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# Ring-Rolling Process for Manufacturing Ti-6Al-4V Plane and Profiled Ring-Products

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**Keywords :** Ring Rolling Process, Plane Ti-6Al-4V Ring, Profiled Ti-6Al-4V Ring, three-dimensional FEM Simulation

**Abstract.** Manufacturing processes of Ti-6Al-4V plane and profiled ring-products were investigated with three-dimensional FEM simulation and experimental analyses. FEM simulation for the ring-rolling process was used to calculate the state variables such as strain, strain rate and temperature. To induce the uniform deformation of the profile ring and reduce the applied load, the final blank was prepared by two-step processes. The mechanical properties of Ti-6Al-4V alloy ring products made in this work were investigated with tensile and impact tests, and compared with the specification(AMS-T-81915).

## Introduction

Ring rolling process is widely used to produce seamless rings by forming gradually progress and continuously with various outer ring diameters for power generation plants, aircraft engines and large cylindrical vessels. Advantages of ring rolling process compared to the ring forging process are the fast working time and the grain flow is formed continuous and favorable. The ring rolling process is a requisite for manufacturing ring products without defects from difficult to forge titanium alloys. In this work, the ring rolling design for Ti-6Al-4V alloy plane and profiled rings were performed with a calculation method and FEM simulation. The mechanical properties of Ti-6Al-4V alloy rings made by plane and profile ring rolling process were carried out and analyzed with the evolution of microstructures.

## Material and experimental procedure

In this work, the materials were used two kinds of Ti-6Al-4V billets. One was Ti-6Al-4V billet developed by breakdown process of a VAR/VAR processed Ti-6Al-4V ingot. This billet was utilized to make the plane Ti-6Al-4V ring. The other was an annealed Ti-6Al-4V billet with a diameter of 14inch manufactured by ALLVAC Co. This billet was utilized for manufacturing the profile Ti-6Al-4V ring. Fig. 1. shows the microstructures of the developed Ti-6Al-4V billet and ALLVAC's Ti-6Al-4V billet at different positions. It can be found that the microstructure at center indicates partly globularized structure including lath α phase around boundary. However, these center parts will be removed by the piercing process. On the other hand, it can be observed that the microstructures at middle and surface positions are composed of equiaxed primary α phase, elongated α phase and transformed β matrix.

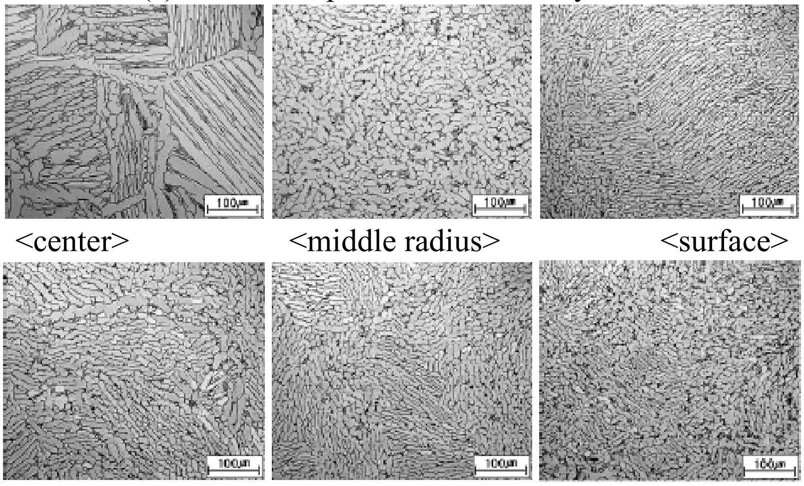
## Results and Discussion

**Design of blank and billet size.** In order to calculate the rolled ring dimensions, blank dimensions and billet dimensions for plane and profile ring rolling processes, the calculation method based on the relationship between the wall thickness and ring height as shown in Eq, (1) was used [1].

$$h_1^2 - b_1^2 = h_2^2 - b_2^2 \qquad (1)$$

Where, the subscripts 1 and 2 denote blank and the finished ring dimensions, h is the height of ring, b is the wall thickness. The detailed approaches for applying the ring rolling process are presented elsewhere [1]

(a) The developed Ti-6Al-4V alloy billet




(b) The Ti-6Al-4V alloy billet(ALLVAC)

Fig. 1. Microstructures of Ti-6Al-4V billets at different locations

Target dimension of plane Ti-6Al-4V ring was OD(out diameter) 2,500×ID(inner diameter) 2,300×H(height) 150mm, and the dimension of profiled Ti-6Al-4V ring was approximately OD 1,340×ID 1,127×H 264mm. The blank size for the plane ring was calculated as OD 894×ID 450×H 249mm by applying the calculation method. However, actual blank size was determined as OD 960×ID 450×H 230mm by considering the environmental conditions such as punch size, the ring rolling mill and working conditions. In order to induce the uniform deformation and reduce the applied load, the final blank for profile ring was prepared by two-step processes. The first step is to make a blank that is usually formed by upsetting and piercing processes. The second step is to form the plain shape closed to the profile ring by using the ring rolling or forging process. From the calculation method, the first blank size was determined by OD 670×ID 185×H 300mm, and the plain shaped ring was calculated by OD 967×ID 700×H 270mm.

**Process design and actual ring rolling process.** A commercial FEM code, SHAPE was used to simulate the effect of process variables in the ring rolling on the distribution of the internal state variables such as strain, strain rate and temperature. Optimum process parameters for ring rolling were suggested to be heating temperature of 950℃ and the feed rate of 0.5mm/s.

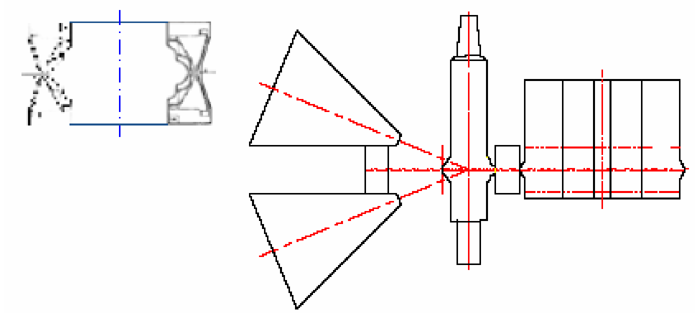
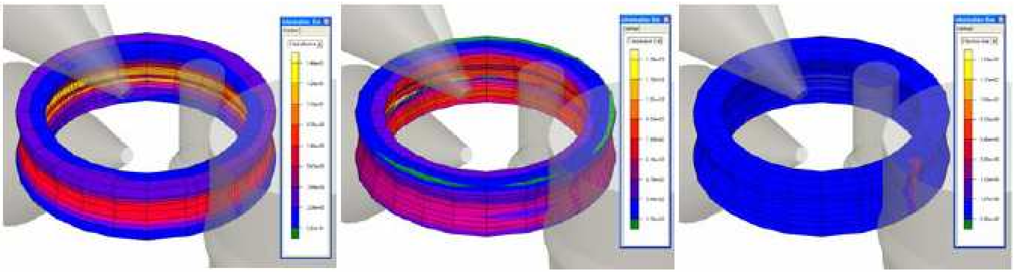


Fig. 2 Profiled ring-shape and die design

In the simulation results of strain and temperature distributions for a plane ring rolling process, the strain level at the surface area is higher than that at the mid-plane, but the temperature level at the surface area is lower than that at mid-plane due to heat transfer between the workpiece and the work roll. The profiled ring product was ring-rolled by mandrel and main roll design as shown in

Fig. 2. Fig. 3 shows simulation results for final profile ring rolling process. In the simulation results, temperature and strain distributions between surface and middle areas indicate a small difference.

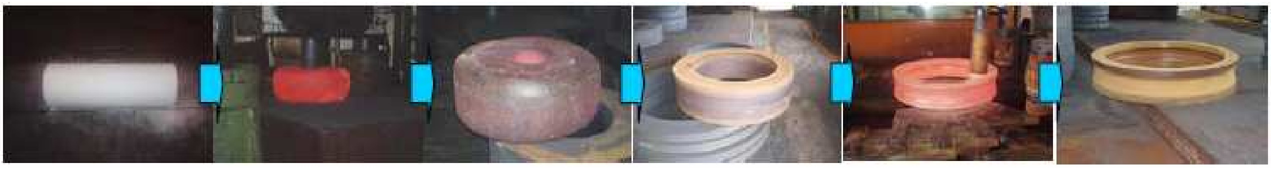


(a) strain (b) temperature (c) strain rate

Fig. 3. FEM simulation of profile ring rolling process

Fig. 4 shows actual plane and profile ring rolling processes. It can be found that the actual plane and profiled rings indicate a relatively uniform shape without forming defects such as fishtail, fold, crack etc.

(a) the plane ring rolling process(Φ2,500mm)



(b) the profiled ring rolling process

Fig. 4. the plane and profiled ring rolling process

**Microstructures and mechanical properties of Ti-6Al-4V alloy rings.** Fig. 5 shows the microstructures of plane ring-rolled Ti-6Al-4V ring observed at different positions. In as-rolled condition, it can be observed that the microstructures at all locations are composed of equiaxed α phase(~30μm) and transformed β phase, and the α and β phases are homogeneously distributed at inner and outer areas. From tensile and impact properties tested in plane Ti-6Al-4V ring as shown in Table 1, it can be found that tensile strength and impact properties at room temperature were satisfied with the specification.

<Inner> <middle> <outer>

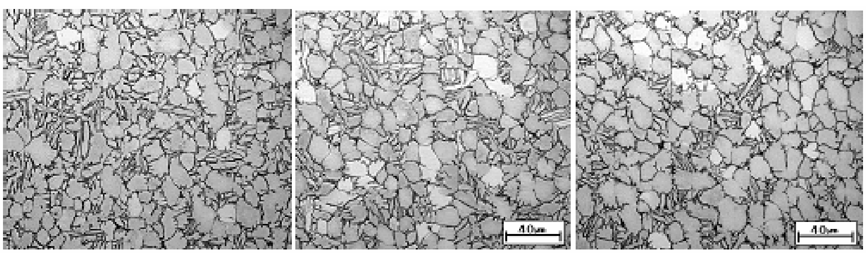


Fig. 5. Microstructures of ring rolled Ti-6Al-4V ring at different locations(Φ2,500mm)

Besides, microstructures observed at the upper and lower part for the profiled Ti-6Al-4V ring were shown in Fig. 6. Like microstructures of plane Ti-6Al-4V alloy ring, relatively uniform α+β microstructures without forming defects are observed in most locations. Also, the tensile and impact properties of profile ring rolled Ti-6Al-4V ring were satisfied with the specification.

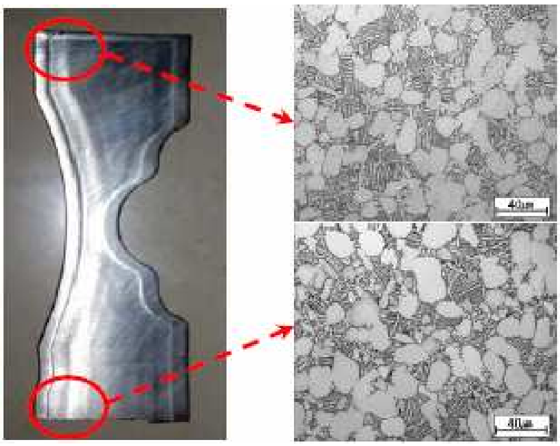


Fig. 6. Locations to evaluate the microstructures of profiled Ti-6Al-4V alloy ring

Table 1. Mechanical properties of the plane and profiled ring rolled Ti-6Al-4V ring

| | YS(MPa) | UTS(MPa) | EL(%) | RA(%) | Absorption Energy(J) | Remark |
|---|---|---|---|---|---|---|
| AMS-T-81915 | 793 | 862 | 8 | 16 | 20 | Specification |
| Plane ring | 885.6 | 943.4 | 22.0 | 45.5 | 33.0 | As rolled |
| Profiled(Upper) | 905.5 | 966.1 | 18.4 | 41.5 | 35.0 | As rolled |
| Profiled(Lower) | 920.5 | 973.5 | 19.0 | 42.6 | 33.0 | As rolled |

**Summary**

In this study, a process design for the ring rolling of plane and profiled Ti-6Al-4V alloy rings was investigated by a calculation method, 3D FEM simulation and actual ring rolling. Initially, blank and initial billet dimensions of the plane and profiled Ti-6Al-4V rings were determined by the calculation method. Optimum process condition of ring rolling process for obtaining sound and defect-free Ti-6Al-4V ring products was determined as heating temperature of 950°C and the feed rate of 0.5mm/s for a given ring mill condition by using FEM simulation and preliminary tests. Finally, from microstructure observations of plane and profiled ring-rolled Ti-6Al-4V rings, it can be found that relatively uniform $\alpha+\beta$ microstructures without forming defects are observed in most locations. Also, the mechanical properties of both Ti-6Al-4V rings were satisfied with the specification.

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