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# Fatigue crack growth behaviour of a near α titanium alloy Timetal 834 at 450 °C and 600 °C

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ABSTRACT

Fatigue crack growth behaviour of a near α titanium alloy Timetal 834 has been studied at maximum dynamic strain ageing temperature (450 °C) and at the service temperature (600 °C). Compact-tension type fracture mechanics specimens have been tested with stress ratio and frequency of 0.1 and 1 Hz, respectively, under constant amplitude loading. The alloy showed higher crack growth rate at 450 °C due to dynamic strain ageing which causes higher stress concentration at the crack tip as compared to 600 °C. The pronounced effect of oxide and roughness induced crack closure revealed from Auger electron spectroscopy and surface profiler, respectively, have been attributed to reduce the stage I as well as stage II fatigue crack growth rate at 600 °C. Fractographic and crack path observations confirmed that the crack growth mechanism remained highly faceted in nature at low $\Delta K$ levels which changes subsequently to striation mode of fracture at relatively higher $\Delta K$ levels.



## 1. Introduction

The compressor disc of advanced gas turbine engine experiences high operating stresses during service loading conditions and falls in the category of "high performance" components [1,2]. In recent past, the service life of compressor discs was generally based on safe-life concept using low cycle fatigue (LCF) design methodology. However, in order to further extend the life of the component, fracture mechanics based damage tolerance code, termed as Engine Structural Integrity Programme (ENSIP), has been recommended. The implementation of damage tolerance philosophy based on fracture mechanics for life extension requires the generation of fatigue crack growth (FCG) database at service temperatures.

Timetal 834 is a near α titanium alloy especially developed for advanced gas turbine engines. LCF behaviour of this alloy at ambient temperature [3], intermediate temperatures [4–6] and at high temperatures [7,8] have already been reported in open literature. The alloy exhibits dynamic strain ageing (DSA) in the intermediate temperature range between 375 °C and 475 °C [4–6] showing maximum DSA effect at 450 °C. However, FCG behaviour of this alloy in DSA regime has not been reported in open literature [9–11]. Dowsen et al. [9] have reported the short and long crack growth behaviour at ambient temperature at different $R$ ratio ranging from 0.1 to 0.7. The study revealed a high degree of interaction between the growing crack tip and the surrounding microstructure. Spence et al. [10] have reported the crack growth behaviour under variable amplitude loading at 350 °C by varying $R$ ratio from 0 to 0.7. Dominant interaction of major and minor fatigue cycles in deter-

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**Nomenclature**

| | |
|---|---|
| $da/dN$ | fatigue crack growth rate |
| $C$ | Paris constant |
| $m$ | Paris constant |
| $\Delta K$ | stress intensity factor |
| $\Delta K_{max}$ | maximum stress intensity factor |
| $\Delta K_{eff}$ | effective stress intensity factor |
| $\sigma_y$ | tensile yield strength |
| $\sigma'_y$ | cyclic yield strength |
| $E$ | young's modulus |
| $\delta_{max}$ | maximum crack tip opening displacement |
| $\delta_{cyclic}$ | cyclic crack tip opening displacement |
| $R_o$ | oxide layer thickness |
| $h$ | average asperity height |
| $R_a$ | average surface roughness |
| $R_{cl}$ | critical value of load ratio |
| $r_P$ | plastic zone size |
| $R$ | sputter rate |
| $M$ | molar weight of the target |
| $r$ | density of the target |
| $e$ | electron charge |
| $S$ | sputtering yield |

mining the overall crack growth rate has been observed. Both the studies [9,10] emphasised the need for using closure corrected data for empirical design purpose for lifting philosophy. Kumar and Nagalaxmi [11] have reported high temperature crack growth behaviour of the alloy by varying frequency. They suggested that at relatively higher temperatures (>550 °C), environmental controlled mechanism such as oxidation can influence the crack growth rate.

In view of the above, the objective of the present study is twofold: (a) to study and compare the crack growth behaviour at 450 °C, where the alloy exhibits maximum DSA effect in comparison to that at 600 °C, and (b) Quantitative estimation of oxide induced crack closure using Auger electron spectroscopy at these test temperatures.

## 2. Experimental

### 2.1. Material and processing

The nominal chemical composition of the near α Timetal 834 titanium alloy is shown in Table 1. Thick plates of 16 mm of Timetal 834 were solution treated (ST) in α + β region at 1025 °C (β-transus temperature ~1045 °C) for 2 h followed by oil quenching. The solution heat-treated plates were subjected to a stabilisation treatment at 700 °C for 2 h before air cooling to room temperature. The microstructure of the heat treated alloy was examined under scanning electron microscopy (SEM; model Leo 440I). The heat treated microstructure as observed is shown in Fig. 1. The alloy shows a bi-modal microstructure which consists of equiaxed primary α in the transformed β matrix. The average size of primary α and prior β grain size was found to be ~10 μm and ~40 μm, respectively. The volume fraction of primary α was estimated to be ~15%.

### 2.2. Fatigue crack growth testing

The standard compact tension type ¾ CT specimens of 6 mm thickness have been extracted from the heat treated 16 mm thick plates in L–T orientation. The fatigue crack growth testing has been conducted under constant load amplitude as per ASTM E 647 standard [12] on Instron 8500 plus servohydraulic test system in air at 450 °C and 600 °C at a stress ratio and frequency of 0.1 and 1 Hz. In order to observe the repeatability of material behaviour, three FCG tests have been conducted under each test conditions. The elastic compliance technique has been used to measure crack length as a function of elapsed cycles.

**Table 1**
Chemical composition of near α titanium alloy Timetal 834.

| Elements | Al | Sn | Zr | Nb | Mo | Si | C | O | N | Ti |
|---|---|---|---|---|---|---|---|---|---|---|
| wt.% | 5.75 | 4.02 | 3.54 | 0.71 | 0.505 | 0.305 | 0.065 | 0.09 | <0.002 | Balance |