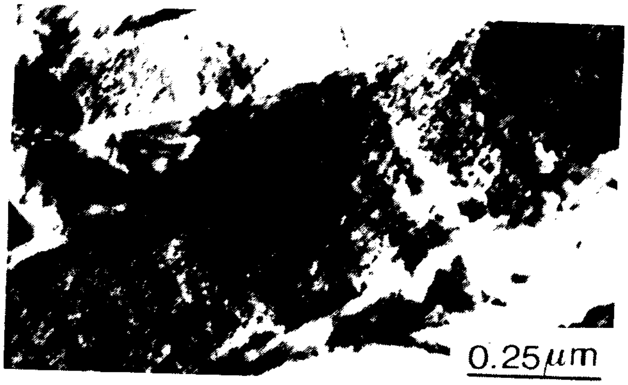

FIG.2: Transmission electron micrograph of a sample quenched from beta phase and aged at 923K for 2 minutes showing a tweed structure.

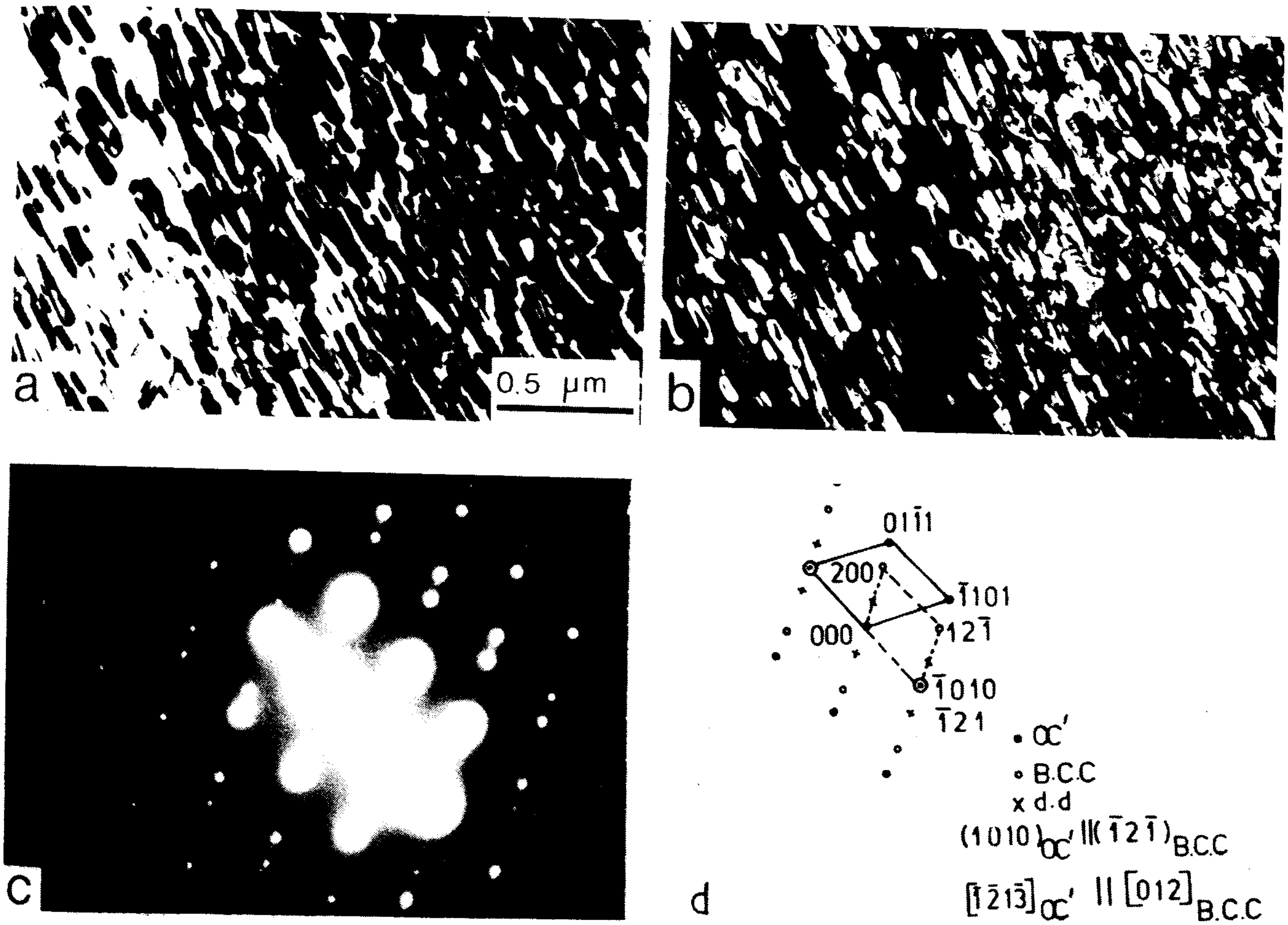

FIG.3: Transmission electron micrograph of a sample quenched from beta phase and aged at 923K for 30 minutes showing metastable b.c.c. phase. (a) bright field (b) dark field (c) selected area diffraction pattern and (d) key to diffraction pattern.

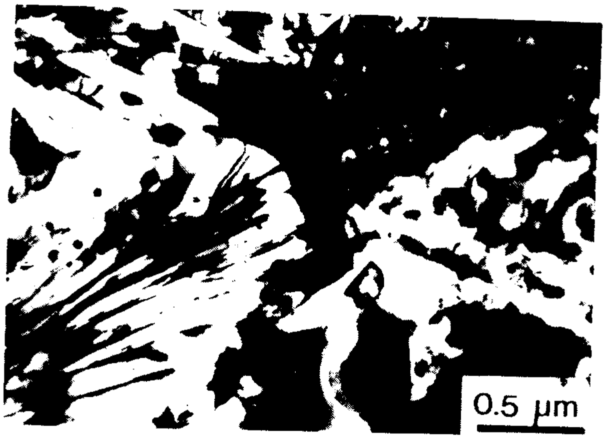

FIG.4: Transmission electron micrograph of beta quenched and aged sample illustrating the formation of lamellar product from the metastable phase.

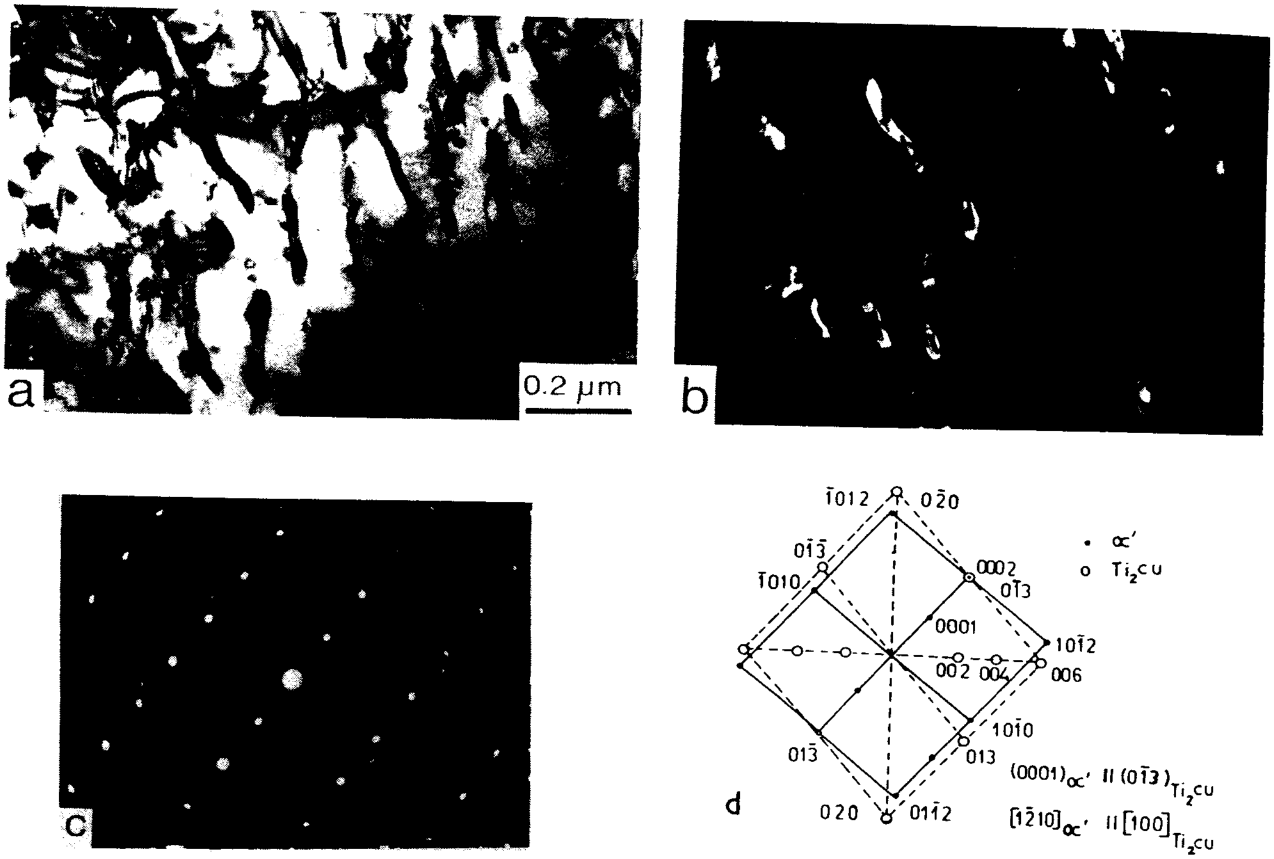

FIG.5: Transmission electron micrograph of the sample quenched from beta phase and aged at 923K for longer duration showing lamellar precipitates. (a) bright field (b) dark field (c) selected area diffraction pattern and (d) key to diffraction pattern.