INFLUENCE OF INITIAL TEXTRUE ON THE COLD ROLLING TEXTURE OF Ti SHEETS①

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ABSTRACT The ODF method according to Bunge was used to analyse the formation of cold rolling texture in commercially pure Ti sheets with different initial textures. The orientation factor distribution of slip and twinning systems in orientation space was calculated, the stability of $\{0001\}$ parallel to rolling plane as well as the instability of $\langle 1\bar{1}00\rangle$ parallel to transverse direction were analysed, and the different stabilities of $\langle 1\bar{1}00\rangle$ parallel to rolling direction were discussed. The multiplicity of micro-deformation mechanisms in pure Ti and multiple stable orientations cause remarkable influence of initial texture on the cold rolling texture.

Key words: Ti Rolling Texture ODF

1 INTRODUCTION

The deformation of pure Ti is accomplished mainly by the glide of slip systems with Burgers vector a/3 $\langle 11\bar{2}0\rangle$ on the basal $\{0001\}$, prismy $\{1\bar{1}00\}$ and pyramidal $\{1\bar{1}01\}$ planes; as well as by the activation of twinning system $\{1\bar{1}02\}\langle 10\bar{1}\bar{1}\rangle$ and $\{11\bar{2}2\}\langle 11\bar{2}\bar{3}\rangle$. Because of the remarkable crystallographic characteristics of plastic deformation in Ti, deformation texture is always produced after cold deformation. The cold rolling texture in Ti sheet was well investigated[1-3], and the modern ODF method was also applied to analyse the rolling texture in Ti sheet[4]. The multiplicity of crystallographic deformation mechanism of pure Ti, on one hand, provides a good ductility, and on the other hand the micro-deformation processes become very complicated. It is very difficult to understand the practical activation process and the combination state of different crystallographic mechanisms during deformation, which could be better investigated by means of analysis of texture formation.

The influence of initial texture on the cold rolling texture of Ti sheet was investigated in present work in order to reveal the practical crystallographic process of Ti sheet during rolling.

2 EXPERIMENTS

Hot rolled commercially pure Ti sheet (99.8%Ti, thickness 1.12 mm) was annealed at 840 ℃ for 1 h and cold rolled in original hot rolling direction (RD) to 36%, 54%, 71% and 78% reduction respectively; an other hot rolled sheet was also cold rolled in original transverse direction (TD) to 77% reduction. Six incomplete pole figures $\{1\bar{1}00\}$, $\{0002\}$, $\{1\bar{1}01\}$, $\{1\bar{1}02\}$, $\{11\bar{2}0\}$ and $\{1\bar{1}03\}$ were measured, and using the series expansion method according to Bunge[5] orientation distribution functions (ODFs) were calculated.

In consideration of stress state during rolling a drawing stress in RD and a compressive stress in normal direction (ND), which cause plastic deforamtion, were supposed[6]. The two stresses are equal in absolute value, but with opposite signs. Under the stress state the orientation factors of slip systems on the basal, prismy and pyramidal planes, as well as the orientation factors of both twinning systems $\{1\bar{1}02\}\langle 10\bar{1}\bar{1}\rangle$ and $\{11\bar{2}2\}\langle 11\bar{2}\bar{3}\rangle$ were calculated in orientation space.

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3 RESULTS

Fig. 1 shows the whole ODFφ_2 sections of Ti sheet before and after cold rolling. In Fig. 1 (a-b) it can be seen that certain inital textures existed in the Ti sheets. According to the initial textures the {0001} plane of grains tend parallel to rolling plane, i. e. the orientation densities distribute around $\varphi = 0°$. However there are some grains, of which ⟨1$\bar{1}$00⟩ direction tends parallel to RD(Fig. 1(a)), $\Phi_1 = 0°$, $\varphi = 0° - 90°$, $\varphi_2 = 0°$) before rolling in the RD mentioned above; and there are also some grains, of which ⟨1$\bar{1}$00⟩ direction tends parallel to TD(Fig. 1(b)), $\Phi_1 = 90°$, $\Phi = 0° - 90°$, $\varphi_2 = 0°$) before rolling in the TD. It was retained after cold rolling that {0001} plane of grains still tended parallel to rolling plane (Fig. 1(c-d)). Also the ⟨1$\bar{1}$00⟩ parallel to RD kept stable(Fig. 1(c)), but the ⟨1$\bar{1}$00⟩ parallel to TD became instable and the corresponding orientation density reduced(Fig. 1(b-c)). Therefore the initial textures could clearly influence the cold rolling texture in Ti sheet.

The changes of the grain orientations, of which the {0001} planes were nearly parallel to rolling plane(near $\Phi = 0°$), can be better seen in the fibre analysis of the ODFs(Fig. 2 (a), Fig. 3(a)). At low reduction (36% rolled) the orientation density along the $\Phi = 0°$ fibre decreased(Fig. 2(a)), but increased again by the further rolling, indicating a slow accumulation of grain orientations along the $\Phi = 0°$ fibre. Fig. 3(a) shows the orientation density along the $\Phi = 0°$ fibre becomes even

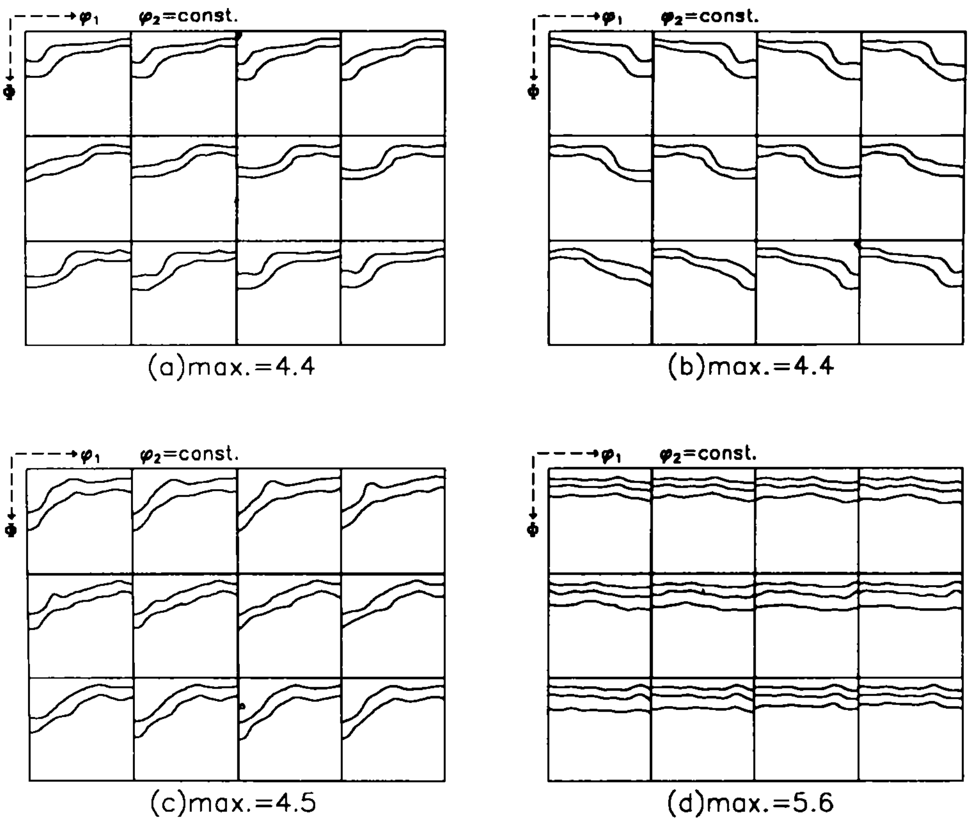

Fig. 1 ODFs of Ti sheets before and after cold rolling(density levels: 2.0, 3.2, 4.4)
(a)—before cold rolling in the RD; (b)—before cold rolling in the TD;
(c)—after cold rolling in the RD; (d)—after cold rolling in the TD

higher after than before the cold rolling in the TD of original hot sheet. The orientation distribution on $\varphi_1 = 0°$, $\Phi = 0° - 90°$, $\varphi_2 = 0°$ fibre has been increased and expanded (Fig. 2 (b)), indicating the native stability of this orientation fibre. On the other hand the grain orientations on the $\varphi_1 = 90°$, $\Phi = 0° - 90°$, $\varphi_2 = 0°$ fibre were instable (Fig. 3(b)).

4 DISCUSSION

The main deformation mechanism of pure Ti is the activation of slip systems. It is generally believed that the {0001} plane of Ti is not the closest packed plane because of its lower c/a value. Therefore the prismy and pyramidal plane should be the main slip planes. The slip deformation becomes rather difficult if the {0001} plane is oriented near the rolling plane (Fig. 1 (a-b), $\Phi = 0°$). In this case the $\{1\bar{1}00\}$ planes are nearly perpendicular to the rolling plane, and the orientation factor of basal slip systems is almost 0, so that they could not be acturally activated. Fig. 4 gives the orientation factor distributions of different deformation mechanisms in the orientation space. It can be observed that not

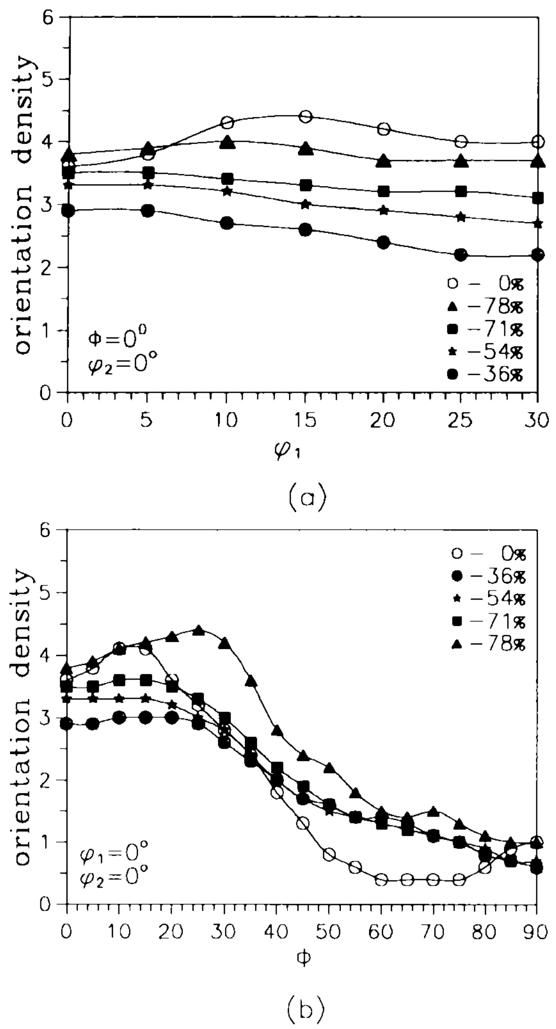

Fig. 2 Orientation fibre analysis of cold rolled sheet in the RD

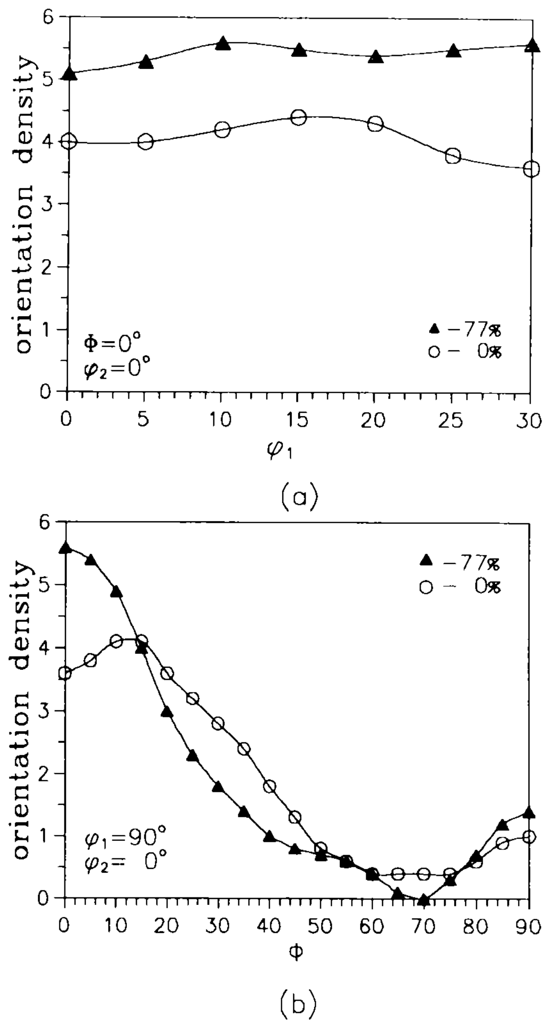

Fig. 3 Orientation fibre analysis of cold rolled sheet in the TD

only the basal slip systems (Fig. 4(a)) but also the prismy and pyramidal slip systems (Fig. 4 (b-c)) could not be activated easily if Φ is equal to 0°. However the twinning systems $\{1\bar{1}02\}\langle 10\bar{1}\bar{1}\rangle$ and $\{11\bar{2}2\}\langle 11\bar{2}\bar{3}\rangle$ could be activated more easily in this case (Fig. 4(e-f)), therefore the twinnings in cold rolling Ti sheet of present work should be very active deformation mechanisms. The twinning and possible non-basal slip induce {0001} plane of grains to leave the rolling plane result in decreasing of orientation density along $\Phi = 0°$ fibre at low rolling reduction (Fig. 2(a)). During the whole rolling process, however, {0001} planes show relative high stability if they are oriented nearly parallel to rolling plane, i. e. with increasing defomration the orientation density along the $\Phi = 0°$ fibre increases (Fig. 2(a) Fig. 3(a)), which could be produced only by the slip on basal plane according to the orientation changes induced by different deformation mechanisms. It cuold be supposed therefore that the slips on basal plane should be also rather active to some extent. Because of decreasing orientation factor the slips on basal plane would stop while the {0001} grain plane rotates towards rolling plane, and then the {0001} plane would leave rolling plane again because of the activation of twinning or non-basal slips. Synthesizing the two opposite rotations of {0001} plane the grain orientations accumulate around $\Phi = 0°$ very slowly (Fig. 2(a)).

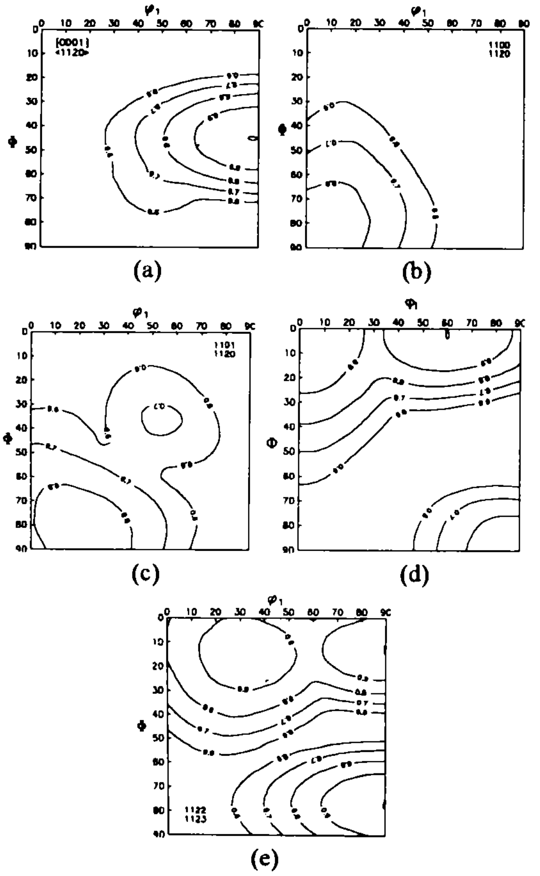

Fig. 4 maximal orientation factors of different slip systems (a, b, c) and twinning systems (d, e) at $\varphi_2 = 0°$ section in the orientation space

The grain orientations move always from instable positions to stable positions, which is determined by the crystallogrphic structure, deformation mechanisms, deformation stresses and deformation degree etc. Generally the stable rolling orientation is not unique, and rolling texture in pure metals would be more or less influenced by the initial textures, which is demonstrated in rolled pure Al[7] and in present work (Fig. 1(c-d)).

Fig. 5 shows the maximal orientation factor m of basal, prismy as well as pyramidal slip system on $\varphi_1 = 0°$ ($\langle 1\bar{1}00\rangle$ parallel to RD) and $\varphi_1 = 90°$ ($\langle 1\bar{1}00\rangle$ parallel to TD) fibre in $\varphi_2 = 0°$ section. It could be imaged that the slip on basal plane would be very active if the grain orientations are located on the orientation fibre shown in Fig. 5(b), and the {0001} plane will rotate towards rolling plane resulting in the changes shown in Fig. 3(b). That may be also the reason that orientation density on $\Phi = 0°$ fibre becomes higher after cold rolling (Fig. 3(a)). The slips on prismy and pyramidal planes, however, should be more actvated along the orientation fibre shown in Fig. 5 (a). The activation of slips on prismy planes results in rotation of grain orientations towards $\{11\bar{2}0\}\langle 1\bar{1}00\rangle$ ($\Phi = 90°$), and the activation of slips on pyramidal planes results in the rotation towards $\{11\bar{2}2\}\langle 1\bar{1}00\rangle$ ($\Phi = 57.8°$). The stability of both orientations was found in low cold rolled Ti sheet[1, 8]. If the slip on basal plane is simultaneously activated either the grain orientations will move towards low Φ angle, and the stable orientation will be located at a position with lower Φ value, e. g. $\{11\bar{2}6\}\langle 1\bar{1}00\rangle$ ($\Phi = 25°$), in present work, sometimes $\{11\bar{2}4\}\langle 1\bar{1}00\rangle$ ($\Phi = 38.4°$)[1] or $\{11\bar{2}5\}\langle 1\bar{1}00\rangle$ ($\Phi = 32.4°$)[8]. The stabilities of these orientations and the corresponding reasons should be investigated further.

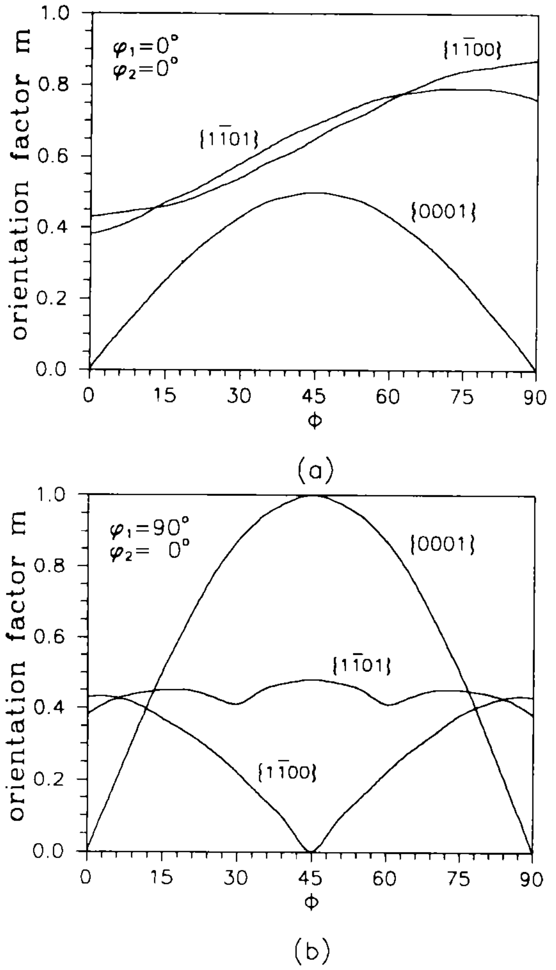

Fig. 5 Maximal orientation factors of different slip systems along the two orientation fibres

5 CONCLUSIONS

The orientation factor distribution of different deformation mechanisms during cold roolling of pure Ti sheets were calculated, and the stabilities of grain orientations as well as the changes of cold rolling textures were analysed. It was shown that the initial textures have clear influences on the rolling textures because of the multiplicities of deformation mechanisms and stable orientations. The stability of $\Phi = 0°$ fibre is induced by the main activation of basal slip systems, companying with twinning and non-basal slips. The orientation fibre, on which the $\langle 1\bar{1}00\rangle$ direction is parallel to rolling direction, has certain stability. The stable orientations on this fibre should be influenced by, such as cold rolling degree etc. The grain orientations with $\langle 1\bar{1}00\rangle$ parallel to transverse direction are not stable because of the dominant activation of basal slip systems.

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