EFFECT OF DYNAMICAL AGING IN SLM Ti-6Al-4V ALLOYS

ЭФФЕКТ ДИНАМИЧЕСКОГО СТАРЕНИЯ В СЛС Ti-6AL-4V СПЛАВАХ

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Abstract: *The application of the selective laser melting (SLM) method requires knowledge of not only the properties of the material after manufacturing, but also after mechanical loading. The aim of this work is to investigate the strain-rate dependence and microstructure of Ti6Al4V samples manufactured by SLM method with different angles to the building platform. SLM Ti-6Al-4V samples were manufactured using the EOSINT M280 (EOS GmbH) at angles of 0°, 30°, 45°, 90° to the building platform. A medicine Ti6Al4V (ASTM grade 23) powder was used for the study. Tensile tests were performed with an Instron test machine using two strain rates 0.5 mm/min and 2 mm/min at room temperature. It was found the strain-rate dependence in the studied samples. The features of the mechanisms of hardening and softening in an investigated SLM Ti-6Al-V alloy are discussed.*

KEYWORDS: TITANIUM ALLOY, SLM, 3D PRINTING, MICROSTRUCTURE, STRAIN RATE DEPENDENCE

1. Introduction

Deformation process of metallic materials at high-temperature conditions is competing with non-equilibrium processes associated with their hardening and softening. An increase in the metal density of dislocations is considered as the main contribution to metal hardening [1]. The experimentally obtained curve of dependence of the deformation resistance σ on the degree of deformation ε may show two different variants of hardening of the deformed materials. In the first case, a wave curve may be observed. The appearance of the waves is associated with the Portwein-Le Châtelier (PLC) effect, which is explained by the occurrence of propagative localized bands [2]. In the second case, the curve shows the repeated hardening of the alloy after past appreciable weakening [1].

In the absence of phase transitions, softening of the alloy occurs by dynamic return, polygonization and recrystallization [1]. Under certain temperature-velocity conditions of deformation, the dynamic deformation aging (DDA) may be occur. DDA effect associated with the increasing of the ductility of the material with increasing of the strain rate in defined range of the temperatures and rates [1]. Increasing in the strain rate usually decreases the mechanical properties of the materials. However, in some cases the effect of dynamical deformation aging was observed in conventional titanium alloys and steels [3-4].

The main purpose of this work is to study the effect of dynamic deformation aging the Ti-6Al-4V alloys manufactured by the selective laser melting.

2. Experimental

Spherical argon-atomized Ti6Al4V (ELI) (45 µm) powder from TLS Technik was used for study. The chemical composition complies with the ASTM B348 (Grade 23) for surgical implant applications. Ti-6Al-4V samples were manufactured by 3D printing using the selective laser melting (SLM) with the EOSINT M280 (EOS GmbH) 3D printing machine equipped with an Ytterbium fiber laser, and operating at 1075 nm wavelength (IPG Photonics Corp.). Standard EOS regime for manufacturing of the titanium alloys was used. SLM Ti-6Al-4V samples were manufactured at angles of 0°, 30°, 45°, 90° to the building platform. Structural studies were done with the QUANTA-200 scanning electron microscope equipped with a Pegasus system for the structural and texture analyses and with an EDAX energy-dispersive spectrometer for the elemental analysis. Tensile tests were performed at room temperature with an Instron test machine using two strain rates: 0.0013 s-1 and 0.0004 s-1. Samples were manufactured in the form of cylinders with a diameter of 12 mm and a length of 55 mm. Samples for mechanical testing were cut from the cylinders in accordance with GOST RF 1497-84. Density of the manufactured samples was defined as 99,7 %.

3. Results and Discussion

Figure 1 shows the schema of orientation of the sample to the building platform.

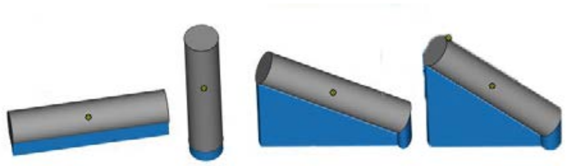

Fig.1 *Schema of the orientation studied samples to the building platform in EOSINT 280M printer.*

At the initial (as-build) state, all of the samples had the martensitic HCP α′-structure. Figure 2 presents the structure of the 45° sample. Such structure was found in all of studied samples.

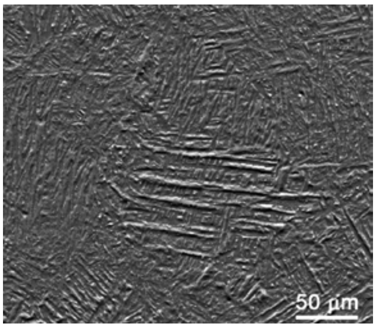

Fig.2 *Structure of 45° sample, scanning electron microscopy.*

In the structure of the as-build samples, we found the pores. Spherical pores are characteristic of materials obtained by selective laser melting. Small pores with dimensions of about 4-10 microns and pores with sizes up to 30 microns may be observed in the structure of the samples (Fig. 3).

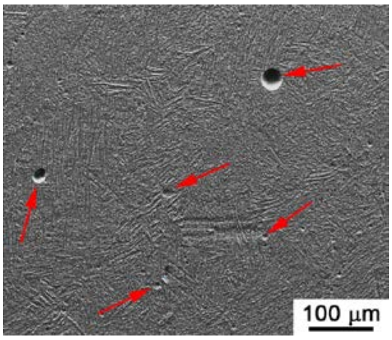

Fig.3 *Pores in the as-build 45° sample, scanning electron microscopy.*

Results of the mechanical testing are presented in the Table 1.

Table 1: Tensile properties of as-built Ti6Al4V samples

Building angle (grad)	UTS, (MPa)	YS, (MPa)	Elongation at break (%)	Strain rate, s^{-1}
45	990	880	6.4	0.0004
45	1020	940	18.6	0,0013
0	1000	940	14.3	0,0013
30	1010	930	16.4	0,0013
90	980	890	13	0,0013

Figure 4 presents the strain-stress curves for 45° sample deformed at different rates. The dependence of the ductility on the strain rate was found in the 45° samples.

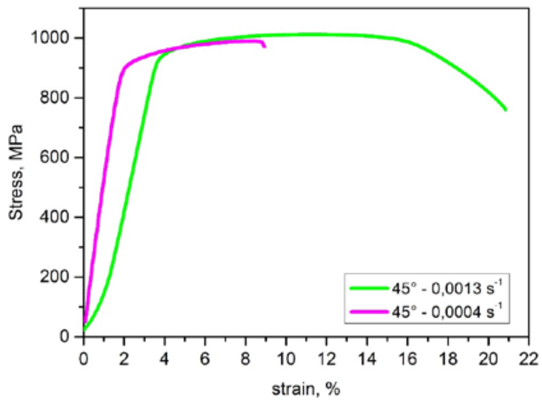

Fig.4 *Strain-stress curves of 45° sample after deformation at different rates.*

It is known that, the mechanical properties of the Ti6Al4V alloy strongly depend on the structure, heat treatment and the method of obtaining the samples [5]. As can be seen from the Table 1, the SLM samples grown at an angle of 45° to the building platform show the greatest plasticity. Increasing in strain rate up to 0.0004 s^{-1} (this strain rate is a standard one for deformation of the small samples) leads to a significant decrease in plasticity of the 45° sample. The results of the mechanical testing at standard strain rate are in good correlation with the literature date for SLM Ti-6Al-4V alloys [5-7]. Usually, the mechanical properties of Ti6Al4V obtained by the SLM method are characterized by high yield strength (YS), high time resistance (UTS) and low ductility. High strength properties and low plasticity are associated with the formation of a martensitic structure at a high rate of crystallization [7].

Structure studies found the different distribution of the pores in the sample after deformation at different rates (Fig. 5).

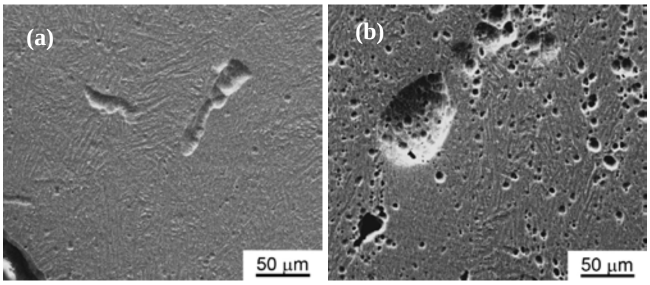

Fig.5 *SEM structure of the pores in the 45 ° sample after deformation at different rates: (a) - 0.0004 s^{-1}; (b) - 0,0013 s^{-1}.*

The sample deformed at standard strain rate (0.0004 s^{-1}) shows the weak neck formation, which is associated with coarsening and coalescence of the pores (Fig. 5a). In the case of the rapid strain rate (0.0013 s^{-1}), deformation occurs by formation of the deep necking region, which is associated with new pore formation and its coalescence (Fig. 5b). The pore behavior under standard rate of deformation was studied in [8]. Authors found the same behavior of the pores in the neck of the sample, which was associated with coarsening and coalescence of the pores in the SLM Ti-6Al-4V sample under deformation.

4. Conclusion

1. Structure and deformation process of the SLM Ti6A4V (grade 23) samples with a density 99.7% were studied. Microstructure of the SLM samples showed the presence of pores with the size from 4 to 30 μm.
2. Deformation process in the sample under different strain rates showed rate dependence of the plasticity of the sample. The elongation at the break was also found depending on the orientation of the sample to the building platform. The most elongation was found in the 45° sample.
3. The ductile fracture mechanism of the samples deformed at rapid strain rate (0.0013 s^{-1}) under tension is associated with formation of the deep necking region, which is associated with new pore formation and its coalescence.
4. The sample deformed at standard strain rate (0.0004 s^{-1}) shows the weak neck formation, which is associated with coarsening and coalescence of the pores.

Acknowledgments

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