EFFECT OF INITIAL MICROSTRUCTURE ON Ti-48Al-2Cr-2Nb ALLOY PLASTICITY

Szkliniarz W.
Silesian University of Technology, Krasińskiego 8, 40-019 Katowice, Poland
e-mail: wojciech.szkliniarz@polsl.pl

VPLYV VÝCHODISKOVEJ MIKROŠTRUKTÚRY ZLIATINY Ti-48Al-2Cr-2Nb NA TVÁRNOSŤ

Szkliniarz W.
Sliezska technologická univerzita, Krasinskiego 8, 40-019 Katowice, Poľsko
e-mail: wojciech.szkliniarz@polsl.pl

Abstrakt

Príspevok je venovaný vplyvu východiskovej mikroštruktúry dvojfázovej zliatiny Ti-48Al-2Cr-2Nb na jej tvárnosť pri teplote okolia, rovnako ako aj podmienkam tvárnenia za tepla založeným na skúškach tlakom uskutočnených pri teplote okolia na skúšobnom zariadení INSTRON 4483 a pri teplote 1000°C využitím simulačného programu systému Gleeble 3800. Bolo zistené, že zliatina v liatom stave sa nedeformuje ani za studena, ani za tepla. Bolo stanovené, že homogenizácia chemického zloženia a mikroštruktúry zliatiny umožňuje obmedzenú deformáciu počas procesu tvárnenia za tepla a deformácia za tepla je možná iba v dôsledku po sebe nasledujúcich procesoch viacstupňového tepelného spracovania. Zjemnenie zrna skúmanej zliatiny a zvýšenie hrúbky lamiel v dvojfázovej $\alpha_2 + \gamma$ mikroštruktúre viacstupňovým tepelným spracovaním spôsobuje výrazné zlepšenie pevnostných a plastických vlastností pri teplote okolia a zvýšenie technologickej prístupnosti v podmienkach tvárnenia za tepla. Pozorovanie mikroštruktúry po deformácii Ti-48Al-2Cr-2Nb zliatiny s rozdielnou východiskovou mikroštruktúrou naznačujú, že hlavným mechanizmom prestavby mikroštruktúry zliatiny je proces dynamickej rekryštalizácie. V mikroštruktúre deformovanej zliatiny dochádza k javom charakteristickým pre deformáciu oblastí s lamelárnou štruktúrou, rovnako ako aj k dynamickej rekryštalizácii a sferoidizácii jednotlivých fáz. Jemnozrnná, takmer úplne rekryštalizovaná mikroštruktúra s globulárnou morfológiou fáz sa dosahuje po približne 70% deformácii zliatiny, ktorá bola podrobená prechádzajúcemu viacstupňovému tepelnému spracovaniu, pozostávajúceho z homogenizačného žíhania, cyklického tepelného spracovania a žíhania pri nadmerne nízkej teplote.

Abstract

The paper presents effect of initial microstructure of two-phase Ti-48Al-2Cr-2Nb alloy on its plasticity in room temperature as well as hot plastic working conditions based on compression tests conducted in room temperature on testing machine INSTRON 4483 and at temperature 1000ºC by using Gleeble 3800 system simulator. It was found, that alloy in as cast state does not deforms both on cold, as and hot. It was also stated, that homogenising of the chemical composition and microstructure of the alloy enables limited deformation during the hot working process and hot deformation is possible only after following consecutive multi-stage heat treatment operations. It was showed, that grain refinement of the investigated alloy and increasing thickness of lamellas inits two-phase $\alpha_2+\gamma$ microstructure by multi-stage heat treatment results in significant improvement in its strength and plastic properties at room temperature and the increase in technological susceptibility under hot working conditions. The observations of microstructure after deformation of Ti-48Al-2Cr-2Nb alloy with different initial microstructures indicate that the main mechanism for reconstruction of the alloy microstructure is dynamic recrystallisation process. In microstructure of deformed alloy, the effects characteristic of deformation of the areas with lamellar construction, as well as dynamic recrystallisation and spheroidisation of particular phases take place. The fine-grained, almost completely recrystallised microstructure with spheroidal phase morphology is obtained upon deformation of approx. 70% of the alloy that was previously put to multi-stage heat treatment comprised of homogenising, cyclic heat treatment and under-annealing.

Keywords: TiAl-intermetallic phase based alloys, heat treatment, deformation, compression test, microstructure

1. Introduction

Intermetallic Ti-Al system-based alloys with low density, high specific strength and good creep and oxidation resistance are new-generation lightweight constructional material for gas turbine blades, turbo-compressor impellers and combustion engine valves, as well as for components of supersonic structures. The fundamental faults of these alloys are very low plasticity at room temperature and under hot working conditions, high resistance to forming, and susceptibility to brittle cracking [1, 2].

Intermetallic Ti-Al system-based alloys, containing from 35 to 48 at. % of aluminium, have two-phase structure that consists of the mixture of TiAl (γ) and Ti_3Al (α_2) ordered intermetallic phases. Their properties are affected by the contents of alloy components and by their microstructure. In general, depending on aluminium content and mechanical working and heat treatment conditions, two types of microstructure can be distinguished in two-phase $\alpha_2+\gamma$ alloys [3, 4]:

- lamellar – coarse grains containing colonies of alternate lamellar precipitations of α_2 and γ phases,
- "duplex" – fine-grained microstructure with grains characterised by $\alpha_2+\gamma$ lamellar morphology and equiaxial grains of γ phase.

The effect of the microstructure on mechanical properties of two-phase $\alpha_2+\gamma$ alloys can be summarised as follows: alloys with coarse-grained lamellar microstructure are characterised by low plasticity, strength, and fatigue strength, in particular at room temperature, yet a relatively good crack resistance and excellent creep resistance. On the other hand, alloys with "duplex" microstructure demonstrate moderate plasticity and strength at room and elevated temperatures, good fatigue strength, and yet low crack and creep resistance [3÷6]. The optimum balance among crack and creep resistance, strength, and fatigue strength is obtained for alloys with fine-grained microstructure characterised by lamellar morphology of $\alpha_2+\gamma$ phases inside the grains. The usable properties of this group of alloys are mainly affected by the grain size the refinement of which not only has a very favourable effect on the increase in strength and plastic properties of the alloys but also improves formability to the extent that fine-grained alloys being formed at low rate may demonstrate superplastic properties [7, 8].

This paper presents the results of investigations on the effect of initial microstructure of Ti-48Al-2Cr-2Nb two-phase alloy on its plasticity at room temperature and under hot plastic deformation conditions.

2. Material and research methodology

In the investigations, Ti-48Al-2Cr-2Nb alloy (at. %) melted in the Leybold-Heraeus vacuum induction furnace IS-III/5 using SiC crucible covered by a thin layer of $SrZrO_3$ and cast into preheated graphite moulds in the form of bars of 13 mm in diameter and 120 mm in length was used. The effect of initial microstructure of the alloy upon casting and upon multi-stage heat treatment (Fig. 1), the fundamental purpose of which was grain refining of investigated alloy, was analysed. The treatment consisted of the following consecutive operations:

1. homogenizing, which was soaking at the temperature of α single-phase area (1400°C) for 1 h with furnace cooling after soaking,
2. cyclic heat treatment (5 cycles), where a single cycle was soaking at 1400ºC for 5 min. with air cooling after soaking,
3. under-annealing, which was isothermal annealing at the temperature of $\alpha+\gamma$ two-phase area (1300ºC) for 16 h with air cooling after soaking,
4. full annealing, which was short-term soaking at the temperature of α single-phase area (1400°C) for 5 min. with air cooling after soaking.

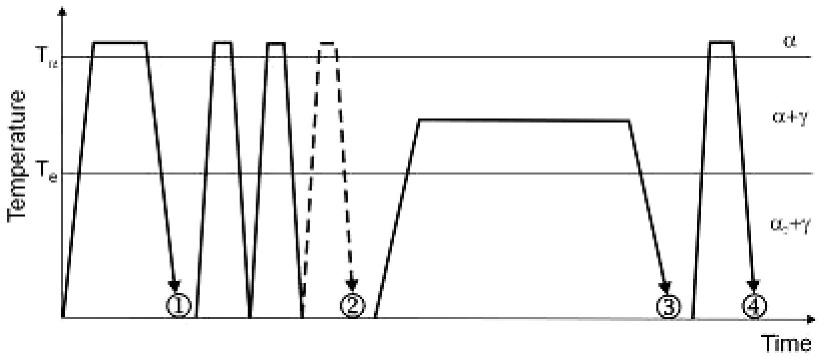

Fig.1 Multi-stage heat treatment diagram

Preparation of the material for microscopy included spark erosion cutting, wet grinding on abrasive papers and electrochemical polishing. The microstructure was disclosed by etching with Kroll reagent. The microstructure was investigated under Reichert MeF2 light microscope. The investigation of mechanical properties was carried out using INSTRON 4483 testing machine, according to PN-57/H-04320. Based on the static compression test the resistance to compression – R_c, yield strength – $R_{c0.2}$ and unit shortening – A_c were determined. The compression test was carried out at room temperature.

Formability of the alloys under investigation was assessed using Gleeble 3800 simulator under uniaxial hot compression conditions. Cylindrical samples with initial dimensions of 8 mm in diameter and 12 mm in height were put to resistance heating up to 1000ºC with rate of 3ºC/s in vacuum, followed by single-phase compression with rate of 0.01 s^{-1} until preset deformation of 1.2 (70%) was obtained. Changes in stress versus real deformation were recorded. In order to reduce friction the graphite and tantalum foil was inserted between the compression head and the sample.

3. Test results

Upon casting, Ti-48Al-2Cr-2Nb alloy with characteristic dendritic microstructure and visible heterogeneity in microstructure (Fig. 2a) is practical deprived of plastic features and its compression resistance is 1220 MPa (Tab. 1). The application of homogenising (stage 1 – Fig. 1) results in microstructure homogenising (Fig. 2b) and has a very favourable effect on improvement in plasticity (unit shortening) and, to the same extent, in compression resistance.

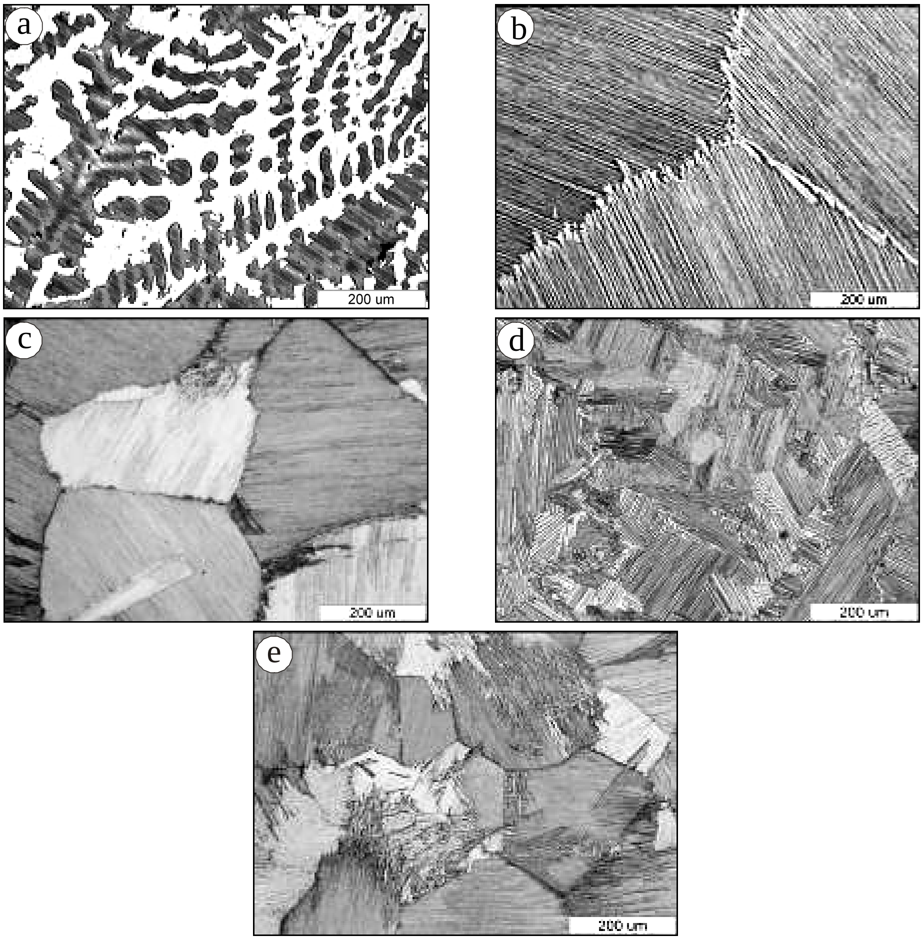

Fig.2 Microstructure of Ti-48Al-2Cr-2Nb alloy upon casting (a) and upon multi-stage heat treatment (Fig. 1): stage 1 – homogenizing (b), stage 2 – cyclic heat treatment (c), stage 3 – under-annealing (d) and stage 4 – full annealing (e)

The application of cyclic heat treatment (stage 2 – Fig. 1) results in considerable refinement of grain (Fig. 2c) and, as a result of that, the increase in compression resistance by 125 MPa and plasticity from 3.1 to 5.2% (Tab. 1) with reference to the condition after homogenising. Under-annealing at 1300°C for 16 h (stage 3 – Fig. 1) results in further grain refinement (Fig. 2d), increase in plastic properties (Tab. 1) and, quite unexpectedly, reduction in compression resistance by 130 MPa. In this case, strength properties of the alloy are the result of grain refinement and thickening of $\alpha_2+\gamma$ lamellar microstructure. Short-term overheating of the alloy to the temperature range of α single-phase area (stage 4 – Fig. 1) results in reduction in lamellas thickness to that characteristic of stage 2 and increase in grain size (Fig. 2e). This results in immediate increase in the alloy's compression resistance (by approx. 150 MPa) at the expense of its plasticity reduction from 6.9 to 5.8% (Tab. 1).

Table 1 Effect of heat treatment on mechanical properties of Ti-48Al-2Cr-2Nb alloy – compression test at room temperature

State	R_c [MPa]	$R_{c0,2}$ [MPa]	A_c [%]
After casting	1220	-	0.2
Multi-stage heat treatment – stage 1	1360	1105	3.7
Multi-stage heat treatment – stage 2	1485	1180	5.2
Multi-stage heat treatment – stage 3	1355	1025	6.9
Multi-stage heat treatment – stage 4	1510	1230	5.8

The observations of samples shape after compression at 1000ºC showed that, depending on their initial microstructure, they deformed with bulging without cracking, with chamfering without cracking, and with cracking (Fig. 3).

a)  b)  c) 

Fig.3 Sample deformation with bulging without cracking (a), with chamfering without cracking (b), and with cracking (c)

Investigation of the effect of initial microstructure on plasticity characteristics of the alloy being tested revealed that the alloy in the state immediately after casting was practically not fit to be deformed at 1000ºC. The alloy in this condition is characterised by high yield stress (Tab. 2), its deformation value reaches 0.24, and then it becomes completely destroyed. The application of homogenising (stage 1 – Fig. 1) resulted in significant reduction in the maximum stress yield by 140 MPa (Tab. 2). Upon homogenising the alloy deformation reaches the value of 0.73, and then cracks appear on its surface. The alloy microstructure is non-homogeneous, partially recrystallised, has the visible effects that are characteristic of deformation of lamellar microstructure, such as change in lamella orientation and “kinking” (Fig. 4a). Only upon cyclic heat treatment (stage 2 – Fig. 1) the alloy can deform to the value of 1.2 (70%) without cracking, although the maximum stress yield value is high (Tab. 2) and deformation takes place with sample chamfering. After this heat treatment, the microstructure of deformed alloy is characterised by considerably higher homogeneity and higher recrystallisation degree, although the remains of partially deformed lamellar microstructure still exist (Fig. 4b).

The best deformation is observed in the alloy put to under-annealing at the temperature of two-phase area (stage 3 – Fig. 1). Upon this treatment, the alloy is characterised by the lowest value of the maximum stress yield (Tab. 2), deforms to 1.2 without cracking, and the deformation takes place with sample bulging rather than characteristic chamfering.

Table 2 Effect of heat treatment on properties of Ti-48Al-2Cr-2Nb alloy – hot compression test at 1000ºC with deformation rate of 0.01 s^{-1}

State	σ_{pm} [MPa]	ε_p	Grain size [μm]	Note
After casting	645	0.15	-	Deformation to ε = 0.24
Multi-stage heat treatment – stage 1	505	0.12	1234	Deformation to ε = 0.73
Multi-stage heat treatment – stage 2	615	0.08	429	Deformation without cracking, with sample chamfering
Multi-stage heat treatment – stage 3	490	0.09	150	Deformation without cracking, with sample bulging
Multi-stage heat treatment – stage 4	530	0.08	225	Deformation without cracking, with sample chamfering

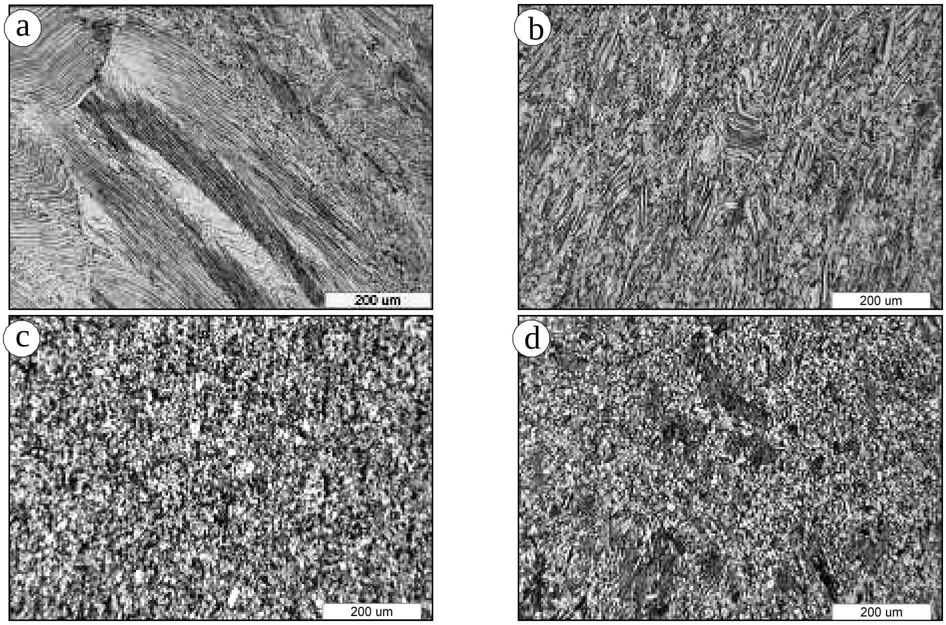

Fig.4 Microstructure of Ti-48Al-2Cr-2Nb alloy upon multi-stage heat treatment (Fig. 1): stage 1 – homogenizing (a), stage 2 – cyclic heat treatment (b), stage 3 – under-annealing (c) and stage 4 – full annealing (d), and upon hot compression at 1000ºC with deformation to 0.73 (a) and 1.2 (b-d) with the rate of 0.01 s^{-1}

Upon deformation, the microstructure of the alloy put to this heat treatment becomes fine-grained, is fully homogeneous and completely recrystallised with spheroidal morphology of α_2 and γ phases (Fig. 4c). Short-term overheating of the alloy to the temperature range of α single-phase area (stage 4 – Fig. 1), which is necessary to improve the alloy's strength properties at room temperature (Tab. 1), makes the alloy deform a little bit worse than after full annealing, however its deformation is still better than after cyclic heat treatment due to lower value of the maximum stress yield (Tab. 2). This also results in appearance, upon deformation, of areas with lamellar microstructure, characteristic of condition upon homogenizing, in its microstructure (Fig. 4d).

4. Summary

Investigation of the effect of initial microstructure on plasticity of two-phase Ti-48Al-2Cr-2Nb alloy, conducted on the basis of cold and hot compression tests, showed its strong influence on the strength and plastic properties at room temperature, value of the maximum stress yield and deformation corresponding to it, as well as the sample shape after hot deformation.

It was found that the alloy in the state immediately upon casting, with characteristic dendritic microstructure, deforms neither under cold nor hot conditions. Homogenising of the chemical composition and microstructure of the alloy slightly improves its properties at room temperature and enables limited deformation during the hot working process.

Grain refinement of the investigated alloy and increasing thickness of lamellas in its two-phase $\alpha_2+\gamma$ microstructure by multi-stage heat treatment results in significant improvement in its strength and plastic properties at room temperature and the increase in technological susceptibility under hot working conditions, which manifests itself as the reduction in value of the maximum stress yield and possibility of applying large deformations (70%) without cracking.

The observations of microstructure after deformation of Ti-48Al-2Cr-2Nb alloy with different initial microstructures indicate that the main mechanism for reconstruction of the alloy microstructure is dynamic recrystallisation process. In microstructure of deformed alloy, the effects characteristic of deformation of the areas with lamellar construction, as well as dynamic recrystallisation and spheroidisation of particular phases take place. The fine-grained, almost completely recrystallised microstructure with spheroidal phase morphology is obtained upon deformation of approx. 70% of the alloy that was previously put to multi-stage heat treatment comprised of homogenising, cyclic heat treatment and under-annealing.

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