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Microstructural banding in titanium alloys

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ABSTRACT

Purpose of this paper was to investigate the phenomenon of microstructural banding in three titanium alloys: Ti-6Al-4V, Ti-10V-2Fe-3Al and Ti-3Al-8V-6Cr-4Mo-4Zr.

Design/methodology/approach: The microstructure of the investigated materials in as-delivered condition was characterized. Compression tests were performed on Gleeble thermomechanical simulator to investigate banding phenomena occurring in the microstructure of each studied alloy. Moreover, banding phenomena was also investigated in the case of forging obtained from Ti-6Al-4V alloy. Heat treatment conditions allowing to reduce banding in the microstructure of the investigated alloys were also determined.

Findings: Thermomechanical processing leading to dynamic recrystallization in the investigated alloys restricts the formation of bands in their microstructure. Homogenizing treatment can also reduce banding in such alloys.

Research limitations/implications: Future research should concern the investigations of grain size in the recrystallized alloys and in the alloys subjected to homogenizing heat treatment.

Practical implications: The results of this research should allow obtaining homogenous microstructure in titanium alloys studied in this paper.

Originality/value: The range of the temperature and strain rate for dynamic recrystallization restricting banding in the microstructure in the investigated alloys was determined. In the case of Ti-3Al-8V-6Cr-4Mo-4Zr alloy the range of the temperature and time of annealing leading to homogenization of the material was identified.

Keywords: Metallic alloys; Titanium alloys; Banding; Homogenizing

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MATERIALS

1. Introduction

Titanium alloys are particularly susceptible to formation of adiabatic shear bands due to their low thermal conductivity [1-5]. In the case of the microstructure of β titanium alloys (bcc) the formation of shear bands was reported in many research papers [6-8], however, it was not considered as phenomenon associated with adiabatic conditions. Some research works discussed hard-to-etch bands in the microstructure of β titanium alloys [9]. Shear bands are also often analyzed in commercially pure titanium (hpc) [10]. The formation of adiabatic shear bands may lead to decohesion of the material [5,11]. However, the attempts ca be made towards utilization of strain accumulation in obtaining new, favorable properties [12-15]. But still most of the producers of titanium alloys and their customers expect titanium alloy parts having uniform microstructure and isotropic properties [16]. Such demand comes from the possible unfavorable influence of nonuniformity of the microstructure on fatigue processes in such alloys [17,18]. Moreover, strain inhomogeneity causes instability of deformation [19-21] and formation of bands in the microstructure of alloy [22].

This research was focused on the phenomenon of microstructural banding in Ti-6Al-4V alloy subjected to deformation, parameters of thermomechanical processing leading to annihilation of banding in the microstructure (Ti-6Al-4V, Ti-10V-2Fe-3Al and Ti-3Al-8V-6Cr-4Mo-4Zr alloys) as well as heat treatment resulting in homogenization of the microstructure in alloys having inhomogeneities in chemical composition (Ti-10V-2Fe-3Al i Ti-3Al-8V-6Cr-4Mo-4Zr).

2. Bands in the microstructure of Ti-6Al-4V alloy products

Forming jaws in surgical forceps used for separating the wounds in surgical tool forging resulted in accumulation of deformation bands in the areas formed at the temperature lower than α+β→β transformation temperature (Fig. 1).

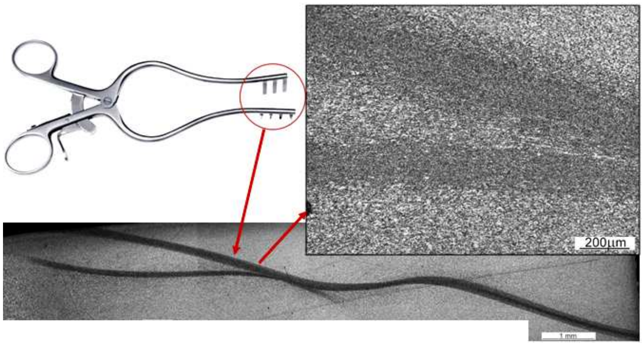

Fig. 1. A part of surgical forcep with marked area of the microstructural analysis [23]

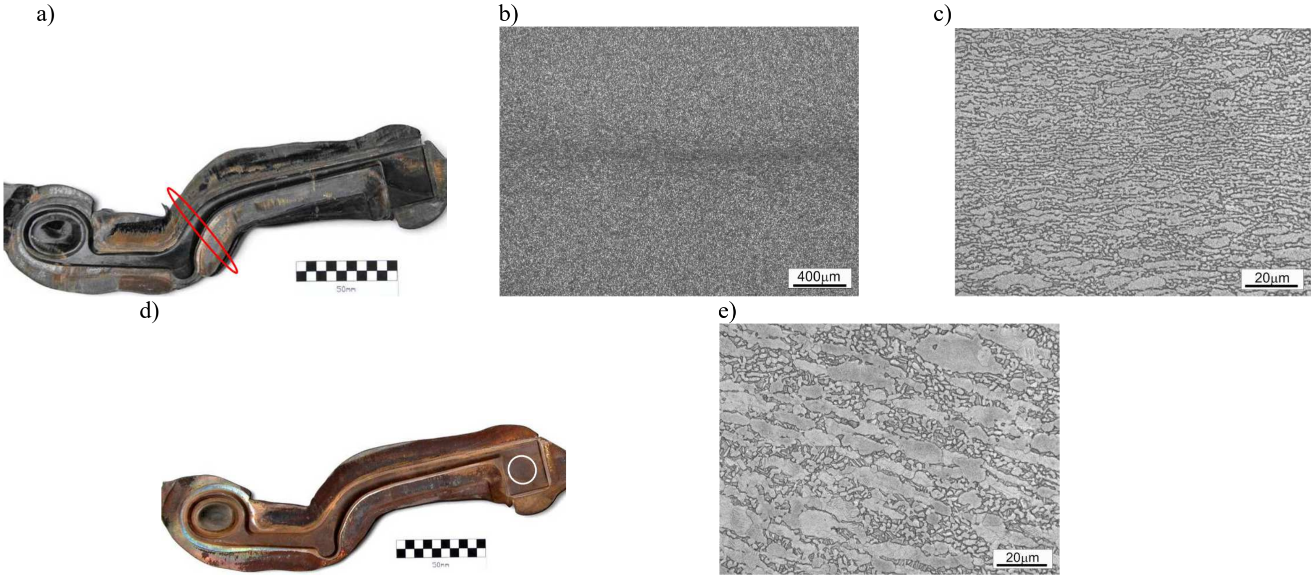

Fig. 2. A forging of surgical forcep and its microstructure: a) forged part produced with use of lubricants, b) microstructure of forged part at the areas marked in Fig. 2a – perpendicular cross-section c) microstructure of forged part showing deformation bands at the area marked in Fig. 2b, d) forged part produced without lubrication, e) microstructure of the forged part at the area marked in Fig. 2d [24].

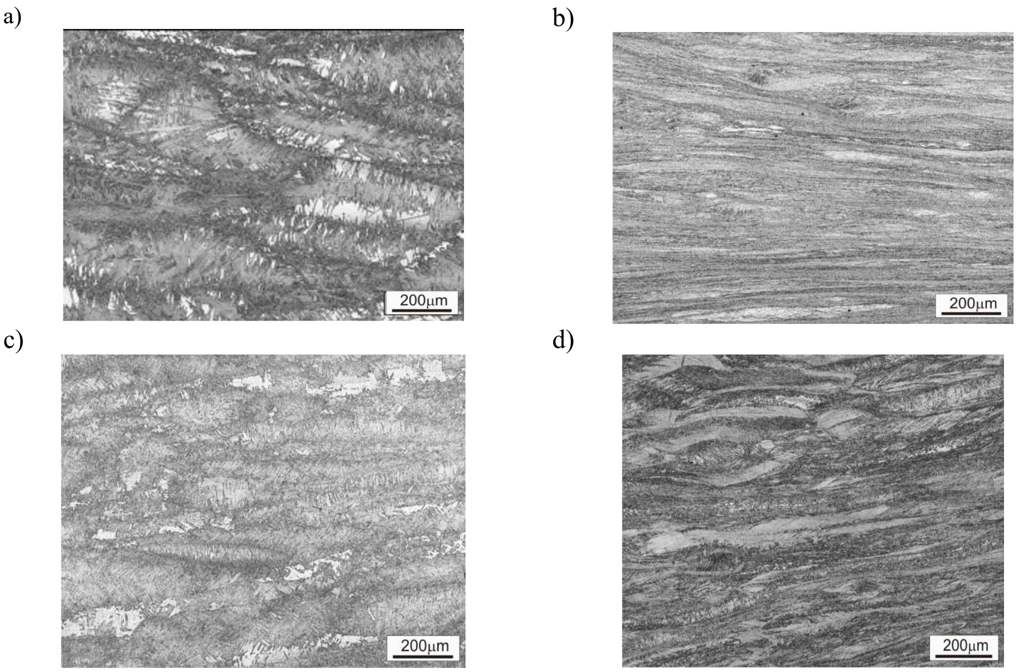

Fig. 3. Microstructure of Ti-6Al-4V alloy part: a) forged at the temperature of 1050ºC from 49 mm high billet, b) forged at the temperature of 750ºC from 49 mm high billet, c) forged at the temperature of 1050ºC from 30 mm high billet, d) forged at the temperature of 950ºC from 30 mm high billet. Light microscope [25]

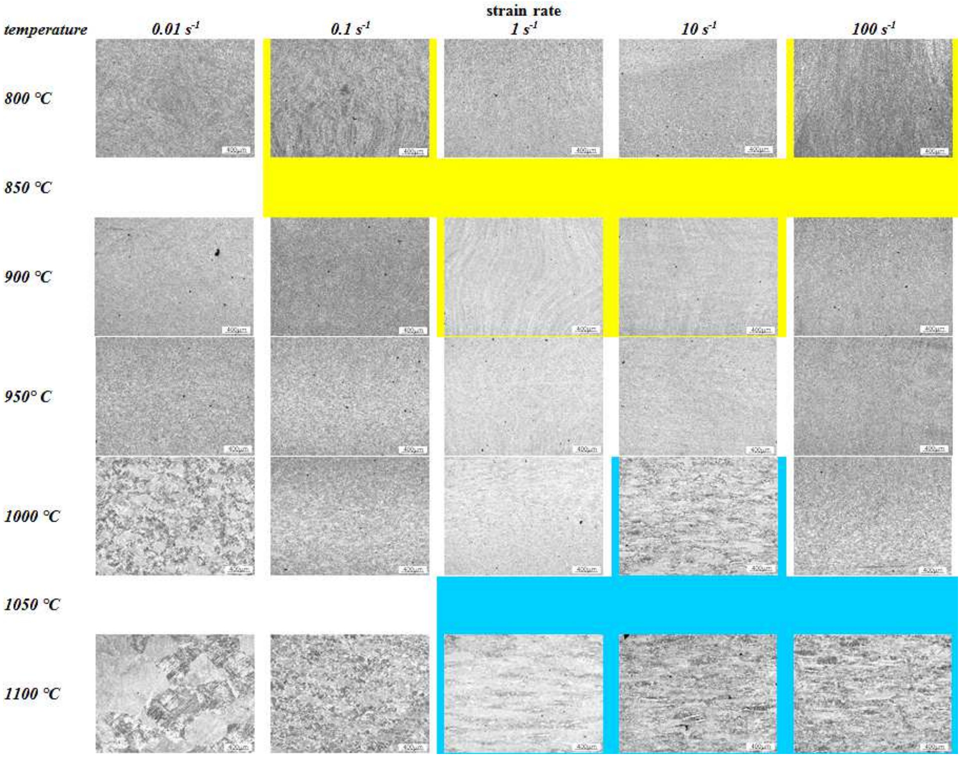

Fig. 4. Microstructure of Ti-6Al-4V alloy after various processing schedules. Processing conditions, that do not cause annihilation of primary banded structure (deformation temperatures 800-900°C) and processing conditions causing formation of new banded structure (deformation temperatures 1000-1100°C) are marked

3. Influence of processing conditions on formation and annihilation of banding in Ti-6Al-4V alloy

Microstructural banding formed during production of Ti-6Al-4V alloy rod can be annihilated by upsetting in direction parallel to this banding (Fig. 4). As can be noticed, deformation to a total true strain of 1 at the temperature of 800°C under strain rates of 0.1 s^{-1} and 100 $^{s-1}$ as well as at the temperature of 900°C under strain rates of 1 s^{-1} and 10 s^{-1}, did not cause annihilation of primary banded structure. It should also be noticed, that lower strain rates result in longer time of deformation at given upsetting temperature. Deformed in compression materials were cooled in forced air [20]. It is surprising, that deformation at the temperature of 800°C under strain rates of 1 s^{-1} and 10 s^{-1} leads to annihilation of primary banding structure. It may be caused by the lack of recrystallization of α phase in areas free from strain accumulation, which undergoes at these strain rates at the temperature of 900°C causing regeneration of primary banding [26]. Deformation in β phase region at the temperature of 1000°C under strain rate of 10 s^{-1} and at the temperature of 1100°C under strain rates of 1 s^{-1}, 10 s^{-1}, and 100 s^{-1} causes formation of new deformation bands in consistency with material flow during upsetting. Such deformation conditions do not cause intense recrystallization of β phase in the investigated material [26].

4. Influence of processing conditions on annihilation of banding in Ti-10V-2Fe-3Al alloy

Microstructural banding formed during production of Ti-10V-2Fe-3Al alloy rod (Fig. 5) can be annihilated by upsetting in direction parallel to this banding (Fig. 6). As can be seen in Fig. 7 in material processed at the temperature higher than 950 °C annihilation of banding structure occurs. Basing on the morphology of banding structure in material deformed at the temperature of 900 °C it is possible to observe, that processing under lower strain rates results in annihilation of such structure. It can be asociated with longer deformation time at given processing temperature resulting in intensification of dynamic recrystallization and dynamic recovery [26].

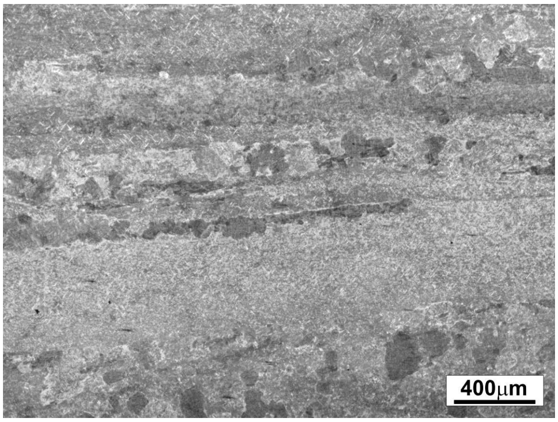

Fig. 5. Microstructure of Ti-10V-2Fe-3Al alloy rod (as-received material) – banding is parallel to rod axis, longer side of the picture is parallel to rod axis. Longitudinal cross-section, light microscope

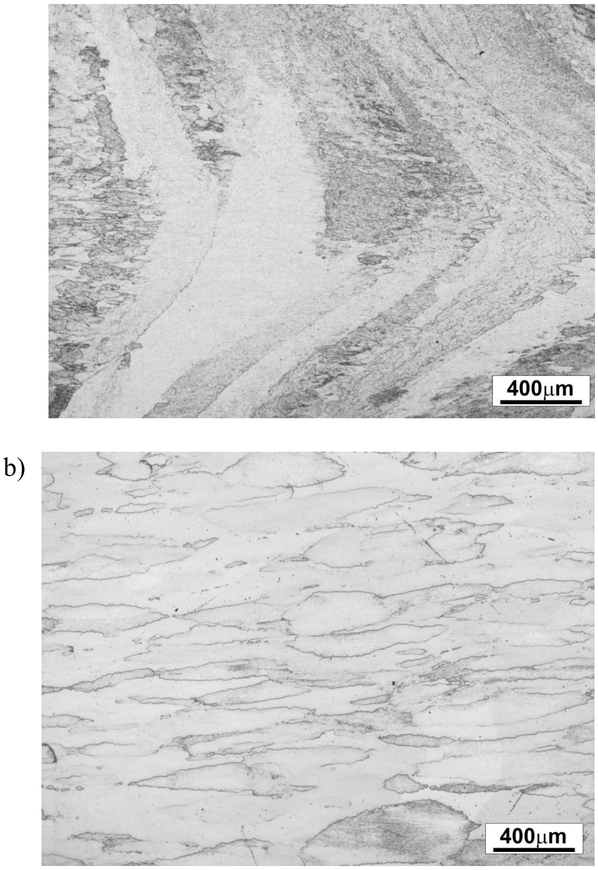

Fig. 6. Microstructures of the samples of Ti-10V-2Fe-3Al alloy after deformation to a total true strain of 1: a) processing strain rate of 1 s^{-1}, deformation temperature of 800°C; b) processing strain rate of 1 s^{-1}, deformation temperature of 1000°C; light microscope

The analysis of diagram shown in Fig. 7 and the results of calorimetric investigations of as-received material (Fig. 8) showed the possibility of annihilation of banding structure only by heat treatment. Heat treatment temperature and time leading to dissolution of existing in as-received material α phase precipitations should be assumed. The temperature of annealing was determined as 950 °C and 1 h annealing time was applied. After such heat treatment the investigated material was cooled in water. These conditions allowed obtaining uniform microstructure in the investigated alloy (Fig. 9).

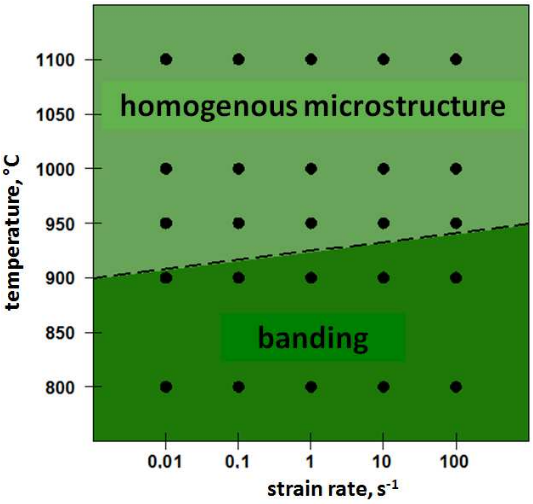

Fig. 7. Diagram showing the range of the occurrence of banding of primary structure of Ti-10V-2Fe-3Al alloy in relation to processing conditions. Points show deformation conditions after which the microstructure of the investigated alloy was analyzed

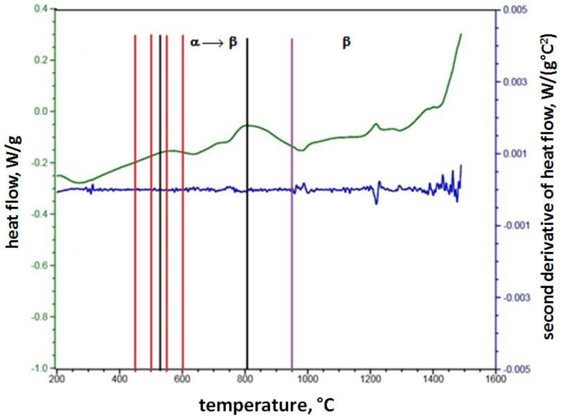

Fig. 8. Calorimetric curve for Ti-10V-2Fe-3Al alloy recorded during heating up from as-received condition with marked region of α→β transformation, temperature of solution treatment and applied ageing temperatures

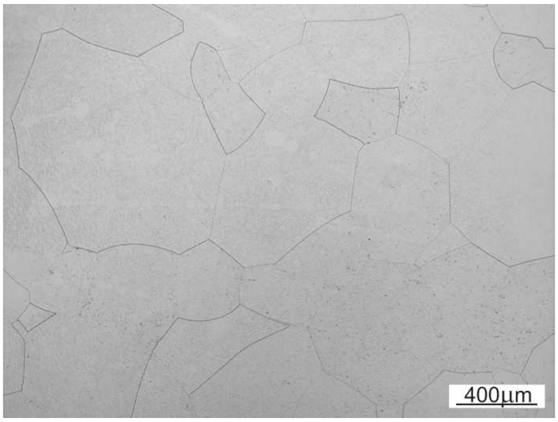

Fig. 9. Microstructure of Ti-10V-2Fe-3Al alloy after solution treatment, light microscope

Homogenization of the microstructure of the investigated alloy was confirmed by the results of ageing showing uniform precipitations of α phase (Fig. 10).

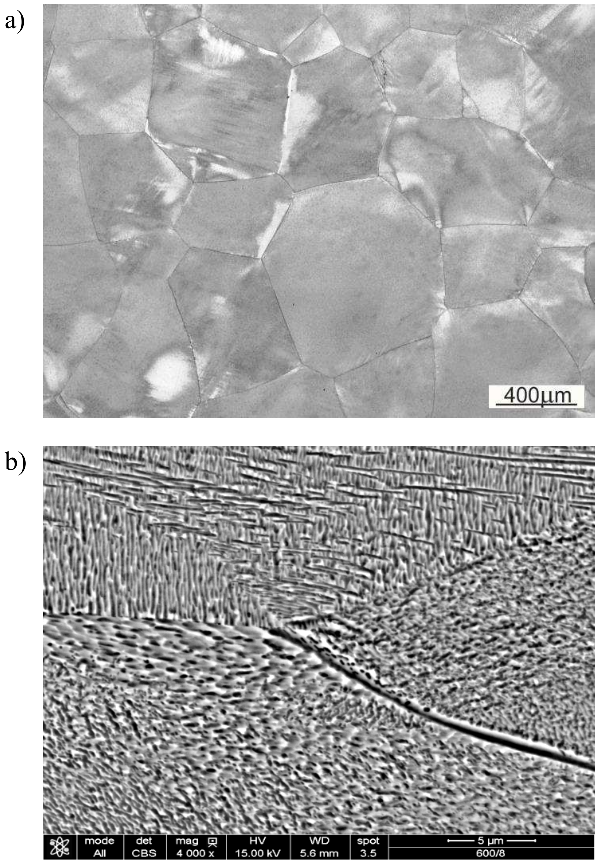

Fig. 10. Microstructure of Ti-10V-2Fe-3Al alloy after solution treatment and ageing during 8 h at the temperature of 600°C: a) light microscope, b) SEM

5. Influence of processing conditions on annihilation of banding in Ti-3Al-8V-6Cr-4Mo-4Zr alloy

Microstructural banding in Ti-3Al-8V-6Cr-4Mo-4Zr alloy formed during production of alloy rod resulted not only from deformation, but also from inhomogeneities in the chemical composition of the alloying elements during crystallization (Fig. 11). Significant differences in the advancement of the ageing processes in dendritic and interdendritic areas were observed. This inhomogeneity was confirmed by the presence of two kinds of β phase having different lattice parameters (Fig. 12).

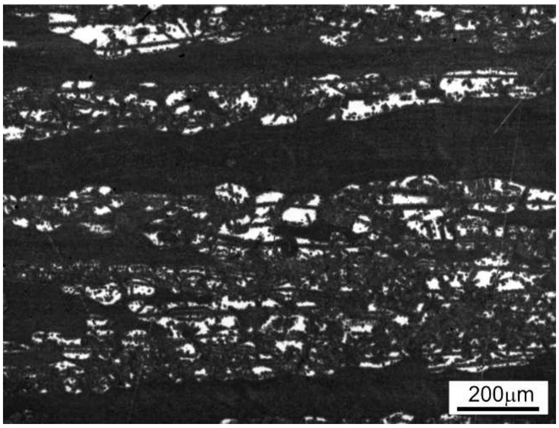

Fig. 11. Microstructure of Ti-3Al-8V-6Cr-4Mo-4Zr alloy rod (as-received material) – banding is parallel to rod axis, longer side of the picture is parallel to rod axis. Longitudinal cross-section, light microscope

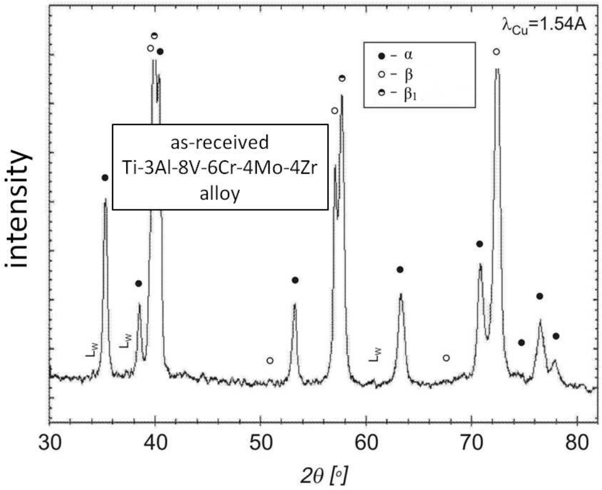

Fig. 12. X-ray diffraction of Ti-3Al-8V-6Cr-4Mo-4Zr alloy

As can be noticed in Fig. 13, annihilation of banding is possible in the materials processed under lower strain rates and at longer deformation time. Intensification of plastic deformation does not influence annihilation of banding significantly. That is why annihilation of banding can be obtained under processing temperature range of 900°C (strain rate 0.01 s^{-1}) and 1000°C (strain rate 100 s^{-1}) in the materials deformed to a total true strain of 1. This should be associated with the necessity of homogenization of the chemical composition and the intensity of dynamic recrystallization and dynamic recovery processes [21]. Exemplary microstructures used for creating diagram 13 were shown in Fig. 14.

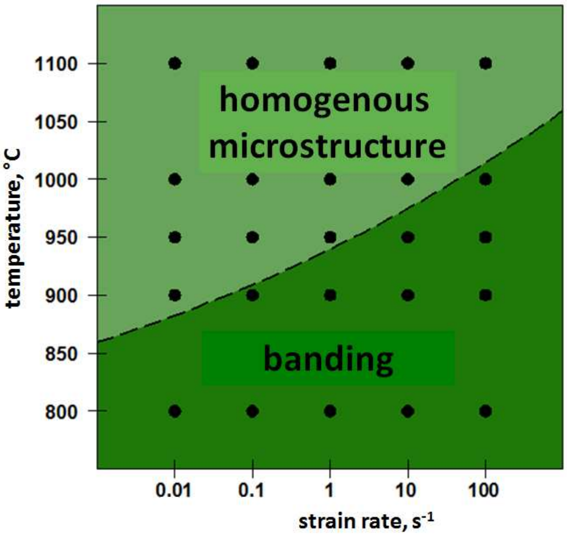

Fig. 13. The range of the occurrence of banding in primary structure of Ti-3Al-8V-6Cr-4Mo-4Zr alloy in relation to the processing conditions. Points show deformation conditions after which the microstructure of the investigated alloy was analyzed

The analysis of the diagram presented in Fig. 13 as well as the results of the calorimetric investigations of as-received material (Fig. 15) showed the possibility of annihilation of banding only by heat treatment. Heat treatment temperature and time leading to dissolution of existing in as-received material α phase precipitations as well as to homogenization of its chemical composition should be assumed. The temperature of annealing (950 °C) and annealing time (1 h) were applied similarly as in the case of previously discussed alloy. These conditions allowed obtaining uniform microstructure in the investigated alloy (Fig. 16).

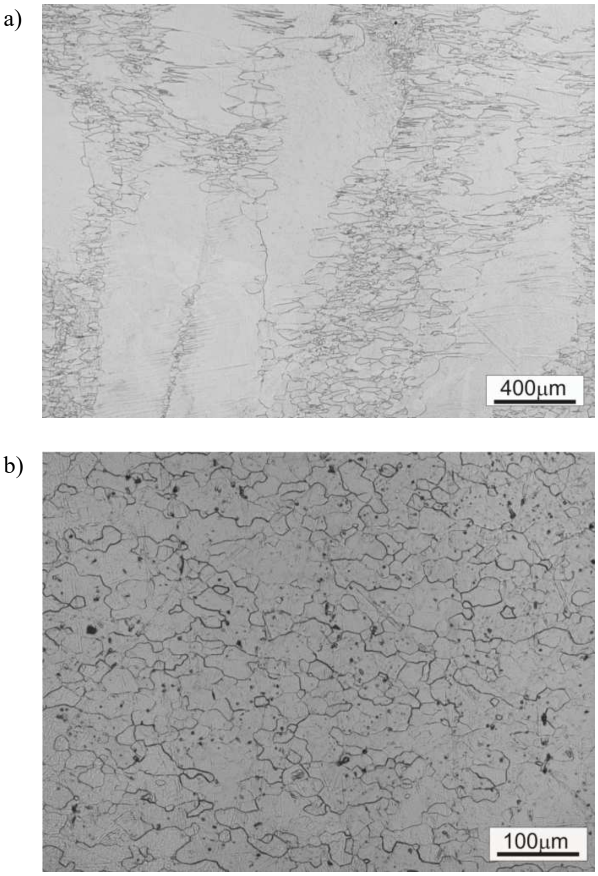

Fig. 14. Microstructures of Ti-3Al-8V-6Cr-4Mo-4Zr alloy samples deformed to a total true strain of 1: a) strain rate of 100 s^{-1}, deformation temperature of 900°C; b) strain rate of 0.01 s^{-1}, deformation temperature of 900°C; light microscope

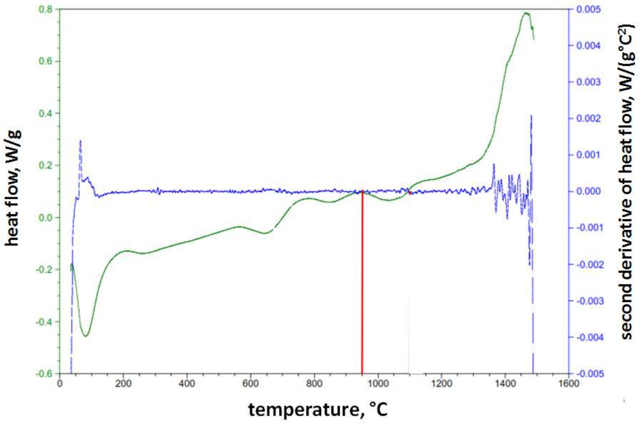

Fig. 15. Calorimetric curve for Ti-3Al-8V-6Cr-4Mo-4Zr alloy recorded during heating up as-received material with marked temperature of solution treatment

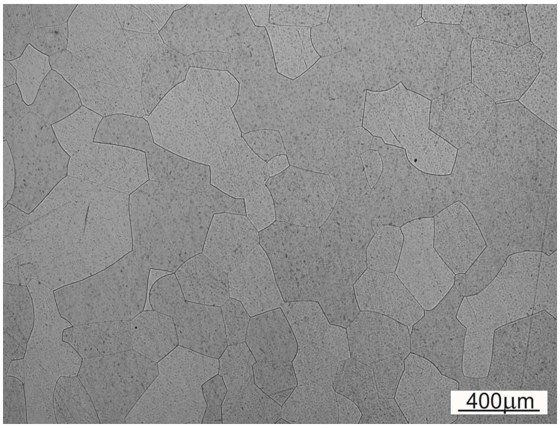

Fig. 16. Microstructure of Ti-3Al-8V-6Cr-4Mo-4Zr alloy after solution treatment, light microscope

6. Summary and conclusions

Basing on the results of the investigations the following conclusions can be drawn:

Due to the possibility of microstructural banding in titanium alloys, manufacturing structural components from such alloys requires precise control of all processing parameters.

Recrystallization of α phase and its coalescence in the areas of strain inhomogeneity promotes microstructural banding in two-phase titanium alloys.

In near β titanium alloys bending can be annihilated by plastic deformation performed at low strain rates. The annihilation of microstructural banding as well as homogenization of the chemical composition is also possible by annealing resulting in α phase dissolution.

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Additional information

Selected issues related to this paper are planned to be presented at the 22nd Winter International Scientific Conference on Achievements in Mechanical and Materials Engineering Winter-AMME'2015 in the framework of the Bidisciplinary Occasional Scientific Session BOSS'2015 celebrating the 10th anniversary of the foundation of the Association of Computational Materials Science and Surface Engineering and the World Academy of Materials and Manufacturing Engineering and of the foundation of the Worldwide Journal of Achievements in Materials and Manufacturing Engineering.

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