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Influence of microstructures on fatigue damage mechanisms in Ti-15-3 alloy

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ABSTRACT

In this study, the fatigue behavior of Ti-15-3 alloy thin plate specimens with two different microstructures was determined. Two kinds of specimens were prepared with different heat treatments: solution treatment (S) and solution treatment followed by aging (S+A). The effects of the microstructures on the fatigue properties and fatigue crack growth behavior were significant in both specimens. The fatigue crack in both specimens propagated in transgranular mode. In the specimen S+A, crack propagation has occurred on non-crystallographic and was closely connected with the configuration of the α-phase platelet, which was caused by the heat treatment. The damage was characterized by dislocation debris clustering ahead of the crack tip.

1. Introduction

β titanium alloys that possess a body-centered cubic lattice structure (bcc) have been developed to overcome the shortcomings of a pure titanium (also known as α titanium) and α + β titanium alloys. The latter are poor in both deformability and machinability, which are common characteristics of materials with a hexagonal close-packed lattice structure (hcp), and low thermal conductivity. The research on β titanium alloy has been a very important subject in the development of titanium alloy for its good heat treatment strengthening effect, perfect creep resistance and good workability [1]. Moreover, these alloys have a high specific strength and good corrosion resistance. For instance, Ti-15-3 alloy is categorized as one of the β titanium alloys that can be cold-rolled at room temperature. The cold formability of Ti-15-3 alloy offers additional economic advantage for thin sheet applications such as face sheets of composite lay-up structures for use on supersonic aircraft [2]. Cold rolling and aging treatments are an effective way to improve the mechanical properties of metals and alloys [3–5]. It is evident that the heat treatment might significantly affect the fatigue crack growth behavior in β titanium alloys [6]. It was reported that the condition for crack propagation is governed by the high density dislocation band structures that develop in slip bands [7,8]. A number of studies have been conducted on effects of solution treatment on the microstructure and mechanical properties [1,9,10] as well as fatigue performance of the microstructural changes induced by the heat treatment [2,11]. Extensive research works on titanium alloy have been made to develop the relationship between microstructure and mechanical properties [4,5,12]. However, few attempts have been made to clarify the fatigue damage mechanisms of β titanium alloys from the microstructural and crystallographic point of view.

The aim of the present study is to further clarify the fatigue damage mechanisms of Ti-15-3 alloy from a microcrystallographic viewpoint. To investigate the effects of the microstructures on the fatigue behavior, fatigue tests were carried out on two different types of specimens that underwent two different heat treatments: solution treatment and solution treatment followed by aging. Microstructural examinations were carried out by optical microscopy as well as scanning (SEM) and transmission (TEM) electron microcopy.

2. Experimental procedure

The material used was Ti-15-3 alloy with an initial thickness 0.5 mm. The chemical composition is given in Table 1. After the plate was cold-rolled at room temperature to a thickness of 0.35 mm: a single edge U-notched specimen (stress concentration factor $K_t = 4.7$) was machined from the plate to a dimension of 10 mm × 55 mm × 0.3 mm. The specimen's geometry is shown in Fig. 1. The heat treatment was conducted in two ways to produce different microstructures in the specimens after annealing for 2 h at 973 K in vacuum (6.7×10^{-3} Pa). The former samples were solution treated for 0.5 h at 1073 K (above the β transus 1033 K), which was followed by fan cooling (hereafter referred as specimen S). The average size of the β-phase grain was 45 μm. In the second case, the samples were aged for 8 h at 773 K after the above solution treatment (hereafter referred as specimen S+A). The microstructure of the specimen before heat treatment is given in Fig. 2. The

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