EFFECT OF DIRECTIONAL CRYSTALLISATION ON MICROSTRUCTURE OF Ti-46Al-5Nb-1W ALLOY

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VLIV SMĚROVÉ KRYSTALIZACE NA MIKROSTRUKTURU SLITINY Ti-46Al-5Nb-1W

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Abstrakt

Slitiny na bázi intermetalické fáze γ-TiAl jsou vyhledávanými a perspektivními materiály pro aplikace ve spalovacích motorech, turbínách apod. Kromě velmi příznivých vlastností, jako jsou nízká hustota a dobrá korozní odolnost mohou ostatní důležité vlastnosti, jako je pevnost, tažnost, lomová houževnatost, nabývat různých hodnot v závislosti na čistotě a mikrostruktuře. Mikrostrukturu výrobků (odlitků) můžeme ovlivnit vhodným chemickým složením nebo procesy při výrobě. Mikrostruktura ve výrobcích (odlitcích) vzniká během jejich krystalizace a v této podobě zůstává po celou dobu životnosti výrobku. Je tedy velmi důležité, znát procesy krystalizace, aby bylo možno nastavit parametry při výrobě způsobem takovým, který přispěje ke zlepšení vlastností výrobků. Tento článek je zaměřen na intermetalickou slitinu Ti-46Al-5Nb-1W (at. %), která byla podrobena směrové krystalizaci pěti konstantními rychlostmi v rozmezí 20 až 425 mm/h. Vzorky slitiny byly vloženy do keramických korundových trubic Al_2O_3. Dosažená mikrostruktura vzorků byly metalograficky zkoumána. Bylo zjištěno, že lamelární mikrostruktura je tvořena střídajícími se lamelami fází α_2 a γ. Dosažená lamelární mikrostruktura byla zdokumentována. Na příčných řezech byla vyvolána buněčná a dendritická mikrostruktura. Rychlost krystalizace má výrazný vliv na mikrostrukturu, a to jak lamelární, tak i dendritickou. S rostoucí rychlostí krystalizace dochází ke zkracování mezilamelární vzdálenosti i vzdálenosti primárních větví dendritů. Byl hodnocen vliv parametrů směrové krystalizace na mikrostrukturu této slitiny.

Abstract

Alloys based on inter-metallic phase γ-TiAl are much sought-after and perspective material for applications in internal combustion engines, turbines, etc. Apart from very favourable properties, such as low density and good resistance to corrosion, some other important properties, such as strength, ductility, fracture toughness, can gain various values in dependence on purity and microstructure. It is possible to influence microstructure of products (castings) by suitable chemical composition or by processes at production. Microstructure is being formed in products (castings) during their crystallisation and it remains in this form during the full service life of the product. It is therefore important to know processes of crystallisation in order to be able to set the parameters at production in a manner that best contributes to enhancement of the product properties. This article is focused on inter-metallic alloy Ti-46Al-5Nb-1W (at. %), which was subjected to directional crystallisation by five constant rate within the range from 20 to 425 mm/h. The samples of this alloy were inserted into ceramic corundum tubes Al_2O_3. The obtained microstructure of the samples was investigated metallographically. It was ascertained that lamellar microstructure is formed by alternating lamellas of the phases α_2 and γ. The obtained lamellar microstructure was documented. Cell and dendritic microstructure was investigated on cross sections. Rate of crystallisation has a significant impact on microstructure – both lamellar and dendritic. With the growing rate there occurs shortening of inter-lamellar distance and distances of primary dendritic arms. Influence of parameters of directional crystallisation on microstructure of this alloy was evaluated as well.

Key words: γ-TiAl, dendritic microstructure, lamellar microstructure, directional solidification.

1. Introduction

Inter-metallic alloy Ti-46Al-5Nb-1W (at. %) fulfils thanks to its aluminium contents the condition for formation of lamellar microstructure, i.e. it has aluminium contents within the range from 44 to 48 at. %. Tungsten influences enhancement of creep properties, niobium improves in γ-TiAl alloys high-temperature properties. This concerns mainly enhancement of creep properties, ductility at room temperature and resistance to oxidation.

Fully lamellar microstructure is the most suitable for industrial applications. The best mechanical properties are obtained in the alloys with fully lamellar microstructure, which contains the phases γ (TiAl) and α_2 (Ti_3Al). Their toughness, strength and fatigue strength depend in great extent on orientation of the lamellar microstructure. This lamellar microstructure is formed either primarily from the phase α, i.e. liquid solution of Ti with HTU, and then individual lamellas are perpendicular to the direction of growth (direction of crystallisation), or the phase β is the primary phase, i.e. solid solution of Ti with the KPC lattice. The best results are achieved when the lamellas are arranged in parallel with the direction of load.

Microstructure of these alloys can be influenced by suitable chemical composition and processing and treatment during production. Microstructure, which is formed during crystallisation of the cast piece, is unchangeable and in principle it cannot be influenced. Directional crystallisation can be successfully used for investigation of regularities related to crystallisation of these alloys. The aim of directional crystallisation consists in production of material with lamellar orientation arranged in such a manner, that it corresponds with the direction of growth. One of the way to it is use of appropriately alloyed materials, another consists in control of solidification in such a way that lamellar microstructure gets arranged along the direction of growth.

Process of modification of structure at crystallisation can be made in two ways. The first method is zonal melting, when only defined part is melted in the ingot, i.e. arrow zone of the given width. The melted zone passes through the ingot and it has two boundaries: (I) melting front and (II) solidification front, in which there occurs crystallisation. The second method is Bridgman method. Its principle consists in slow moving of the phase boundary crystal-melt through the melted ingot. It is realised with the melt in ceramic mould. This influences purity of the final product, since namely in case of titanium alloys there occurs contamination of the alloy by ceramic mould due to their high reactivity, as it was already described above [1-5].

2. Experiment

Directional crystallisation

Directional crystallisation was made in the device of the Bridgman's type. Top oxidic layer was removed from the sample by turning and the sample was then inserted into the ceramic tube Luxal 203. Diameter of the samples was 8 mm and length was 100 mm. Directional crystallisation was realised under protective argon atmosphere. Argon purity was 4N5. The device consisted of heating part of furnace and movable equipment. Tube containing melt was fixed to this movable equipment In dependence on selected rate of crystallisation this equipment pulled out the tube with melt at a constant rate from the hot zone through water cooled copper mold and ensured thus the required crystallisation of the melt in accordance with the pre-set parameters. We chose for the alloy Ti-46Al-5Nb-1W the melting temperature T_M=1650°C. Dwell at this temperature was 900 s and then the shifting began. We chose for shifting five constant rates, 20 mm/h, 50 mm/h, 100 mm/h, 200 mm/h and 425 mm/h. After removal of tubes with crystallised melt from the furnace space the samples were taken out and cut longitudinally and perpendicularly by saw with carbide disc. The samples were then sealed with Dentacryl resin and prepared by grinding and polishing for metallographic investigation. Composition of the etching agent used was: HNO_3, HF and distilled water. Etching time was from 5 to 10 seconds. Investigation of structure was performed with use of optical metallographic microscope Olympus GX-51.

3. Results

On longitudinal sections, Fig. 1, the lamellar microstructure is. All the samples had identical type of microstructure - lamellar. Lamellas grown continuously in dendritic and in inter-dendritic area, which is perceptible in cross sections, see Fig. 2. It is apparent from the Fig. 1, that with increasing rate the distance between lamellas shortens.

Microstructure was formed by lamellar grains, in which alternated lamellas of the phases γ (TiAl) and α_2 (Ti_3Al). Lamellar grains are oriented in parallel with the direction of crystallisation, and with the direction of heat removal from the melted sample. Lamellas in them are oriented mostly in the direction perpendicular to the direction of crystallisation.

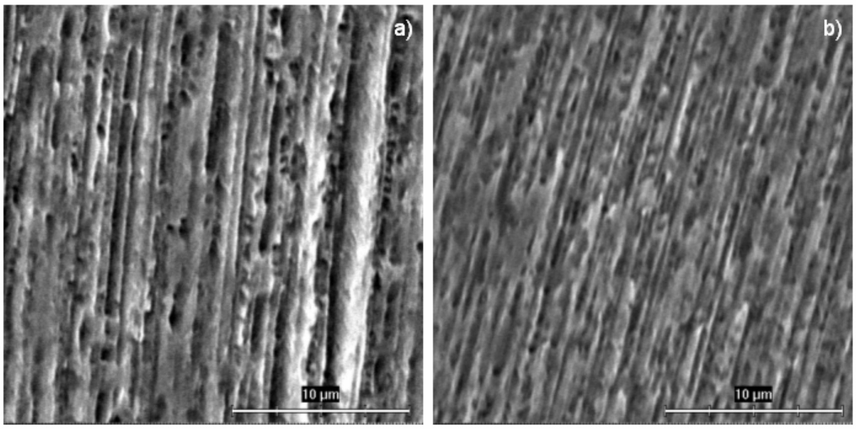

Fig.1 Lamellar microstructure of the alloy Ti-46Al-5Nb-1W after directional crystallisation a) V=100 mm/h, b) V=425 mm/h.

Dendritic structure is visible on cross sections cut at the distance of 35 mm from the top end of the sample. Rate of crystallisation had influence on the distance of primary arms of dendrite, see Fig. 3.

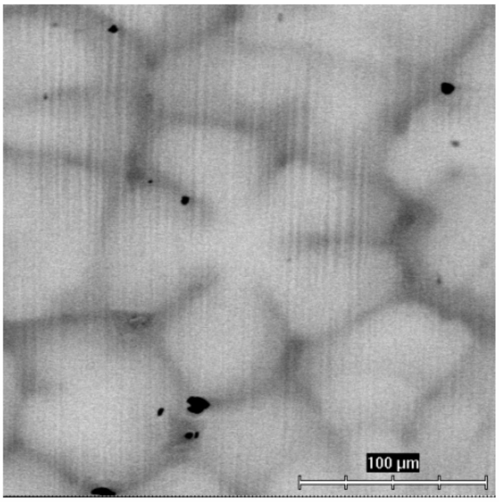

Fig.2 Microstructure of the alloy Ti-46Al-5Nb-1W after directional crystallisation, V=425 mm/h, cross section. Continuous growth of lamellas in dendrites and in inter-dendritic areas is well visible.

The sample with rate of crystallisation 20 mm/h had cellular structure, the dendritic microstructure was formed only at the rate of crystallisation 50 mm/h and more. In the samples with rate of crystallisation 50, 100, 200 and 425 mm/h there was measured the distance of primary arms of dendrites.

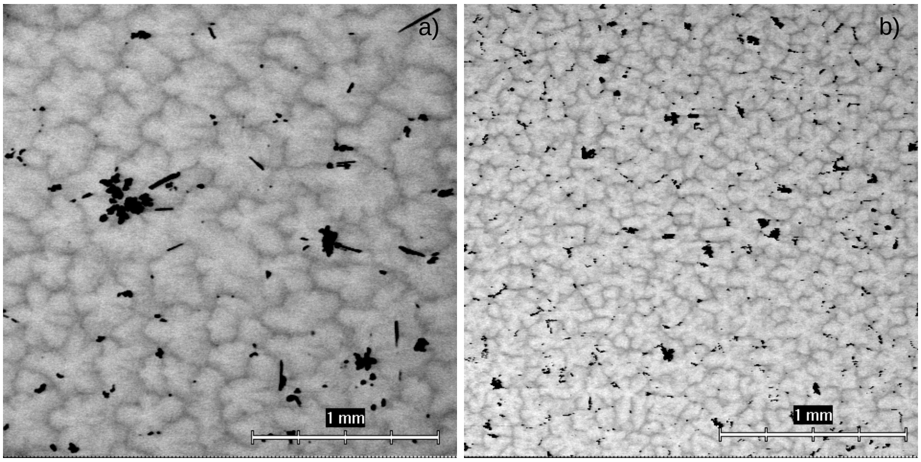

Fig.3 BSE photos of dendritic microstructure in the samples after directional crystallisation a) V=100 mm/h, b) V=425 mm/h.

The obtained values are plotted in the diagram shown in the Fig. 4. It is evident that inter-dendritic distance λ_d shortened with the increasing rate of crystallisation. During the measurement the stress was put on measurement of just primary armss of dendrites. The distance between primary arms of dendrites increases in accordance with the following relation:

$$\lambda_d = M_d \cdot V^{n_d} \tag{1}$$

λ_d ... distance of primary arms of dendrites
M_d … material constant
V … rate of crystallisation
n_d … exponent of rate of crystallisation

The relation (1) can be calculated with use of regression analysis and expressed in the following form:

$$\lambda_d = 1432{,}7 \cdot V^{-0{,}34} \tag{2}$$

Regression coefficient of this expression is R^2=0,98. The exponent of rate of crystallisation for the alloy Ti-46Al-5Nb-1W (at. %) is –0.34.

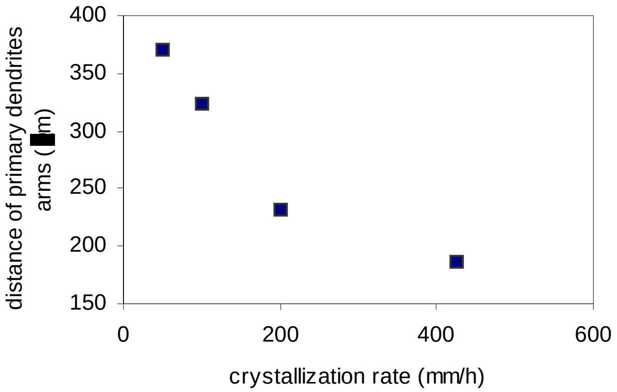

Fig.4 Dependence of inter-dendritic distance on rate of crystallisation.

4. Conclusion

The alloy Ti-46Al-5Nb-1W was subjected to the directional crystallisation by five constant rates. It was ascertained that rate of crystallisation has influence on microstructure of the alloy – both lamellar and dendritic. Inter-lamellar distance shortens with increasing rate of crystallisation. Increasing rate of crystallisation has similar impact on distance of primary arms of dendrites as this distance also shortens with increasing rate of crystallisation.

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