STUDYING OF THE STRUCTURE, PHYSICAL AND MECHANICAL PROPERTIES OF Ti-Nb ALLOY BILLETS PRODUCED BY ARC MELTING BEFORE SEVERE PLASTIC DEFORMATION

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ИССЛЕДОВАНИЕ СТРОЕНИЯ И ФИЗИКО-МЕХАНИЧЕСКИХ СВОЙСТВ ЗАГОТОВОК СПЛАВА TI-NB ПЕРЕД ИНТЕНСИВНОЙ ПЛАСТИЧЕСКОЙ ДЕФОРМАЦИЕЙ

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В работе представлены результаты исследования структуры и физико-механических свойств слитков сплава Ti-Nb разного состава, изготовленных электродуговой плавкой. Для исследования применялись методы рентгеноструктурного и микроструктурного анализов, измерялась микротвердость, оценивались значения модуля упругости.

One of the most perspective materials for producing bioimplants are alloys of titanium-niobium because their value of the Young's modulus is considerably lower than for pure titanium and a number of its alloys. Moreover, their technological properties allow producing nano-sized structures by means of severe plastic deformation (SPD) [1]. Billets of such alloys are prepared by arc melting in a vacuum or argon. Then they are plastically deformed to produce blanks. During metallurgical manufacturing of alloys in the process of crystallization chemical heterogeneity and internal dendritic liquation can be formed on the ingot [2]. Thus, inhomogeneity is formed in ingots. It affects the further processes of producing these billets from ingots by means of SPD methods, so it is essentially important to study the structure of the ingot.

The possible inhomogeneity of structure, physical and mechanical properties of Ti-Nb alloy ingots of different composition made by arc melting was investigated.

The initial billets (or buttons) made of the Ti-Nb alloys with different concentration of Nb (10, 25 and 40wt.%) were investigated in this study. They were provided by Institute of Non-ferrous Metals, Beijing. The buttons were made by arc melting with nonconsumable electrode. X-ray diffraction analysis was performed on the X-ray diffractometer DRON-7. The microstructural analysis was carried out by the microscope Carl Zeiss AxioObserver. Micro hardness and the Young's modulus values were estimated by "Nano Hardness Tester" NHT-S-AX-000X by the unrestored print method.

The X-ray diffraction pattern of the casting alloy Ti-10wt.% Nb shows that the main phase is an α-Ti (Fig. 1a). Probably, there is a small amount of α'-phase, as indicated by the broadening of the peaks at high angles: reflex corresponding to the angle $130{,}06^0$ blends into the background.

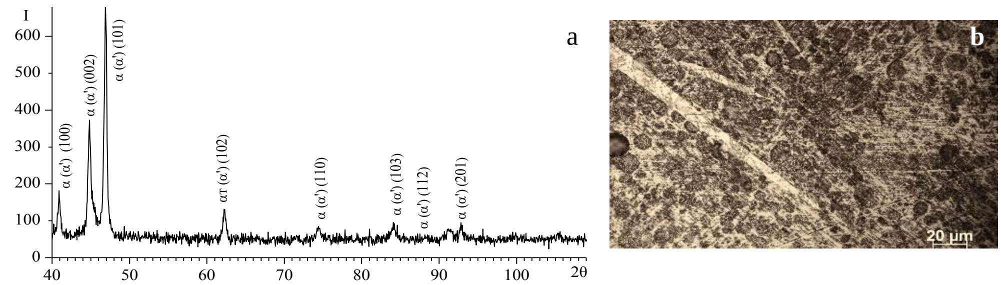


Fig. 1.Fragment of X-ray diffractogram of the casting alloy Ti-10wt. % Nb (a), metallographic image of thin section of casting alloy Ti-10wt.% Nb – (b).

The microstructural analysis confirms availability of α'-phase. Both phases are clearly seen on metallographic images (Fig. 1b). α-phase consists of primary dendrites with a size of about 12 microns, spaced evenly across all study sites. The acicular structure in the picture indicates formation of non-equilibrium α'-martensitic phase. The width of martensitic needles is about 10 microns and their length is up to 300 microns. α-phase is represented by dark patches of metallographic images. The mean hardness is HV_{av} = 1958 MPa; the average value of the Young's modulus is E_{av} = 106 GPa. α'-phase is represented by needle-shaped areas. HV_{av} = 1850 MPa and E_{av} = 92,4 GPa.

Figure 2a shows a fragment of the X-ray diffraction patterns of the cast alloy Ti-25wt.% Nb. Diffractogram shows that an alloy is represented by α''- and β-phases. α''-phase is characterized by a split of the interference lines but to trace it in this case is not possible. All reflexes go into the background so we don't see this split. Reflex with the maximum intensity and the corresponding angle value 59.66^0 is likely to belong to α- or α'-phase.

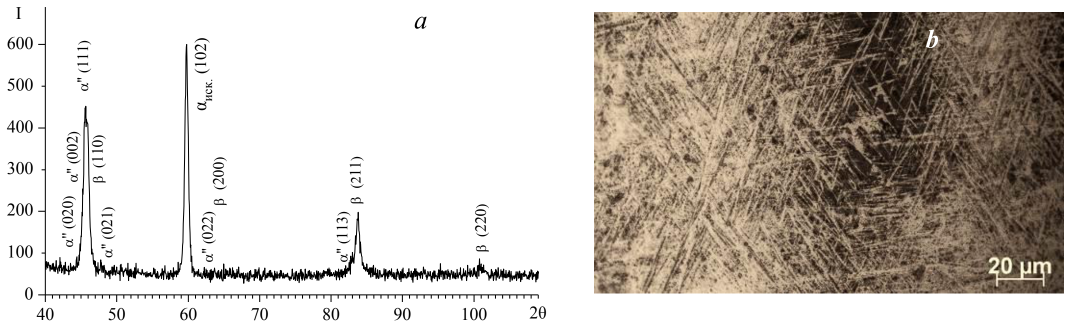
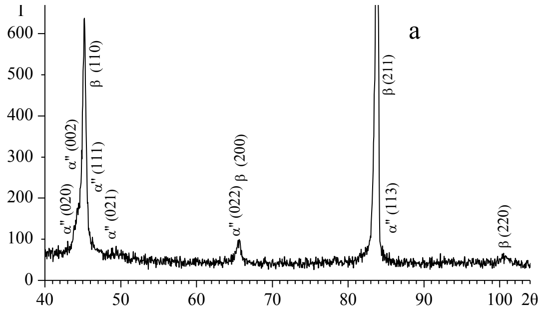


Fig. 2. Fragment of X-ray diffractogram of the casting alloy Ti-25wt.% Nb (a), metallographic image of thin section of casting alloy Ti-25wt.% Nb – (b).

Such phase structure is confirmed by microstructural analysis (Fig. 2b). As can be seen the alloy is heterogeneous in its structure. There are dendrites with finely acicular martensitic structure which is disposed uniformly throughout the sample. The fine-needle structure which occupies most of the volume is α''-phase. Besides, the white portions in a sample with high magnifications are observed. They occupy a small area of studied surface and presumably represented by β-structure. Micro hardness measurements revealed that the structural region of α''-phase has HV_{av} = 4100 MPa, E_{av} = 140,8 GPa. β-structural region has HV_{av} = 4060 MPa and E_{av} = 140 GPa. Most likely, the structural heterogeneity is associated with dendritic segregation.

Figure 3 shows a fragment of X-ray diffraction patterns of the cast alloy Ti-40% Nb. The main is the β-phase in the initial cast state. There may be a small amount of α''-phase as indicated by X-ray line asymmetry in the angular range 43–46^0. Structure formation of casting occurs under conditions of directional solidification as indicated by the redistribution of the peaks intensity.



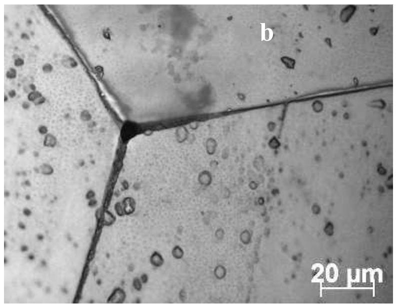


Fig. 3. Fragment X-ray diffractogram of the casting alloy Ti-40wt.% Nb (a), metallographic image of thin section of casting alloy Ti-40wt.% Nb – (b).

Primary dendritic structure is well discernible by metallographic analysis at low magnifications. It is pronounced and has clear boundaries. There are clearly visible grain boundaries which are well established and have linear form at high magnification (Fig. 3b). The grain size is about 600-1200 microns. According to the results of X-ray analysis the main phase grains are β-phase. As a separate structural component for metallographic images α''-phase isn't observed. The micro hardness determining results confirm it. Throughout the volume of the ingot micro hardness is HV_{av} = 3220 MPa. Young's modulus is E_{av} = 86,5 GPa.

Conclusions

1. Equilibrium and non-equilibrium phases are formed during the formation of ingots of the alloy Ti-Nb by arc melting. Their presence and amount is determined by the alloy composition: at 10wt.% Nb it is observed α-phase and non-equilibrium α'-phase; with 25wt.% Nb – β-phase and non-equilibrium α'- and α''-phases are observed; with 40wt.% Nb – β-phase is observed.
2. There is no observed pronounced structural heterogeneity in ingots of alloy Ti-Nb. It allows using them for severe plastic deformation.

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