The Anisotropic Properties of Rolled Pure Titanium Sheet

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The pronounced textures of rolled pure titanium cause strong anisotropy of mechanical properties and have a detrimental influence on working and shaping properties. The relationship between texture and mechanical anisotropic properties of pure titanium has been investigated in this study. The pure titanium after hot rolling and cold rolling was investigated to clarify the effect of the process on the texture and mechanical properties. Results show the anisotropy of mechanical properties of pure titanium was closely related to the crystallographic texture. Hot-rolled titanium sheet exhibits strong anisotropy of mechanical properties due to the {10-10}<11-20> and {11-20}<10-10>. The {10-10}<11-20> and {11-20}<10-10> textures were suppressed and (0002) basal texture was developed after cold rolling and annealing treatment, the anisotropy in the yield strength decreased and R-value increased. CSC's 0.6mm titanium sheets are equipped with outstanding forming ability and pass the roof forming test. CSC's 0.6mm titanium sheets have been used in the architectural material for the National Taiwan Normal University, International Kang Chiao School, and Taipei Dome.

Keywords: Pure Titanium, Anisotropy, Cold Rolled, Texture

1. INTRODUCTION

Pure titanium has been widely used in the petrochemical, architectural, aerospace, energy, and ocean industries because of its low density, outstanding corrosion resistance, favorable mechanical properties, good weldability, and excellent forming properties(1-2). This research studies the rolling and heat-treatment process of pure titanium and successfully develops the cold-rolled titanium coil. A series of microstructural observations, texture analysis, and mechanical property measurements were conducted to study how rolling and heat-treatment processes affect the properties of microstructure, texture, anisotropy property, and R-value (Lanford value) of titanium sheets. Moreover, the misorientation angle and pole figure of the twin cold rolled titanium sheet were investigated to clarify the deformation mechanism of the twin and dislocation.

The results of the EBSD analysis show the direction of the c-axis is the key factor of anisotropy of titanium sheet. The anisotropy of hot rolled titanium plate and sheet is more obvious than cold rolled sheet because their c-axis is paralleled to the transverse direction. After proper cold rolling and heat treatment, the c-axis would tend to be vertical to the normal plane of a titanium sheet, resulting in cold rolled titanium sheet equipped with high R-value and low anisotropic properties.

The cold rolled titanium sheet/coil has successfully been developed and has sold more than 1100 tons via this study. The cold-rolled titanium sheet/coil has been used in the architectural, civil, energy, and petrochemical industries, creating more than 100 million NTD production value.

2. EXPERIMENT METHOD

The material used in this study was commercial pure titanium, containing 0.04wt.% O, 0.003wt.% H, 0.03wt.% Fe, 0.02wt.% C and 0.0075wt.% N. The titanium ingot was melted by 3 tons VAR (vacuum arc remelting) and then forged into a slab. The titanium slab was hot-rolled and cold-rolled to plate and sheet. The plate and sheet were annealed at 973 K for 1 h in a vacuum atmosphere or air.

To investigate the effects of texture on the anisotropy of mechanical properties of titanium sheet. Specimens with tensile axes parallel and normal to rolling direction were denoted as RD and TD. Mechanical tests were conducted at room temperature with a strain rate of 10^{-3} s^{-1} for tensile specimens. To achieve the surface quality required for EBSD, transverse cross-sections were cut from the specimens, mechanically polished then electropolished in a solution consisting of 5ml perchloric acid and 95 ml methanol at 35V and -30°C. The prepared samples were analyzed in a JEOL JSM-7001 FEG-SEM operating at 25kV and equipped with the HKL OIM EBSD software.

3. RESULTS AND DISCUSSION

The result of the mechanical test shows that the anisotropy of titanium sheets cold rolled with over 50% reduction rate is more inconspicuous than that of hot rolled or cold rolled with 20% reduction rate. The difference in yield strength between the T and L directions of titanium sheet cold rolled with a 75% reduction rate and then heat treated under a vacuum atmosphere is as low as 3MPa, as shown in Table 1.

The EBSD-based inverse pole figure maps of Ti products with different rolling processes are shown in Fig.1. These six titanium products are all of small uniform equiaxed grains with an average grain size of 60um. The color difference of inverse pole figure maps is not apparent. However, the titanium sheet after 75% cold rolled and vacuum annealed possessed more grains with red color.

Figure 2 is the (0002), (11-20), and (10-10) pole figure of titanium products with different rolling processes. These results show the basal poles of the heavy plate and hot rolled sheet located close to the plate-normal transverse direction (ND and TD).

Table 1 The mechanical properties of titanium products with different rolling processes

	30mm hot-rolled heavy plate		2.4mm hot-rolled sheet		20% cold rolled + continuous Annealing 1.9mm sheet		50% cold rolled + continuou annealing 1.2mm sheet		twice 50% cold rolled + continuou annealing 0.6mm sheet		75% cold rolled + vacuum Annealing 0.6 mmsheet	
	T	L	T	L	T	L	T	L	T	L	T	L
YS(MPa)	278	214	290	201	279	202	235	206	229	215	213	210
ΔYS $_{(T, L)}$	64		89		77		29		14		3	
TS(MPa)	346	334	320	311	343	325	329	326	335	328	341	339
EL(%)	39.3	40.1	38.1	38.2	35.3	35.6	38.1	38.9	37.1	36.1	35.6	39.4

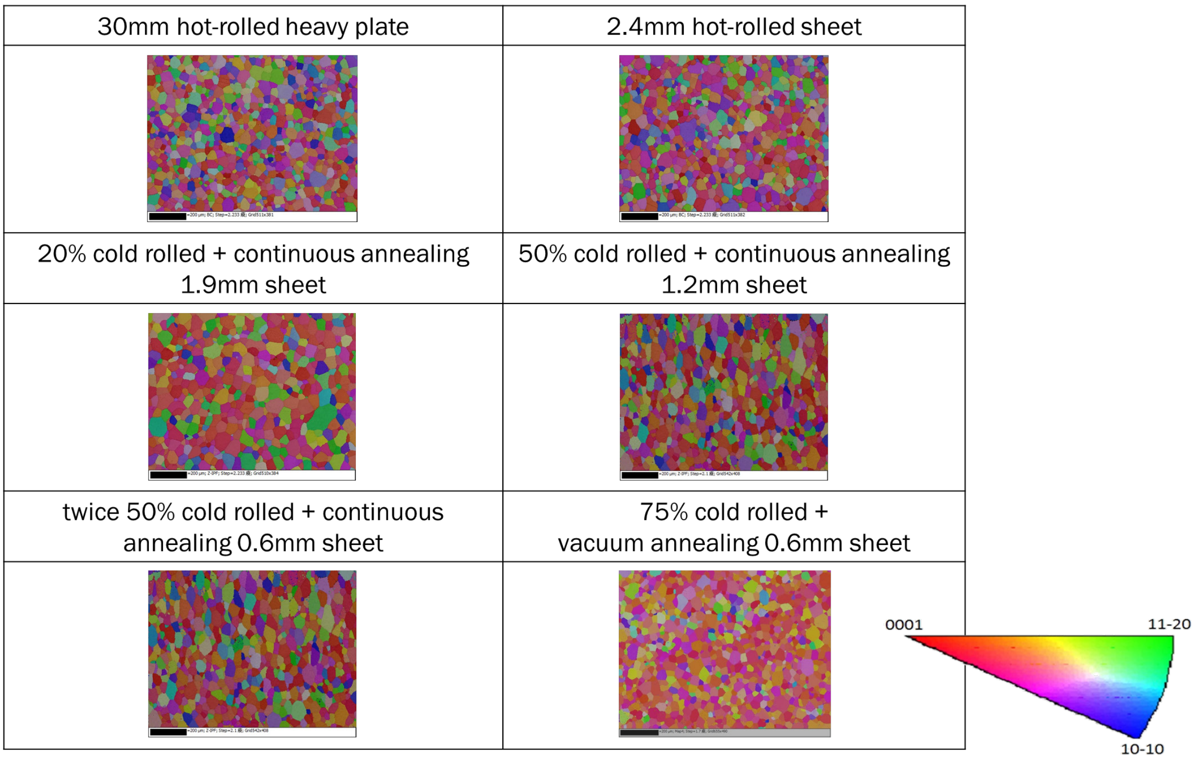

Fig.1. EBSD-based inverse pole figure maps of CP-Ti products with different rolling processes.

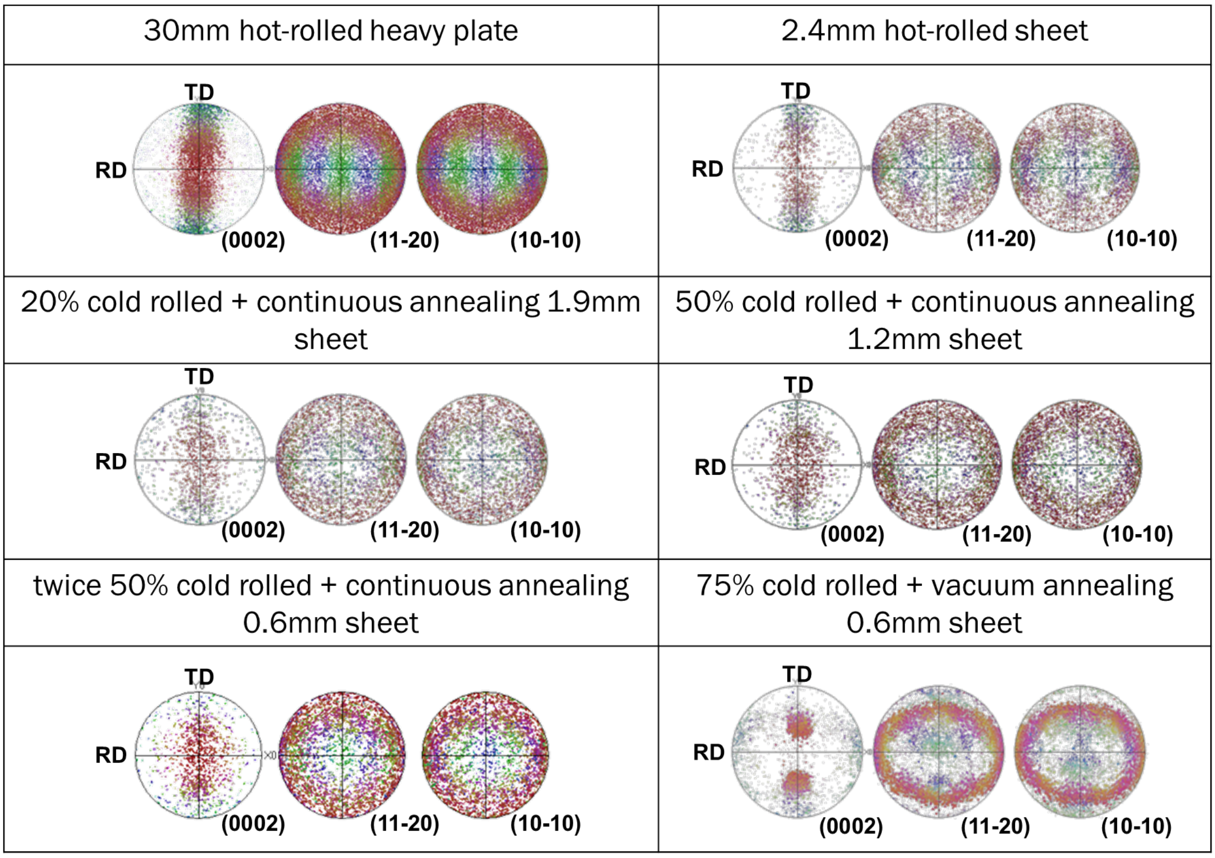

Fig.2. The (0002), (11-20), (10-10) pole figures of titanium products with different rolling processes.

Moreover, the basal poles of the titanium sheet with a reduction rate of over 50% are aligned with the normal direction.

For commercial pure titanium, Young's modulus of the c-axis is about 145 GPa higher than the a-axis[3-4]. Therefore, once the c-axis was aligned with the transverse direction, the yield strength of the transverse direction of the titanium plate or sheet would be higher than that of the rolling direction, causing obvious anisotropy properties[5-7].

The R-value of titanium products with different rolling processes is shown in Table 2. The results show the cold-rolled titanium sheet with a 75% reduction rate with vacuum annealing has the highest R-value (3.77). The R-value of a hot rolled heavy plate is only about 1.7. The R-value is the strain ratio of the width direction and thickness direction. Young's modulus of the c-axis is 45% higher than the a-axis. Once the c-axis is aligned with the normal direction, the thickness direction of a titanium sheet is not as easy to deform as the width direction. Therefore, if the c-axis of titanium is aligned in the normal direction, the titanium sheet will possess a higher R-value.

Figure 3 is the ODF maps for the Φ2=0° and 30° section and inverse pole figure of hot rolled heavy plate. The ODF maps show the hot rolled heavy plate not only has {-2115}<01-10>, {10-13}<2-1-10> and {0002} basal fiber that can align the c-axis with the normal direction, but also has {10-10}<11-20> and {11-20}<10-10> fiber that makes the c-axis parallel to the transverse direction. Therefore, the anisotropy of hot rolled heavy plate is more obvious and the R-value is smaller.

The ODF maps for the Φ2=0° and 30° section and inverse pole figure of 50% cold rolled and continuous annealing titanium sheet are shown in Figure 4. After cold rolling with a 50% reduction rate and continuous annealing, the {10-10}<11-20> and {11-20}<10-10> fiber become weaker. It means the c-axis is not parallel to the transverse direction anymore. Therefore, the R-value of the titanium sheet increases and the anisotropic property becomes inconspicuous. However, the heating time of continuous annealing is not enough to vanish the {10-10}<11-20> and {11-20}<10-10> fiber. The R-vale of the titanium sheet after continuous annealing can not be increased to 3.

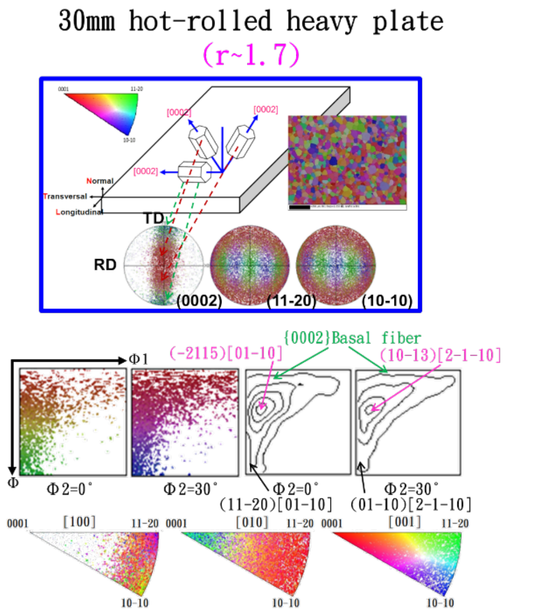

Fig.3. The ODF maps for the Φ2=0° and 30° section and inverse pole figure of hot rolled heavy plate.

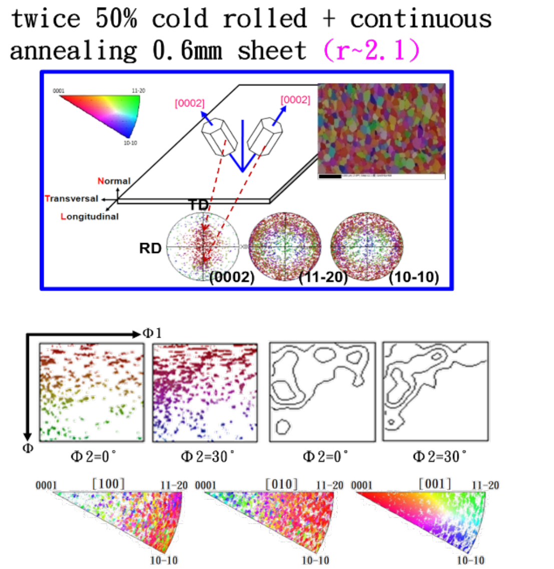

Fig.4. The ODF maps for the Φ2=0° and 30° section and inverse pole figure of 50% cold rolled and continuous annealing titanium sheet.

Figure 5 shows the ODF maps for the Φ2=0° and 30° section and the inverse pole figure of 75% cold rolled titanium sheet after vacuum annealing. The ODF results show the {10-10}<11-20> and {11-20}<10-10> fiber of titanium sheet has vanished, and the {-2115}<01-10>, {10-13}<2-1-10> fiber that can align the c-axis with normal direction become stronger after cold rolling and vacuum annealing. Therefore, the r-value of cold-rolled titanium via vacuum annealing can be increased to 3.7.

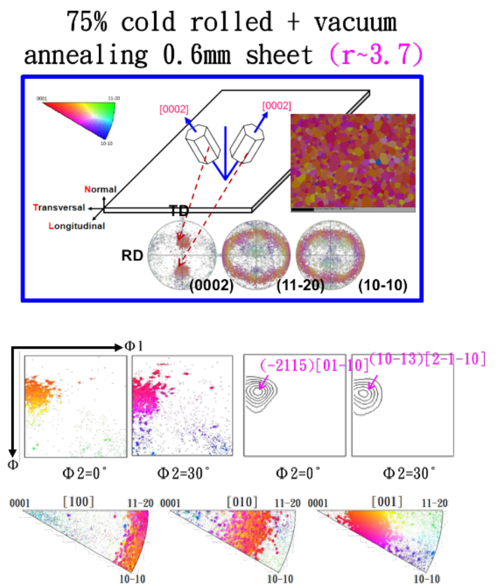

Fig.5. The ODF maps for the Φ2=0° and 30° section and inverse pole figure of 75% cold rolled and vacuum annealing titanium sheet.

4. CONCLUSIONS

1. The hot rolled heavy plate not only has {-2115}<01-10>, {10-13}<2-1-10> and {0002}basal fiber that can align the c-axis with the normal direction, but also has {10-10}<11-20> and {11-20}<10-10> fiber that makes the c-axis parallel to the transverse direction. The anisotropy of hot rolled heavy plate is more obvious and the R-value is smaller.

Table 2 The mechanical properties of titanium products with different rolling processes

	30mm hot-rolled heavy plate			2.4mm hot-rolled sheet			20% cold rolled + continuous Annealing 1.9mm sheet			50% cold rolled + continuou annealing 1.2mm sheet			twice 50% cold rolled + continuou annealing 0.6mm sheet			75% cold rolled + vacuum Annealing 0.6 mmsheet		
	T	L	45	T	L	45	T	L	45	T	L	45	T	L	45	T	L	45
r	2.02	0.91	1.94	2.04	0.78	1.86	1.96	0.89	1.80	2.39	1.19	2.20	2.43	1.51	2.31	4.40	2.30	4.20
$\bar{r}=(r_T+2r_{45}+r_L)/4$	1.70			1.63			1.61			2.01			2.12			3.77		

2. After cold rolling with a 75% reduction rate and vacuum annealing, the {10-10}<11-20> and {11-20}<10-10> fiber of titanium sheet has vanished, and the {-2115}<01-10>, {10-13}<2-1-10> fiber that can align the c-axis with normal direction has become stronger. Therefore, the R-value of cold-rolled titanium after vacuum annealing can be increased to 3.7.
3. The results of the EBSD analysis show the direction of the c-axis is the key factor of anisotropy of titanium sheet. The anisotropy of hot rolled titanium plate and sheet is more obvious than cold rolled sheet because their c-axis is paralleled to the transverse direction. After proper cold rolling and heat treatment, the c-axis would tend to be vertical to the normal plane of the titanium sheet, resulting in a cold-rolled titanium sheet equipped with low anisotropic properties.

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