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Strain ageing in γ(TiAl)-based and $\alpha_2(Ti_3Al)$ titanium aluminides

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Abstract

Deformation of $\alpha_2(Ti_3Al)$ and γ(TiAl)-based alloys between 150 and 550 °C is characterized by negative strain-rate sensitivity and strain ageing effects. These phenomena are usually associated with dislocation locking according to the Portevin-LeChatelier effect. The dislocation pinning processes associated with these phenomena were studied by static strain ageing experiments. The dislocation locking is generally more significant for off-stoichiometric compositions, when compared with stoichiometric α_2 or γ alloys leading to the conclusion that antisite atoms are involved in the dislocation locking mechanism. The main features of this mechanism are described in the present paper together with its effects on the deformation behaviour.

Keywords: A. Titanium aluminides based on TiAl and Ti_3Al; B. Strain ageing; D. Defects: point defects

1. Introduction

Gamma-based titanium aluminide alloys are promising candidates for high temperature structural applications. Current investigations focus on Ti-rich alloys close to the stoichiometric composition of γ(TiAl) with modest amounts of several ternary elements [1,2]. These alloys are mainly composed of the intermetallic phases $\alpha_2(Ti_3Al)$ and γ(TiAl) (Fig. 1). The yield stress of the two-phase alloys was found to be nearly independent of temperature in the temperature interval 25−700 °C. Nevertheless, there are three domains in this temperature interval where different dislocation mechanisms occur. At room temperature the dislocation velocity is controlled by a combined operation of lattice friction, jog dragging, and localized pinning in particular due to antisite defects [4]. The glide resistance provided by these mechanisms gradually decreases with increasing temperature and apparently disappears at 150 °C. This is indicated by the fact that the reciprocal activation volume becomes zero at this temperature, thus indicating that there is sufficient thermal energy for the barriers to be overcome by thermal activation alone. Deformation at temperatures in excess of 600 °C is determined by dislocation glide and climb.

Deformation in the intermediate domain between 150 and 450 °C is characterized by discontinuous yielding, negative strain rate sensitivity, and strain ageing effects. These phenomena were associated with dislocation locking according to the Portevin-LeChatelier effect [5,6]. For γ-based TiAl alloys the relevant pinning mechanism was investigated by static strain ageing experiments [5,6]. Recent studies have shown that the strain ageing phenomena are strongly enhanced in alloys with off-stoichiometric compositions giving supporting evidence that antisite defects are strongly involved in dislocation locking [4,7]. The locking mechanism and its effects on tensile elongation and fatigue properties will be discussed.

2. Experimental methods

The paper extends previous studies [4,7] in that additional alloys were investigated, for which the details are listed in Table 1. The EDX analysis and the microstructural investigations were performed on a Zeiss DSM 962 scanning microscope. The tensile samples with a gauge diameter and gauge

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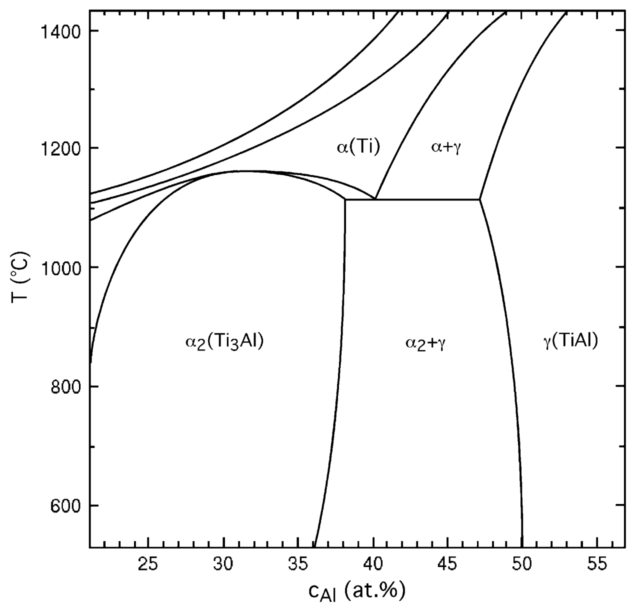

Fig. 1. TiAl phase diagram [3].

length of 3.5 and 21 mm, respectively, were prepared by spark erosion, turning, grinding and final polishing. The mechanical tests were performed on a servo-hydraulic close loop machine (MTS 810.22) with the sample elongation used as feed-back parameter.

3. Strain ageing locking mechanism

It has been widely accepted that strain ageing phenomena are closely related to the presence and mobility of atomic defects, which in titanium aluminide alloys depend on deformation parameters and composition. The experiments were designed to identify the controlling mechanism by measuring the extent of strain ageing as function of temperature, time, and alloy composition. The samples were deformed in compression to different levels of pre-strain, aged under a relaxing stress for certain ageing periods t_a starting from the flow stress σ_ϵ of the material at strain ϵ. On reloading distinct yield points $\Delta\sigma_a$ occurred after which the original stress strain curve was retraced so that there was no permanent hardening effect. This deformation behaviour corresponds to a situation in which pinning of dislocations occurs due to the formation of defect atmospheres. Thus, the degree of dislocation locking should be reflected in the extra stress increment $\Delta\sigma_a$ necessary for continuing the deformation. Fig. 2 shows the load elongation trace of a strain ageing experiment and defines the ageing parameters σ_ϵ, $\Delta\sigma_a$, and t_a utilized in the study.

Fig. 3 demonstrates the dependence of the stress increments $\Delta\sigma_a$ on the ageing time t_a determined for different temperatures on a two-phase Ti–48.5Al–0.37C alloy. For this evaluation only the values estimated at the beginning of deformation at strain $\epsilon = 1.25\%$ were used in order to avoid any influence of the strain dependence of $\Delta\sigma_a$. As indicated by the double logarithmic plot of the data (Fig. 3b), the strain age yield point apparently becomes saturated over the time scale of the experiments leading to saturation values $\Delta\sigma_s$.

The influence of composition on strain ageing was investigated by comparing the saturation values $\Delta\sigma_s$ of the stress increments $\Delta\sigma_a$. These stress increments represent the maximum pinning strength of the dislocations that can be achieved under the respective ageing conditions and might thus be

Table 1
Alloy compositions, thermo-mechanical treatments and microstructures

Alloy	Composition (at.%)	Processing	Microstructure
1	Ti–47Al	HIP(1220 °C/4 h/180 MPa) IF(1250 °C/80%) TT(1030 °C/2 h/FC)	Equiaxed, average γ grain size 30 μm
2	Ti–47.5Al–1.5Nb–1Mn–1Cr–0.2Si–0.5B	HIP(1185 °C/4 h/140 MPa) IF(1250 °C/80%) TT(1030 °C/2 h/FC)	Equiaxed, average γ grain size 30 μm
3	Ti–47Al–1.5Nb–1Mn–1Cr–0.2Si–0.5B	HIP(1220 °C/4 h/180 MPa) IF(1250 °C/80%) TT(1030 °C/2 h/FC)	Equiaxed, average γ grain size 20 μm
4	Ti–45Al–10Nb	HIP(1185 °C/4 h/140 MPa) IF(1300 °C/90%) TT(1030 °C/2 h/FC)	Nearly lamellar, average colony size 100 μm

All alloys were prepared by double or triple vacuum arc melting (VAR) and supplied as 30–150 kg ingots. HIP: hot isostatic pressing, IF: isothermal forging, TT: thermal treatment.

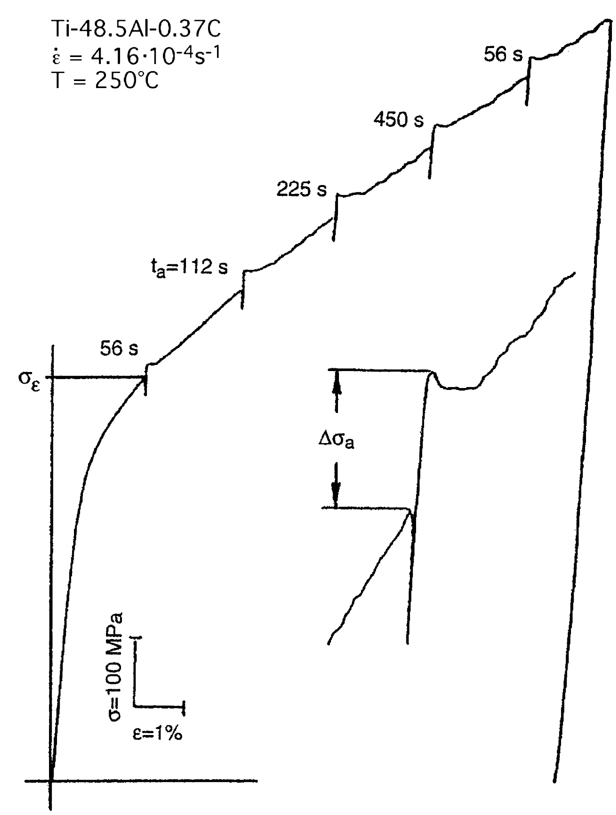

Fig. 2. Sequence of a strain ageing experiment performed under a relaxing stress on a Ti–48.5Al–0.37C alloy. The stress increments $\Delta\sigma_a$ were measured as the difference in stress before ageing and the upper yield point occurring on reloading. Different time intervals t_a between unloading and subsequent reloading are indicated. Note the dependence of the stress increments on strain ϵ.