

[Article ID] 1003- 6326(2002) 04- 0601- 04

Effects of can parameters on canned forging process of TiAl base alloy(II) ^①

—Mechanical behavior

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[Abstract] By using thermal simulation technique and computer simulation, the conventional canned forging process of TiAl base alloy was studied. The effect of can parameters on the mechanical behavior of TiAl alloys with different H/D ratios was analyzed in this process. The results show that, the peak stress of TiAl base alloy without canning is far higher than that with canning. Compared with the samples with the same H/D ratio, the peak stress decreases with increasing can thickness; while compared with the samples with the same can thickness, the peak stress decreases with increasing H/D ratio. The decrease of the true stress of TiAl base alloy with canning were analyzed according to the theory of plastic deformation and results of computer simulation.

[Key words] TiAl base alloy; thermal mechanical treatment; mechanical behavior; computer simulation

[CLC number] TG 146.2

[Document code] A

1 INTRODUCTION

TiAl 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]. On industry scale, the processing of TiAl alloy includes casting^[4,5], forging and heat treating^[6~9]. Forging is one of the most important steps influencing the final properties of TiAl base alloy. Because of its simple process and low cost, conventional canned-forging has been an effective process for grain-refining of TiAl base alloys^[10,11]. In previous work, how the can parameters and height-to-diameter ratio of the ingot influence the microstructures of TiAl base alloy has been studied. This work was concentrated on the influence of these processing parameters on the mechanical behavior of the ingot by using Gleeble-1500 thermal simulation equipment.

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 °C for 4h. 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 the previous work. TiAl base alloy and the

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	2.5
6	8/6	3.0	14	15/6	2.0
7	12/6	-	15	15/6	3.0
8	12/6	1.0			

can were heated by electric current with a heating rate of 550 °C/min, and then held at 1100 °C 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%. All the mechanical data can be recorded automatically by the computer connecting with the equipment. In order to understand the mechanical behavior of the forging process, the computer simulation of canned-forging process for the sample with a H/D ratio of 8/6 and a can thickness of 2 mm was conducted on DEFORM^{3D} work station.

The equations for calculation of the true stress and strain are

$$\varepsilon = \ln[h_0/(h_0 - h)] \quad (1)$$

$$\delta = p/A = 4ph/\pi d^2 h_0 \quad (2)$$

① **[Foundation item]** Project (715- 005- 0040) supported by the National Advanced Materials Committee of China

[Received date] 2001- 10- 08

where ε is the true strain; h_0 and h are the initial height and the actual height respectively, and the latter is adopted from the data given by the computer automatically; σ is the true stress; p is the load which can be given by the computer automatically; A , d are the area and diameter, respectively, of the sample and can.

3 RESULTS

3.1 True stress—true strain curve

Figs. 1(b), (c) and (d) show the true stress—true strain curves of the samples made from Ti-48Al-2Cr alloy with different H/D ratios during forging. It indicates that the true stress of the samples at first increases quickly with increasing strain, and then drops after it arrives at a peak value. It is interesting to note that the peak stress values of the samples without canning are much higher than those with canning. For example, with a same H/D ratio of 8/6, the peak stress of sample 1 is 281 MPa; while those with canning are from 80 MPa to 140 MPa, and the value decreases with increasing the can thickness, as shown in Fig. 1(b). Moreover, the peak stress of the samples with a same can thickness varies very slightly with increasing the H/D ratio. For example, with a can thickness of 2.0 mm, the peak stress for samples of H/D ratios of 8/6, 12/6 and 15/6 are 131, 129 and 125 MPa, respectively.

3.2 Computer simulation of canned-forging process

Fig. 1(a) shows the original true stress—true strain curve of the steel can with a H/D ratio of 8/6. Based on the data from Fig. 1(a) ~ (d) the computer simulation was conducted. Fig. 2 shows the original finite elemental units for canned-forging. It is interesting to note that when the peak stress of TiAl alloy without canning (~ 480 MPa) was input to the data base, the calculation can not go on because the strength difference between the steel and TiAl alloy was so big that the steel can had deformed too quickly. When the peak stress of TiAl alloy was assigned to be about 100 MPa, the calculation can go on smoothly. Fig. 3 shows the distribution of the stress and the strain in different deformation steps. It can be seen that the deformation of TiAl alloy ingot begins from its central part. It is difficult for the head and the bottom of sample to deform due to the friction of the punch.

4 DISCUSSION

Without canning (as shown in Fig. 4(a)), the punches can be considered as rigid parts and do not deform, thus limit the radial flow of TiAl alloy. Under this condition, the direction of the friction force is inward. With canning, there are steel pads intersecting between the punch and TiAl alloy. Being softer than TiAl alloy, the pads would flow along the

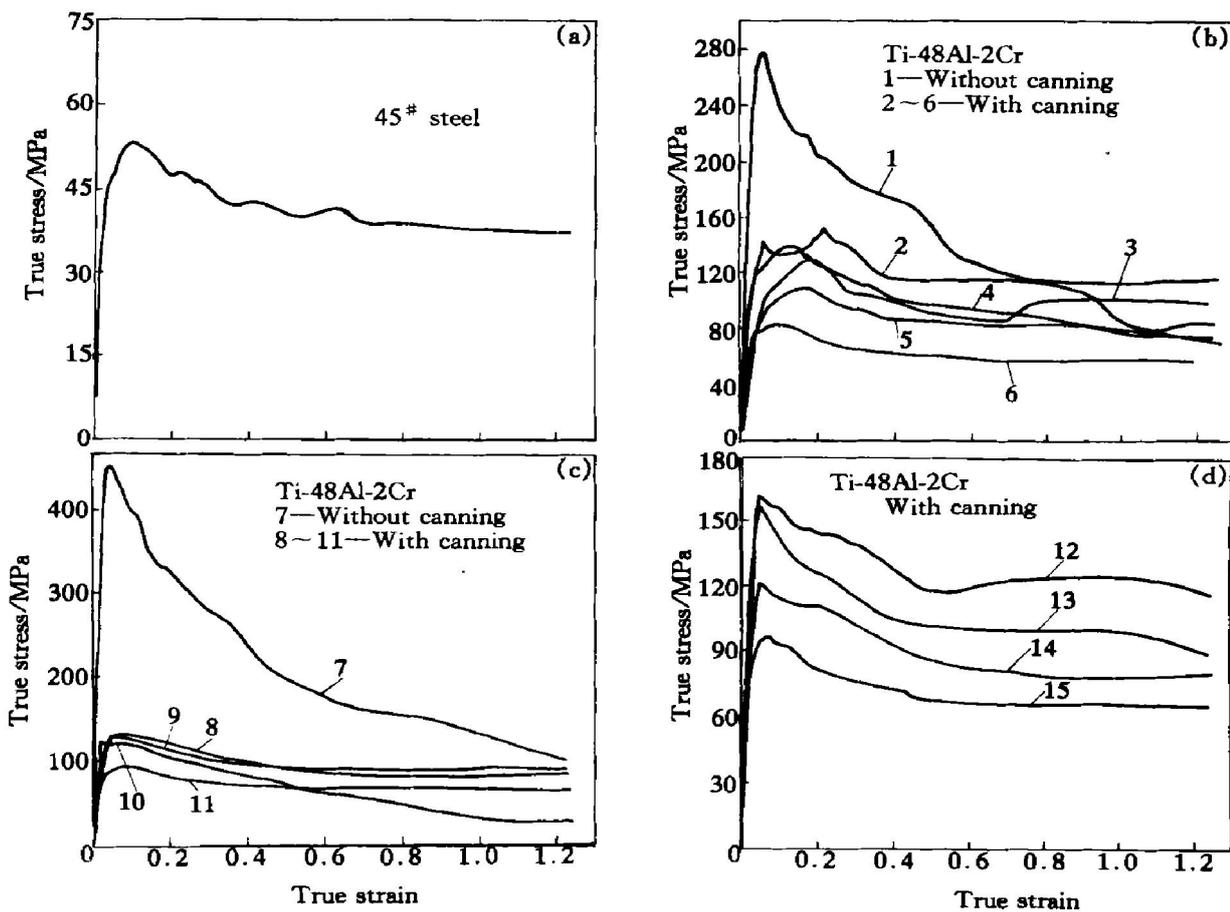


Fig. 1 True stress—strain curves of samples (number 1~ 15)
 (a) —Steel can; (b) — $H/D = 8/6$; (c) — $H/D = 12/6$; (d) — $H/D = 15/6$

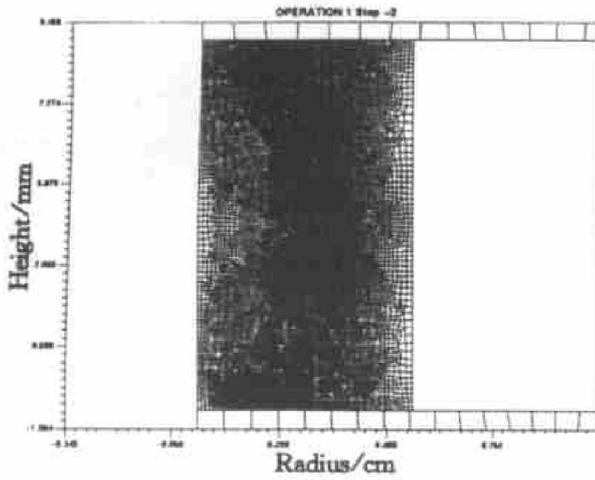


Fig. 2 Original finite elemental units for canned forging

radial direction at first, which was confirmed by the computer simulation result, as shown in Fig. 3(b), (d) and (f). The data indicate that that of pads are higher than the strain of TiAl contacting with the pads, i. e. the steel pads deform faster than that of TiAl alloy, thus constrain the surface of TiAl alloy to flow outward. Therefore, the direction of the friction force under this condition is outward, as shown in Fig. 4(b).

According to stress differential equation^[12]:

$$\partial \sigma_r / \partial r + \partial \tau_{zr} / \partial z + (\sigma_r - \sigma_\theta) / r = 0 \quad (3)$$

and under uniform deformation, $d\epsilon = d\epsilon_\theta$ and $\sigma_r = \sigma_\theta$, then we obtain

$$\partial \sigma_r / \partial r + \partial \tau_{zr} / \partial z = 0 \quad (4)$$

Supposing τ_{zr} is proportional to z , then

$$\tau_{zr} = 2T_z r / h,$$

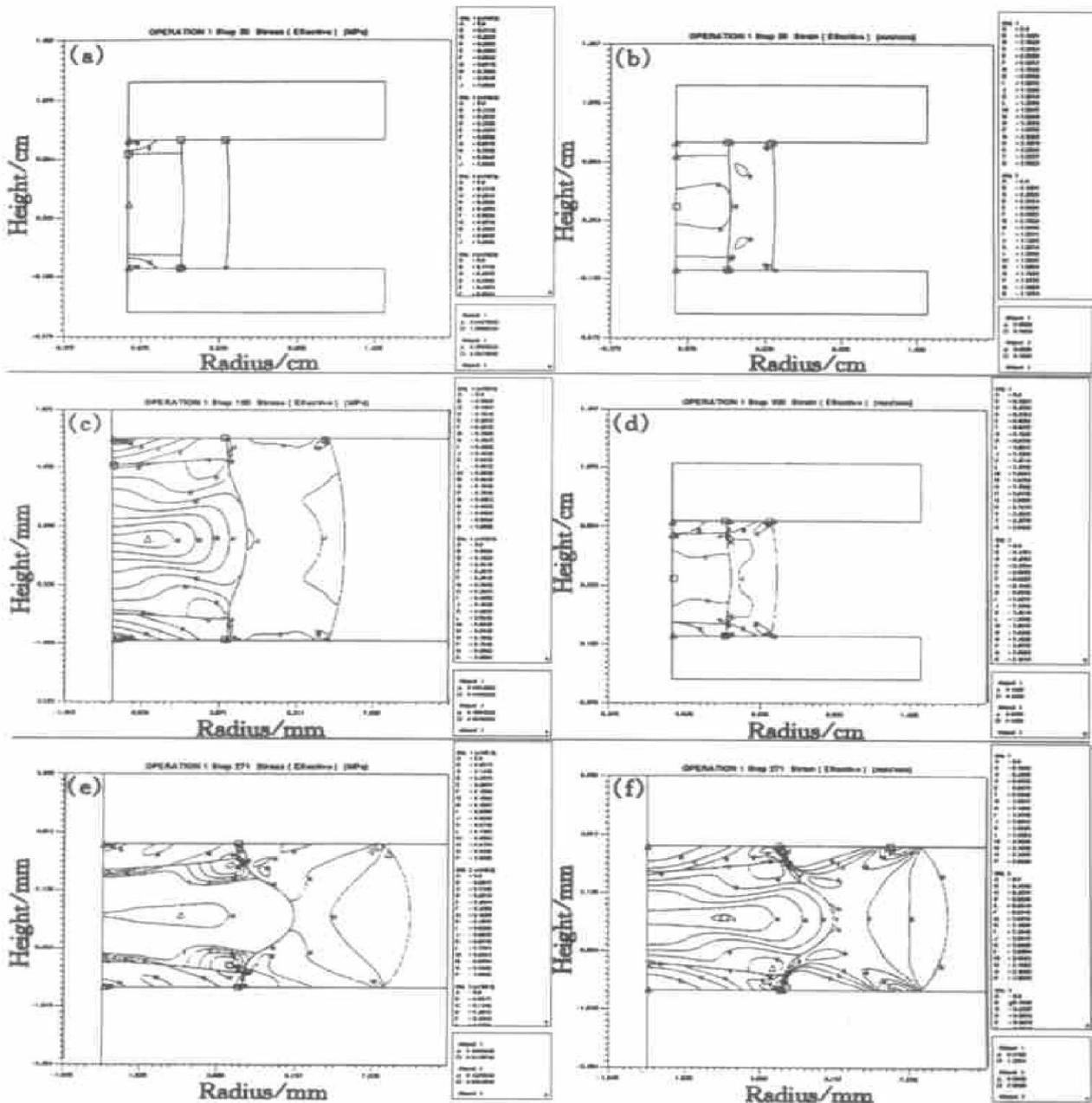


Fig. 3 Distribution of stress and strain in different deformation steps
 (a) —Stress of step 50; (b) —Strain of step 50; (c) —Stress of step 100;
 (d) —Strain of step 100; (e) —Stress of step 271; (f) —Strain of step 271

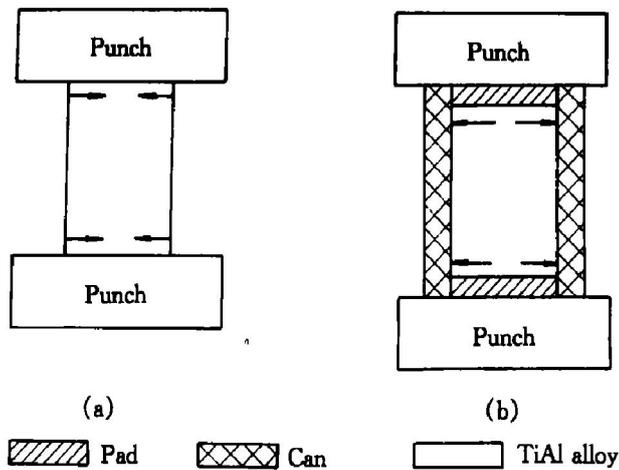


Fig. 4 Schematic direction of friction force of TiAl alloy

(a) —Without canning; (b) —With canning

$$d\tau_{z\rho}/dz = 2T_{z\rho}/h$$

where $\tau_{z\rho}$ is the shear stress induced by the surface friction, $T_{z\rho}$ is friction shear stress. As σ_p is only related to the coordinate of ρ , we get

$$d\sigma_p/d\rho + 2T_{z\rho}/h = 0 \tag{5}$$

According to the plastic yielding condition $p_z = \sigma_p$ that is $dp_z = d\sigma_p$, it can be obtained that:

$$dp_z/d\sigma_p + 2T_{z\rho}/h = 0 \tag{6}$$

In the contacting surface, assuming the friction coefficient is constant, the equation of friction shear stress is $T_{z\rho} = \mu p_z$, and Eqn. (6) can be rewritten as

$$dp_z/p_z = 2\mu d\rho/h \tag{7}$$

using the boundary condition that $p_z = \sigma_s$ when $\rho = d/2$, it can be obtained that

$$p_z = \sigma_s e^{2\mu(\rho - d/2)/h} \tag{8}$$

and the total pressure will be

$$p = 2\pi \int_0^{d/2} p_z \rho d\rho \tag{9}$$

Combining Eqn. (8) and Eqn. (9), we get

$$p = 2\pi\sigma_s (h/2\mu)^2 (e^{-\mu d/h} + \mu d/h - 1) \tag{10}$$

and the average stress is

$$\bar{p} = p/S = p/(4d) \tag{11}$$

When taking Eqn. (8) into Eqn. (9), the average stress can be

$$\bar{p} = 2\sigma_s (h/2\mu)^2 (e^{-\mu d/h} + \mu d/h - 1) \tag{12}$$

Let $\mu d/h = C$ (constant), the coefficient of stress state n_σ is

$$n_\sigma = \bar{p}/\sigma_s = 2(e^{-c} + c - 1)/c^2 \tag{13}$$

When the direction of the friction force is inward, the stress state coefficient can be obtained also by the above calculation as that:

$$n'_\sigma = \bar{p}/\sigma_s = 2(e^c - c - 1)/c^2 \tag{14}$$

It can be proved that $n_\sigma < n'_\sigma$.

According to the above calculation, the yielding stress (defined as the peak stress) of TiAl alloy decreases after canning. According to Eqn. (13), when increasing H/D ratio, c increases and n_σ decreases, hence the peak stress decrease, as shown in Fig. 1. At the same H/D ratio, when increasing the can thickness, the deformation of the pads would be restricted as the deformation rate of the can decreases, which would lead to the increase of the friction coefficients in the surface of TiAl alloy. Also according to Eqn. (13), c increases and n_σ decreases, hence the peak stress decreases, as shown in Fig. 1.

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(Edited by YANG Bing)