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TEXTURE AND RESIDUAL STRESSES IN Ti-Al AND Ti-Al-Nb ALLOY SUBJECTED TO SEVERE PLASTIC DEFORMATION

ANALIZA TEKSTURY I NAPRĘŻEŃ SZCZĄTKOWYCH W STOPACH Ti-Al I Ti-Al-Nb PODDANYCH DUŻEMU ODKSZTAŁCENIU PLASTYCZNEMU

The paper presents an analysis of the residual stresses and texture in two alloys of the Ti-Al and Ti-Al-Nb systems (in the Ti_3Al phase, which predominated in these alloys), before and after subjecting them to severe plastic deformation. In the as-received state, the texture of the Ti-Al alloy is relatively weak. The Ti-Al-Nb alloy texture has a similar character but contains a well-marked <001> component. After deformation, the texture of the Ti-Al alloy can be described by a single axial <012> component, deflected by 25° from the <001> axis, whereas the texture of the Nb-enriched alloy is much less pronounced than before deformation (in the as-received state). This can be interpreted as a result of its destruction during the deformation process.

The magnitudes of the compressive residual stresses in the as- received samples ranged from 5 MPa (Ti-Al) to 15 MPa (Ti-Al-Nb). However, these results contain a relatively large error due to the large grain size. In the as-received state, the alloys are practically free of stresses. After deformation, the residual stresses were found to be again compressive and near 660 MPa in the Ti-Al alloy and 420 MPa in the Ti-Al-Nb alloy.

Keywords: Ti-Al alloys, High Pressure Torsion, texture, residual stresses

W pracy przedstawiono analizę zmian naprężeń szczątkowych i tekstury w dwóch stopach na osnowie faz międzymetalicznych z układu Ti-Al i Ti-Al-Nb przed i po dużym odkształceniu plastycznym. Analiza tekstury nie odkształconych próbek wykazała, że w stopie Ti-Al ma ona charakter osiowy o zróżnicowanym stopniu ukształtowania. Podobny charakter ma tekstura stopu Ti-Al-Nb jednakże z wyraźną składową typu <001>. Po odkształceniu tekstura próbek stopu Ti-Al daje się opisać jedną bardzo wyraźną składową osiową <012>, która jest odchylona o około 25° od osi <001>. Natomiast stop z dodatkiem Nb jest znacznie słabiej steksturowany w porównaniu ze stanem wyjściowym, co można zinterpretować jako "niszczenie" tekstury w procesie odkształcania.

Wartość naprężeń własnych w nie odkształconych próbkach badanych stopów wahała się od — 5 MPa (Ti-Al) do — 15MPa (Ti-Al-Nb). Uzyskane wyniki są jednak obciążo-

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ne stosunkowo dużym błędem ze względu na dużą wielkość ziarna, wobec czego należy przyjąć, że w stanie wyjściowym stopy te są praktycznie pozbawione naprężeń mierzalnych zastosowaną metodą. Z kolei w próbkach odkształconych stwierdzono obecność naprężeń ściskających: -600 MPa i –420 MPa, odpowiednio dla stopu Ti-Al i Ti-Al-Nb.

1. Introduction

Plastic deformation can be used to modify the structure and the properties of pure metals and their alloys. Classical plastic metal-forming methods, such as rolling, forging and extrusion, only permit limited deformation magnitudes. Recently new methods of plastic deformation have been proposed which can be used to produce strains exceeding 10 in logarithmic sense. These methods allow to obtain ultra fine-grained materials of superior mechanical properties.

The historical first method of manufacturing ultra fine-grained materials was High-Pressure Torsion developed by Bridgman [1]. Next method of grains refinement is the Equal Channel Angular Extrusion [2]. It consists in successive pressing through a bent channel (sample's cross-section remains constant). New techniques emerged in the last years include the Cyclic Extrusion Compression method developed by Richert and collaborators [3, 4], and the cyclic closed-die forging [5] which consists in alternate compression of the material in 2 or 3 axes at plain state of strain. The Accumulative Roll-Bonding method was developed at the Osaka university [6]. In 2001, Zhu and collaborators achieved ultra fine-grained structures through Repetitive Corrugation and Straightening of the material [7]. Hydrostatic Extrusion is also an effective method of obtaining fine- crystalline structures [8].

The aim of the present study was to examine the texture and residual stresses of Ti-Al and Ti-Al-Nb alloys subjected to heavy deformation by the High-Pressure Torsion method.

2. Materials and experiment

Two alloys, chemical compositions given in Table 1, were examined in this study.

The casted materials were homogenized by annealing at the temperature 1050°C for 1h in the case of Ti-Al and at the temperature 1100°C for 3h in the case of Ti-Al-Nb. The plastic deformation was induced by High-Pression Torsion (HPT) method — compression applied simultaneously with torsion (about 5 GPa).

TABLE 1

Chemical composition of the examined alloys

Component (weight %)	Ti	Al	Nb	Mo	Cr	Mn	Ni	Cu
Ti-Al	84.19	15.81	—	—	—	—	—	—
Ti-Al-Nb	56.57	15.87	27.03	0.18	0.10	0.20	0.03	0.01

Fig. 1. Schematic diagram of the deformation induced by High Pressure Torsion

The samples were subjected to HPT using Bridgman anvils (Fig. 1). Deformation was performed at room temperature. Magnitude of deformation induced by torsion depends on the distance from the center of the sample. Torsion straining of a cylindrical sample of diameter $2R$ and height h produces a shear strain that varies from zero on the sample axis to a maximum value γ_{max} on the lateral surface (situated at a distance R from the axis):

$$\gamma_{max} = 2\pi nR/h$$

where n is the number of rotations of the mobile anvil.

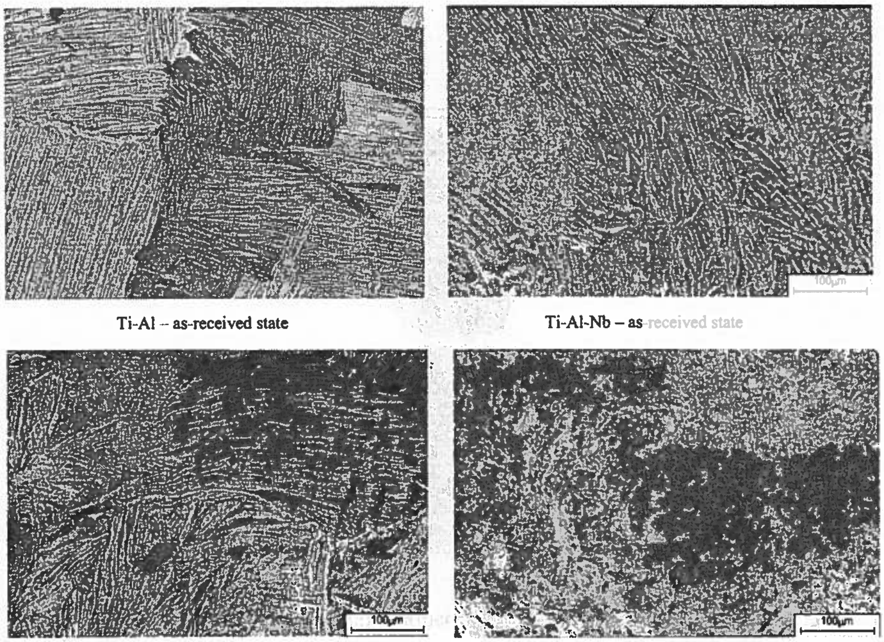
The number of turns was 5, h=0.3 mm, R=4mm. Maximum shear strain of the samples was 415. Microstructures of the examined alloys before and after deformation are present in Figure 2.

It has been found that Ti_3Al phase is a major constituent of all studied alloys. The texture (pole figure, orientation distribution function-ODF) and the residual stresses (determined by the $\sin^2\Psi$ method) were analyzed using the X-ray diffraction method.

For the simplicity of the present text, different samples used in this study were marked as follows:

- Ti-Al-0 (as-received state),
- Ti-Al-5 (deformed by n = 5),
- Ti-Al-Nb (as-received state),
- Ti-Al-Nb-5 (deformed by n = 5).

Texture analysis was performed based on incomplete pole figures *(200)*, *(002)* and *(201)* of the Ti_3Al phase, measured using Schulz reflected beams method [9]. Measurements were performed using Philips type X'Pert X-ray diffractometer



Ti-Al – as-received state | Ti-Al-Nb – as-received state

Ti-Al – middle of the deformed sample | Ti-Al-Nb – middle of the deformed sample

Fig. 2. Microstructure of the examined alloys before and after plastic deformation

equipped with ATC-3 texture goniometer. Filtered CoK_{α} radiation and the so-called pseudo position sensitive technique of detection of diffracted signal was employed [10]. Based on the registered pole figures, orientation distribution function (ODF) was calculated according with the discrete ADC method [11]. ODFs were presented in form of two-dimensional profiles.

Analysis of residual stresses was carried out based on the $\sin^2\Psi$ method. Measurements were performed using the same equipment as for texture measurement. For the Ti-Al sample analysis was based on reflection (004), and for the Ti-Al-Nb sample — on reflection (220).

3. Results and discussion

3.1. Texture analysis

As-received state

Based on the performed analysis it can be stated that texture of as-received samples has an axial character with varying intensity. *Ti-Al-0* sample shows weak texture, which is difficult to describe with a strictly specified component. On the other hand, texture of *Ti-Al-Nb-0* sample is more pronounced and shows distinct axial character <001>

and strong components constituting strongly heterogeneous fiber near the axis <012> (Fig. 3 and 4).

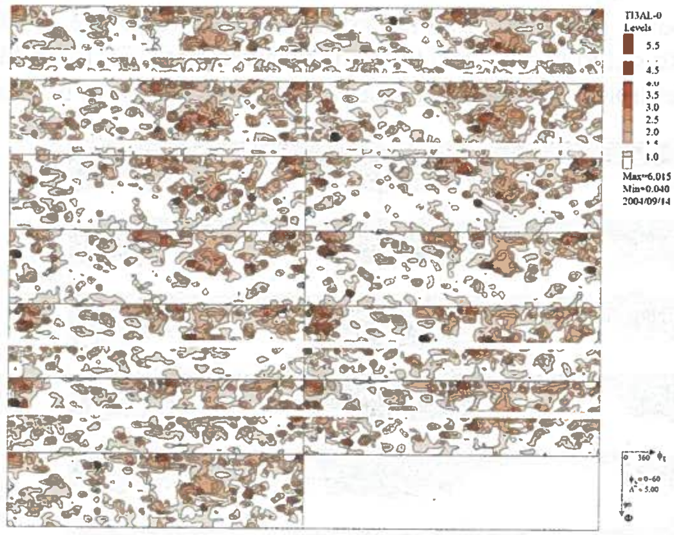


Fig. 3. ODF profiles for constant angle ϕ_2 values in the range 0- 60°/5° for the Ti-Al-0 sample

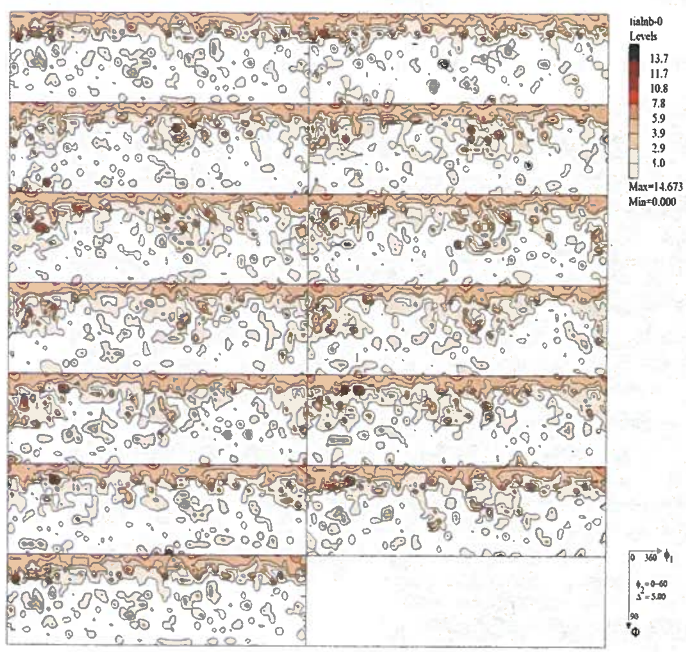


Fig. 4. ODF profiles for constant angle ϕ_2 values in the range 0- 60°/5° for the Ti-Al-Nb-0 sample

Deformed samples

The *Ti-Al-5* sample texture can be described with one, clear axial component <012>, deflected by about 25° from the <001> axis. However, the *Ti-Al-Nb-5* sample is much less textured in comparison to the as-received state (*Ti-Al-Nb-0*), what can be interpreted as destruction of texture in the deformation process (Fig. 5 and 6).

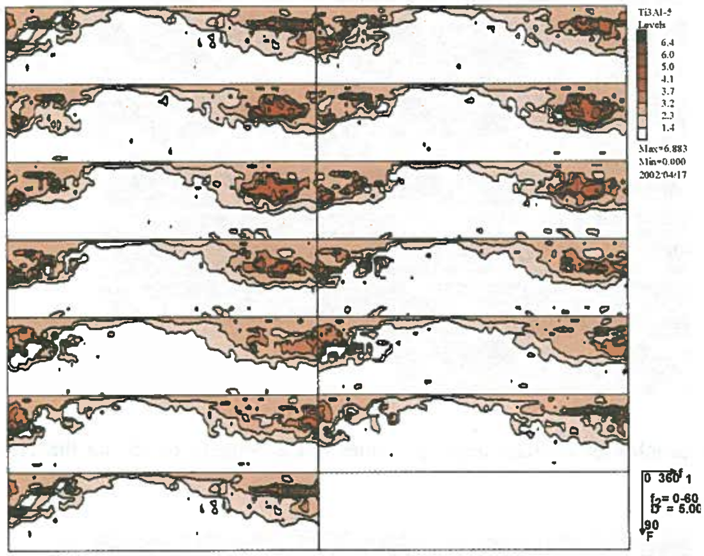


Fig. 5. ODF profiles for constant angle ϕ_2 values in the range 0- 60°/5° for a deformed Ti-Al-5 sample

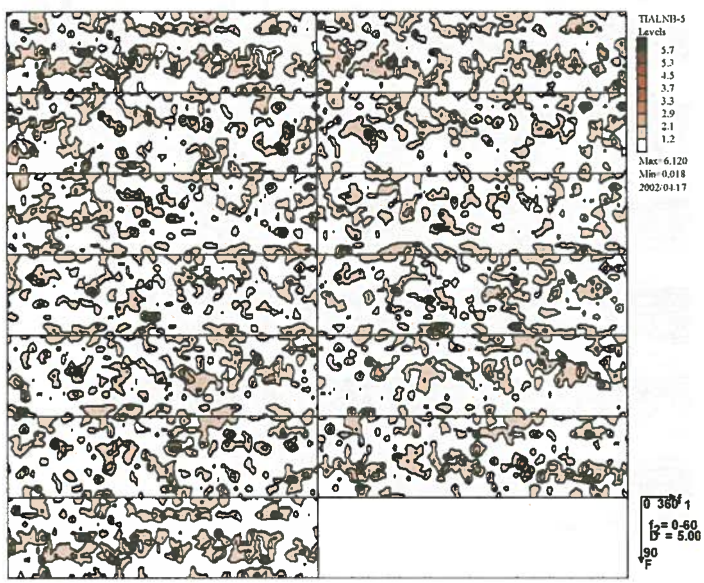


Fig. 6. ODF profiles for constant angle ϕ_2 values in the range 0- 60°/5° for a deformed Ti-Al-Nb-5 sample

3.2. Analysis of residual stresses

The experiment conditions allowed to obtain data from the 15 μm-thick near-surface layer of the sample. Compressive residual stresses of the examined alloys in the initial state ranged from about 5 MPa to 15 MPa for alloy Ti-Al and Ti-Al-Nb respectively. However, the obtained results contain a relatively large error, due to large grain size in the as-received state. Therefore, it should be stated that there are practically no residual stresses in the samples measured with the employed method. Deformed samples were also subjected to residual stresses analysis. Compressive stresses in the range of a couple of hundreds MPa were found in the samples, based on the performed calculations (Tab.2).

TABLE 2

Identified residual stresses in the examined samples

Sample symbol	Stress value before deformation [MPa]	Stress value after deformation [MPa]
Ti-Al	-5	-662
Ti-Al-Nb	-15	-419

4. Summary

The texture measurement of the Ti_3Al phase in examined alloys showed that in the as- received samples it has axial character with varying degree of intensity. Although in the Ti-Al alloy it is difficult to separate a specific texture component, in the alloy with addition of Nb type <001> component was clearly pronounced. Similar characteristic can be applied to the texture of deformed samples. However, the employed deformation method either strengthens or weakens this tendency depending on the alloy. The Ti-Al alloy after deformation shows clear type <012> axial component, and the Ti-Al-Nb sample, compared with the as-received state, is, on the other hand, much less textured, which can be interpreted as destruction of texture in deformation process.

Analysis of residual stresses revealed, that after deformation they gain character of compressive stresses and their value increases significantly compared with the as-received state.

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