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LAYERED MATERIAL MANUFACTURED FROM TITANIUM ALLOY Ti-6Al-4V

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Abstract. Titanium alloy Ti-6Al-4V is used to manufacture the layered material by means of diffusion bonding techniques. The layered material consists of sheets with nano- and microcrystalline structures. The layered material is investigated by conducting the mechanical tests and metallographic studies. The possibility to achieve isotropy in mechanical properties of the layered material is demonstrated. The characteristic features of the fractured specimens are studied.

1. INTRODUCTION

Titanium alloys are widely used in different branches of industry due to their high specific strength and corrosion resistance. In particular, these alloys are of exceptional interest when mass-saving is considered to be a decisive factor, e.g., in airspace industry. Layered materials made of titanium alloys can be considered as advanced materials for manufacturing various structural components. The main advantage of such materials as compared with monolithic ones consists in the possibility to optimize the orientation of composed layers with respect to the direction of acting loads.

There are various methods of manufacturing layered materials; diffusion bonding is one of them. It is possible to manufacture a layered material using titanium alloy Ti-6Al-4V sheets by means of diffusion bonding [1]. Due to the presence of a zone of a welded joint in these materials, special attention should be paid to the quality of a solid state joint (SSJ).

It is well-known that welded joints may contain pores. As a rule, the absence of such defects indicates the formation of SSJ with properties close to primary material [2,3]. Fracture toughness is conventionally believed to be the most reliable parameter characterizing the joint's quality, since it is a more sensitive characteristic as compared with other parameters, e.g., yield strength.

In the present paper the results of study of structure and properties of the layered material manufactured by means of diffusion bonding of Ti-6Al-4V alloy sheets with different microstructure are presented.

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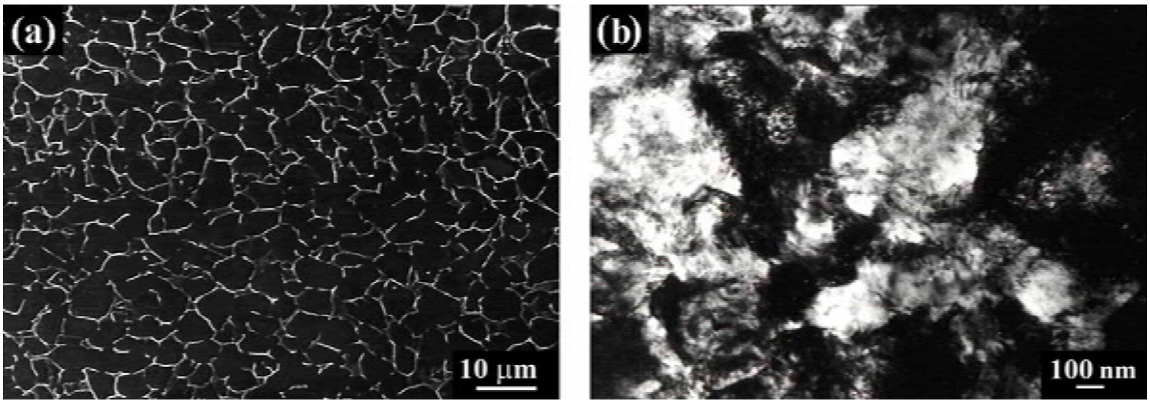

Fig. 1. Microstructures of MC (a) and NS (b) sheets of Ti-6Al-4V.

2. EXPERIMENTAL PROCEDURE

Microcrystalline (MC) and nanostructured (NS) sheets of 0.8 mm Ti-6Al-4V alloy were used to manufacture the layered materials. The MC sheets with a grain size of about 3 μm (Fig. 1a) were produced by VSMPO, Verhnyaya Salda, Russia. The NS sheets with a grain size of about 0.2 μm (Fig. 1b) were processed by multiple step forging [4] and subsequent isothermal rolling [5]. Microcrystalline ∅18 mm rod of the monolithic material with an average grain size of about 2 μm was used to carry out the comparative studies.

Two different types of layered materials were investigated. The layered material of type I was manufactured by using 5 MC sheets. The sheets in a package were assembled so that the angle between rolling directions in the neighboring sheets was 90°. The layered material of type II was manufactured by using 3 MC and 2 NS sheets, the NS sheets are placed between MC sheets.

Diffusion bonding of sheets, assembled in a package and placed in a die with wedge-type stop, was carried out in the electrical vacuum furnace OKB-8086. The sheets were pressurized by means of application the gas (argon) through special flexible membrane. Bonding of MC sheets was conducted at temperature 900 °C [6, 7] and duration under pressure (τ) equal to 20 min and 120 min. Bonding of NS and MC sheets was conducted at temperature 750 °C [7] and τ=120 min.

The specimens for mechanical tensile and impact tests were cut from the layered materials in two perpendicular directions (directions 1 and 2 respectively). The layers in the tensile specimen are disposed parallel to the tensile load. The layers in the impact specimen are disposed perpendicularly to the notch (Fig. 2). In this case the arrangement of layers is termed as “separating” the crack for convenience. The test specimens were cut also from the monolithic material in the longitudinal direction.

The specimens with dimensions 25 mm gauge length and 4 mm × 5 mm cross-section were used for tensile tests. Fracture toughness was determined in accordance with European EN 10045 standard by using the specimens with dimensions 4 mm × 10 mm × 55 mm with *U*-type notch and radius of concentrator *R*=1 mm.

Mechanical tests were carried out at the room temperature by using “INSTRON-1185” (tensile test) and Schenck Trebel RPSW 150/300 (impact test) testing machines. Metallographic examinations and fractography analysis were carried out using an optical microscope Nikon L150 and a JXA-6400 scanning electron microscope. The fractured surfaces of specimens cutting in direction 1 were studied.

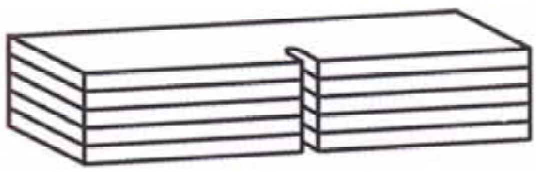

Fig. 2. Specimen for impact tests.

Table 1. Mechanical properties of the layered materials at room temperature.

Type of the layered material (microstructure of sheets)	*Duration under pressure,* τ, min	*Rolling direction (RD) in the sheets*	*KCU,* MJ/m^2		σ_Y, MPa		δ, %	
			*Direction of cutting**					
			1	2	1	2	1	2
I (MC/MC)	120	Coinciding RD	0.83	0.97	1067	1000	19	20
		Different RD (in one sheet)	0.84	0.88	1048	1010	19	19
	20	Coinciding RD	0.82	0.94	1041	1020	20	20
		Different RD (in two sheets)	0.90	0.91	1046	1055	18	19
II (MC/NS)	120	Coinciding RD	0.86	0.8	1024	1021	17	15
Monolithic material			0.99	-	1022	-	16	-

*Remarks: Directions of cutting 1 and 2 are perpendicular

3. RESULTS AND DISCUSSION

Microstructure analysis of the layered material of type I have shown that the isolated spherical pores with dimensions less than 1 μm were found in the SSJ processed at τ=20 min. The pores are disposed both along the grain boundaries and inside grains (Fig. 3a). The average grain size in the layers is about 5 μm. At the same time, the pores were not detected in the SSJ of the layered material processed at τ=120 min. In this case, the microstructure in the zone of the welded joint is almost same as the microstructure of the primary material (Fig. 3b), an average grain size in the layers is about 6 μm.

The SSJ of the layered material of type II contain both separate extended pores having the dimensions up to 2 μm and linear porosity disposed along the line of junction (Fig. 3c). The average grain size in the layers with initial nanostructure is about 2 μm while the average grain size in the layers with MC structure is about 4 μm. Fig. 3d represent macrostructure of the layered material of type II.

The results of mechanical tests are collected in Table 1. As one can see from the results presented in this table, the mechanical properties are rather isotropic and sufficiently high in value. The isotropy of the properties can be considered as an important advantage of the layered materials as compared with the commercial sheet titanium alloys since the latter ones are known to have an inherent anisotropy of mechanical properties. The anisotropy of mechanical properties of commercial titanium sheets is usually considered as a negative factor at manufacturing and exploitation of articles. It is to be emphasized that in the layered material of type I the isotropy of mechanical properties can be achieved only when the sheets in the layered material are disposed with alteration of rolling direction. In particular, the alteration of rolling direction in one layer leads to a decrease in the anisotropy of mechanical properties of the layered material. The level of anisotropy of the layered material of type II is decreased also. The using of NS sheets with isotropic mechanical properties [8] as intermediate layers can explain this fact. In addition, the rolling directions in the MC sheets coincide.

The results of mechanical tests allow concluding that the pores containing in the zones of the SSJ do not influence the ductile and strength properties of the studied materials as well as their fracture toughness. It is noted that the fracture toughness is most sensitive characteristic with respect to the quality of the SSJ as compared with other mechanical properties. The value of fracture toughness for the layered material is comparable with that for the monolithic material.

Thus, the layered material with isotropic mechanical properties can be manufactured by two methods: 1) by assembling the sheets into a package with alteration of rolling direction in them; 2) by alternation of MC and NS sheets. It is noted that the second method is preferable due to the decrease of diffusion bonding temperature up to 150 °C. Further enhancement of properties of the layered ma-

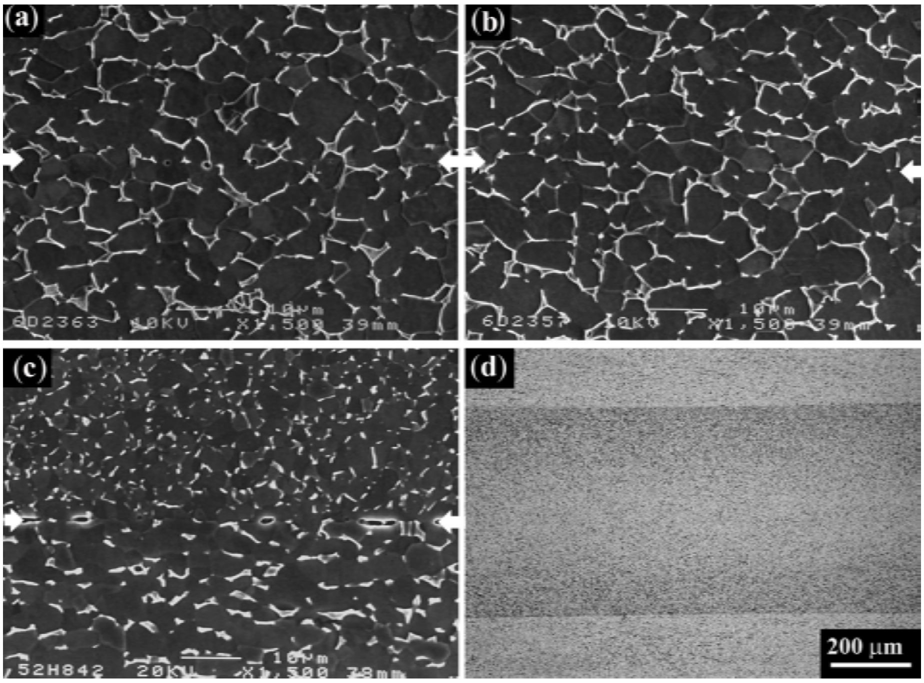

Fig. 3. Microstructures of the SSJ in the layered materials of type I (a, b) and II (c, d).

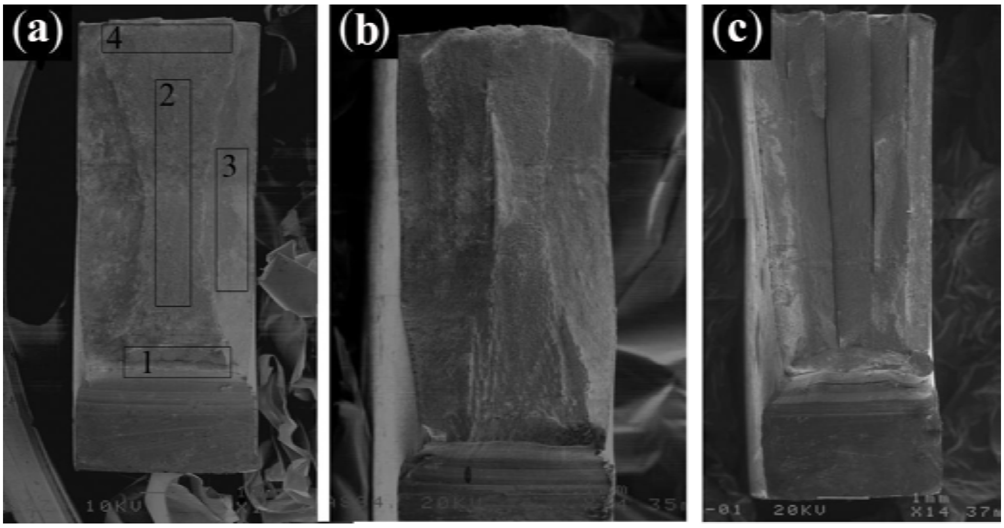

Fig. 4. Fracture surfaces of specimens cut of the layered material of type I (a, b) and II (c).

terial composed of MC and NS sheets can be achieved when the difference in the grain size of the contacting layers is more essential. Such an approach requires the optimization of the manufacturing procedure. Combining the high-strength and plastic layers along with artificially introduced contact interfaces it becomes possible to withstand effectively the crack propagation [9].

The surfaces of fractured specimens of the layered materials are presented in Fig. 4. As seen from Fig. 4, the fracture surface in the layered material with alteration of rolling direction (Fig. 4b) is different from that in the layered materials having coinciding rolling directions (Fig. 4a). The fracture surface is lusterless and has a dimpled ductile character. The appearance of fracture surface of the lay-

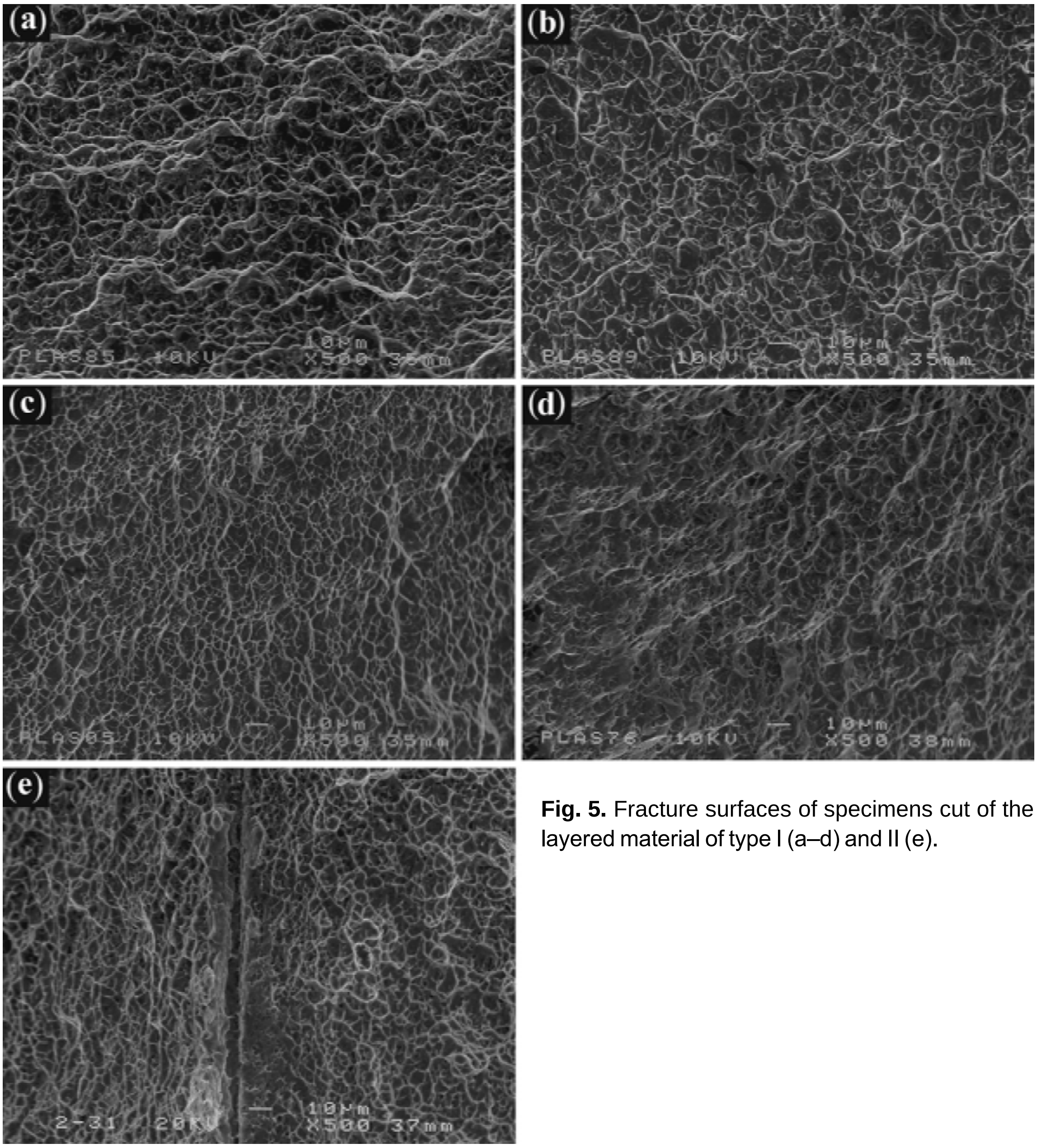

Fig. 5. Fracture surfaces of specimens cut of the layered material of type I (a–d) and II (e).

ered materials of type I is similar to that for the monolithic material that is possibly connected with almost faultless joint of layers. The fracture surface includes 4 zones (see Fig. 4a): 1 – adjoining the notch (Fig. 5a), 2 – main zone (Fig. 5b), 3 – the slope zone (Fig. 5c) and the finishing zone (Fig. 5d). The similar zones are present on fracture surface of the layered materials of type II but they differ in the extension.

Zone 2 in the layered material of type I with coinciding rolling directions has a pronounced X-type shape. When the rolling directions do not coincide the zone 2 has fuzzy edge. It is known [10], that the main amount of energy absorbed during fracture is determined by the extension of zone 2. Probably, the bigger extension of zone 2 and the blurring of its edges cause high impact strength (0.9 MJ/m^2).

The fracture surfaces of the layered material of type II are more complicated. The displacement of layers (Fig. 4c) appears to be related with the presence of the linear porosity in the zone of the SSJ.

Zones 2 and 3 are present in each layer and can not be distinguished one from another. Zone 4 is interrupted and has a “nail-type” shape.

Zones 2 and 3 in the layered material of type I with alteration of rolling directions as well as those in the material of type II are characterizing by drawn dimples (Fig. 5e). While in the layered material of type I with coinciding rolling directions the dimples are equiaxed (Fig. 5b).

4. CONCLUSIONS

Microstructures and mechanical properties of the layered materials of sheet Ti-6Al-4V alloy produced by means of diffusion bonding techniques were investigated. It was established that the pores existing in the zones of the solid state joint do not influence considerably the studied properties, including the most sensitive characteristic, fracture toughness, when layers are perpendicular to the notch. The value of fracture toughness of the layered materials is comparable with that of the monolithic one.

It was shown that isotropy of mechanical properties of the layered materials can be achieved by assembling the sheets with alteration of rolling directions or by alternation of layers with different microstructure.

The application of nanostructured sheets allows manufacturing a layered material with regulated complex of properties at temperature 750 °C.

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