An innovation forging technology for the world's largest austenitic stainless steel ring

F. Wang, W. Yin, Y. Niu, X. Ren, M. Sun, B. Xu, L. Zhao

One world record breaking——the world's largest austenitic stainless steel forging ring with a diameter of 15m was successfully forged in China. It have be used as a part of critical support devices for a new generation power plants of China. In order to meet the strict requirements of raw materials and specifications for new energy power equipment, ultra large rings were forged by an innovation process, which combined the metal construction forming technology with the forging & rolling technology. In this paper, based on describing the technical scheme and forging process in details, we analyzed the difficulties and advantages of forging technology of the ultra large austenitic stainless steel ring. Finally, the testing results of the ring indicated that, comparing to traditional ingot forging process, the combination of metal construction forming technology and forging & rolling technology has satisfactory advantages in terms of external dimension control and material performance. This study has created a new forging technology for high-quality and ultra large rings, which is of great significance for the high-quality development of large-scale mechanical equipment in future.

KEYWORDS: 316H, AUSTENITIC STAINLESS STEEL, LARGE FORGING RING, METAL CONSTRUCTION FORMING, FORGING & ROLLING

INTRODUCTION

Ring is generally used in the key parts of mechanical and engineering equipment of power, chemical industry and other fields[1]. With development of industrial, the ring with larger size and less welded ring are required by customers. Although the diameter of forging ring has reached 12m, it still cannot meet the growing needs of customers[2], that an 316H steel forging ring with a diameter of 15m is required[3,4].

However, there are two problems for production. The first is the manufacturing of stainless steel billet. During the solidification process of large ingot, especially for austenitic stainless steel, will form macro segregation, the center loose and hollow[5-10], which will cause crack and quality risk of forging[11-13]. The second is the forming of large ring. If free forging is used, with diameter of ring increasing, which means not only more forging time and risk increasing, but also need to increase 30% weight of the billet. So the difficulty and risk of ingot supply are further increased[14].

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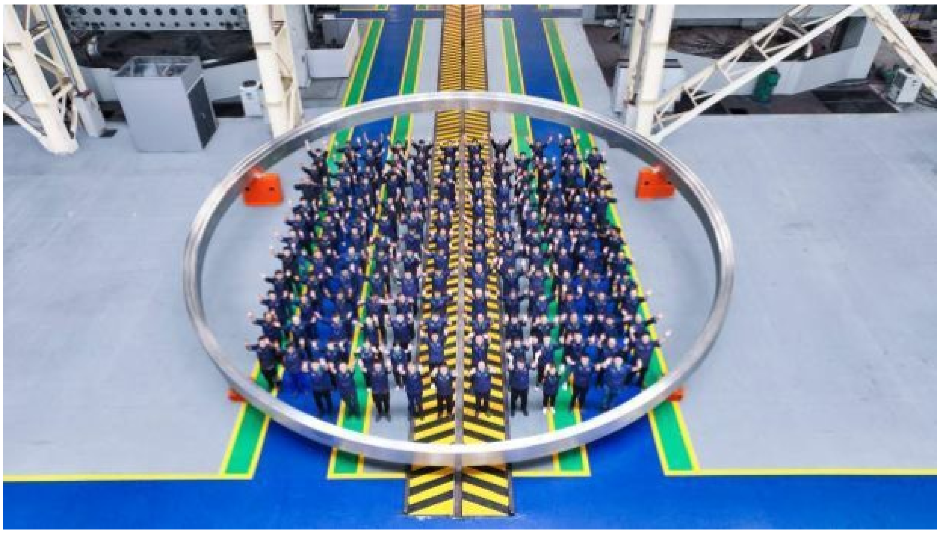

Fig.1 - World's largest forging ring.

According with problems mentioned above, we developed the metal construction forming technology to solve the metallurgical quality problems of large billet[15]. meanwhile a forging-rolling technology of 15m-level ring was developed[16]. In May 2022, based on the innovation technology and process, we made the world's largest 316H steel forging ring with diameter of 15m, as shown in Fig.1. It was not only reduces the weight of billet, but also decreasing the manufacturing time. Most important, it could greatly improve the uniform and service safety of the ring, which is the innovation solution for the high-quality development of large-scale mechanical equipment in future.

MANUFACTURING PROCESS

Manufacturing of billet

Metal construction forming technology (so called MCF) is a type of additive manufacturing with continuous casting slab as the construction units. For one billet, multi-layer slabs are interface diffused and integrated by stack-up, vacuum-package, high temperature, high pressure and large deformation, as shown in Fig.2. Compared with traditional casting ingot, MCF billet is with no obvious solidification problems such as macro segregation and loose in center area, attributing to the purity and uniformity of continuous casting slab[15]. Moreover, MCF could save 30% raw material for forging, that MCF billet is without bottom and riser, however ingot have to cut them.

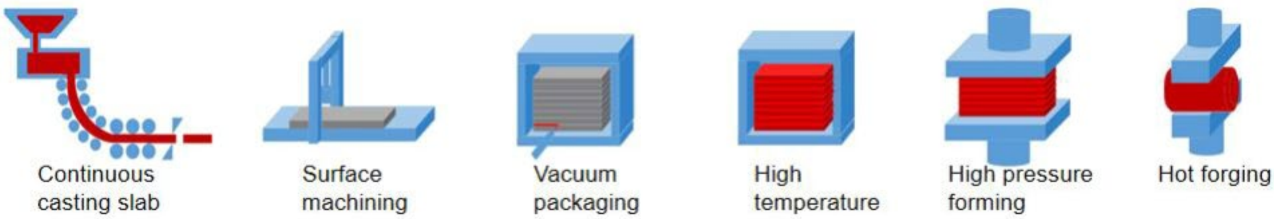

Fig.2 - Technical process of metal construction and forming.

For this work, 250 tons MCF billet was made by 200mm thick continuous casting slab of 316H steel, which was produced through EAF+AOF+LF+CC process with 3 heats. The chemical composition of continuous casting slab as shown in Tab.1 and MCF billet forming process as shown in Fig.3.

Tab.1 - Chemical composition of 316H steel slab.

	C	Si	Mn	Cr	Ni	Mo
1# heat	0.042	0.43	1.63	17.46	11.80	2.52
2# heat	0.043	0.44	1.69	17.32	12.25	2.52
3# heat	0.040	0.47	1.65	17.27	11.80	2.54

Fig.3 - Construction forming process of 316H steel slab.

FORGING & ROLLING OF RING

It was first time to make so large a forging ring. Considering about disadvantage factors of characteristics of austenitic stainless steel for forging, we specially designed a large ring forming process as shown in Fig.4. First of all, the free forging was used for upsetting and punching with 13,500 tons forging press, then rolling ring.

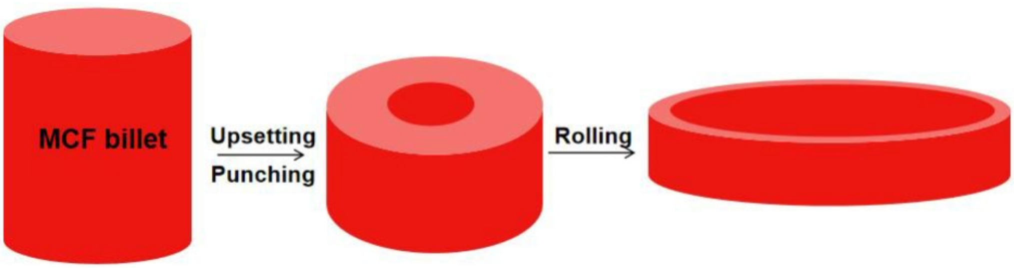

Fig.4 - Forging-rolling process of ring.

It should be point that the rolling process is in two steps by ring rolling mill. On the first step, the axial rolling force reached 100%, the growth rate was about 10mm/s, and the outer diameter was controlled to 7.5m. On the second step, for steady growth, the maximum growth rate of ring reached 20mm/s and the growth rate was gradually reduced to 0.8mm/s. After rolling, the ring was taken to water cooling immediately.

The scratch failure mode of the AlCrN film can be described, first, as the chipping off the side of the scratch track of the outer part of the coating. The spalled areas became progressively larger with increasing the load, until they extended across the entire width of the track. Then, at the delamination load, the entire coating was spalled off and the substrate was detected. Actually, the initial chipping failure never occurred at the coating/substrate interface. Infact, cracks proceeded transversely along the columnar grain boundaries, crossing part of the coating thickness and were deflected along a longitudinal path above the substrate interface. This means that the layer also possessed rather good adhesion to the substrate, so that initial failure is of a cohesive nature, and complete coating removal occurs only at a later stage.

Thus, it is concluded that, using the L-PBF Ti6Al4V substrates (especially when subjected to the lower-temperature heat-treatment at 740 °C), the adhesion strength is comparable to or significantly competitive with the adhesion of conventionally manufactured substrates.

Fig.5 - Two steps rolling process of ring.

PERFORMANCE ANALYSIS

UT testing

According to the NB/T20003.2-2010 standard, an A-type pulse reflection UT detector was used. That the top and bottom sides, outer circle and the inner hole were tested by straight probe, double crystal probe and oblique probe along circumferential and axial direction of the ring, repeatedly. UT test result demonstrated that, there was no abnormal defect in the ring, and no information of construction interface of slabs was found, which certainly proved that the MCF billet had reached the goal of integration.

Chemical composition, hardness and micro-structure

Chemical composition, hardness and micro-structure along heights of the ring, as shown in Fig.6. In Fig.6a, composition of the ring was consistent with the continuous casting slabs, and the element contents varied in small-scale along the height. Similarly, the hardness at different heights also fluctuated vary small. It indicated MCF billet had achieved the result of high-level homogenization. In Fig.6b, all the micro-structure at different heights of the ring were equiaxed grain, the grain size of the top and bottom of the ring were 4 grade, and the middle height is 3 grade. Which implied the forging-rolling process achieved the structure controlling target.

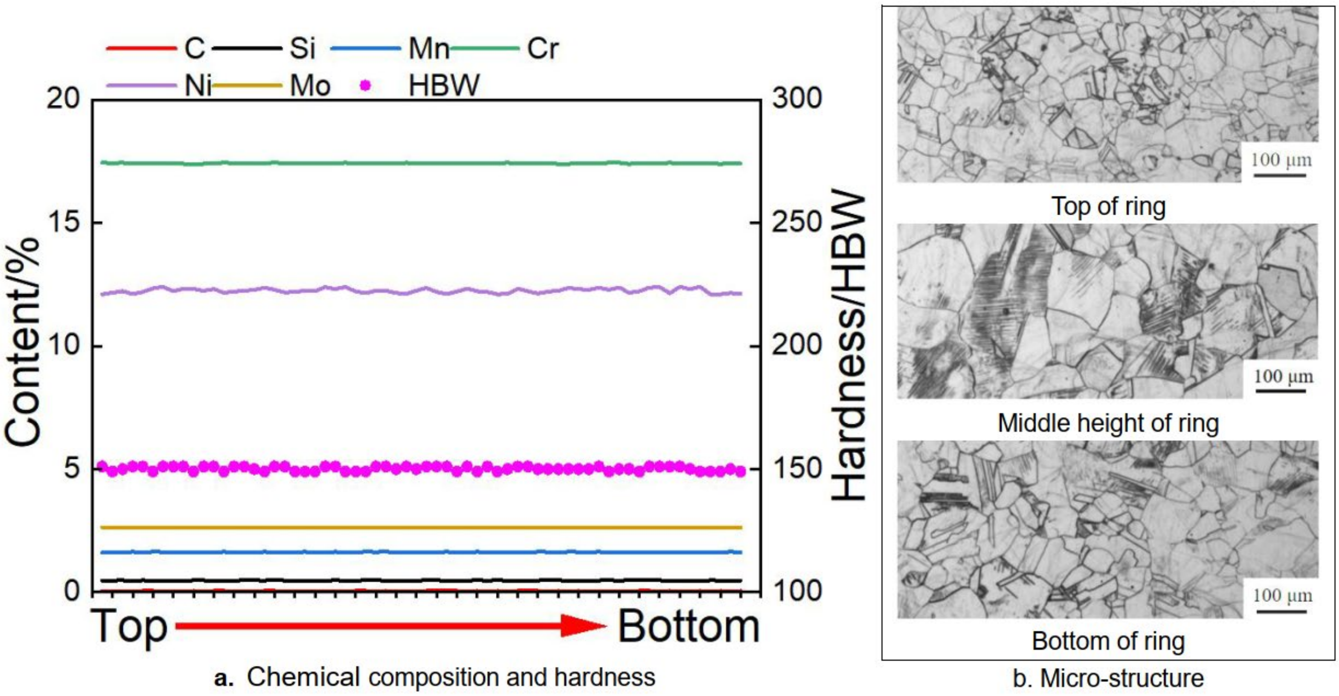

Fig.6 - Chemical composition, hardness and micro-structure along height of the ring.

Mechanical properties

Mechanical strength data and impact data along the height in different directions were shown in Fig.7. Fig.7a and b showed the tensile and yield strength data were relatively stable along the heights, and there is no obvious distinction between the mechanical strength data of different directions. In Fig.7c, the impact results suggested the similar situation, that impact data was with less fluctuation, relatively stable and no obvious differences in different directions.

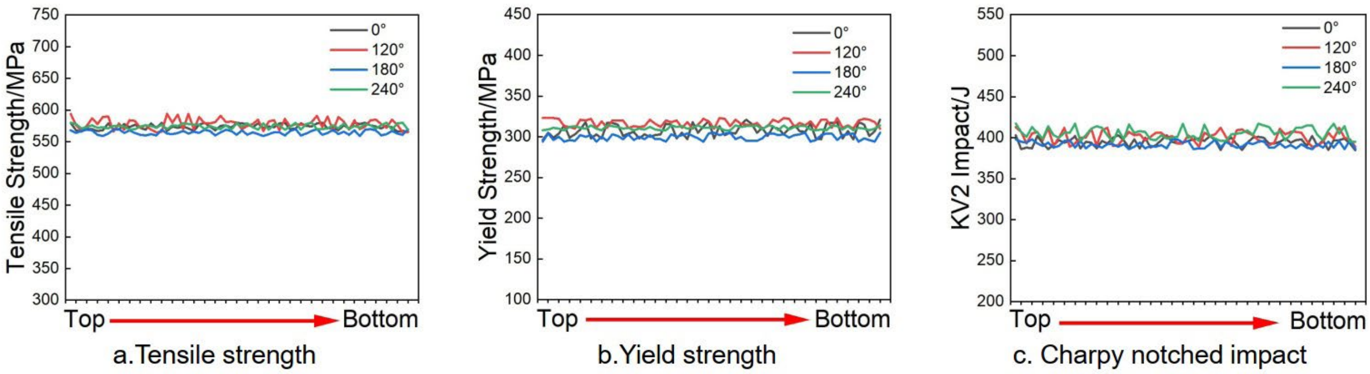

Fig.7 - The tensile, yield strength and impact of different directions along height of the ring.

Based on the analysis above, it showed that the process of MCF technology and forging-rolling technology had greatly improved the performances of austenitic stainless steel forging ring. Meanwhile the performances satisfied the requirements of customer very well.

SUMMARY

A 316H steel super-large forging ring was manufactured by a innovation forming process, which was combined with metal construction forming and forging-rolling technologies. It successfully challenged the traditional process of the large forging ring, which broke the world record of diameter of the large forging ring:

1. Compared with the traditional steel ingot, weight of the MCF billet manufacturing was reduced by nearly 30%. And the homogenization of matrix of MCF billet was revolutionized obviously.
2. The forging-rolling technology had realized fast manufacturing of super-large forging ring, and shortened the manufacturing time by more than 40%.
3. The test results showed that, performance of the super-large forging ring manufactured by the new process, was gratifying on integration, homogenization, stabilization.

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