Heading process design of titanium alloy dental screws

To cite this article: Yeong-Maw Hwang and Bo-Hong Chen 2018 J. Phys.: Conf. Ser. 1074 012177

View the article online for updates and enhancements.
Heading process design of titanium alloy dental screws

Yeong-Maw Hwang and Bo-Hong Chen

Department of Mechanical and Electro-Mechanical Engineering, National Sun Yat-Sen University, No. 70, Lien-Hai Rd., Kaohsiung, Taiwan

E-mail: ymhwang@mail.nysus.edu.tw

Abstract. This study is to investigate the effects of the process parameters on the heading load and metal flow pattern during heading processes of titanium alloy dental screws. The flow stresses of titanium alloy Ti-6Al-4V at different forming temperatures and strain rates are obtained by compression tests. A heading process composed of two stages of shaft extrusion and head forging is proposed. The material flow pattern of the billet inside the die is analyzed using the finite element analyses. The effects of the upper die stroke and forming speed on the heading loads and product shapes are discussed. On the other hand, die stress analysis inside the punch and lower die are also investigated.

1. Introduction

Titanium alloys have been widely applied in aerospace industry due to their high strength, light weight and high corrosion resistance. Recently, they are also applied in biomedical purpose because of their nontoxic properties, especially titanium alloy screws are applied as dental implants. However, due to the HCP structure, titanium alloys have very poor formability at room temperature. As a result, titanium alloys parts are usually manufactured at elevated temperatures.

Concerning head forging researches, Gontarz et al. [1] presented a new forming process of screw spikes. They used the finite volume method (FVM) and finite element method (FEM) to discuss the material flow in the screw spike head forming process. Experiments with lead metal were also conducted to verify the numerical values of heading forces and flow kinematics. Pater et al. [2] developed a new thread rolling technology for sleeper fixing screws by means of two flat wedges provided with special grooves. The numerical simulation results of thread rolling process using finite volumes method (FVM) and finite element method (FEM) were compared with the experimental test results with commercial lead metal. Lin et al. [3] applied Computer Aided Engineering (CAE) combined with finite element simulation to micro screws thread rolling process design to shorten the testing time of a new product design process. Yoshida [4] conducted cold drawing and warm heading on a magnesium alloy to produce a micro screw. So far, most screws are made of carbon steels, stainless steels or aluminum alloys. Few works were involved in the forming process of titanium alloy screws. The forming technology, such as the process and die design in the heading process, has not been established. The finite element method is adopted to analyze the heading process of Ti-6Al-4V dental screws, and the effects of the forming parameters on forging forces and product formability are investigated.

2. Finite element analysis

A finite element code “DEFORM 2D” is used to analyze the plastic flow pattern of the titanium alloy Ti-6Al-4V during the heading process of a screw. The flow stresses of Ti-6Al-4V at different strain...
rates and temperatures are obtained by compression tests. The whole heading process is divided into two stages: (1) shaft extrusion and (2) head forging. The schematics of these two processes are shown in figure 1. The left and right halves denote the object configurations before and after forming, respectively. In the shaft extrusion process shown in figure 1(a), a billet with a dimension of 6.38 mm in diameter and 6.56 mm in length is extruded through a die. In the head forging process shown in figure 1(b), the top part of the billet is compressed by an upper punch. The expected shape and dimensions of the billet at the initial, intermediate and final stages are shown in figure 2. The shape and dimension of the lower die for the first stage are shown in figure 3. During simulations, the dies are assumed to be rigid and the billet is rigid-plastic. The forming temperature is set as 900°C (Ahmed et al. 2014). Due to axis-symmetric, DEFORM 2D is used. The relevant forming conditions are summarized in table 1 (Ahmed et al. [5]).

![Figure 1. Schematic of whole heading processes.](image)

![Figure 2. Shape and dimensions of billet at different stages.](image)
3. Results and discussion

Figures 4(a) - 4(e) show the mesh configurations after the first stage with strokes of $S_1=11.5, 11.6, 11.7, 11.8,$ and $11.9$ mm, respectively. Clearly, a larger stroke of the upper punch can make the die cavity be filled up by the billet more completely.

Figures 5(a) - 5(e) show the mesh configurations after the second stage for strokes of $S_1=11.5, 11.6, 11.7, 11.8,$ and $11.9$ mm at the first stage, respectively. The stroke of the upper punch at the second stage is $S_2=2.3$ mm. As $S_1=11.7, 11.8,$ and $11.9$ mm, the die cavity at its bottom part can be filled up completely by the billet. Although the die cavity can filled up at $S_1=11.8$ and $11.9$ mm, the forging loads needed at the second stage are much larger than that at $S_1=11.7$ mm. Therefore, in the following simulations, the strokes of the upper punch for the first and second stages are set as $S_1=11.7$ and $S_2=2.3$ mm, respectively.

Table 1. Forming conditions of heading process used in finite element analysis.

| Software          | DEFORM-2D |
|-------------------|-----------|
| Material          | Ti-6Al-4V |
| Upper punch stroke, $S_1$ | 11.5-11.9 [mm] |
| Upper punch speed  | 1 [mm/s]  |
| Friction factor, $m$ | 0.3       |
| Forming temperature| 900 [°C]  |
| Mesh number       | 7500      |
Figure 4. Mesh configurations after the first stage at different strokes.

Figure 5. Effects of strokes at first stage on product shapes after second stage.
Figure 6 shows the forging loads during the first stage of the heading processes with different forging speeds. It is known that the heading process finished earlier as the forming speed increases. At first, the loads increase rapidly as the billet flows into the narrow upper part of the lower die. Then, the loads decrease as the billet flows into its parallel middle part. Finally, the loads increase as the billet flows into its bottom tip part. The final load increases with the forming speed.

Figure 6. Effects of upper punch speed on forming load at first stage.

Figure 7 shows the forging loads during the second stage of the heading processes with different forging speeds. It is known that the heading process completed earlier as the forming speed increases as the case for the first stage. The forming load increases with the forming speed. At the last instant of the forming process, where the billet is ready to fill up the die cavity, the load increases dramatically. The maximum loads for speeds of 0.5, 1, 1.5, and 2 mm/s are 16.8, 48.5, 49.8, and 149 kN, respectively. The load for $V_2=2$ mm/s is about 9 times of that for $V_2=0.5$ mm/s.

Figure 7. Effects of upper punch speed on forming load at second stage.

Figure 8 shows the effective stress distributions within the upper punch and lower die for different forming speeds. It is known that the maximum stress occurs at upper center part of the upper punch and the tip part of the lower die. Only at $V_2=0.5$ mm/s the maximum effective stress is smaller than 1350 MPa, the yielding stress of SKD61. For higher speeds, the upper punch and lower die should be made of materials with stronger strength, such as tungsten.
Figure 8. Die stress distribution at the upper punch and lower die for different forming speeds.
4. Conclusions
A heading process composed of two stages of shaft extrusion and head forging was proposed. The material flow pattern of the billet inside the die was analyzed using the finite element analyses. The flow stresses of titanium alloy Ti-6Al-4V at different forming temperatures and strain rates were obtained by compression tests. The effects of the process parameters on the heading load and metal flow pattern during heading processes of titanium alloy dental screws were discussed. The better strokes of the upper punch for the first and second stages that make the billet fill up the die cavity were $S_1=11.7$ and $S_2=2.3$ mm, respectively. The final load increased with the forming speed. On the other hand, die stress analysis inside the punch and lower die were also investigated. The maximum stress occurred at upper center part of the upper punch and the tip part of the lower die.

References
[1] Gontarz A, Pater Z and Weronski W 2004 Head forging aspects of new forming process of screw spike Journal of Material Processing Technology 153-154 736-740
[2] Pater Z, Gontarz A and Weronski W 2004 New method of thread rolling Journal of Material Processing Technology 153-154 722-728
[3] Lin Y F, Kao Y C, Cheng H Y and Wang K J 2007 The study of computer aided thread rolling for micro screw Proceedings of 24th National conference of Chinese Society for mechanical Engineers Taoyuan, Taiwan pp.4286-4290
[4] Yoshida K 2009 Cold drawing of magnesium alloy wire and fabrication of micro screw Journal of Japanese Society for Technology of Plasticity 50 919-923.
[5] Ahmed Y M, Sahari KSM, Ishak M and Khidhir B A 2014 Titanium and its alloy International Journal of Science and Research 3 1351-1361