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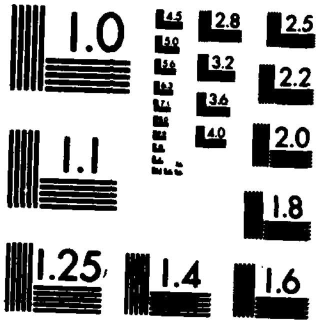

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*Present address: School of Engineering and Applied Science, George Washington University, Washington, D.C. 20052.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Fatigue crack growth behavior has been examined in a Ti-4.5Al-5Mo-1.5Cr alloy, for two different levels of β-phase metastability. The resistance to fatigue crack growth appears to be marginally enhanced with the presence of metastable β-phase in a microstructure also containing some primary α-phase (≃30 pct) of high aspect ratio. This enhancement appears slightly greater for β-phase water quenched from 899°C, than as more slowly cooled in helium from this same solution treatment temperature, at approximately an air-cooling rate. In the case of the former, nearly full retention of solute in the β-phase is apparent, while in the latter, significant precipitation of secondary α-phase is evident in thin-foil transmission electron micrographs.

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CONTENTS

ON FATIGUE CRACK GROWTH IN A Ti-4.5Al-5Mo-1.5Cr ALLOY WITH METASTABLE β-PHASE

Charles M. Gilmore[1], George R. Yoder[2] and M. Ashraf Imam[1]

Mechanics of Materials Branch
Material Science and Technology Division
Naval Research Laboratory
Washington, DC 20375

INTRODUCTION

The Ti-4.5Al-5Mo-1.5Cr or "CORONA 5" alloy has been successfully developed as a superhigh toughness α/β alloy [1-4], though preliminary work has not revealed a *similar superiority* in resistance to fatigue crack growth - particularly at lower levels of stress-intensity range (ΔK). Work in the recent past with conventional α/β alloys has shown, however, that resistance to fatigue crack growth can be significantly enhanced through microstructural modification [5-7] - and indeed, such efforts have been attempted with the CORONA 5 alloy [4,8].

One of the more fascinating approaches toward enhancement of resistance to fatigue crack growth is through use of TRIP (transformation-induced plasticity) effects, as successfully demonstrated in the case of steels [9,10]. Moreover, Imam and Gilmore [11-13] have ascribed a considerable enhancement of fatigue life in a Ti-6Al-4V alloy to TRIP effects associated with metastable β-phase, as water quenched from a solution treatment temperature high in the α/β phase field.

The purpose of the present study is to examine, on a preliminary basis, whether such a TRIP effect might be found to enhance fatigue crack growth

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[1] School of Engineering and Applied Science, George Washington University, Washington, DC 20052

[2] Material Science & Technology Division, Naval Research Laboratory, Washington, DC 20375

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resistance in the CORONA 5 alloy. This alloy is hardenable after water quenching from the solution treatment temperature, and to a lesser extent, hardenable after air cooling [14]. Therefore, results are examined for two cases: the alloy as (i) water-quenched, and (ii) as cooled in helium at approximately an air-cooling rate from a solution treatment temperature of 899°C.

EXPERIMENTAL

A description of the plate material used has already appeared in Ref. [4]. The alloy was high β processed, with a reported beta transus of 938°C and the following chemical analysis (in wt pct): Ti-4.4Al-5.1Mo-1.46Cr-0.183O-0.011N-0.0018H-0.20Fe-0.065C. In the present study, the material was annealed at 982°C (1 hr), then cooled in vacuum to 899°C and held for 4 hours, followed by either a water quench or helium purge to room temperature.

Determinations of fatigue crack growth rates (da/dN) were made from precracked MC(T)(T-L) type specimens [15], with a thickness (B) of 10.2 mm, a width (W) of 64.8 mm and a half-height to width ratio (h/W) of 0.486. Specimen geometry is illustrated in Fig. 1; the equation for calculating the stress-intensity factor (K) for this specimen is given in Ref. [16]. Specimens were cyclically stressed with a haversine loadform of constant amplitude, a stress ratio ($\sigma_{min}/\sigma_{max}$) of $R = 0.10$ and a frequency of 5 Hz in ambient air, using a closed-loop servohydraulic loading machine. The precision measurement technique described in Ref. [17] was employed to determine fatigue crack growth rates in accord with ASTM E647-81 [18]. Crack length was determined as a function of elapsed cycles from measurements of crack-mouth-opening displacement, using the calibration equations of Ref. [16]. In some instances, crack length was also measured optically at the two faces of the specimen with a traveling microscope at 15x. Values of da/dN were determined for levels of stress-intensity range between 12 and 30 MPa$\sqrt{m}$.

Mechanical properties were determined from cylindrical tensile specimens of the T orientation [19], with a diameter of 6.3 mm. A gage length of 25.4 mm was used; the rate of stressing was $\dot{\sigma} = 175$ MPa/min.

RESULTS AND DISCUSSION

The photomicrograph in Fig. 2 of the alloy as quenched from 899°C indicates that ~70% β-phase was present at the solution treatment temperature. The thin-foil transmission electron micrograph in Fig. 3(a) and the selected area diffraction pattern in Fig. 3(b) illustrate that a significant fraction of the β-phase remained untransformed in material water quenched from 899°C. By contrast, material cooled more slowly in helium from 899°C exhibits a significant degree of precipitation of fine, secondary α-phase (Widmanstätten morphology) as shown in the thin-foil micrograph in Fig. 3(c).

Uniaxial tensile properties for these two material conditions are presented in Table 1. Though the difference in ultimate tensile strength for the two conditions is relatively small, the yield strength of the helium cooled material (1007 MPa) is more than twice that for the water quenched condition (466 MPa) - an observation consistent with the precipitation apparent within the β-phase pools of the former, as shown in Fig. 3(c)*. A lower value of Young's modulus (E) is also apparent for the water quenched material (95 vs. 112 GPa) - which is consistent with the higher volume fraction of β-phase, which is anticipated to have a lower modulus than the α-phase [20,21].

Fatigue crack growth rates (da/dN) for the two material conditions are plotted in Figs. 4 and 5. As shown in Fig. 4, the fatigue crack growth resistance of the helium cooled material is virtually coincident with the lower bound data trend line ("LB") from an earlier study [4]. A bilinear form of the data plot is apparent, as anticipated [7], with a transition point at ΔK_T. As shown in Fig. 5, the water quenched material exhibits a fatigue crack growth resistance that appears to be marginally enhanced relative to that in Fig. 4 - possibly owing to the greater potential for a TRIP effect to be operative**.

It is important to elaborate on the three different sets of data plotted in Fig. 5. First of all, it is evident that data obtained from readings of crack length made optically at the specimen faces ($\bar{a}_s$) are not in agreement with those made from measurements of crack-mouth-opening displacement, using the value of modulus obtained from the tensile test ($\bar{a}_c$, $E_T = 95$ GPa). However, if the modulus is measured from the crack growth specimen itself [17],

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*This observation could conceivably be linked to a TRIP effect, though evidence has yet to be obtained in support of this possibility.

**Unfortunately, at the higher levels of ΔK in Fig. 5, invalidity of the data is a problem associated with deviation of the fatigue crack from the Mode I crack plane in excess of 5°.

then values of da/dN obtained via the crack-mouth-opening displacement technique ($\bar{a}_C$, $E_C = 83$ GPa) are in excellent agreement with those determined from the surface optical measurements, $\bar{a}_s$. The much lower value of modulus obtained in the latter case might be related to a greater potential for phase transformation to occur in the triaxial stress field of the crack growth specimen.

CONCLUSIONS

1. Fatigue crack growth resistance appears to be marginally enhanced with the presence of metastable β-phase in a microstructure also containing some primary α-phase (~30%) of high aspect ratio.

2. This enhancement appears slightly greater for β-phase water quenched from 899°C than as cooled more slowly in helium (at approximately an air-cooling rate). In the case of the former, nearly full retention of solute in the β-phase is apparent, while in the latter, significant precipitation of secondary α-phase is evident.

3. The potential for major TRIP effects on fatigue crack growth in the presence of metastable β-phase requires further study - e.g., a wide range of solution treatment temperatures needs to be explored, as prior experience with Ti-6Al-4V suggests.

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Table 1 - Mechanical Properties

Material Condition	0.2 Pct Yield Strength, σ_y(MPa)	Tensile Strength, σ_{uts}(MPa)	Reduction in Area, Pct	Elongation in 25.4 mm G. L., Pct	Young's Modulus, E (GPa)
Helium Cooled	1007	1110	9	5	111.7
Water Quenched	466	1046	10	8	95.3

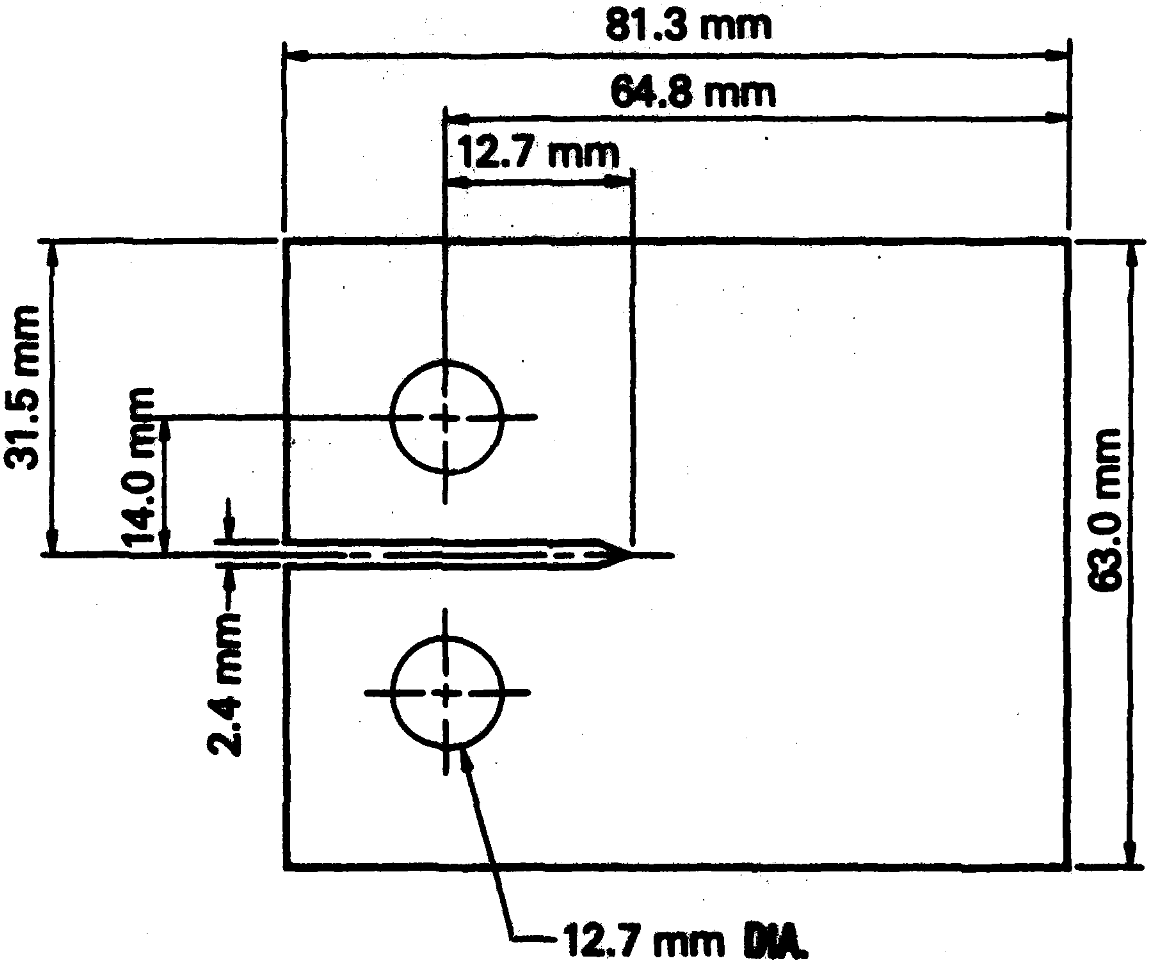

Fig. Dimensions of crack growth specimen.

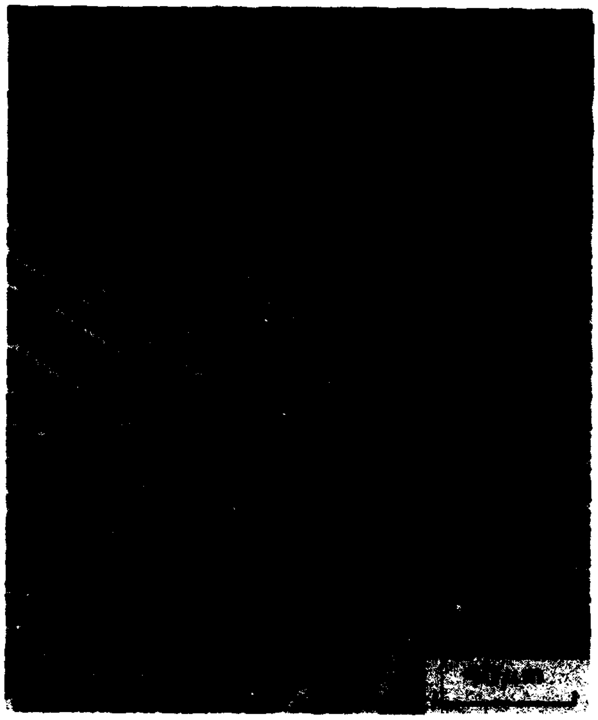

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Fig. 2 - Light optical photomicrograph of alloy as water quenched from 899°C. Etched with Kroll's reagent.

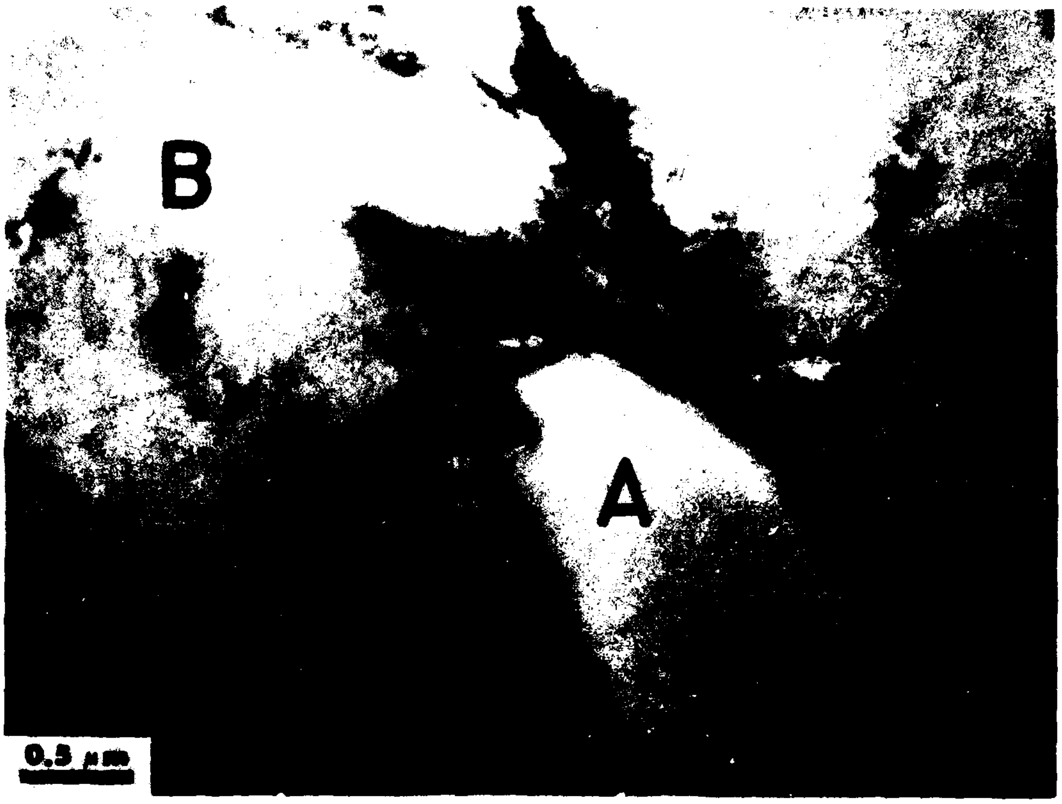

Fig. 3(a) - Transmission electron micrograph of material water quenched from 899°C. The matrix phase, marked "B", was identified to be a mixture of retained β-phase and martensite. The α-phase is marked "A".

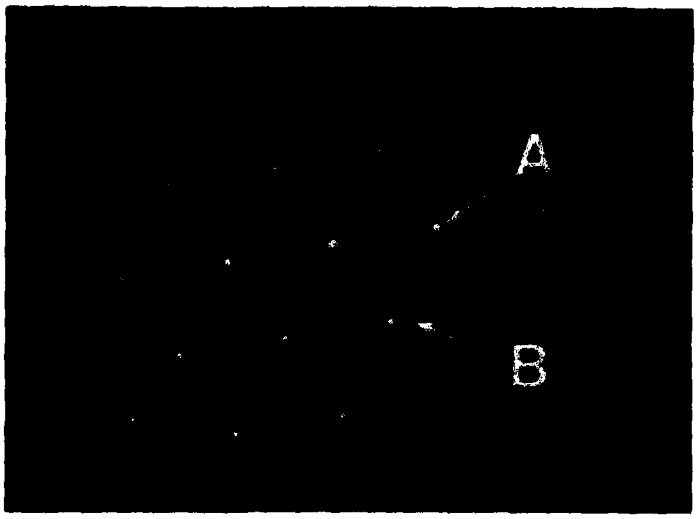

Fig. 3(b) - Electron diffraction pattern taken from the matrix of the water quenched material showing

A. $(\bar{1}010)$ lattice point of the [0001] HCP zone axis

B. (101) lattice point of the $[\bar{1}11]$ BCC zone axis

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Fig. 3(c) - Transmission electron micrograph of the material cooled in helium from 899°C.

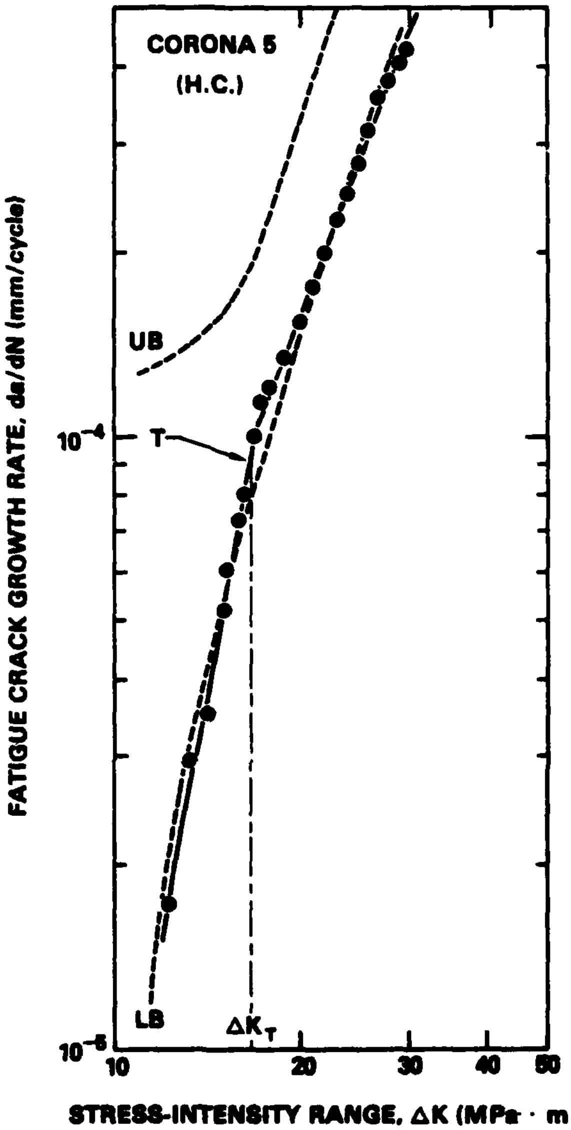

Fig. 4 - Fatigue crack growth rates for alloy as cooled in helium from 899°C.

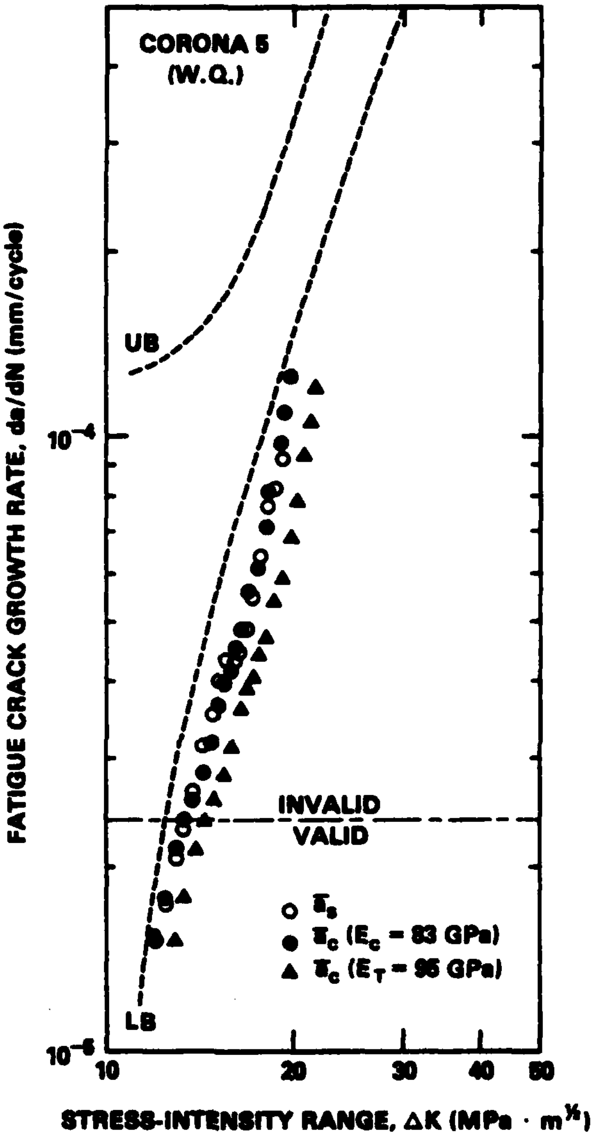

Fig. 5 - Fatigue crack growth rates for alloy as water quenched from 899°C.