Ti-2007 Science and Technology, edited by M. Ninomi, S. Akiyama, M. Ikeda, M. Hagiwara, K. Maruyama
The Japan Institute of Metals (2007)

Microstructures and Mechanical Properties of Gum Metal Sheets Correlated with Cold Rolling Reduction

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"Gum Metal" is a newly developed beta titanium alloy, which has an ultra-low elastic modulus, high strength, super elasticity, super plasticity, invar property and elinvar property. In this study, microstructural features including texture and mechanical properties of sheets of a Gum Metal, Ti-363Nb-2.03Ta-2.88Zr-0.31O, have been investigated as a function of cold rolling reduction. The results obtained were compared with those of a Ti-15V-3Cr-3Sn-3A1, typical beta titanium alloy. In the optical microstructures, no large difference was found between the two alloys: as the cold rolling reduction increased, the deformation bands were introduced and increased in number while coarse and equiaxed original grains became monotonically elongated to the rolling direction. Also, work hardening behavior of the Gum Metal was almost the same as that of Ti-15-3: only a slight hardening was observed at the beginning of rolling but was soon saturated. The rolling texture of the Gum Metal was basically (111)<011> in contrast to (001)<110> of Ti-15-3 when the cold rolling reduction was about 50%, but both became diffuse and similar to each other as the rolling reduction increased.

Keywords: Gum Metal, Ti-15 V-3Cr-3Sn-3A1, beta type titanium alloy, microstructure, texture, cold rolling, work hardening

1. Introduction

In recent years, materials with a low elastic modulus and high strength have been needed in various fields including machine components such as bolts and springs. However, the elastic modulus of metals relates directly to atomic force and electron state, and essentially can not be controlled by processing procedures. In addition, materials with a low elastic modulus generally have a low strength. Therefore, it is an extremely difficult issue to balance a low elastic modulus and high strength in metallic materials[1)].
"Gum Metal" is a newly developed beta titanium alloy that has an ultra-low elastic modulus, high strength (Fig. 1), super elasticity, super plasticity, invar and elinvar properties[2)]. It is one of the alloys currently attracting

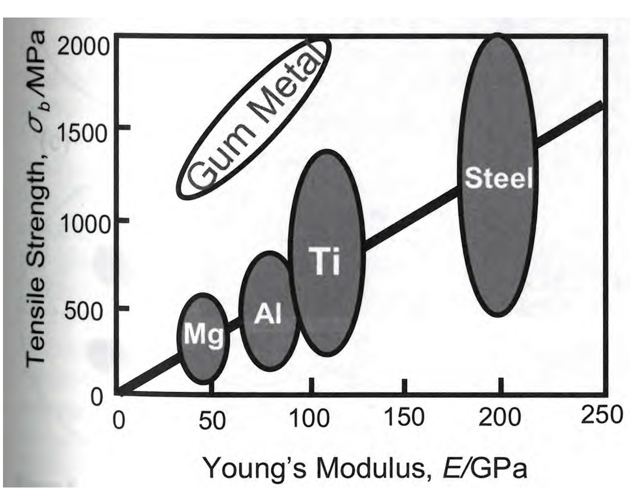

Figure 1. Relationship between tensile strength and Young's modulus".

attention. In the previous reports, Gum Metals were investigated mainly in the form of wires and rods, while little work has been made on sheets. In this study, microstructural features including texture and mechanical properties of sheets of a Gum Metal have been investigated as a function of cold rolling reduction. The results obtained were compared with those of a Ti-15V-3Cr-3Sn-3A1, typical beta titanium alloy.

2. Specimens and Experimental Procedure

A 12mm-thick Gum Metal plate produced by powder metallurgy, forging and solution treatment at 850˚C for 5h, and a 13mm-thick hot-rolled plate of Ti-15V-3Cr-3Sn-3A1 alloy commercially produced by ingot metallurgy and hot rolling were used in this study. The Ti-15V-3Cr-3Sn-3A1 alloy will be called Ti-15-3 hereafter. The composition of the two plate specimens are indicated in Table 1. These plates were scalped at both surface up to 8mm in thickness and then cold-rolled by up to 99%.
Optical microstructures of the specimens, original plates and cold-rolled sheets, were observed on L-ST plane after polishing and etching by Kroll's reagent. Texture of the specimens was assessed by a (110) pole figure measured by means of X-ray diffraction (Schulz's reflection method) on the half thickness plane (after one side of the surface was ground until the thickness became half). The surface and 3/4 thickness plane were also measured in specimens cold-rolled by 87.5% to investigate the effect of the distance from the surface. Work hardening behavior of each specimen was investigated by Vickers hardness test (load: 4.9N, loading time: 15s).

Table 1. Chemical composition of the two alloys in mass%.

	Nb	Ta	Zr	O
Gum Metal	36.3	2.03	2.88	0.31

	V	Cr	Sn	Al	Fe	O	C	N	H
Ti-15-3	14.7	2.95	2.94	3.18	0.13	0.115	0.0085	0.014	0.007

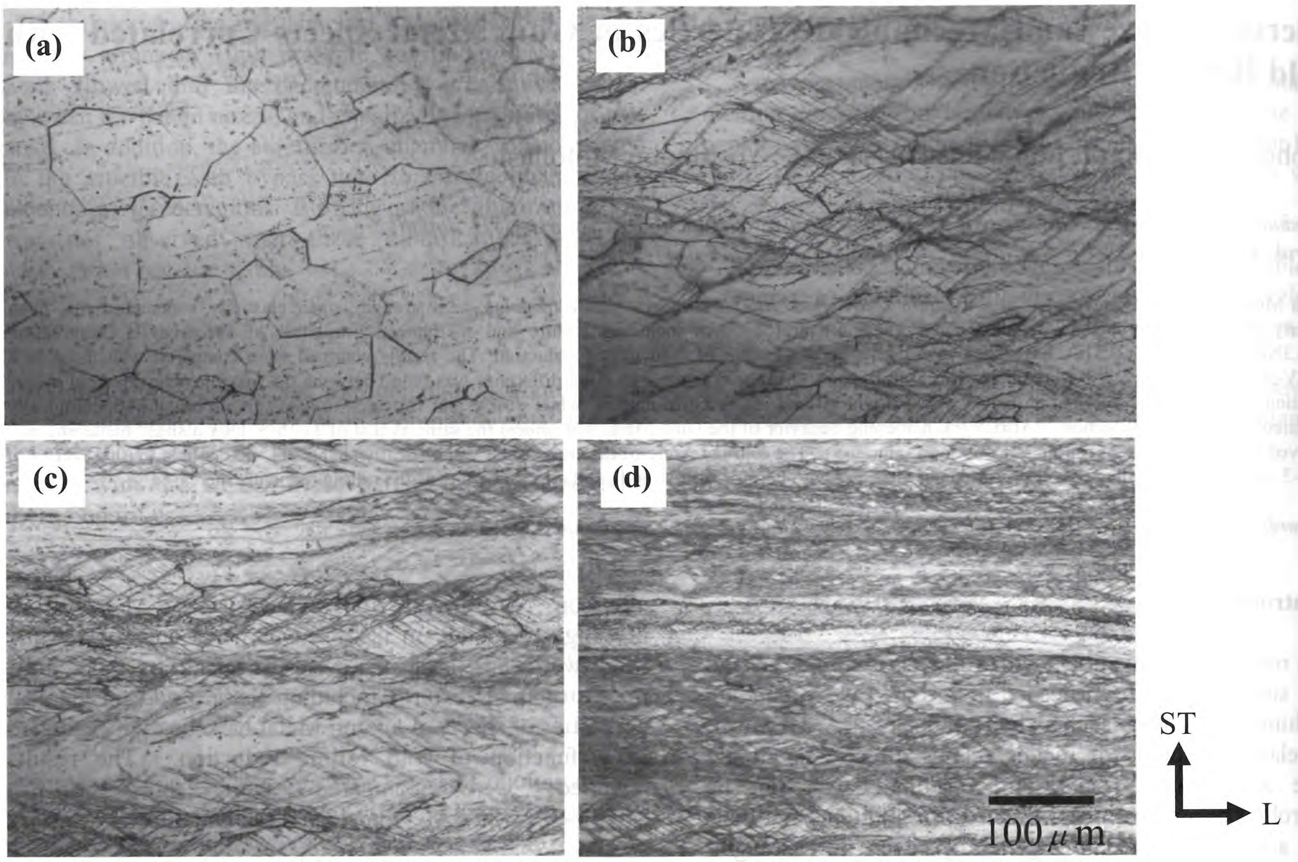

Figure 2. Optical microstructures of the Gum Metal on L-ST plane. (a) original plate (as solution-treated), (b) cold-rolled by 50%, (c) cold-rolled by 75%, (d) cold-rolled by 87.5%.

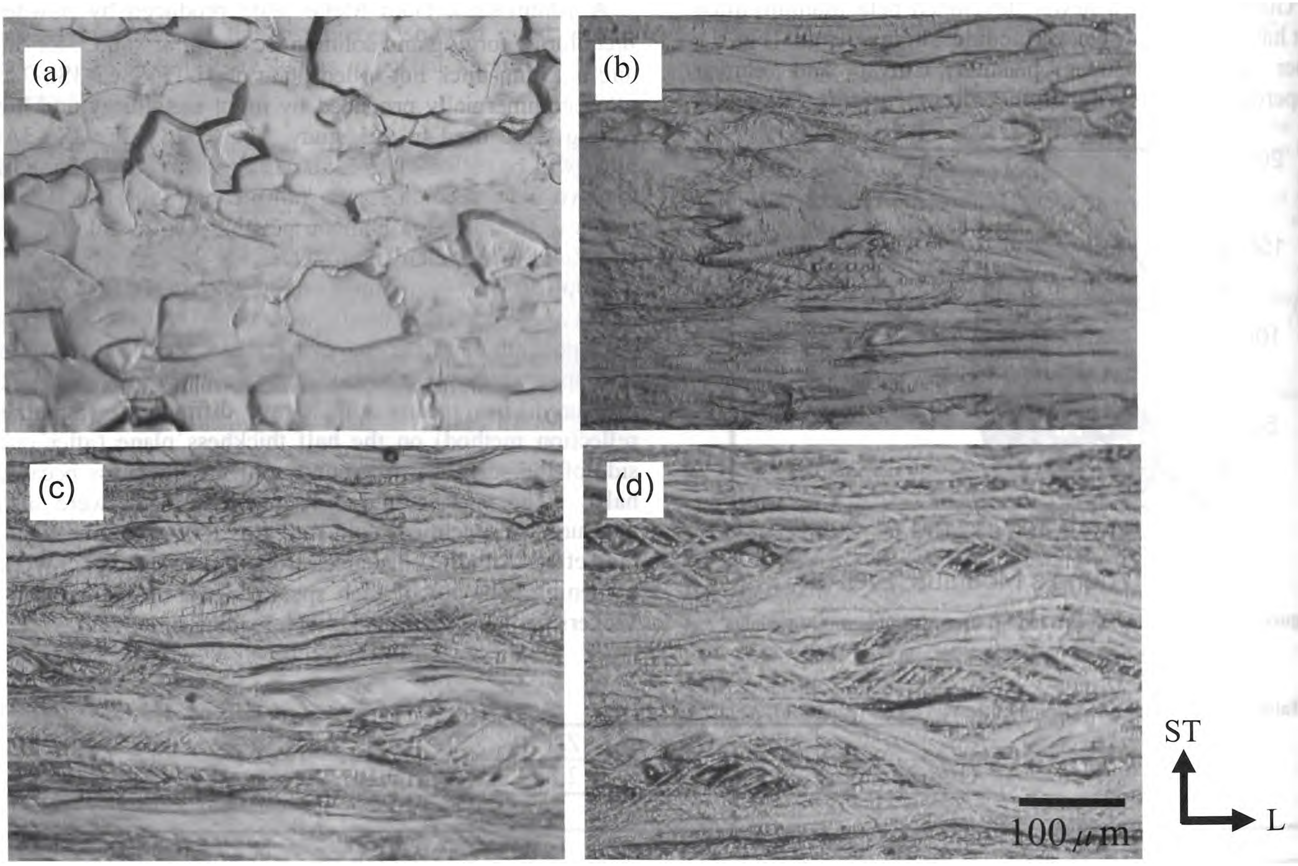

Figure 3. Optical microstructures of the Ti-15-3 on L-ST plane. (a) original plate (as hot-rolled), **(b)** cold-rolled by 50%, (c) cold-rolled by 75%, (d) cold-rolled by 87.5%.

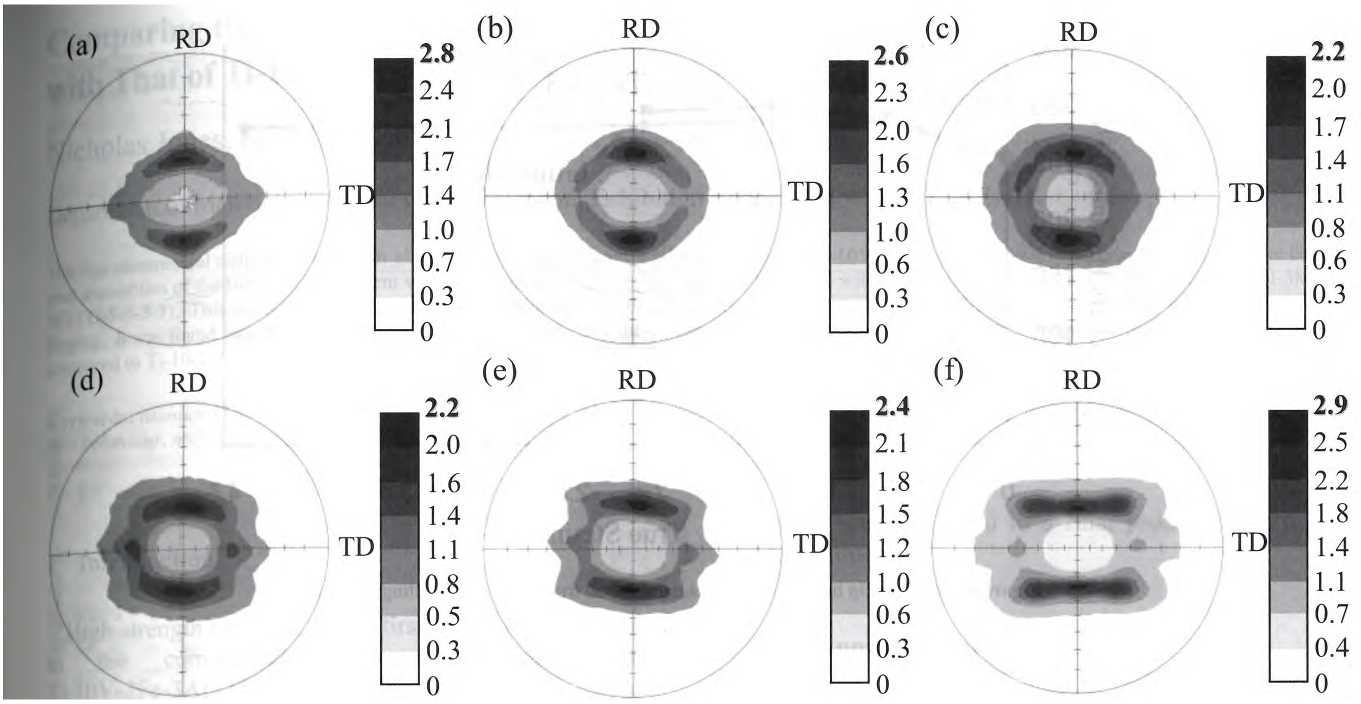

Figure 4. (110) pole figure of the Gum Metal. (a) original plate on half-thickness plane, (b) 50% cold-rolled on half-thickness plane, (c) 75% cold-rolled on half-thickness plane, (d) 87.5% cold-rolled on half-thickness plane, (e) 87.5% cold-rolled on 3/4-thickness plane, (f) 87.5% cold-rolled on the surface.

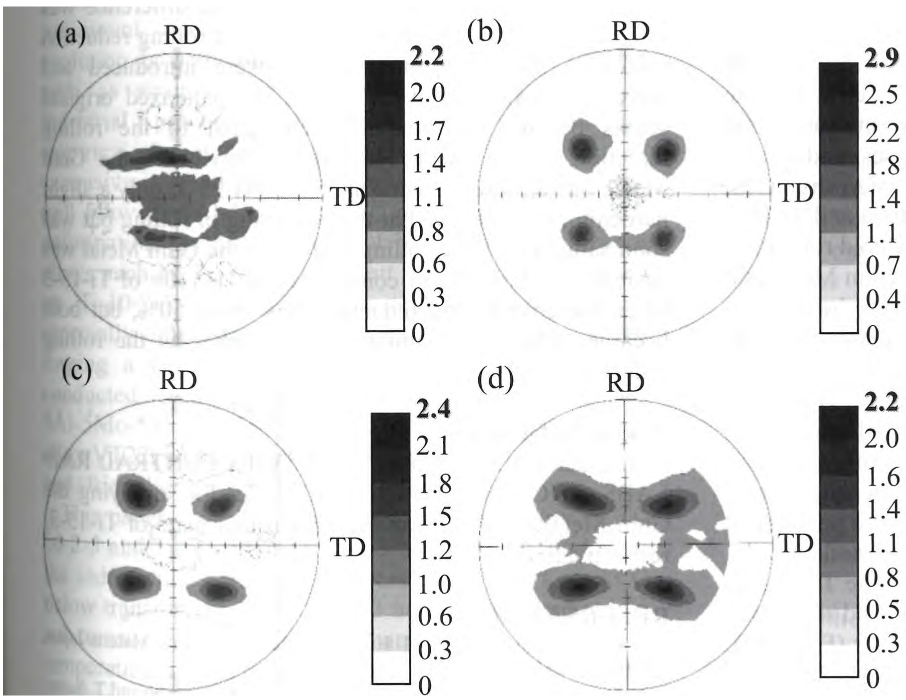

Figure 5. (110) pole figure of the Ti-15-3 on half-thickness plane. (a) original plate, (b) 50% cold-rolled, (c) 75% cold-rolled, (d) 87.5% cold-rolled.

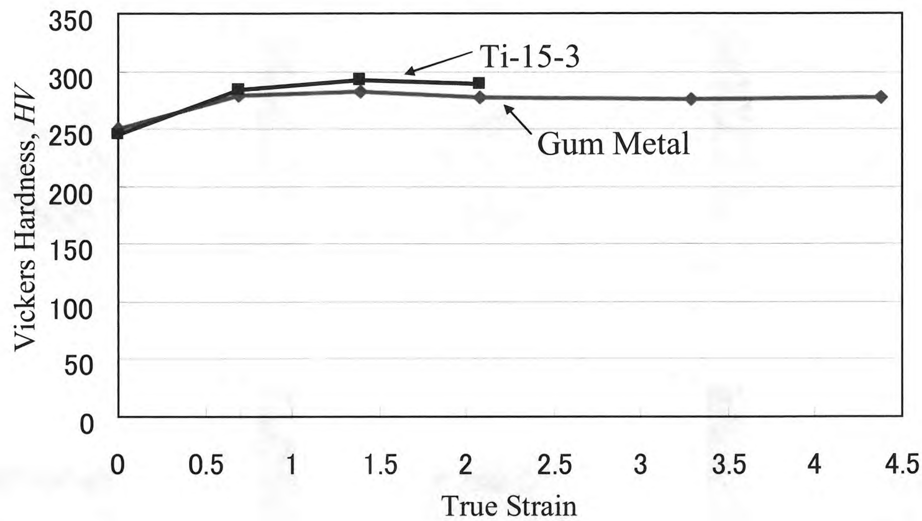

Figure 6. Relationship between Vickers hardness and true strain (cold rolling reduction).

3. Results and Discussion

Optical microstructures of the two alloys affected by the cold rolling reduction are shown in Figs. 2 and 3. While coarse equiaxed grains of about 100μm in size are observed in the original plates of both alloys, many deformation bands are introduced and grains begin to be stretched by the cold rolling by 50%. As the reduction increases, the density of the deformation bands increases and grains become further stretched. In the optical microstructures, no obvious difference between the Gum Metal and Ti-15-3 can be seen in the microstructural change by cold rolling.

Figure 4 shows (110) pole figures of the Gum Metal as a function of cold reduction and distance from the surface. In the middle of the thickness, a pair of moderate peaks of (111) <011> can be seen spreading in the transverse direction in the solution-treated specimen (Fig.4(a)). These peaks weaken and spread around normal direction as the rolling reduction increases (Figs.4(b),(c) and (d)). With respect to the distance from the surface, the texture sharpens as the distance decreases, and the two peaks tend to spread in the transverse direction (Figs.4 (e) and (0).

In Fig. 5 are shown (110) pole figures of the Ti-15-3 in the middle of the thickness as a function of cold reduction. Although by cold rolling by medium reductions (Fig.5 (b)), the (001)<110> texture is sharpened compared to the hot-rolled state (Fig.5 (a)), it again becomes diffuse towards the transverse direction leading to a similar texture to the surface texture of the Gum Metal (Fig. 4 (f)) when the reduction increases (Fig.5 (d)).

Relationship between Vickers hardness and cold reduction (true strain) is shown in Fig. 6. Only a slight work hardening can be seen at the beginning of rolling in both alloys and it is soon saturated at and above a true strain of about 0.7.

4. Conclusion

In the optical microstructures, no large difference was found between the two alloys: as the cold rolling reduction increased, the deformation bands were introduced and increased in number while coarse and equiaxed original grains became monotonically elongated to the rolling direction. Also, work hardening behavior of the Gum Metal was almost the same as that of Ti-15-3: only a slight hardening was observed at the beginning of rolling but was soon saturated. The rolling texture of the Gum Metal was basically (111)<011> in contrast to (001)<110> of Ti-15-3 when the cold rolling reduction was about 50%, but both became diffuse and similar to each other as the rolling reduction increased.

Acknowledgement

The authors are grateful to TOYOTA CENTRAL R&D LABS., INC. and NIPPON STEEL Co. for supplying the Gum Metal specimens and the hot-rolled plate of Ti-15-3, respectively.

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