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A review on the effect of creep and microstructural change under elevated temperature of Ti6Al4V alloy for Turbine engine Application.

Ochonogor O. F[a], Esther T. Akinlabi[b] and DidierNyembwe[a,b,]*

a. *Department of Mechanical Engineering Science, Faculty of Engineering and the Built Environment University of Johannesburg, Kingsway Campus Auckland Park, Johannesburg, 2006*

b. *Department of Engineering Metallurgy, Faculty of Engineering and the Built Environment, Doornfontein Campus University of Johannesburg 2986*

Abstract

Creep is the likelihood of a solid material to permanently respond to deformation primarily due to initial mechanical stresses.Creep could be severe failure condition in materials that are subjected to heat and structural load which often occur near the melting point for a long period of time as it is the case in turbine engine under operating conditions. Creep is however strain accumulated and time dependent. This paper presents a review on processes models of experimental activities on the creep behavior of Ti6Al4V alloy under different high temperature applications andapplied stresses. This review was conducted by considering the material characterizations that have been carried out on some Ti6Al4V alloys at various levels of high temperatures by previous researchers. This will also feature in a related on-going investigation from a research study currently being undertaken by the authors. It however describes the major causes of mechanical failure of engineering components or structure due to creep mechanism.

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1. Introduction

Creep is the tendency of a solid material to deform permanently due to the influence of mechanical stresses resulting from applied forces. This type of deformation is time-dependent and often reported to occur at elevated temperature and constant stresses [1]. Moreso, this mechanical failure does not occur immediately upon the application of load. The mechanism is however a build-up process ass train accumulates due to long-term stress effect [2].

This study is important for nuclear power plants, jet engines and heat exchangers, also this will enable improvement on the day to day design of many new engineering materials that require high temperature application. Creep behavior is studied by analyzing the creep damage after tests, where the stress exponent (n) and the activation energy (Q) could be calculated.

* Corresponding author. Tel.: +27610564124;
E-mail address: engr.frankiebaba@gmail.com

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The characterization of the operations behind creep deformation mechanisms is therefore possible by analyzing crept microstructure using the TEM. By comparing the calculated values of n and Q and matching values to the literature in correlation to the TEM analysis will lead to better understanding about the operating creep deformation mechanisms [3].The temperatures of a working jet engine could reach up to 1400°C (2550°F) which can be fabricated with Ti6Al4V alloy. Creep mechanism of a fabricated Ti6Al4V alloy especially for turbine application requires very high temperature [4]. At this temperature region, creep deformation is initiated and it becomes so important that the creep deformation behavior of the materials should be well understood.

Titanium and its alloys are known for their excellent and suitable applications for structural components due to reasons that they can be subjected to high temperatures in order to improve their strength- to- weight ratio and corrosion resistance thereby attaining metallurgical stability. However, one of the single neglected but a major factor limiting the application of this special alloy at high temperatures is their affinity to oxygen in response to creep resistance [5]. In order to experience a safe operating life of Ti6Al4V alloys components under conditions at elevated temperature, a good understanding of their creep properties is also highly required. That is, the time-dependent deformation at elevated temperature and constant stress.

Creep behavior of Ti6Al4V alloy is generally a concern in metallurgical and engineering field whenever operating components is subjected to high stresses and high temperature evaluation. This eventually helps in monitoring and predicting the time required for failure of materials to occur. Experimental determination of the rate of accumulated creep strain would help checkmate excessive deformation during the component's service life to aid in quantifying the effects of creep life of the component in question. This can therefore help relieves tensilestresses that might otherwise lead to major failure like cracking**.**

The temperature range at which creep deforms may occur at different levels depending on the response of material to deformation [6]. The rate of deformation is however a function of material properties, exposure to time, temperature and applied structural load[2]. These three dependent variables determine the levels at which creep is degraded resulting to failure. Creep however co-relates to strain as strain is accumulated and determined by a general equation 1.1 as follows:

$$\frac{d\varepsilon}{dt} = \frac{C\sigma^M}{d^b} e^{\frac{-Q}{KT}} \quad \text{..........1.1}$$

where ε is the creep strain, *C* is constant and dependent on the material and creep mechanism, *m* and *b* are exponents dependent on the creep mechanism, *Q* is the activation energy of the creep mechanism, σ is the applied stress, *d* is the grain size of the material, *k* is Boltzmann's constant, and *T* is the absolute temperature.

Investigating the rate at which the creep strain is accumulated would help checkmate excessive deformation during the component's service life. Creep prediction over a range of applied conditions have been proven to correlate to creep strain by the following equation, ε, to time, t,

Using: $\varepsilon=\theta_{1}(1-e^{-\theta 2t}) + \theta_3 (e^{\theta 4t}-1)$ 1.2

Where θ_k (k = 1–4) are the 4-θ coefficients obtained from the experimental behavior. Equation 1.2 can further be broken down into two parts to reveal the two creep mechanism in operation, regarded as: the primary creep which may be represented as $\theta_1 (1-e^{-\theta 2t})$, where θ_1= magnitude of primary strain. θ_2 = determines the rate of decay.

The second part of the creep mechanism is regarded as creep rate due to tertiary effects and can be represented as θ_3 $(e^{\theta 4t}-1)$ with θ_3 scaling the tertiary creep strain and θ4 determines the increase in rate. The coefficients θ_1- and θ_3 are termed "scale" parameters whereas θ_2 and θ_4 are the "rate" parameters (Figure 2.6 below). This method has been shown to accurately predict the creep curves for most pure metals and alloys [7].