INVESTIGATION OF CREEP BEHAVIOR OF Ti-ALLOY BY IMPRESSION TEST

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ABSTRACT

Impression creep tests of Ti-6211 alloys at room temperature with punching stresses of 1500-5661 MPa are reported. For stress under 3000 MPa the creep behavior is essentially exhausted type and obeys the logarithmic law. The exponent value of time is in good agreement with that obtained by conventional tensile and compression creep tests. For stresses larger than 4000 MPa, a steady state creep behavior was observed with a stress exponent equal to 7.6. The calculated activation areas for room temperature steady state creep falls into the predicted region of correlation between activation area and stress for all materials.

KEYWORDS

Impression creep; titanium alloys; activation area; steady state; microstructure; stress

INTRODUCTION

A new indentation test method to characterize the creep behavior of homogeneous materials has been recently introduced by Li and co-workers (Chu, 1977; Chu, 1979; Yu, H.Y., 1977; Yu, E.C. and Li, 1977). In this test, a cylindrical indenter with a flat end is allowed under the action of constant load to make a shallow impression on the surface of a solid. An accurate determination of the depth of penetration of the indenter at a given stress is measured as a function of time to evaluate the kinetics of creep. This test offers several advantages over the conventional creep test, viz, small quantity of testing material, temperature and stress dependence of creep rate obtainable on a single sample, constant stress at constant load, and absence of tertiary stage creep. For materials like molecular crystals (Chu, 1977), LiF (Yu, E.C. and Li, 1977), β-Tin single crystals (Chu, 1979), Cu-Ni single crystals (Yu, E.C., 1977), and Zn polycrystals (Murthy, 1982), it was found that both the stress and temperature dependence of the steady state impression velocity agreed with the corresponding dependence of the creep rate in conventional creep tests.

Thus impression creep has been established as a convenient way of obtaining extensive information on creep from small material samples.

In the present investigation the creep behavior of the titanium alloy, Ti-6Al-2Cb-1Ta-0.8Mo (Ti-6211) has been investigated using impression test method.

EXPERIMENTAL PROCEDURE

Material

Ti-6Al-2Cb-1Ta-0.8Mo alloys (Ti-6211) with oxygen contents of 0.075 and 0.290 wt % (0.22 and 0.87 at %), were prepared in 125 lb heats and fabricated by upset-forging and hot rolling at 1065°C followed by an annealing treatment at 926°C for one hour and air cooling. The oxygen levels of the alloys have been identified, for this study, as A and E and are listed in Table I.

TABLE I Composition of Ti-6211 in Wt. Percent (H_2 in ppm)

	Element							
Sample	Al	Cb	Mo	Ta	O	H(ppm)	N	C
A	6.0	1.95	0.7	0.88	0.075	40.0	0.010	0.02
E	5.9	2.16	0.7	1.06	0.290	54.0	0.008	0.03

Specimens of size 25 mm X 25mm X 8mm with two parallel flat surfaces were cut for impression creep test. The microstructure and the related mechanical and fracture tolerant properties of these alloys has been systematically evaluated and reported on by Imam and colleagues (1983). The microstructure shows the formation of grain-boundary alpha decorating the prior beta grains independent of oxygen content. The prior-beta grain sizes in this alloy which is under identical heat treatment conditions varies inversely with oxygen content, ranging between 0.7mm to 3mm. The crystallographic texture evaluation showed that all samples have a very weak transverse basal texture and are nearly independent of oxygen content. The microhardness, macrohardness, yield stress, ultimate tensile strength and fracture stress, all show a linear increase with increasing oxygen content.

Apparatus

The testing arrangement for impression creep test is shown schematically in Fig. 1. A flat end cylindrical punch with 1 mm diameter, machined from tungsten carbide rod, was used for the impression test. The test was performed at room temperature in a closed loop MTS hydraulic testing machine under load control conditions. The displacement of the punch was monitored by an LVDT attached between load cell and the sample and was recorded as a function of time for each creep test.

RESULTS AND DISCUSSION

The room temperature creep properties of Ti-6211 with 0.073 wt% oxygen had been investigated by Chu (1970, 1976, 1980). Both tensile and compression creep tests had been conducted with creep stress in the range from 558 MPa to 724 MPa (the 0.2% offset yield strength at room temperature is 703 MPa). The results show that the creep behavior of this alloy obeys the logarithmic law and can be identified as exhaustion creep (Chu, 1980). For 1000 hours tests, the creep strain can be represented as:

$$\varepsilon = 2.30 \times 10^{-40}\, \sigma^{13.89}\, t^{0.183}, \quad \text{for tensile creep and} \qquad (1)$$

$$\varepsilon = 1.22 \times 10^{-29}\, \sigma^{9.89}\, t^{0.183}, \quad \text{for compression creep} \qquad (2)$$

where σ is the applied stress (MPa), t is time (hours) and ε is total creep strain (%). In order to compare the results of the present study with those obtained from conventinal creep test results of Chu (1970, 1976, 1980), samples from the A batch of Ti-6211, having chemical composition same as that of Chu were chosen. Five stress levels were used in the impression creep tests. These creep stresses were 1500 MPa, 2000 MPa, 2500 MPa, 3000 MPa and 3500 MPa. Under these stress levels, it is found that the room temperature creep behavior of Ti-6211 is essentially of the exhaustion type. The results are shown in Fig. 2 and can be expressed as:

$$\delta_d = 9.33 \times 10^{-8}\, (\sigma)^{2.38}\, t^{0.17} \qquad (3)$$

where δ_d is normalized impression displacement (displacement divided by the diameter of the punch X 100). The normalized displacement can be linearly related to the strain ε (Yu, 1984, in press) by the following relation

$$\delta_d = \alpha\varepsilon \qquad (4)$$

where the proportionality constant α is of the order of 1. The time exponent in the above equations is in good agreement with each another which suggests that one can use the impression creep test to obtain the exponent value instead of the conventional creep test.

Since the deformation in impression creep is stable having no tertiary stage (Chu, 1977), tests can be carried out to study the creep behavior under large stress (the applied stress larger than the ultimate tensile strength of the material) which can not be performed by conventional tests. Four stress levels between 4137 MPa to 5561 MPa were used in this investigation to study the creep behavior of sample E. A typical plot between indenter displacements and time for sample E is shown in Fig. 3. The creep behavior of Ti-6211 under such high stresses shows steady state creep rate. The effect of stress steady state impression velocity is shown in Fig. 4. The result gives a straight line indicating the following power law relationship at room temperature.

$$V_d = \beta\sigma^n \qquad (5)$$

Where V_d is the steady state penetration velocity normalized by the diameter of the indentor, β is a constant and n is the stress exponent determined by the least squares method and is found to be 7.6.

For creep deformation, a general correlation between activation area and stress for all materials has been suggested by Balasubramanian (1970) based on the assumptions that the creep is single rate process and the dislocation structure remains essentially constant during a change of temperature, pressure or stress. The single rate process creep rate is expressed as:

$$\dot{\varepsilon} = \dot{\varepsilon}_c \exp\,(-\Delta F/kT) \qquad (6)$$

where ΔF is the standard free energy of activation, $\dot{\varepsilon}_c$ is the maximum attainable creep rate at $\Delta F=0$, k is the Boltzmann constant and T is absolute temperature. The correlation they suggested is seen that within a scatter of $\pm$ 0.5 the logarithms of the activation areas of all materials lie on a straight line (with a slope of about -0.9) when plotted against the logarithm of the stress. The activation area of creep deformation is defined as:

$$A = \frac{kT}{b}\left(\frac{\partial \ln \dot{\varepsilon}}{\partial \tau^*}\right)_T \qquad (7)$$

where A is the activation area, τ^* is effective shear stress, T is absolute temperature and b is the Burgers vector of the dislocation. Based on equation (6) and (7), it is suggested that the applied stress can contribute to the activation free energy. For creep mechanism that is due to the motion of dislocation, the external stress can contribute to the activation free energy by helping the dislocation to cross the energy barrier.

The relation between impression stress σ and compression stress σ_c for puri Ti (Imam, 1984, to be published) is found to be:

$$\sigma_c = 0.29\sigma \qquad (8)$$

and this relation is used for Ti-6211 alloy. Assuming the following relationship between effective shear stress and the compression stress:

$$\sigma_c = 2\tau^* \qquad (9)$$

and substituting equations (4), (5), (8) and (9) into equation (7), the activation area for impression creep is obtained as:

$$A = 9.52 \text{ X } 10^{-23}\ \frac{nT}{\sigma},\ \left(\frac{cm^3}{b}\right) \qquad (10)$$

where impression stress is in unit of MPa. A plot of the activation areas obtained from present investigation together with the correlation given by Balasubramanian and Li are given in Fig. 5. The good agreement between the two results indicates that the external stress indeed can contribute to the activation free energy. It further suggests that at certain critical temperature Tc, a steady state creep is possible only by the effect of external applied stress. The relations between critical temperature Tc and the magnitude of minimum external applied stress for steady state creep of different materials can be studied systematically by impression creep tests in order to provide a further understanding of creep mechanism.

CONCLUSIONS

1. The impression creep test can be used to obtain time exponent value of Ti-6211 in the exhaustion creep range.

2. External applied stress at room temperature can activate Ti-alloy to a steady state creep region. The stress exponent was found to be 7.6.

3. The calculated activation area was found to be in good agreement with the predicted behavior of other materials.

4. Impression creep tests under stresses larger than the ultimate strength of material, which can not be performed by conventional tests, are well suited to obtain a relation between critical temperature T_c and the magnitude of the minimum external applied stress for steady state creep and a further understanding of creep mechanism.

REFERENCES

Balasubramanian, N. and Li, J.C.M. (1970). J. Mat. Sci., 5, 434.

Chu, H.P. (1970). J. Mat. Sci., 5, 633.

Chu, H.P. (Jan 1976). Naval Ship Research and Development Center (NSRDC) Report MAT-75-68.

Chu, H.P. (April 1980). NSRDC Report DTNSRDC-SME-80/08.

Chu, S.N.G. and Li, J.C.M. (1977). J. Mat. Sci., 12, 2200.

Chu, S.N.G. and Li, J.C.M. (1979). Mat. Sci. Eng., 39, 1.

Imam, M.A., Rath, B.B., Ehrlich, A. and Gillespie, D.J. (1983). Effect of oxygen on microstructure and properties of Ti-6Al-2Cb-1Ta-0.8Mo alloy. Proceedings of Ti-6211.

Murthy, G.S. and Sastry, D.H. (1982). Phys. Stat. Sol., 70, 63.

Yu, E.C. (1977). Ph.D. Thesis, University of Rochester, N.Y.

Yu, E.C. and Li, J.C.M. (1977). Phil. Mag., 36, 811.

Yu, H.Y., Imam, M.A. and Rath, B.B. (1984). Study of strain rate sensitivity by impression test. J. Mat. Sci., to be published.

Yu, H.Y., Imam, M.A., and Rath, B.B. (1984). Study of the deformation behavior of homogenous materials by impression tests. J. Mat. Sci., in press.

Yu, H.Y. and Li, J.C.M. (1977). J. Mat. Sci., 12, 2214.

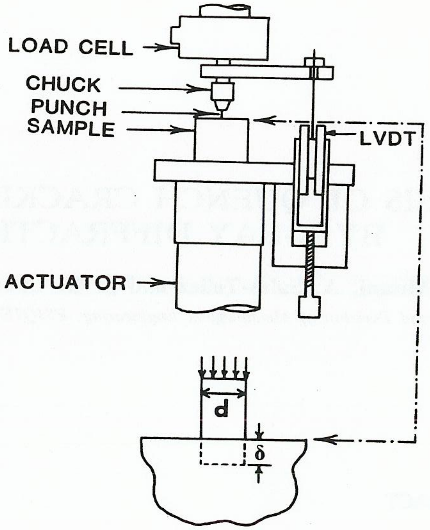

Fig. 1. Schematic of test arrangement for impression creep test.

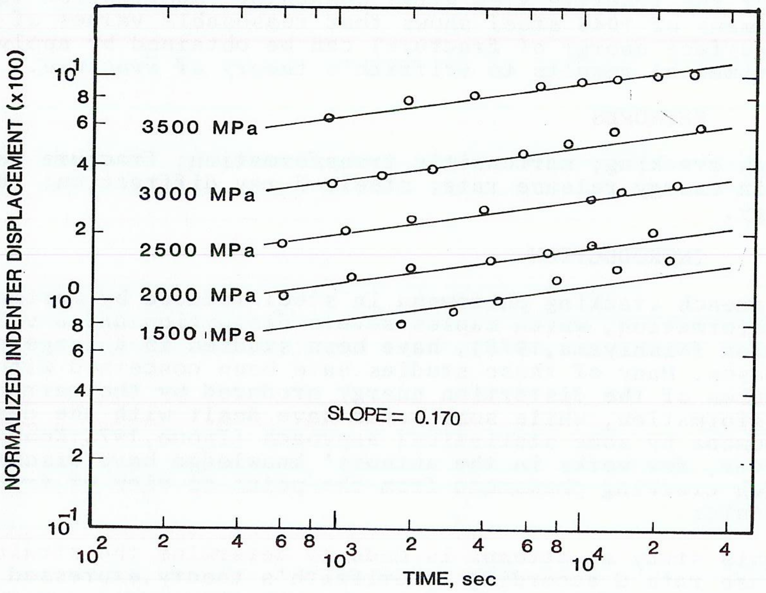

Fig. 2. Impression creep data on Ti-6211 sample A alloy at different stress level.

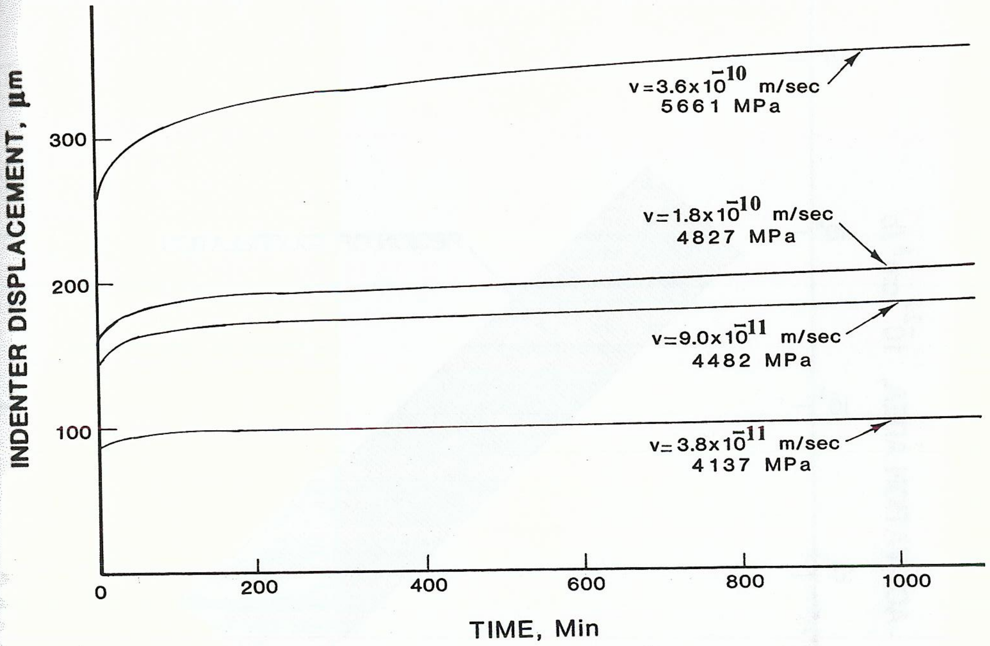

Fig. 3. Typical impressing displacement-time relations in sample E of Ti-6211 alloy.

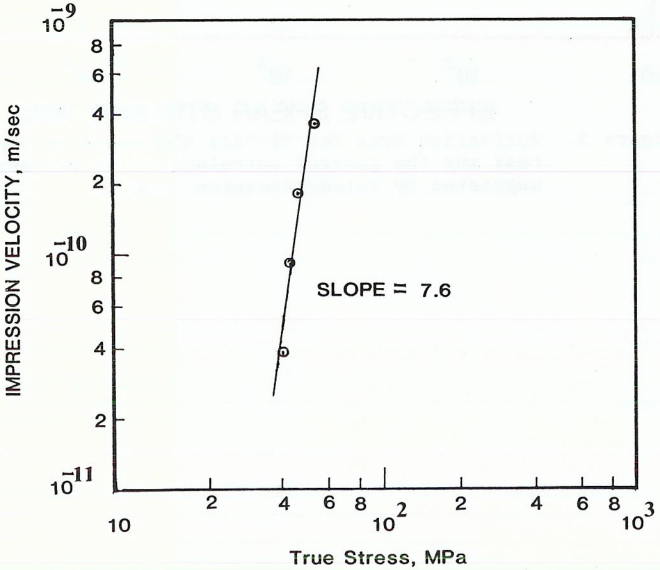

Fig. 4. Stress dependence of steady state impression velocity for sample E of Ti-6211 alloy at room temperature.

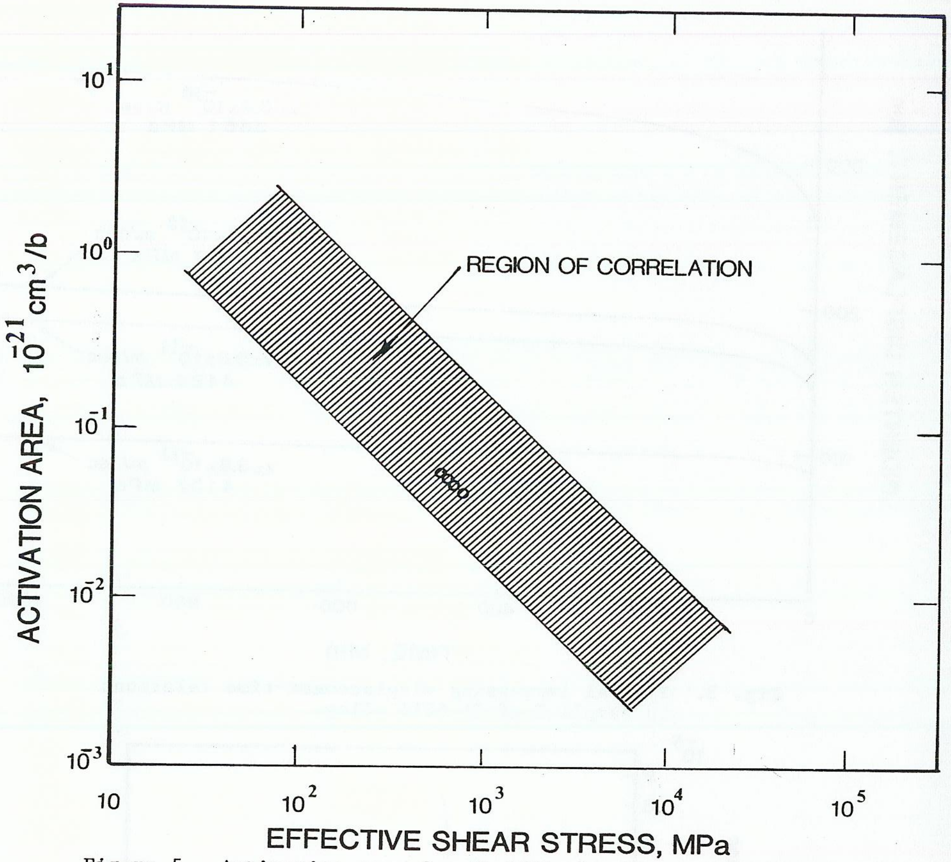

Figure 5. Activation area for Ti-6211 obtained by impression creep test and the general correlation of all materials as suggested by Balasubramanian and Li.