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Effects of can parameters on canned-forging process of TiAl base alloy(Ⅰ) ①

——Microstructural analyses

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[Abstract] By using thermal simulation technique, the conventional canned-forging process of TiAl based alloy was studied. The effect of can parameters on the microstructures of TiAl alloy was analyzed in this process. The results show that, the deformation microstructure of TiAl based alloy without canning is inhomogeneous. In lateral area, crack and shearing lines can be found; while in central area, fine-grained shearing zone can be found. The effect of can is to reduce the secondary tensile stress. However, only when the deformation of the steel can is coincidental with that of TiAl alloy ingot, can this effect be effective. Moreover, a thick can would enhance the microstructural homogeneity in TiAl based alloy. With the H/D ratio of the ingot increasing, the deformation of TiAl alloy would be more unsteady, therefore, a thicker can should be needed.

[Key words] TiAl based alloy; thermal mechanical treatment; microstructure
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1 INTRODUCTION

TiAl based alloy has long been considered as a promising material for high temperature application, due to its excellent high temperature properties and light-mass[1~3]. Since it was extensively studied at early 1980's, TiAl based alloy has gained significant improvement on microstructural control, room temperature ductility, high temperature creep and fatigue behavior[4]. Some aeroplane companies have paid great effort in application of TiAl alloy on such parts as impellers and turbines[5]. On industry scale, the processing of TiAl alloy includes casting, forging and heat treating. Forging is one of the most important steps influencing the final properties of TiAl based alloy. Two forging methods are usually adapted for TiAl based alloy: isothermal forging and conventional canned forging[6,7]. The former involves large equipment and long time, hence is of high cost; while the later is a much simple and cost-effective process. This work was concentrated on the influence of can parameters and height-to-diameter ratio on the microstructures of TiAl based alloy.

2 EXPERIMENTAL

Ti-48Al-2Cr (mole fraction, %) ingot was prepared by melting in water-cooled non-consumable copper crucible. The ingot was then HIPped at 150 MPa, 1350 ℃ for 4 h. Samples with different height-to-diameter ratios were cut from the ingot and canned in steel cans with different thickness. Table 1 indicates the sizes of samples and cans.

Thermal simulation tests were conducted on Gleeble-1500 dynamic material test machine, as shown in Fig. 1. TiAl base alloy and the can were

Table 1 Sizes of samples and cans

Sample	H/D	δ/mm	Sample	H/D	δ/mm
1	8/6	–	9	12/6	1.5
2	8/6	1.0	10	12/6	2.0
3	8/6	1.5	11	12/6	3.0
4	8/6	2.0	12	15/6	1.0
5	8/6	2.5	13	15/6	1.5
6	8/6	3.0	14	15/6	2.0
7	12/6	–	15	15/6	3.0
8	12/6	1.0			

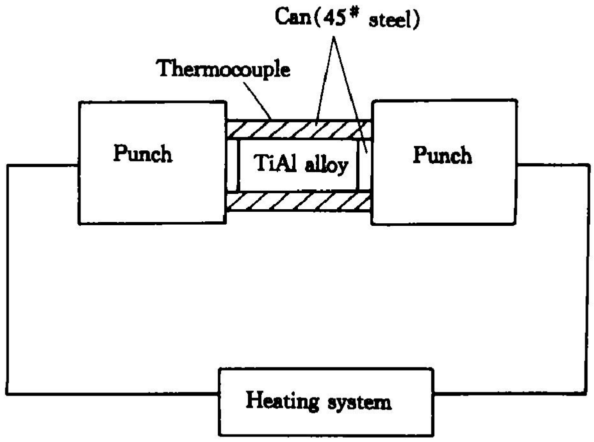

Fig. 1 Schematic representation of thermal simulation tests

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heated by electric current with a heating rate of 550 ℃/min, and then held at 1 100 ℃ for 5 min. Pressure was exerted on the sample through the punch with a nominal strain rate of $10^{-1}s^{-1}$, and the deformation of the sample was 70%. Microstructures of the samples were observed on Polyvar-met optical microscope. The etching agent was (1%~ 2%) HF+ 2% HNO_3+ H_2O(Bal.) (mole fraction).

3 RESULTS

3.1 Macrostructures

Fig. 2 shows the macrostructures of the samples with an H/D ratio of 8/6 after forging. Crack and very inhomogeneous flowing lines can be found in the sample without canning. When the thickness of the can is less than 2 mm, the deformation of steel cans is irregular with double bumping and apparent shearing, and there is a seam between the can and TiAl alloy. Therefore, the deformation between the can and the ingot is not coincidental. With a larger thickness, only single bumping occurs in the can and the seam between the can and the ingot is hard to detect. Therefore the deformation between the can and the ingot is more coincidental. This phenomenon can also be found in the samples with H/D ratios of 12/6 and 15/6, as shown in Fig. 3 and Fig. 4. With the H/D ratio increasing, the deformation of the can is much more irregular and the seam between the can and the ingot is larger when the thickness of the can is not large enough. Moreover, as the H/D ratio of the ingot increases, thicker cans are necessary to ensure a coincidental deformation between the can and the TiAl ingot, as shown in Fig. 5.

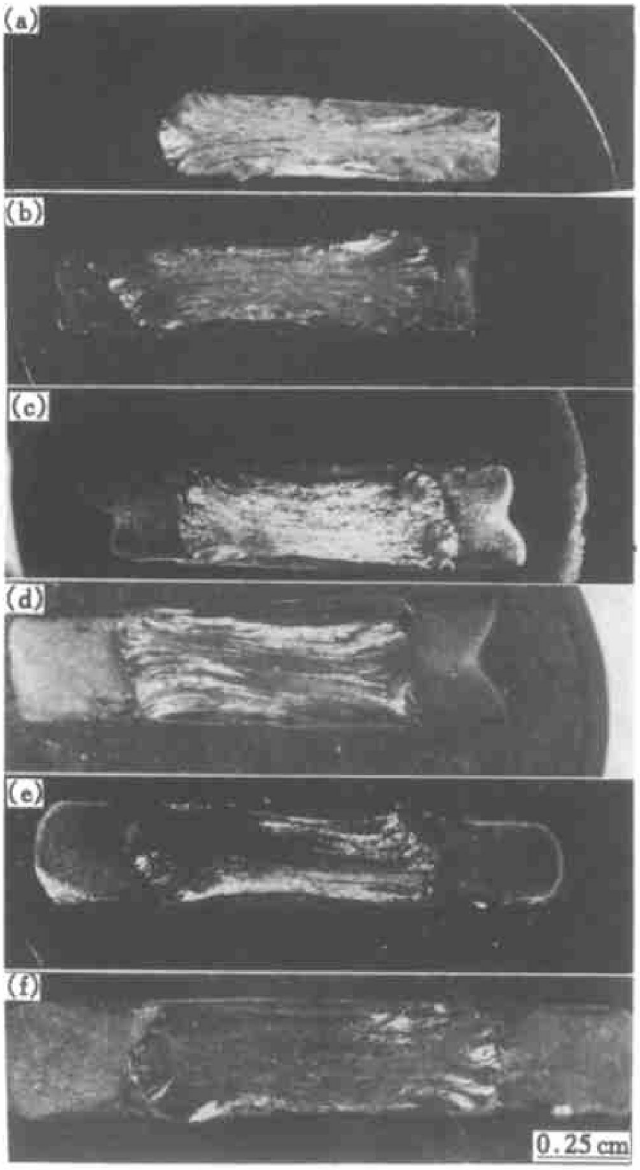

Fig. 2 Deformation macrostructures of samples with H/D ratio of 8/6

(a) —δ= 0 mm; (b) —δ= 1.0 mm; (c) —δ= 1.5 mm; (d) —δ= 2.0 mm; (e) —δ= 2.5 mm; (f) —δ= 3.0 mm

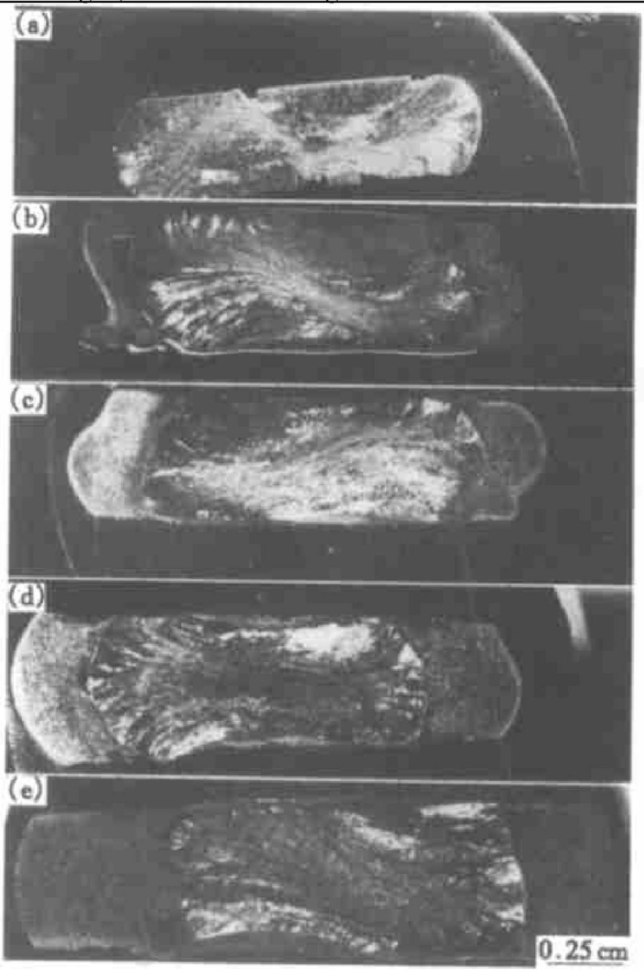

Fig. 3 Deformation macrostructures of samples with H/D ratio of 12/6

(a) —δ= 0 mm; (b) —δ= 1.0 mm; (c) —δ= 1.5 mm; (d) —δ= 2.0 mm; (e) —δ= 3.0 mm

3.2 Microstructures

Fig. 6 shows the original microstructure of TiAl based alloy before forging. It indicates that the microstructure consists of coarse lamellar colonies with a mean colony size of about 800 μm. The deformation microstructure of the TiAl alloy is inhomogeneous at different location in the samples. This microstructural inhomogeneity is much more serious in the samples without canning. Fig. 7 shows the deformation microstructure of the sample with an H/D ratio of 8/6 after forging without canning. Near the upper and

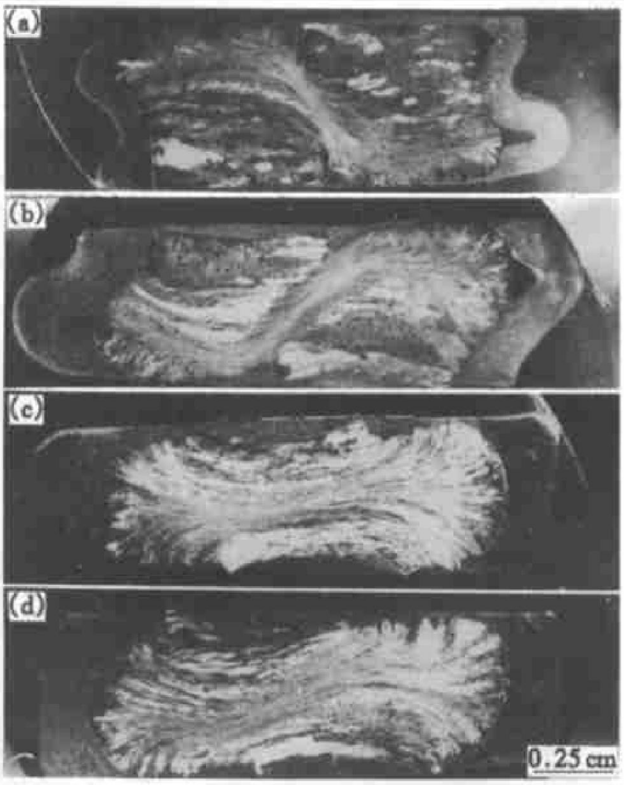

Fig. 4 Deformation macrostructures of samples with H/D ratio of 15/6
(a) —δ= 1.0 mm; (b) —δ= 1.5 mm;
(c) —δ= 2.0 mm; (d) —δ= 3.0 mm

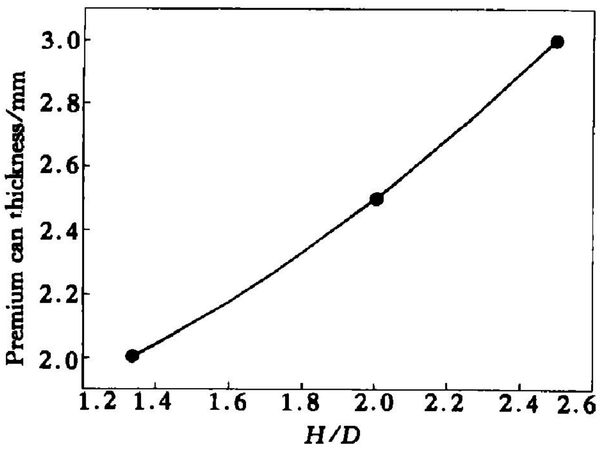

Fig. 5 Change of premium can thickness with H/D ratio

lower surface of the sample the deformation of the lamellar colony are much slighter than those in other locations, and only little bending of lamellae occurs. Near the lateral surface of the sample, adiabatic shearing has occurred and shearing lines appear, while shearing bands consisting of very fine microstructures form in the center of the sample. With the thickness of the can increasing, the number of the shearing lines and shearing bands decreases, and the deformation microstructures are more homogeneous and the lamellar colonies are mainly stretched perpendicular to the forging direction. Moreover, the larger the H/D ratio of the samples, the thicker the can is needed to ensure a homogeneous microstructure, as shown in Fig. 8.

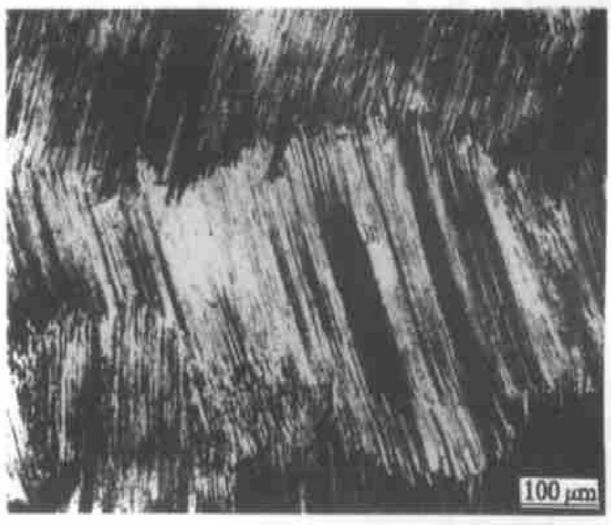

Fig. 6 Original microstructure of TiAl base alloy before forging

4 DISCUSSION

4.1 Influence of H/D ratio

In conventional forging, owing to the friction between the punch and the ingot, the deformation of the ingot can be divided into three zones, as shown in Fig. 9[8]. Zone Ⅰ is hard to deform because the friction of the punch restrict the deformation of the ingot. Zone Ⅱ is a free deformation area, as no force restricts the flow of the ingot in lateral direction. In this zone secondary tensile stress exists and is apt to bringing about crack of the ingot. Zone Ⅲis a homogeneous deformation area, as no friction and secondary tensile stress exists. When the H/D ratio is lager than 1.5, the deformation zone will be more complex and more inhomogeneous. For example, double bumping or unsteady flow would occur, as shown in Fig. 3.

4.2 Deformation behavior of lamellar colony

The deformation of the lamellar colony is highly dependent on its orientation with the pressure direction and its location in the sample[9, 10]. It is difficult for the lamellar colony to deform when its orientation is perpendicular or parallel to the pressure direction (hard orientation); while it will be easy when the orientation angle is 45° (soft orientation). In hard orientation, the lamellar colony will be sheared, for example, through the formation of shear lines or twinkled bands to adapt for the outside pressure. In soft orientation, the lamellar colony will rotate to the direction parallel to the outside pressure. During this process, the movement of the colonies leads to the shearing of the colony boundary[11, 12], which will be broken, i.e. the end of lamellae will fracture to form small α_2 or γ particles. These kinds of fine grains do well to gliding along the colony boundary, and enhance the formation of the shearing zone. In different deformation zone, the deformation behavior of the

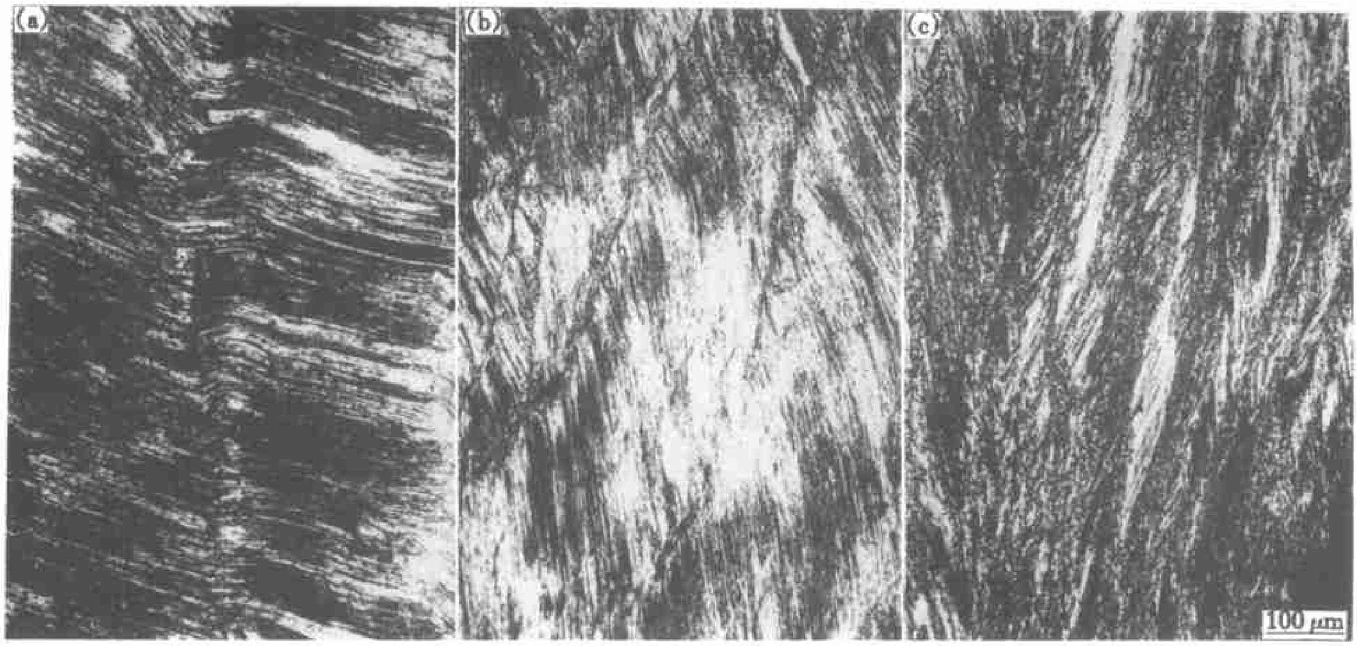

Fig. 7 Deformation microstructure of sample with a H/D ratio of 8/6 after forging without canning
(a) —Zone center; (b) —Near lateral surface; (c) —Central part

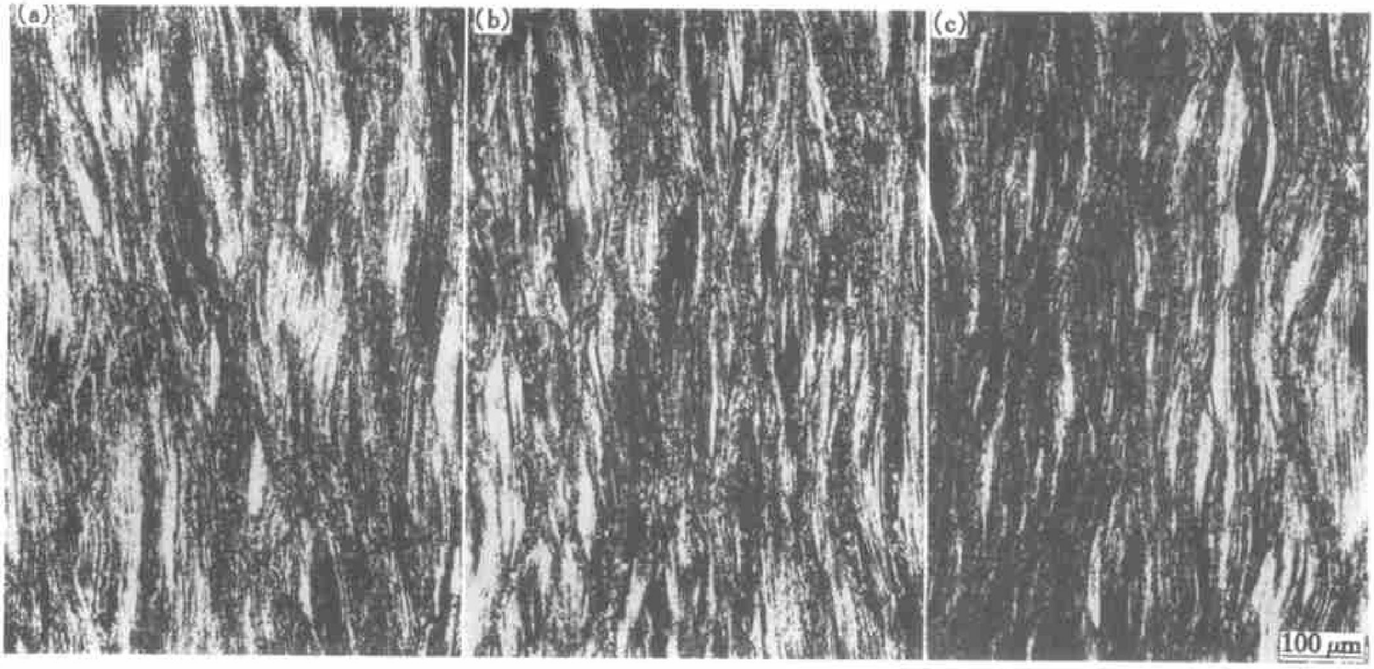

Fig. 8 Deformation microstructure in center part of samples with various H/D ratio
(a) —H/D = 8/6, δ = 2.0 mm; (b) —H/D = 12/6, δ = 2.5 mm; (c) —H/D = 15/6, δ = 3.0 mm

lamellar colony is also influenced by its location in the sample. In Zone Ⅰ, the deformation of the sample is hindered, and lamellar colonies also show little deformation, i.e. slightly bending. In zone Ⅱ, the lateral flow of the sample leads to the formation of the secondary tensile stress in this area, constraining the lamellar colonies to deform. In addition to the outside pressure, some hard-to-deform colonies (hard orientation) form adiabatic shearing lines to adapt for this stress state. In zone Ⅲ, as the deformation is homogeneous in this area, most of the lamellar colonies would deform through bending, rotating or the formation of fine-grained shearing zone in colony boundaries.

4.3 Influence of can parameters

The role of the can in canned-forging is to restrict the formation of the secondary tensile stress and the flow of the ingot in lateral direction, hence avoiding cracking of the ingot[13]. However, the effect of the can is dependent on whether its deformation is coincidental with the ingot or not. As the yield strength of the steel can is lower than that of TiAl alloy ingot, the deformation of the can will be faster than TiAl

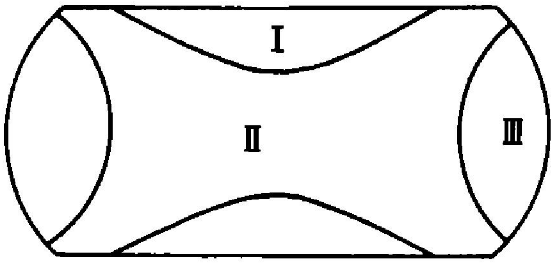

Fig. 9 Schematic representation of deformation zones of conventional forging[8]
Ⅰ —Hard deformation area;
Ⅱ —Free deformation area;
Ⅲ—Homogeneous deformation area

alloy ingot. With a small thickness, the deformation of the can will be detached from the ingot, leading to double bumping or the formation of a large seam near the ingot, hence the restricting effect of the can is deteriorated. With a large thickness, the can could deform coincidentally with the ingot, hence restricting the lateral flowing of the ingot and cracking. Moreover, with a thick can, the ingot is mainly located in the center of the sample (deformation zone Ⅰ), which means that the deformation zone Ⅱ and zone Ⅲ decrease and the deformation of the ingot will be more homogeneous. Therefore, the thickness of the can should be large enough to ensure homogeneous microstructure.

5 CONCLUSIONS

1) The deformation microstructure of TiAl base alloy without canning is inhomogeneous. In lateral area, cracking and shearing lines can be found; while in center area, fine-grained shearing zone can be found.

2) The effect of can is to reducing the secondary tensile stress. However, only when the deformation of the steel can is coincidental with that of TiAl alloy ingot, can this effect be effective. Moreover, a thick can would enhance the microstructural homogeneity in TiAl alloy.

3) With the H/D ratio of the ingot increasing, the deformation of TiAl alloy would be more unsteady, therefore, a thicker can should be needed.

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