INFLUENCE OF TEST TEMPERATURE ON FRACTURE OF TIALCRNB ALLOY

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VPLYV SKÚŠOBNEJ TEPLOTY NA LOM TIALCRNB ZLIATINY

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Abstrakt

Študovali sa intermetalické zliatiny Ti-48Al-2Cr-2Nb, vyrobené z elementárnych práškov metódami práškovej metalurgie. Homogenizovaná zmes prášku bola lisovaná izostaticky za studena (CIP), a potom za tepla deformovaná jednostupňovým, alebo dvojstupňovým pretláčaním. Nakoniec sa skúšobné tyče kovali izostatickým lisovaním za tepla (HIP). Takto pripravené materiály sa skúšali skúškou v ťahu pri teplote 20 a 700°C. Skúmali sa vzťahy medzi mechanickými vlastnosťami, technológiou výroby, skúšobnou teplotou, konečnou mikroštruktúrou, analyzovali sa lomové povrchy a študovali sa mechanizmy porušovania. Pri 20°C bol dominantný mechanizmus lomu - transkryštalické štiepenie gama fázy a transkryštalické štiepenie lamelárnej štruktúry. Naopak pri 700°C u oboch materiálov pokleslo transkryštalické štiepenie gama fázy pod 8%. Hlavným mechanizmom lomu bolo transkryštalické štiepenie lamelárných kolónií a interkryštalický lom gama fázy. Navrhli sme model lomu veľmi jemnej lamelárnej štruktúry a popísali lomový mechanizmus takejto mikroštruktúry.

Abstract

Intermetallic Ti-48Al-2Cr-2Nb alloys manufactured from the elementary powders by two PM technologies were studied. The homogenized mixture was compacted by cold isostatic pressing (CIP), then deformed by hot single, or double extrusion, and finally compacted by hot isostatic pressing (HIP). The prepared materials were tensile tested at room temperature and 700°C. Mechanical properties were related to the production technology, test temperature, microstructure, fracture surfaces were analyzed, and fracture mechanisms were studied. The dominant fracture mechanisms were at room temperature transcrystalline cleavage of gamma phase and transcrystalline cleavage of lamellar colonies. On the other side, at 700°C for both tested materials transcrystalline cleavage of gamma phase decreased to less than 8%. Main mechanisms of fracture were transcrystalline cleavage of lamellar colonies and intercrystalline fracture of gamma grains. A fracture model of the very fine lamellar structure was proposed, and fracture mechanism was described for the obtained microstructure.

Introduction

Intermetallic Ti-Al based PM alloys are marked by very attractive combinations of mechanical properties suitable firstly for high temperature applications. In comparison with commercial titanium alloys they have higher Young's modulus, lower specific density, higher strength, for temperatures up to 800°C, and better resistance to oxidation. Their application is however limited, due to very low ductility, and fracture toughness [1-3].

Pure titanium has got two allotropic modifications: the low-temperature alpha phase with hexagonal lattice, and the high-temperature beta phase with cubic body centered lattice. Alloying elements are classified as alpha stabilizers (Al, C, N, O_2), or beta stabilizers (Mo, Cr, V, Nb), according to their different solubility in alpha or beta phases. The binary Ti-Al phase diagram shows existence of Ti-alpha phase at high temperatures for the composition range of 44-48 at.%Al. It is decomposed at 1125°C to eutectoid Ti_3Al-alpha2 phase and TiAl-gamma phase, Fig.1 [4].

Fig.1 Binary Ti-Al phase diagram

The Ti_3Al-alpha2 phase has a regular hexagonal lattice with five independent sliding directions. Deformation at different temperatures is achieved by dislocation movement (1/3)<1120> on prismatic, (0001) basal and {1011} pyramidal planes. Ductility of Ti_3Al phase can be increased by adding of Nb, a stabilizing substituent of the beta phase. In this way a two phase alpha2+beta microstructure can arise. Cr is also a stabilizing substituent of the beta phase resulting higher strength. Alloys with Cr decompose at higher temperatures to eutectoid beta phase, with a deposition of $TiCr_2$, the later decreasing the plasticity of the alloy. To increase strength, it is more favorable to use such alloying elements as Mo or V, causing no deposits by the eutectoid reaction [3].

The phase TiAl-gamma has a tetragonal lattice. Cleavage in the TiAl-gamma phase occurs on cleavage planes {111}. In accordance with Ti-Al binary phase diagram for Al content 46-52 at. %, the alloy can have one phase (gamma) or two phases (gamma + alpha2). The most common alloying elements are V, Cr, Mo, Nb, Ta, playing important role in the increase of strength, plastic properties or oxidation resistance [4,5].

Experimental material,test methods, and results

Intermetallic PM alloy Ti-48Al-2Cr-2Nb was prepared, starting with elementary powders of Ti, Al, Cr, Nb. The material was blended in the required percentage. The homogenized mixture was compacted by cold isostatic pressing (CIP) at 110 MPa. Single or double hot extrusion was applied. The single one at a reduction rate 12.6, the double at 131.5. The reduction rate is calculated as the original divided by the final cross-section area. Extrusion temperature was 700°C. After extrusion the material was encapsuled and hot isostatic pressed (HIP temperature 1270°C, pressure 200 MPa during 4 hours). Then annealing followed at 1000°C during 24 hours.

Test pieces for tensile testing were machined for tests at room temperature and 700°C. The microstructure of the tested material were studied by light microscopy and scanning electron microscopy (SEM). The microstructure as well as the fracture surfaces were analyzed by LINK ISIS 300 microanalyzer, and microhardness tested by Vickers HV 0.02. Microhardness was measured in gamma grains (GG) and lamellar colonies (LC). Test pieces were labelled according to the production technology and test temperature applied as shown in Tab.1.

Table 1 Ti-48Al-2Cr-2Nb preparation technology and test results

Sample No.	Preparation technology	Test temp. [°C]	Strength Rm [MPa]	Microhardness HV 0.02 GG	LC
S20	single extr. + HIP	20	382	332	586
S700	single extr. + HIP	700	370	322	493
D20	double extr. + HIP	20	511	371	603
D700	double extr. + HIP	700	430	306	465

Microstructure and fractography

Sample No. S20

The microstructure on cut-offs from this sample after testing at room temperature contained: irregular polyhedral grains of gamma phase (TiAl) and lamellar grains formed by two phases, alpha2 phase (Ti3Al), and gamma phase (TiAl). Grain sizes ranged for gamma phase from 30 to 50 µm, and gamma phase grains represented 25% of area. The size of lamellar colonies was in range from 120 to 150 µm, Fig.2. Quantitative chemical analyses were made by LINK ISIS 300 microhead on the metallographic samples Analyses showed in gamma phase grains Ti (50.1-54.36 at%), Al (39.3-42.3 at%), Cr (2.5-2.7 at%), Nb (2.2-3.4 at%); in localities with lamellar microstructure: Ti (60.4-62.6 at%), Al (32-35.6 at.%), Cr(2.3-2.6 at%), Nb (1.2-1.8 at%). Microhardness measured in areas of gamma phase was 314-350 HV 0.02, and in areas of lamellar microstructure 504-667 HV 0.02. Strength was 382 MPa, the plastic properties less than 2%. Fracture surface showed, the transcrystalline cleavage was the main mechanism of failure, Fig.3. Intercrystalline fracture was not observed at all. Two types of transcrystalline cleavage has been identified: transcrystalline cleavage of gamma phase and transcrystalline cleavage of lamellar colonies, Fig.4. The transcrystalline facets of gama phase showed river like marks, suggesting reinitiation of the transcrystalline cleavage.

Sample No. S700

The microstructure after testing this material at 700°C consisted as in the previous sample the same structural components: irregular polyhedral gamma phase grains and lamellar colonies of alpha2 phase and gamma phase. However, their percentage was different. The proportion of gamma phase was 21%. Grain size of gamma grains ranged from 50 to 60 µm and the size of lamellar colonies from 150 to 200 µm. Chemical compositions were for localities of gamma phase Ti (51.8-52.9at%), Al (39.8-42.7at%), Cr (2.5-2.9at%), Nb (2.0-3.4at%), and localities of lamellar microstructure Ti (61.4-62.1at%), Al (33.4-35.4at%), Cr (2.3-2.4at%), Nb (1.2-1.6 at%). Microhardness measured in areas of gamma phase was 249-389 HV 0.02 and in areas of lamellar structure 440-575 HV 0.02. Strength of this material was 370 MPa, and less than 1%.

The dominant fracture mechanism was transcrystalline cleavage of lamellar colonies, and intercrystalline separation, Fig.5. The later fracture mechanism represented 30-35 % of the fracture. The transcrystalline cleavage of gamma phase occurred only in few spots. On intercrystalline fracture surfaces increased content of O_2, C, Fe was measured by LINK ISIS 300 microanalyzer.

Sample No. D20

The microstructure of samples tested at room temperature contained gamma phase Ti3Al and lamellar colonies (alpha2 plates+gamma slats). Grain size of polyhedral gamma grains was from 30 to 35 µm and the size of lamellar colonies from 80 to 150 µm. The portion of gama phase represented 50%, Fig.6. Chemical analyses resulting in gamma phase grains Ti (53.2-54.1at%), Al (37.2-41.8at%), Cr (2.3-2.4at%), Nb (2.1-2.4at%), in localities with lamellar microstructure Ti (61.2-62.7at%), Al (32.7-34.6at%), Cr (1.9-2.3at%), Nb (1.1-1.6at%). Microhardness measured in areas of gama phase was 350-392 HV 0.02 and in areas of lamellar structure 539-667 HV 0.02. Strength was 511 MPa and plasticity less than 1%. Fractography analyses confirmed, the main mechanism of failure of the material is transcrystalline cleavage both of gamma phase and lamellar colonies. Transcrystalline cleavage of gamma phase showed facets with rivers, Fig.7.

Sample No. D700

Microstructure contained: irregular polyhedral gamma phase (TiAl) and lamellae formed by alpha 2 (Ti3Al) and gamma phase (TiAl). Gamma grain size was from 30 to 50 µm and the size of lamellar colonies from 120 to 150 µm. Proportion of gamma phase was 42%. Chemical analysis results showed in gamma phase Ti (54.8-55.8 at%), Al (38.8-39.7at%), Cr (1.4-1.8 at%), Nb (2.1-2.3at%); in localities of lamellar microstructure Ti (60.35-61.1at%), Al (33.4-34.4at.%), Cr (2.1-2.3at%), Nb (1.6-1.9at%). Microhardness measured in the gamma phase grains was 298-314 HV 0.02, and in areas of lamellar microstructure 392-520 HV 0.02. Strength was 430 MPa, and the plasticity less than 1%. The following mechanisms of failure were identified: transcrystalline cleavage of gamma grains, transcrystalline cleavage of lamellar colonies, and intercrystalline separation, Fig.8. Transcrystalline cleavage of gamma phase was exceptional in the fracture surface. The main fracture mechanism was transcrystalline cleavage of lamellar colonies, and intercrystalline separation of gamma grains, Fig.9. On intercrystalline fracture surfaces increased content of O_2, C, Fe was measured by LINK ISIS 300 microanalyzer.

Discussion

From the point of strength double extrusion of Ti-48Al-2Cr-2Nb appears to be the best choice. The gamma grain was relatively fine (30 µm) and the lamellar colonies, too (size 120 µm). The highest strength value was measured by tests at room temperature. Fractography analyses proved that transcrystalline cleavage of gamma phase, and cleavage of lamellar colonies were the main fracture mechanisms at room temperature. The main mechanism of fracture at 700°C changed to cleavage of lamellar colonies with intercrystalline fracture of gamma grains.

Cleavage of lamellar structures lead to rough fracture surfaces. The rugged surface of cleaved lamellar facets is caused by the fact that cleavage is a discontinuous process in this body. The propagation is a succession of crack arrests and reinitiations with several nucleations. The fracture surface is profiled by ductile tearing ligaments between cleavage cracks in the alpha 2 phase. Rivers on cleavage facets more or less follow the direction of lamellae.

The process of failure is understood as the process introduced in Fig.10. showing cleavage planes in non-polyhedral microstructure of alpha2 phase slats with small mutual disorientation. Deformation can start in a locality by a dislocation crack oriented along the {1000} plane, Fig.10a. The slats are not wide. The crack will not achieve the Griffith's size and does not spread as a cleavage crack into the whole grain or set of slats. It is arrested on the first obstacle, sub grain boundary, or in gamma phase. The crack tip is a stress concentrator influencing the repeated nucleation of cleavage somewhere near in adjacent subgrains. However, in majority, the next cleavage would be in a different direction or different plane. Ductile tearing interconnects the cracks. The fracture has a directed trajectory by the microstructure, controlled by cleavage planes. We suppose, it would be suitable to call this mechanism as quasi cleavage.

In a microstructure with greater gamma grains, the cleavage process is continuous. Lamellar microstructure has specific stages of cleavage on facets, several reinitiations and so the process is incoherent. We define the difference between cleavage and quasi cleavage fractures by the fact, that new cracks in quasi-cleavage fractures are nucleated in front of the initial crack but they do not start from that one. The interconnection of the initial crack and new ones is formed later by ductile tearing of the left ligaments, Figs.11,12.

Fig.10 Fracture of lamellar colonies

Significant decrease of strength was measured at 700°C. Considerable amount of intercrystalline fracture was observed. It's portion corresponded approximately to the content of gamma grain in the metallographic sample. The change from transcrystalline cleavage to intercrystalline separation is explained by weakening grain bounds at 700°C. It is caused by impurities on grain boundaries. Segregation of impurities was identified by LINK ISIS 300 microanalyzer. On intercrystalline fracture surfaces increased content of O_2, C, Fe was measured.

Conclusion

Fracturing samples after single or double extrusion at room temperature showed: the dominant fracture mechanisms were at room temperature transcrystalline cleavage of gamma phase and transcrystalline cleavage of lamellar colonies.

For both tested materials at 700°C fractography showed: transcrystalline cleavage of gamma phase represented less than 8%. Main mechanisms of fracture were transcrystalline cleavage of lamellar colonies and intercrystalline fracture of gamma grains.

The change from transcrystalline cleavage to intercrystalline separation is explained by weakening grain bounds at 700°C.

A fracture model of lamellar microstructure was intoduced and described.

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