EFFECT OF MICROSTRUCTURES ON CYCLLC-OXIDATION BEHAVIOUR OF TiAL ALLOY①

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ABSTRACT The influence of microstructures on the cyclic oxidation behaviour of Ti-33Al-3Cr-0.5Mo(%) alloy was investigated. It was clarified that the oxidation behaviour of the alloy with near-gamma, duplex and fully-lamellar microstructure are very similiar in air at 1 173K and their mass gain is much lower than that of the alloy with nearly-lamellar microstructure. The reason for the difference in oxidation behaviours was attributed to the morphologies of Al_2O_3 layer in the oxide scale.

Key words γ-TiAl oxidation microstructure morphology Al_2O_3 oxide scale

1 INTRODUCTION

In recent years, γ-TiAl has attracted extensive attentions from the aerospace community and the automobile industry because of its potentially attractive properties for high temperature structural applications, such as low density and high temperature strength retention[1-3]. However, their room-temperature brittleness and inadequate oxidation resistance at above 1173K are the hindrances for application. It has been well known that the mechanical properties of γ-TiAl depend strongly on the microstructures[4], which can be classified as four groups, that is, near gamma (NG), duplex (DP), nearly-lamellar (NL) and fully-lamellar(FL), Many investigations[5,6] showed that homogeneously fine-grained microstructure can yield better mechanical properties. However, the effect of microstructures on the oxidation behavours of γ-TiAl has seldom been studied, although a lot of papers on the oxidation properties of TiAl-based alloys have been published[7-10]. In the present paper, it will be shown that different microstructures can lead to different oxidation behaviours of γ-TiAl. The reason for these behaviours wil be discussed.

2 EXPERIMENTAL

Ingot of alloy, with nominal composion of Ti-33Al-3Cr-0.5Mo (%) was prepared with selfconsumable arc melting technique, using titanium sponges (99.9% in purity), aluminium platelets (99.9% in purity), pure chromium and pure molybdenum as raw materials. After the alloy was processed with multi-step thermal-mechanical treatment(MSTMT)[11], four types of microstructures, that is, near-gamma, duplex, nearly-lamellar and fully-lamellar, were controlled through the final heat treatment as follows: 1000 ℃, 24h; 1250 ℃, 4h; 1280 ℃, 3.5h; 1310 ℃, 2.5h.

Oxidation test cylinders with a dimension of *d* 5mm × 10mm were cut from the processed pancake. After specimens were polished mechanically, cyclic oxidation, consisting of repeated heating at 1173K for 10h and cooling to room temperature in static air, was carried out. The oxidation behaviour was evaluated by measuring the mass gain per unit area of the specimen. Optical microscope, EDAX (energy-dispersive anslysis of X-ray) and WDAX (wave-dispersive analysis of X-ray) were used to analyze the oxide scales formed on the specimens.

① Supported by the National Natural Science Foundation of China; Received Sep. 10, 1995, accepted Jan. 17, 1996

3 RESULTS

3.1 *Oxidation Behaviours*

By MSTMT, four types of microstructures, i. e., near-gamma, duplex, nearly-lamellar and fully-lamellar, were formed in the alloy,

Fig. 1 Cyclic oxidation kinetic curves of Ti-33Al-3Cr-0.5Mo alloy
1—DP; **2**—FL; **3**—NG; **4**—ML

and the grain size was about 20μm. Fig. 1 shows the cyclic oxidation behaviour of these specimens with the four types of microstructures. It was found that the oxidation rate of all specimens progressed according to a parabolic law. The specimens with duplex, near-gamma and full lamellar microstructure have very similiar oxidation behaviours, and the oxidation resistance of the specimen with duplex microstructure is slightly higher than those of the specimens with near-gamma and fully-lamellar microstructures. near-gamma and fully-lamellar microstructures. Compared with the three specimens mentioned above, the oxidation resistance of the specimen with nearl-lamellar microstructure is much lower. After cyclically oxidated at 900℃ for 60h, the mass gain of the specimen with NL is 1.75 times that of DP, 1.5times that of FL, and 1.48times that of NG.

3.2 *Morphologies of Oxide Scales*

Fig. 2 shows the optical images of typical specimen cross-sections after being oxided cyclically at 1173K for 60h. In all cases, the oxidescales were similar and can be divided into seven layers according to the morphologies of the microstructures. The composition of the selected area in the scale was given by EDAX, as shown in Table 1. The table shows that there are differences in chemical composition among the seven layers. By measuring the distribution of oxygen in the scale with WDAS, it is confirmed that the compositions of the layers are corresponding to Ti_3Al, TiO_2+ Al_2O_3 and TiO_2, respectively.

Table 1 Average compositions of the layers in the scale of the sample with fully-lamellar microstructure

mole fraction/ %

Composition	Layers						
	A	*B*	*C*	*D*	*E*	*F*	*G*
Ti	74	56	39	30	21	42	76
Al	24	42	58	65	74	53	18
Cr	2	2	3	5	4	5	6

Note: Layer *A* is the closest layer to the matrix, and layer *G* is the outer layer.

It is noticeable that the morphology of Al_2O_3 layer depends on the alloy microstructure. In the scale on the specimens with near gamma, duplex or fully-lamellar microstructures, the Al_2O_3 layer is continuous, but the Al_2O_3 layer in the scale on the specimen with nearly-lamellar microstructure is uncontinous. Thus, it can be concluded that the different oxidation behaviours were caused by the different morphologies of the Al_2O_3 layers.

4 DISCUSSION

The morphology of Al_2O_3 layer played an important role in the growth of oxide scale. During the formation of the scale, the porous TiO_2 act as channels for atoms to transport. The dirfusion of Ti atoms outward to oxygen atoms inward could occur along the channels. If the Al_2O_3 laver is continuous, it can change the inter-diffusion rate, and act as a barrier for atoms to transport. But when the Al_2O_3 grows as nod-

oss-sections of Ti-33Al-3Cr-0. 5Mo alloy with NG(a), DP(b), NL(c) and FL(d) microstructures after oxidation for 60h at 1173K, × 300

ules outward, the continuity of the Al_2O_3 layer would be lost. As a result, the diffusion of atoms in the scale would be very easy and the oxide scale would grow rapidly. Therefore, the conti-nuity of the Al_2O_3 layer is most important in this case. It is the uncontinuity of the Al_2O_3 layer in the scale on the specimen with nearly-lamellar microstucture that leads to the poorer oxidation rdsistance.

In order to improve the oxidation resistance of the TiAl-based alloys, it may be necessary to obtain homogeneously fine-grained microstructure besides beneficial additives. Gil *et al*[12] showed that the oxidation behaviour of the γ-TiAl was strongly affected by the distribution of α_2 and γ phase in this alloy, as well as by the grain size. They found that in all cases γ-TiAl is an alumina former whereas most α_2-composition forms a titania scale. If small smount of α_2-phase is homogeneously amd finely dispersed in γ phase, the formation of could be avoided initially and finely dispersed in γ-phase, the formation of titania could be avoided initially and a vontinuous alumina oxide layer would be frmed eventually, just as shown in Fig. 2(a), (b) and (d). If the TiAl-based alloys have large epuiaxed grains, the aluminum diffusion in these grains is too difficult to form a stable alumina layer, and a big tendency to form a non-protective titania-based scale would occur. Howver, the effect of the relative amount of the two phases on the oxidation behavior is still unknown. The mechanism of diffusion of atoms in the γ-Tial with different microstructures is under investigation.

5 CONCLUSIONS

(1) The oxidation behaviour of the TiAl-based alloys depends strongly on the alloy microstructures. The alloys with near-gamma, duplex and fully-lamellar microstructure have very

similar oxidation beaviors, but the alloy with nearly-lamellar microstructure corresponds to poorer oxidation resistance.

(2) The scales on the samples with four types of microstures in the present study have almost the same structure, except that the morphologies of the Al_2O_3 layer are different, which depend on the alloy microstructure.

(3) The differences in oxidation behaviors for the specimens with nearly-lamellar and other three types of microstructures resulted from the dirrerent morphologies of the Al_2O_3 layer in the scales. The uncontinuity of the Al_2O_3 layer leaded to poorer oxidation resistance of the specimen with nearly-lamellar microstructure.

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(Edited by Peng Chaopun)

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Taking it into consideration that no difference in cutting mechanism exists between non-full depth cuts and full depth cuts, so the friction angles β and shear stresses τ_s in Table 1 are still used in calculation. In face the data obtained in full depth cutting tests are used to predict the cutting forces of non-full depth cuts. It is shown that the theoretical values predicted in this way agree well with experimental results.

4 CONLUSIONS

(1) A mechanics model for circular form tool cutting is proposed. Based on this model the theoretical cutting force formula and cutting equation are derived. The theoretical values predicted according to the formula presented in this paper are verified experimentally and results show that theoretical predictions agree well with experimental results.

(2) Circular form tool cutting may be considered as the extension of orthogonal cutting.

(3) The specific cutting force of circular form tool cutting changes with different cutting geometry. The reason for this is that under the same cutting conditions the shear angle for non-full depth cuts is smaller than that for full depth cuts. The specific cutting force of the former is therefore larger than that of the later.

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(Edited by Zhu Zhongguo)