PHYSICAL MODELING OF HOT FORGING OF CAST AND P/M Ti-6Al-4V ALLOY

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Abstract

Titanium alloys such as Ti-6Al-4V are applied in production of structural parts mainly in aircraft and automotive industry, mostly due to favorable relationships between density and mechanical properties as well as good corrosion and crack resistance. Nowadays the most common process of plastic deformation of this material at the industry is hot forging. In search of cost reduction, powder metallurgy method is very promising, because of potential benefits like more precise control of process parameters. In this respect, determining the parameters of thermo-mechanical processing is crucial due to low formability of Ti-6Al-4V alloy. This paper presents the results of the physical modeling of hot forging of cast and P/M Ti-6Al-4V alloy. Both types of the billets were subjected to hot compression tests using the Bähr MDS 830 thermo-mechanical simulator, under various thermal and strain-rate conditions. The microstructures of the samples manufactured by casting and machined from the compacts were observed and compared after deformation. Moreover, the results of the hardness measurements shown the relationships between the conditions of hot deformation and strengthening of the materials. In the result of the investigations, the favorable combinations of thermo-mechanical parameters of Ti-6Al-4V alloy processing were determined.

Keywords: Physical modeling, Ti-6Al-4V alloy, hot forging, microstructure, properties

1. INTRODUCTION

Ti-6Al-4V alloy is one of the most widely used titanium alloy especially due to attractive mechanical properties and low density [1]. This alloy is applied for responsible structural parts in such areas as aircraft industry, automotive, military and chemical industry. Another very important application can be found in medical industry due to good corrosion resistance and biocompatibility of such alloy [1-5]. In the case of manufacturing products from this alloy with application of metal forming technologies, the most common technique is hot forging. For proper design of this process very important is knowledge of the relationships between parameters of hot forming and the microstructure, what determines the mechanical and physical properties of final products [6, 7]. Hence, manufacturing structural parts from Ti-6Al-4V alloy demands strictly defined parameters of thermo-mechanical processing such as hot forging [1, 8]. In this respect, powder metallurgy method can be promising, because of benefits such as more precise control of deformation process and cost reductions comparing to conventional method like casting [9]. Changing the thermo-mechanical parameters such as temperature or strain-rate influences both mechanical properties and microstructure of Ti-6Al-4V alloy. This work discusses the most advantageous combination of thermo-mechanical conditions for processing Ti-6Al-4V alloy obtained by powder metallurgy method and casting.

2. EXPERIMENTAL RESEARCH

2.1. Aim and scope of the study

The aim of this research was to determine the most favorable thermo-mechanical conditions of hot deformation of cast Ti-6Al-4V alloy and P/M Ti-6Al-4V alloy obtained by mixing of the elemental powders. The investigations involved compression tests under various temperature and strain-rate conditions, using the Bähr MDS 830 thermo-mechanical simulator. The influence of deformation conditions on the microstructures of both types of samples was analyzed. Hardness measurements showed the effect of hot deformation on the mechanical properties of the investigated alloy.

2.2. Materials for study

The initial materials used in the compression tests were P/M Ti-6Al-4V alloy compact obtained by sintering of blended elemental powder as well as cast Ti-6Al-4V alloy. Specimens with 14 mm height and 8 mm diameter were machined from compacts and cast material respectively. **Table 1** presents the chemical composition of the investigation alloy. **Figure 1** shows microstructures of as-received P/M (**Figure 1A**) and cast (**Figure 1B**) Ti-6Al-4V alloy. Chosen physical and mechanical properties of the investigated alloy were shown in **Table 2.**

Table 1 Chemical composition (wt.%) of Ti-6Al-4V alloy (ISO 5832/3)

O	V	Al	Fe	H	C	N	Ti
<0.2	3.5	5.5	<0.3	<0.0015	<0.08	<0.05	Balanced

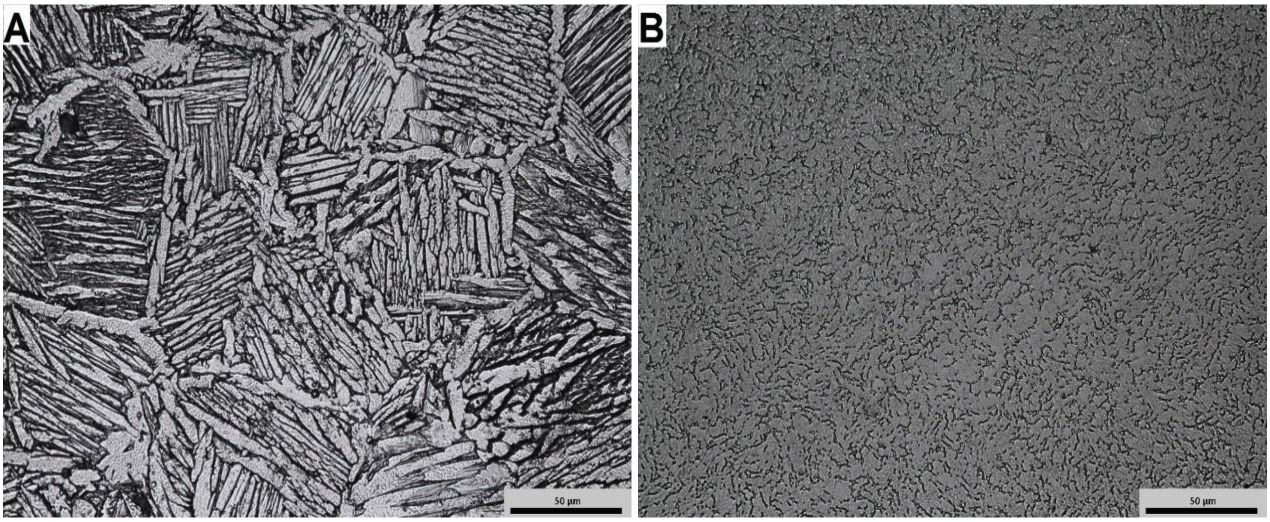

Figure 1 Microstructure of as-received P/M (A) and cast (B) Ti-6Al-4V alloy

Table 2 Chosen physical and mechanical properties of cast [10] and P/M [8] Ti-6Al-4V alloy

	Density (g/cm^3)	Relative density (%)	Hardness (HV)	Tensile yield strength $R_{p0.2}$ (MPa)	Ultimate tensile strength R_m (MPa)	Young Modulus E (GPa)
Cast	4.43	-	321	880	950	110-114
P/M	4.40	99.4	339	1013	1029	104.6

2.3. Compression tests

Compression tests were performed on Bähr MDS 830 thermo-mechanical simulator, available at the Institut für Metallformung of TU Freiberg in Germany. The general schedule of the conducted research was shown in **Figure 2**. Each sample was heated up to the temperature of 1000 °C, held at this temperature for 5 min, cooled down to the deformation temperature and deformed in compression. After deformation the samples were cooled at room temperature. The parameters of the performed tests for P/M Ti-6Al-4V alloy as well as for cast alloy were shown in **Table 3**.

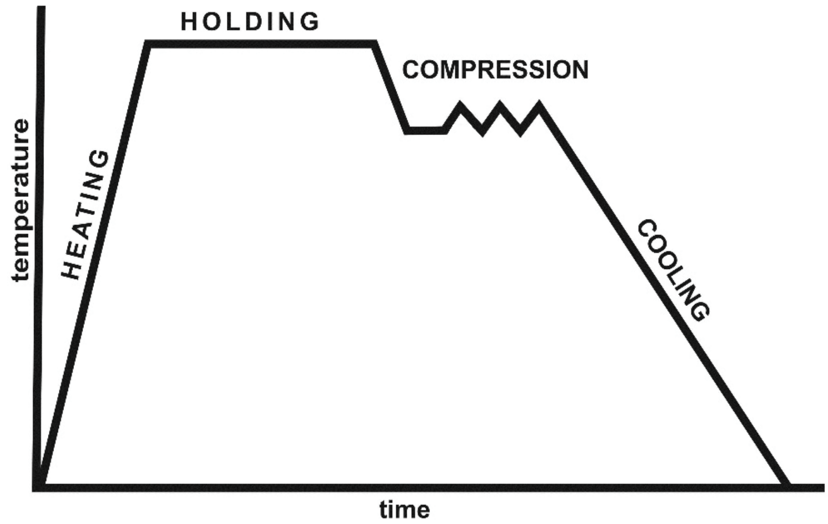

Figure 2 Schematic representation of the compression tests performed on Bähr MDS 830

Table 3 The parameters of compression tests performed on Bähr MDS 830

Heating rate (K/s)	Holding temperature (°C)	Holding time (min)	Test temperature (°C)	Strain rate (s^{-1})	Cooling
5	1000	5	850; 900	0.1; 1; 10; 30	Room temperature

In the results of plastometric tests stress-strain curves were obtained (**Figure 3** and **Figure 4**). Due to applied parameters of deformation process, compression in lower temperature and high strain rate, with chosen set of tools was impossible to perform. It was revealed, that ceramic tools used in compression tests were inadequate to proposed thermo-mechanical parameter of process. The end point on stress-strain curves indicates the moment of ceramic plates cracking.

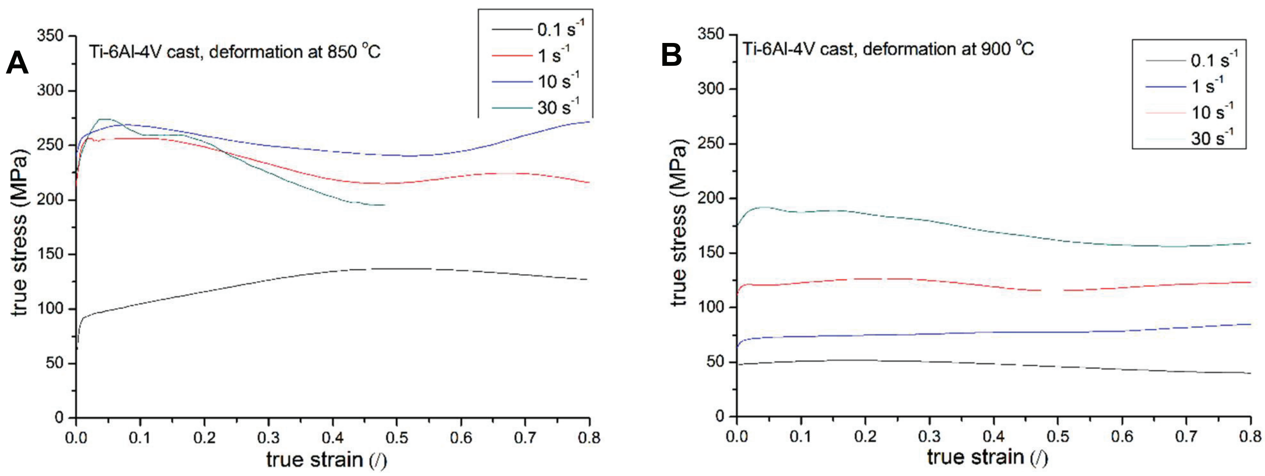

Figure 3 Stress-strain curves obtained in compression tests of cast Ti-6Al-4V alloy at the temperatures of 850 °C (A) and 900 °C (B)

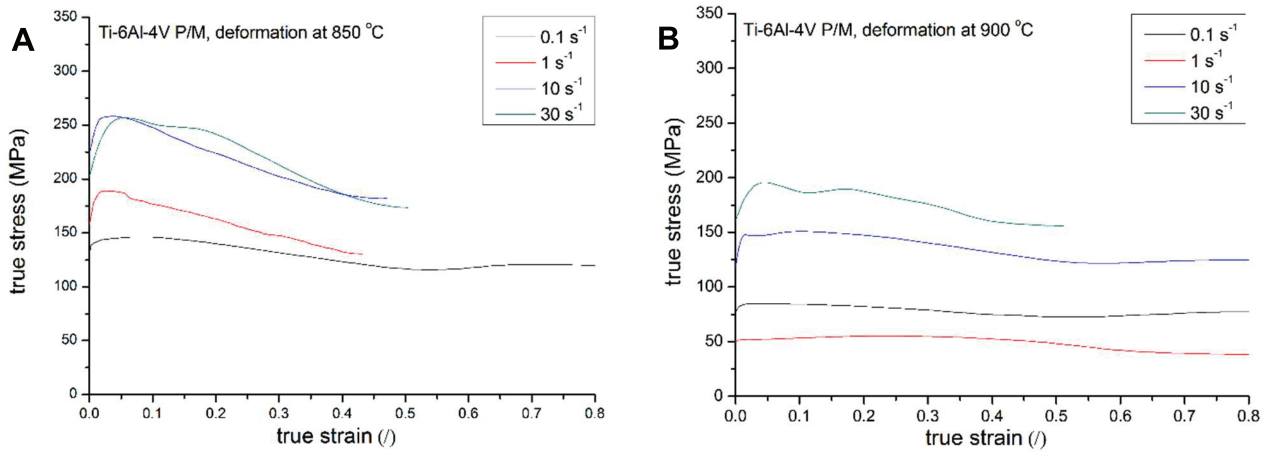

Figure 4 Stress-strain curves obtained in compression tests of P/M Ti-6Al-4V alloy at the temperatures of 850 °C (A) and 900 °C (B)

True stress required to achieve assumed amount of deformation was lower at the temperature of 900 °C for cast samples as well as for P/M material. Ceramic tools used in compression tests cracked more often at testing temperature of 850°C. Such situation was also observed in the case of tests performed on P/M Ti-6Al-4V alloy samples.

2.4. Metallographic investigations

The observations of microstructures of cast and P/M Ti-6Al-4V alloy after hot deformation were conducted using optical microscope LEICA DM4000M. Chosen microstructures of cast material were shown in **Figures 5A, B, C** and for P/M material in **Figures 5D, E, F**.

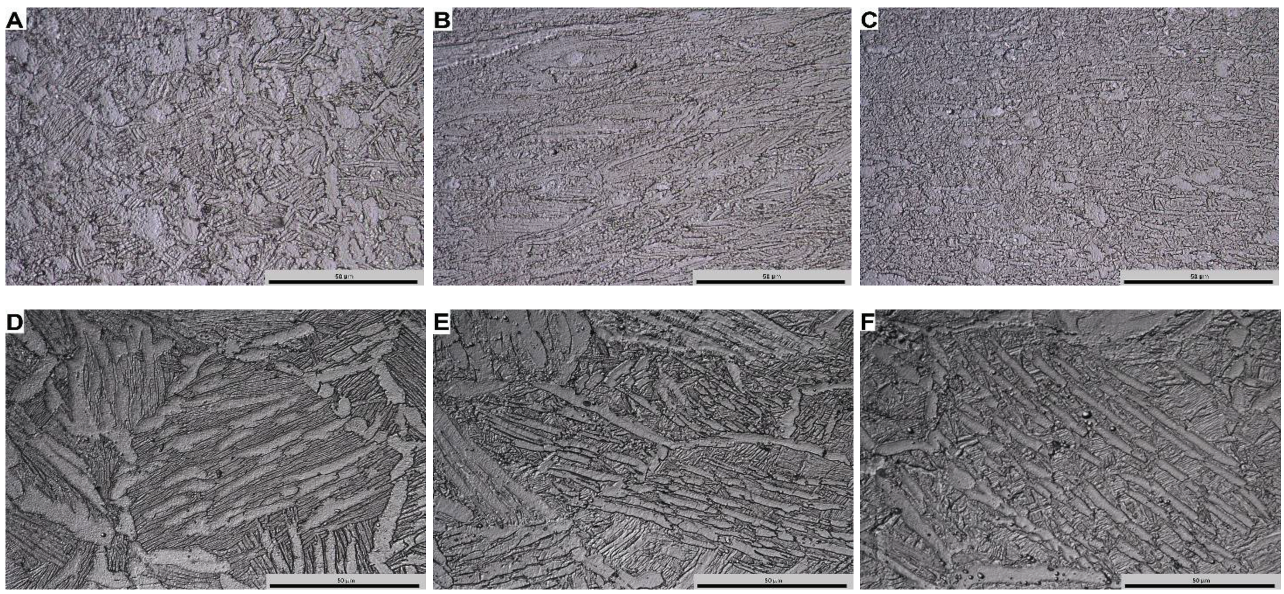

Figure 5 Microstructures of cast Ti-6Al-4V alloy after hot compression at the temperature of 850 °C and strain rate of 0.1 s^{-1} (A), 850 °C and strain rate of 10 s^{-1} (B), 900 °C and strain rate of 30 s^{-1} (C), and microstructures of cast Ti-6Al-4V alloy after hot compression of P/M Ti-6Al-4V alloy at the temperature of 850 °C and strain rate of 0.1 s^{-1} (D), 900 °C and strain rate of 0.1 s^{-1} (E), 900 °C and strain rate of 10 s^{-1} (F)

In both investigated materials the fragmentation of grains after hot deformation was observed. In cast Ti-6Al-4V alloy the microstructure had a bimodal character, having regular as well as lamellar grains. In the samples made by powder metallurgy method, thick lamellas of α phase located in β phase matrix were observed. In both types of material with increasing strain rate grains were more and more stretched and elongated in material flow direction.

2.5. Hardness measurements

Hardness measurements were conducted on samples after compression tests, in the case of which the deformation process has been successful. Hardness was measured on longitudinal cross-section in center region of the sample. **Table 4** presents the average of HV2 hardness values with standard deviation. Major differences between hardness values in relation to the strain rate were not observed. For specimens obtained by powder metallurgy, higher hardness values were measured as compared to the cast samples. In comparison to the initial material, hardness increased only slightly, what indicates that in both cases material was strengthened insignificantly. In each case the value of the standard deviation did not exceed 10 HV2.

Table 4 Hardness measurements results.

Strain rate (s^{-1})	Hardness in 900 °C, HV2	
	CAST	**P/M**
0.1	352 ± 3	359 ± 4
1	348 ± 8	354 ± 5
10	352 ± 7	356 ± 3

3. CONCLUSIONS

Basing on the results of the performed compression tests of cast and P/M Ti-6Al-4V alloy and also on metallographic analysis and hardness measurements, the following conclusions can be drawn:

- Examination of stress-strain curves has shown that the strain rate, as well as the temperature of deformation had strong influence on the stress values required to deform the material and on the nature of the material flow.
- Applied combinations of thermo-mechanical processing parameters caused cracking of compression tools, and in the result, the full stress-strain curves were not obtained for some samples.
- In the result of hot upsetting, the microstructure of both of the investigated materials was fine grained in comparison with that of the initial materials. The influence of the applied strain rate on the resulting microstructure of the processed material was observed. In cast material the microstructure had bimodal character, while in P/M Ti-6Al-4V alloy lamellar grains of α phase present in β phase matrix were observed.
- Hardness tests revealed that HV2 values in the result of compression test increased only slightly and hardness changed only in a narrow range. No significant influence of the proposed thermo-mechanical parameters on hardness value for the specimens after hot compression was observed. It was found, that the application of powder metallurgy method for obtaining Ti-6Al-4V alloy results in higher hardness of the material after deformation as compared to the processed cast material.
- The results of the performed investigations can be useful in describing the behavior of Ti-6Al-4V alloy in a wide range of thermo-mechanical conditions as well as in designing the parameters of processing such as hot forging, especially for the material obtained by powder metallurgy route for which a lack of adequate information in the technical literature exists.

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