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Constitutive equations for elevated temperature flow stress of Ti–6Al–4V alloy considering the effect of strain

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ABSTRACT

In order to study the workability of Ti–6Al–4V alloy, the experimental stress–strain data from isothermal hot compression tests, in a wide range of temperatures (800–1050 °C) and strain rates (0.0005–1 s^{-1}), were used to develop the constitutive equation of different phase regimes ($\alpha + \beta$ and β phase). The effects of temperature and strain rate on deformation behaviors a represented by Zener–Holloman parameter in an exponent-type equation. The influence of strain was incorporated in constitutive analysis by considering the effect of strain on material constants. Correlation coefficient (R) and average absolute relative error ($AARE$) were introduced to verify the validity of the constitutive equation. The values of R and $AARE$ were 0.997% and 9.057% respectively, which indicated that the developed constitutive equation (considering the compensation of strain) could predict flow stress of Ti–6Al–4V alloy with good correlation and generalization.

1. Introduction

As a kind of $\alpha + \beta$ type titanium alloy, Ti–6Al–4V alloy has an attractive combination of characteristics in terms of high mechanical properties, elevated corrosion resistance and low density, which make it an ideal choice for industrial and aeronautical applications [1,2]. The importance of this alloy was testified from the fact that it covered more than 50% of the titanium alloy industrial production [3]. It is well known that the deformation behavior of Ti–6Al–4V alloy is sensitive to the processing parameters such as temperature and strain rate [4]. Therefore, a thorough study on elevated temperature deformation behavior of Ti–6Al–4V alloy is essential to properly design the deformation parameters.

Nowadays, Finite Element Method (FEM) has been widely used as a common tool to find out the optimum deformation parameters. Constitutive equation which represents the flow behavior of materials is used as input to the FEM code for simulating the material's response under the specified loading conditions [5]. The reliability of simulation results are seriously influenced by the accuracy of prediction of the constitutive equation [6]. Most of the constitutive equations are analytical, phenomenological and empirical models. A phenomenological method was proposed by Sellars and McTegart [7] where the flow stress is expressed by the sine-hyperbolic law in an Arrhenius type of equation. Considerable amount of works had been done to modify this equation to suitably applying it to a range of materials [8–10]. A strain-dependent parameter was introduced in the sine-hyperbolic constitutive equation to predict the flow stress of wrought magnesium alloy [11]. A revised sine-hyperbolic constitutive equation was proposed considering the compensation of strain and strain rate to predict the flow stress in 42CrMo steel and Ti-modified austenitic stainless steel [12,13]. A comprehensive review on constitutive equations of austenitic stainless steel, carbon and alloy steels, ferritic steel and Al alloys at elevated temperature was reported in [14].

The objective of this study is to establish the suitable constitutive equation to predict the evaluated temperature flow stress of Ti–6Al–4V alloy. Toward this end, isothermal hot compression tests were conducted over a wide range of temperatures (800–1050 °C) and strain rates (0.0005–1 s^{-1}). The experimental stress–strain data were then employed to derive the constitutive equation relating flow stress, strain rate and temperature considering compensation of strain. Finally, the validity of the developed constitutive equation was examined over the entire range of temperatures and strain rates.

2. Experimental procedure

Commercial Ti–6Al–4V alloy was used for the test. The chemical composition and micrograph are given in Table 1 and Fig. 1 respectively. As shown in Fig. 1, the microstructure of as received Ti–6Al–4V alloy consists of equiaxed primary α phase (hexagonal close-packed) and intergranular β phase (body-centered cubic).

The β transus temperature of Ti–6Al–4V alloy is about 990 °C. Cylindrical specimens were machined with a diameter of 10 mm and a height of 12 mm. In order to obtain the heat balance, each

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