Effect of Brasssheathing on ECAP of Ti-6Al-4V Alloy by Deform-3D Simulation and Experimentalanalysis

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Abstract. The Deform-3D software was used to simulate and analyze the equal channel angular pressing (ECAP) of Ti-6Al-4V alloy with and without brass sheathing. The results show that the Ti-6Al-4V alloy samples with and without brass sheathing is both maintain a regular shape after ECAP. The effective strain of points on the cross section of sample with brass sheathing is smaller than that of sample without brass sheathing, but the extrusion load of sample with brass sheathing is smaller, and the difficulty of Ti-6Al-4V alloy in ECAP process was reduced. The experimental result also proves the feasibility of ECAP of Ti-6Al-4V alloy with brass sheathing, and the change of microstructure is accord with the deformation characteristic of ECAP.

1. Introduction

Titanium and titanium alloys are the most popular materials in the fields of aerospace and aviation, navigation, and shipping due to its high specific strength and stiffness, good formability, reasonable ductility, and ability to withstand high temperatures and resist corrosion [1-3]. Ultrafine grained titanium alloy usually refer to the titanium alloy with average grain size of less than 1μm. The ultrafine grained metal materials have super performance in ductility, toughness, strength, corrosion-resistant etc, compared to traditional materials [4, 5]. Equal channel angular pressing (ECAP) technology is one of the most popular methods for producing ultrafine grained metal materials, and has been successfully applied to the preparation of ultra-fine grained materials such as aluminum alloy, magnesium alloy and titanium alloy [6-8]. However, the ultra-fine grained titanium alloys are difficulty to be processed by ECAP owing to its several inherent properties [9-11]. The multiple passes ECAP of titanium alloys can be successfully conducted only at 500 ~ 600 °C isothermal conditions, and the moulds are subject to wear and tear quickly in ECAP process [12, 13].Sheathed extrusion is an effective method to decrease the difficulty of the titanium alloy ECAP. A layer of other metal materials with lower strength and higher plasticity was wrapped on the outside of titanium alloy specimen in ECAP process, it is cannot only reduce the overall extrusion load of ECAP, but also decrease the friction between titanium alloy specimen and moulds, and weaken the wear and tear of moulds, then extend the service life of ECAP moulds [14, 15].
The finite element simulation analysis of sheathed ECAP process of titanium alloy has not been reported. Base on Ti-6Al-4V alloy as the extrusion materials and brass as the sheathed material in this paper, the ECAP process of Ti-6Al-4V alloy with and without brass sheathing was simulated and analyzed by Deform-3D software. The effect of brass sheathing on ECAP of Ti-6Al-4V alloy was comparatively analyzed on the base of simulation and experimental results.

2. ECAP simulation Process of Ti-6Al-4V Alloy

The Deform-3D software is used to simulate the ECAP process of Ti-6Al-4V alloy with and without brass sheathing due to ECAP deformation process belongs to the typical volume deformation with characteristic of unchanging sample cross-sectional area. The models of ECAP simulation process is shown in Fig. 1. The channel of ECAP die was designed as circular cross section with diameter of 20 mm, the inner contact angle (Φ) and the arc of curvature (φ) at the outer point of contact between channels of the die were 110° and 20°, respectively. The Ti-6Al-4V alloy sample with the diameter of 20 mm and a height of 40 mm and without brass sheathing is shown in Fig. 1(a). The Ti-6Al-4V alloy sample with brass sheathing is shown in Fig. 1(b), the diameter and height of Ti-6Al-4V alloy is 18 mm and 40 mm, respectively, and the thickness of brass sheathing is 1 mm. The plunger and ECAP dies are both defined as rigid body. The material model, including material parameters, structure parameters and physics parameters, of plastic deformation materials are both selected from material store of Deform-3D software, among them, Ti-6Al-4V alloy was defined as Ti-6Al-4V-warm[200-1000F(100-600C)] and brass sheathing was defined as BRASS-CDA-365[400-1600F(200-900C)] in Deform-3D software. The temperature of Ti-6Al-4V alloy and brass sheathing were set to 500 °C and 25 °C, respectively, and the heat-transfer coefficient between Ti-6Al-4V alloy and brass sheathing was defined as 0.0005 W/m²·K. The friction coefficient between Ti-6Al-4V alloy and moulds in Fig. 1(a) is set to 0.2, but in Fig. 1(b), the friction coefficients between Ti-6Al-4V alloy and brass sheathing, and between brass sheathing and moulds are both set to 0.15.100mm·min⁻¹ was selected as the extrusion speed. The heat exchange between brass sheathing and moulds is ignored due to the time of whole ECAP process is less than 20s.

![Figure 1. The ECAP Deform-3D model: a) Ti-6Al-4V alloy without brass sheathing; b) Ti-6Al-4V alloy with brass sheathing](image)

3. Results and Analyses of ECAP Simulation

3.1. Deformation Process of ECAP Simulation

The deformation nephograms of Ti-6Al-4V alloy at different stage in ECAP simulation process were shown in Fig. 2. When the sample was pressed into the channel-extrude-out, the corner of two channels was filled up due to uniform distribution of structure and mechanical properties of the whole ECAP sample, as shown in Fig. 2(a). The sample deforms under extrusion pressure until the whole sample completely into the channel-extrude-out. The deformed Ti-6Al-4V sample is still remained in a
regular morphological form, as shown in Fig. 2(c). As to the sample sheathed with brass, the Ti-6Al-4V sample tilted in the channel, and a slight bending deformation was occurred in the corner due to the strength of brass is lower than Ti-6Al-4V alloy. The thickness variation of brass at inner and outer of corner is different. Thickness decreased at the outer of corner because of squeezing action between Ti-6Al-4V sample and ECAP dies. But the thickness of brass at the inner of corner changes little due to lower squeezing pressure, and Ti-6Al-4V sample was still sheathed by brass. The shape of the whole ECAP sample, include Ti-6Al-4V sample and sheathed brass, is also remained in a regular morphological form. However, unlike the ECAP sample without brass sheathing, the deformation zone of Ti-6Al-4V sample with brass sheathing is not very clearly, and the Ti-6Al-4V sample bended slightly.

Figure 2. The simulation process of Ti-6Al-4V alloy with and without brass sheathing: a, b, c) Ti-6Al-4V alloy without brass sheathing; d, e, f) Ti-6Al-4V alloy with brass sheathing

According to the characteristics of ECAP deformation, the deformation of ECAP sample without brass sheathing is nearly pure shear deformation, as shown in Fig. 2(c), the shape of main deformation zone is a parallelogram, and the cross section shape of ECAP sample is not change. Although slightly bending was occurred in the Ti-6Al-4V sample with brass sheathing in ECAP simulation process, as shown in Fig. 2(f), the shape of main deformation zone also likes a parallelogram, and the shear deformation is still the main deformation mode in ECAP process.

3.2. Loading Analysis
The load-displacement curves of samples with and without brass sheathing in ECAP simulation process are displayed in Fig. 3. The change rule of the two ECAP process is same. ECAP load
increased with increasing of displacement before the sample completely extrude into the corner, the deformation resistance at this stage is mainly composed of two parts: the friction between samples and mould, and the deformation resistance caused by slightly bend when samples through the arcof curvature. However, the ECAP load of sample without brass sheathing is smaller than sample with brass sheathing, this is because the Ti-6Al-4V sample with brass sheathing can deform easier due to the lower strength of brass. After the samples being subjected to shear deformation around the corner of die route, the load remain stable until to the end of ECAP process.

![Load of ECAP simulation process](image.png)

**Figure 3.** Load of ECAP simulation process

Base on the comparison of load-displacement curves of samples with and without brass sheathing in ECAP simulation process, we can see that the ECAP load of Ti-6Al-4V sample with brass sheathing reduced by one-fifth compared to Ti-6Al-4V sample without brass sheathing. The difficulty of ECAP of Ti-6Al-4V alloy was reduced significantly by the brass sheathing. The causes which reduced ECAP load are mainly lying in following three aspects: first of all, the section area of effective shearing deformation of Ti-6Al-4V alloy was decreased from 314mm² (diameter of 20 mm) to 254.34mm² (diameter of 18 mm) by the brass sheathing, and this is the main reason for decreasing of ECAP load; secondly, the friction of sample with brass sheathing is smaller than without brass sheathing in ECAP process; thirdly, slightly bending was occurred in the ECAP process of sample with brass sheathing (Fig. 2d,e,f), and the load that needed by bending deformation is smaller than shearing deformation.

3.3. **Equivalent Strain Analysis**

Three point (a1, b1, c1 and a2, b2, c2, respectively) at the same position which on the centre section of samples with and without brass sheathing were selected, and the equivalent strain–displacement curves of those points are displayed in Fig.4. Shearing deformation is the main deformation mode in ECAP process, therefore, the equivalent strain of a1, b1, c1 is considered as the real equivalent shear strain. Although slightly bending was occurred in the ECAP process of sample with brass sheathing, the shearing deformation still dominates. The real equivalent shear strain may be slightly smaller than equivalent strain of a2, b2, c2. As shown in Fig.4, the equivalent strain, with value of 0.8, of a1, b1, c1 are almost the same as the theoretical calculation results [16]. The equivalent strain change of a1, b1, c1 have the following characteristics: 1), the closer of point to the inner of corner, the earlier of shear deformation happen; 2), the deformation mainly occurs in intersections of two channels; 3), the equivalent strain of a1, b1, c1 have little change before and after the points being subjected to intersections of two channels. All of the characteristics correspond with the rule of ECAP deformation. However, the equivalent strain–displacement curves of a2, b2, c2 are completely different from a1, b1, c1. The equivalent strain with values between 0.6 and 0.7 are smaller than that of a1, b1, c1. The point
c2 which close to the inner of corner has the biggest equivalent strain with value of 0.7, and point close to the outer of corner has the smallest equivalent strain with value of 0.6. The equivalent strain of a2, b2, c2 almost increase at the same time, but as same as the ECAP simulation process of sample without brass sheathing, the point c2 firstly reach the biggest value of equivalent strain and point a2 lastly. Moreover, larger deformation was consumed in the process of equivalent strain of a2, b2, c2 increase from zero to the biggest value, which also indicates that slightly bending was occurred in the early of ECAP process of the sample with brass sheathing.

(a) Ti-6Al-4V alloy without brass sheathing; (b) Ti-6Al-4V alloy with brass sheathing

**Figure 4.** Equivalent strain change in ECAP simulation process

4. ECAP Experiment of Ti-6Al-4V Alloy with Brass Sheathing

In order to verify the correctness of the simulation process, the ECAP experiment of Ti-6Al-4V alloy with brass sheathing was conducted. ECAP dies were heated to 300°C before experiment so as to reduce the heat transfer between sample and moulds. The Ti-6Al-4V sample was heated to 550°C in furnace, which higher than the temperature in simulation in order to make up heat loss in the process of transfer Ti-6Al-4V sample from furnace to ECAP dies. The rest of the parameters in experiment are same to simulation. The samples before and after ECAP experiment are shown in Fig. 5, and we can see that the experimental result is similar to the result of simulation. The sample’s shape after ECAP experiment still remains cylindrical, and slightly bending also occurred in the sample.

**Figure 5.** Samples of Ti-6Al-4V alloy with brass sheathing before and after ECAP

The microstructure evolution of Ti-6Al-4V alloy in ECAP experiment is shown in Fig. 6. The as-received material is comprised of equiaxed primary α phase and β transformation structure (βT)
which actually contains the secondary lamellar α phase and residual β phase, as shown in Fig. 6(a). The microstructure of Ti-6Al-4V after ECAP experiment is shown in Fig. 6(b), the phase ratio of α and β changes little, but the shape of grains changes a lot. All the grains are elongated along ECAP shear deformation direction, which in accordance with the characteristics of ECAP of Ti-6Al-4V without brass sheathing [17, 18]. The microstructure evolution also proved that grain refinement of Ti-6Al-4V can be achieved by ECAP process with brass sheathing.

(a) Before ECAP; (b) After ECAP  
**Figure 6.** Microstructure of Samples of Ti-6Al-4V alloy with brass sheathing

5. Conclusions  
(1) The macro morphology characteristics, extrusion load and equivalent strain of Ti-6Al-4V alloy with and without brass sheathing in ECAP process were analyzed by finite element simulation using Deform-3D software. Although the equivalent strain is slightly lower than Ti-6Al-4V alloy without brass sheathing, the ECAP process of Ti-6Al-4V alloy with brass sheathing also achieves the effect of shear deformation. On the other hand, brass sheathing decreases the ECAP load of Ti-6Al-4V alloy significantly, and the ECAP difficulty of Ti-6Al-4V alloy and wear of the moulds were also reduced.

(2) ECAP experiment of Ti-6Al-4V alloy with brass sheathing was conducted. The results of simulation and experiment are consistent, and the microstructure evolution of experiment is in accordance with the characteristics of ECAP of Ti-6Al-4V without brass sheathing.

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7. References  
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