THERMOMECHANICAL PROCESSING OF P/M Ti-6Al-4V ALLOY

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Abstract

Ti-6Al-4V alloy is used mainly in aircraft industry due to its low density, excellent corrosion/oxidation resistance, and attractive combination of mechanical properties. This alloy has relatively low formability, so forming parts of complex geometries out of this alloy requires precisely controlled thermomechanical processing parameters. In this respect, powder metallurgy methods are very promising, since the processing parameters in the case of P/M materials can be controlled more precisely. This work is aimed at the analysis of P/M Ti-6Al-4V alloy processing. The samples of Ti-6Al-4V alloy powder compacts, obtained from the blended mixtures of elemental powders, were subjected to plastometric tests under various temperature-strain rate conditions. The microstructures of both Ti-6Al-4V alloy powder compacts and hot deformed in compression on Gleeble simulator P/M Ti-6Al-4V alloy samples were analyzed. Moreover, basing on the results of plastometric tests, thermomechanical parameters of forging P/M Ti-6Al-4V alloy were determined. The investigated alloy was successfully forged in industrial conditions, what was also discussed in this study. The investigations showed a significant influence of processing parameters on development of the microstructure and mechanical behavior of P/M Ti-6Al-4V alloy.

Keywords: titanium alloy, powder metallurgy, microstructure, forging

1. INTRODUCTION

Ti-6Al-4V alloy is widely used mainly in aircraft industry mostly due to its low density and attractive combination of strength, crack resistance and corrosion resistance [1]. The most common processing routes for this group of alloys in industrial practice involve extrusion or forging [2]. The mechanical properties of Ti-6Al-4V alloy are strongly connected with its microstructure [3, 4]. Many research works were also focused on the parameters of thermomechanical processing of this alloy [5-7]. Producing complex-shape parts from this alloy requires precisely determined parameters of thermomechanical treatment due to its relatively low formability. Powder metallurgy methods are very promising, because the processing parameters in the case of P/M materials can be controlled more precisely [8, 9]. P/M Ti alloys can be classified into two groups based on the processing route: blended elemental and prealloyed. Blended elemental parts possess the attribute of low cost, but usually their mechanical properties are lower than those of cast parts. In contrast, parts obtained from prealloyed powders usually have satisfactory properties, while the cost is significantly higher than that of blended elemental parts, reducing competitiveness with respect to cost reduction. Therefore, the challenge is to either reduce the cost of prealloyed powder parts or increase the performance of blended elemental parts. Based on recent developments, the latter may be more promising. This work discusses the influence of processing parameters on development of the microstructure and mechanical behavior of P/M Ti-6Al-4V alloy obtained from the mixture of elemental powders.
2. EXPERIMENTAL RESEARCH

2.1 Aim and scope of the study

The aim of this research was to describe the parameters of forming high quality forgings from Ti-6Al-4V alloy obtained by powder metallurgy method. The investigations consisted of hot pressing of blended mixtures of elemental powders and testing the mechanical behavior of compacts under various strain rate-temperature conditions using Gleeble thermomechanical simulator. Basing on the results of these tests, the parameters of forging the investigated alloy powder compacts were determined. The correctness of these parameters was verified by forging tests in industrial conditions.

2.2 Material for the investigations

As a starting material for his study, a mixture of Ti, Al and V powders, giving desired chemical composition of Ti-6Al-4V alloy, was used. Figure 1 shows the starting powder mixture. EDS analysis of the powder mixture was also performed using Hitachi TM3000 microscope. The obtained results are shown in Figure 1B. Table 1 shows the chemical composition of the investigated alloy, which is typical for the composition of Ti-6Al-4V alloy. Small deviations from the chemical composition of standard chemical composition of Ti-6Al-4V alloy were due to randomly chosen amount of Ti-6Al-4V alloy powder mixture selected for this investigation.

![Fig. 1. Morphology of Ti-6Al-4V alloy powder (A), and the results of EDS chemical analysis of Ti-6Al-4V alloy powder (B)](image)

| Table 1. Chemical composition of Ti-6Al-4V alloy powder mixture (ISO 5832/3) |
|---|---|---|---|---|---|---|---|---|
| O  | V  | Al | Fe | H  | C  | N  | Ti |
| <0.20 | 3.5 | 5.5 | <0.30 | <0.0015 | <0.08 | <0.05 | balance |

2.3 Forming of compacts

Fully densified Ti6Al4V powder compacts were manufactured using Thermal Technology Inc. press available at AGH University of Science and Technology in Krakow. The compacts of Ti-6Al-4V alloy were formed at 1200°C under 25 MPa pressure and under an argon atmosphere during 3 hours. Fig. 2 shows the compact shape after compacting and machining.
2.4. Mechanical properties and microstructure of the investigated alloy

The physical and mechanical properties of the investigated alloy were examined. Plastometric tests were performed on Gleeble 3800 thermomechanical simulator. Basing on axisymmetrical compression tests results, flow stress curves for the investigated material deformed under various temperature-stress-strain rate conditions were obtained. The microstructure of Ti-6Al-4V alloy powder compacts as well as the microstructure of hot compressed P/M Ti-6Al-4V alloy samples was also examined.

Physical and mechanical properties of Ti-6Al-4V alloy powder compacts

The relative density of the compacts was determined. Brinell and Vickers hardness tests were also performed. Moreover, room temperature tensile tests were conducted on the samples machined from the investigated alloy powder compacts. The results obtained from the tests are shown in Table 2. This part of the research showed, that hot pressing of the mixture of elemental powders is effective way of obtaining P/M Ti-6Al-4V alloy. It was also observed, that the mechanical properties of the investigated material were slightly higher than these of cast Ti-6Al-4V alloy.

Table 2. Chosen properties of Ti-6Al-4V alloy powder compacts

<table>
<thead>
<tr>
<th>density g/cm²</th>
<th>relative density, %</th>
<th>Hardness HB</th>
<th>Hardness HV</th>
<th>R₀.₂ MPa</th>
<th>Rm MPa</th>
<th>E GPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.40</td>
<td>99.4</td>
<td>335</td>
<td>339</td>
<td>1013</td>
<td>1029</td>
<td>104.6</td>
</tr>
</tbody>
</table>

Plastometric tests

Plastometric tests were performed on Gleeble 3800 thermomechanical simulator available at the Institute for Ferrous Metallurgy in Gliwice. Fig. 3 shows schematic representation of the performed compression tests.
The parameters of axisymmetrical compression tests are shown in Table 3. Chosen true stress-true strain curves obtained from the performed tests are shown in Fig. 4.

Table 3. Parameters of plastometric tests

<table>
<thead>
<tr>
<th>heating rate, °C/s</th>
<th>time of holding before compression, s</th>
<th>Test temperature, °C</th>
<th>Strain rate, s⁻¹</th>
<th>cooling rate, °C/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>10</td>
<td>800, 900, 950</td>
<td>10, 100</td>
<td>~10</td>
</tr>
</tbody>
</table>

The obtained at various thermomechanical conditions flow stress curves can be used in designing the technology of P/M Ti-6Al-4V alloy processing as well as boundary conditions for numerical simulations of P/M Ti-6Al-4V alloy forming.

![Graph A](image1)

![Graph B](image2)

Fig. 4. True stress – true strain curves obtained from compression tests of P/M Ti-6Al-4V alloy at 900°C at strain rate of: 10 s⁻¹ (A), and 100 s⁻¹ (B)

Microstructures

The observations of the microstructure of Ti-6Al-4V alloy powder compacts and alloy samples after hot compression tests were performed using light microscopy. Fig. 5A shows the microstructure of Ti-6Al-4V alloy powder compact and Figs. 5B,C,D show the microstructures of the investigated alloy samples machined from the compacts and tested in compression on Gleeble simulator. The microstructure in both cases was fine grained and uniform. Moreover, comparing the microstructure of the compacts to the microstructure of the samples after compression tests it was noticed, that hot compression tests caused disintegration of α phase lamellas located in β phase matrix. The examinations of the microstructures did not reveal any porosity in the investigated compacts, what confirms that the obtained material was fully-dense.
2.6. Tests in industrial conditions

Elaborated in the present study thermomechanical parameters for processing the investigated P/M Ti-6Al-4V alloy were verified by forging tests performed in industrial conditions. Forging trials were performed at GfK Forge forging plant in Goleszów. Fig. 6A show a model of gear wheel chosen as a final forging. Cylindrical specimens with a height of 30 mm and a diameter of 70 mm were machined from fully-dense Ti-6Al-4V alloy powder compacts and used as a starting material for forging. The samples were heated up to 1000°C for 15 minutes in a gas furnace. Then, the samples were cooled down to 900°C and forged in two stages. Figure 6B shows the obtained forging. A good quality, defect-free forging of P/M Ti-6Al-4V alloy gear wheel was obtained.

Fig. 6. Forging of P/M Ti-6Al-4V alloy gear wheel: A - model, B – real forging.
3. SUMMARY

Basing on the results of this research the following conclusions can be drawn:

1. Ti-6Al-4V alloy can successfully be formed by hot pressing of mixture of elemental powders.

2. Examination of density of the obtained compacts proved, that their relative density equals the standard density of Ti-6Al-4V alloy. The applied parameters of hot pressing resulted in full densification of powder mixtures, what was also confirmed by the observations of the microstructure of the obtained compacts.

3. Tensile tests as well as hardness measurements performed on the samples machined from Ti-6Al-4V alloy powder compacts showed, that the mechanical properties of the investigated material are slightly higher than these of cast Ti-6Al-4V alloy.

4. Plastometric tests performed on Ti-6Al-4V alloy powder compacts allowed determining true stress-true strain curves for the investigated alloy at various temperature-strain-rate conditions. These results can be used in designing the technology of P/M Ti-6Al-4V alloy processing as well as boundary conditions for numerical simulations of P/M Ti-6Al-4V alloy forming.

5. The observations of the microstructure of Ti-6Al-4V alloy powder compacts and alloy samples after hot compression tests revealed, that the microstructure in both cases was fine grained and uniform. Moreover, comparing the microstructure of the compacts to the microstructure of the samples after compression tests it was noticed, that hot compression tests caused disintegration of α phase lamellas located in β phase matrix.

6. The forging test in industrial conditions resulted in obtaining good quality gear wheel from P/M Ti-6Al-4V alloy.

ACKNOWLEDGEMENTS

Financial support of Structural Funds in the Operational Programme - Innovative Economy (IE OP) financed from the European Regional Development Fund - Project WND-POIG.01.03.01-12-004/09 is gratefully acknowledged.

REFERENCES


