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Formation of shearing bands in the hot-rolling process of AZ31 alloy

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ABSTRACT

Three types of AZ31 alloy samples, numbered with A, B, C, with various texture and microstructure condition were hot-rolled in single pass to investigate the different mechanism of shearing bands formation. Shearing bands came into being via twinning related grain fragmentation and DRX in Sample A while via rotational recrystallization in Sample B. Twinning played the most important role in shearing bands formation in Sample C. DRX and twinning are the two major elements in the formation of shearing band in magnesium alloys. Contrastive study indicated that sharper texture would increase the influence of twining while small size would promote the recrystallization in shearing bands formation.

1. Introduction

In recent years, magnesium alloys have attracted an increasing interest in the field of automotive, astronomy due to their low densities and other excellent properties such as heat dissipation, electro-magnetic shielding, etc. As the most widely used magnesium alloy products, magnesium sheets were usually produced with hot/warm rolling methods. A characteristic and inevitable phenomenon in rolling process is the formation of shearing bands [1–3]. The study on the forming mechanism of shearing bands would be of great help in understanding the mechanism of plastic deformation in magnesium alloys and improving the quality of their sheets products. Different phenomenon have been reported for shearing band formation in magnesium alloys and a number of models have been introduced, such as double-twinning [3–6], rotational recrystallization (RDRX) [7], etc. However, previous studies mainly concentrate on only one type of samples, little attention has been paid to the influence of initial state on bands forming mechanism. Since such material factors as grain size, texture, etc., always played a most important role in the deformation behavior of mg alloys, they were expected to exert a profound influence on the forming process of shearing bands.

In the present work, three types of samples with different texture and mean grain size were obtained for single pass hot-rolling experiment to investigate the influence of initial state on the shearing bands formation in rolling process.

2. Materials and methods

The material used in this study was AZ31B sheets fabricated by twin-roll casting (TRC) method. The nominal composition was 3 wt% Al, 1 wt% Zn and balance Mg. Three types of samples, numbered as A, B, C, were prepared following the procedures as described in Table 1. Single pass hot-rolling experiments were conducted on the three types of samples at 375 °C. This temperature was chosen in order to avoid prevalent precipitation of β-phase ($Mg_{17}Al_{12}$) [1,8]. The rolling facility was furnished with two Ø157 mm rollers that rotated at a speed of 18 rpm, and the rollers were heated to about 100 °C before rolling.

Metallographic observation was conducted on the RD-ND plane. The samples were prepared following conventional mechanical polishing procedure and etched using a solution of picric-acetic. Macro-texture tests were carried out on RD-TD plane with Cu Kα radiation in reflection geometry, using Bruker D8 Discover X-ray diffractometer (BRUKER AXS Inc.). Texture samples were cut from the middle part of the rolled sheet. Microstructure observation was carried out on FEI Tecnai G^2 operated at 200 kV. TEM samples were firstly sectioned parallel to the RD-ND plane, grounded to 100 μm, punched into Ø3 mm discs and finally double-jet electro-polished to perforation with commercial AC-2 electrolyte.

3. Results and discussion

3.1. Microstructure and texture before rolling

Fig. 1 shows the optical microstructure of the three samples prior to rolling. All the samples had equal-axial grains with a mean grain size of 20 μm, 5 μm and 20 μm respectively. Their textures were presented in (0 0 0 2) pole figures, as shown in Fig. 2. Although all of these samples exhibited typical basal texture, their texture intensity showed significant discrepancy. It could be seen clearly that Sample A had a maximum basal pole density of only 5.5, while

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Table 1
Preparation procedures of Samples A, B and C.

Sample	Preparation procedure	Mean grain size/μm	Maximum pole density
A	Twin-roll cast → 430 °C/2 h	20	5.5
B	Sample A → 60% hot-rolled → 375 °C/20 min	7–8	11.6
C	Sample A → 60% hot-rolled → 460 °C/2 h	20	11.2

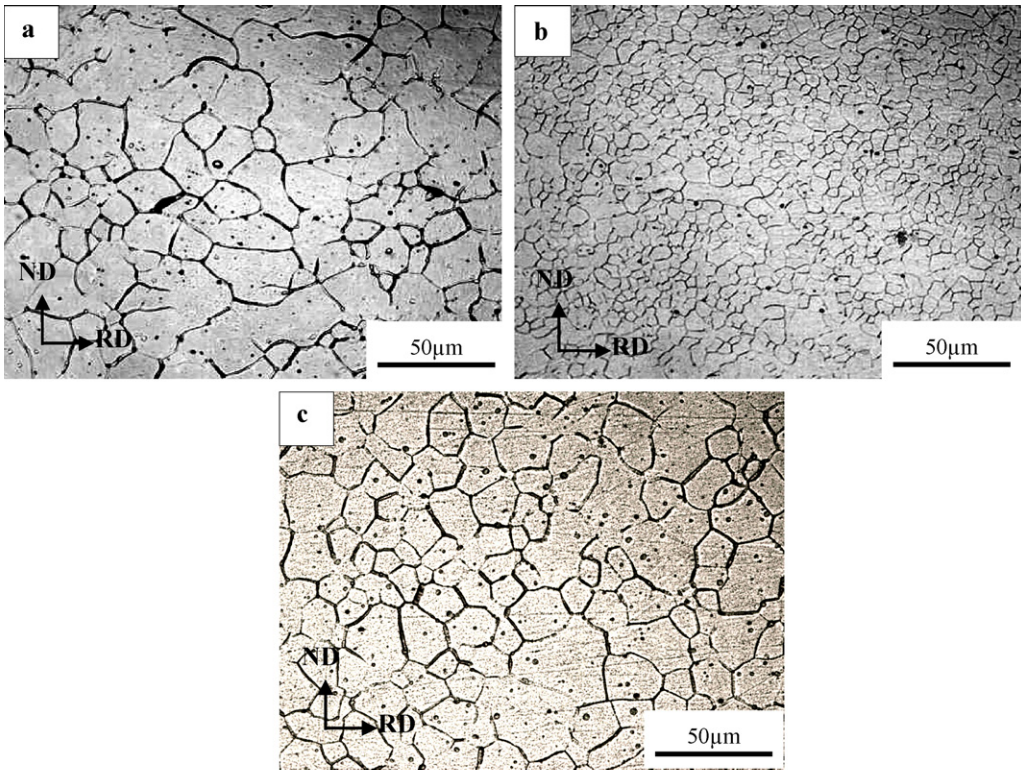

Fig. 1. The microstructure of (a) Sample A, (b) Sample B and (c) Sample C prior to rolling process.

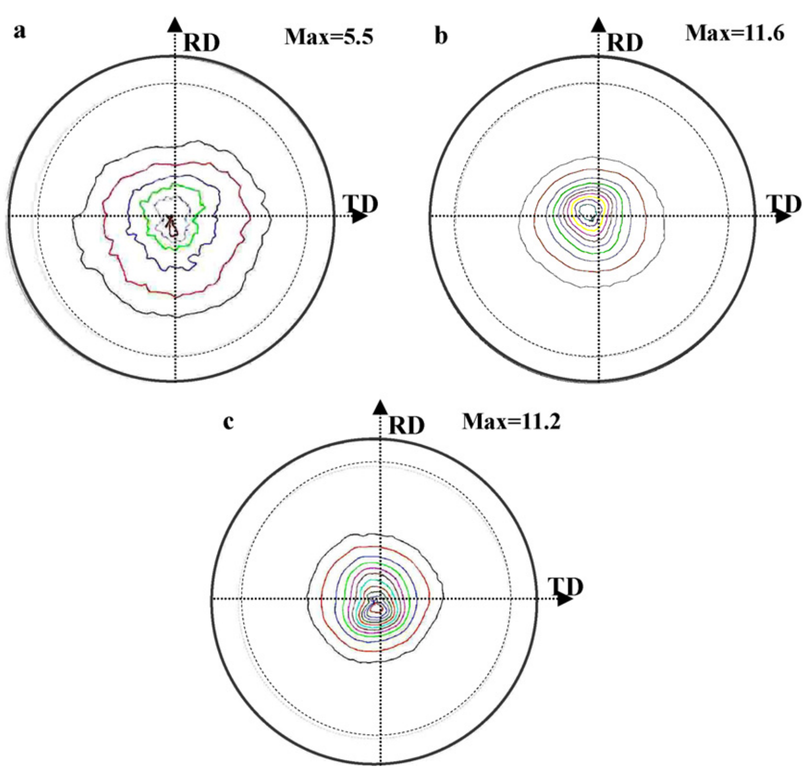

Fig. 2. The (0 0 0 2) pole figures of (a) Sample A, (b) Sample B and (c) Sample C prior to rolling process.

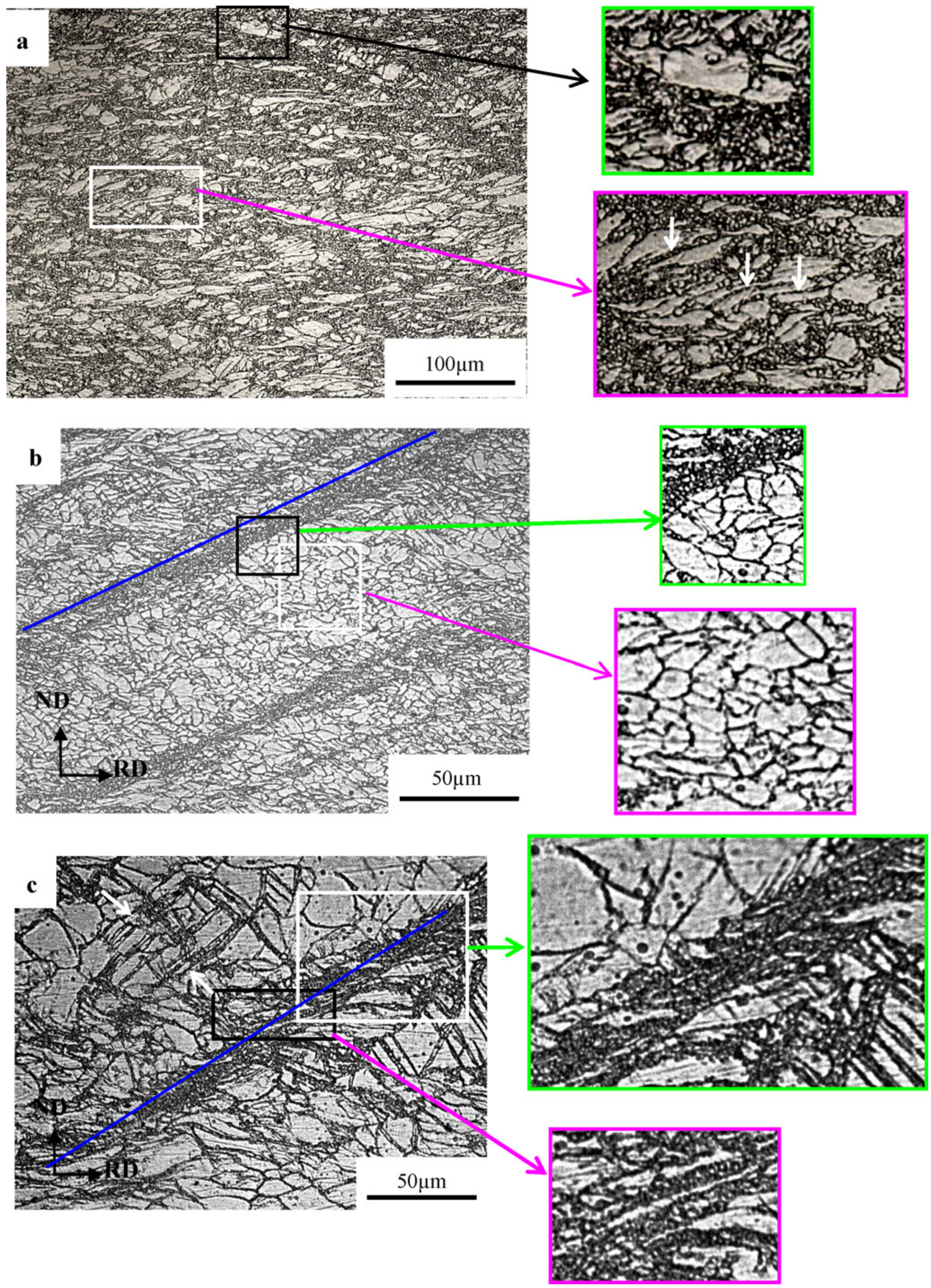

Fig. 3. The optical microstructure of regions close to shearing bands in (a) Sample A after 60% rolling strain and (b) Sample B, (c) Sample C after 20% rolling strain.

Samples B and C owned much shaper basal texture with a maximum basal pole density of about 11.

3.2. Microstructure evolution in the rolling process

It was found in Sample A that only after the rolling reduction reached 60% could shearing bands become visible, as shown in Fig. 3(a). Since Sample A had the weakest basal texture, it was expected to accommodate the largest strain before crack failure among these three samples. It could also be seen in Fig. 4 that thin twins had been activated when the rolling strain increased to 20%, and dynamic recrystallization (DRX) tend to take place locally within these twinning regions, as indicated by red ellipse in the figure. In addition, serrated grain boundaries were found prevalent in this 20% rolled sample, which indicated the start of inhomogeneous DRX at grain boundaries. Furthermore, despite the fragmentation morphology caused by this kind of DRX in the 60% rolled Sample A, characteristic thin twins could still be clearly distinguished, as indicated by arrows in Fig. 3(a). It was thus reasonable to think that at initial strains twinning played a more important role in Sample A, which firstly divided original grains into smaller pieces, with the increase of strain, dislocation slip continuously proceeded and accumulated at original grain boundaries, producing cellular structure in these areas, which may provide preferred sites for the nucleation of DRX, as shown in Fig. 5(a). These fine recrystallized grains gradually consumed

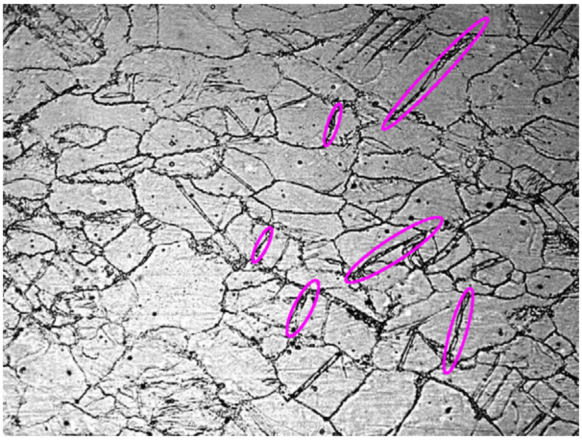

Fig. 4. The optical microstructure of Sample A after 20% rolling strain.

parent grains and resulted in fragmentation morphology. With continuous increase of rolling reduction, these new formed fine grains tend to be arranged around 30–40° to the rolling direction (RD), forming shearing bands. This process is illustrated in Fig. 6(a).

Both Samples B and C, however, accommodated much smaller strain (around 30%) before crack than Sample A in the rolling process. It was also found in both samples that shearing bands had already become distinct when the rolling reduction reached only 20%, compared with 60% in Sample A. As could be seen in Fig. 3(b), shearing bands were found to consist of fine recrystallized grains in Sample B, however twins were rarely detected. This mechanism could be explained with rotational recrystallization (RDRX) model introduced by Ion et al. [7]. As described above, DRX has a strong tendency to nucleate at original grain boundaries. Compared with those grains formed at boundaries which were parallel or perpendicular to the compression direction, recrystallized grains nucleating at boundaries parallel to the planes of maximum shear stress have much more probability to rotate to a new orientation more than 30° away from basal orientation. Strain could be easily accommodated in these soft oriented regions and it was expected that more and more grains would be formed at these inclined boundaries on further straining than other sites, producing ductile shearing bands inclined 30–45° to the rolling direction within primal equal-axial grains, as shown in Fig. 6(b).

It was a totally different phenomenon in Sample C that extensive twinning bands were found within original grains and these twins distorted towards the direction of shearing bands as they approached such bands with the increase of rolling reduction, as shown in Fig. 3(c). This absolutely implied that the formation of shearing band was concerned with mechanical twinning in this sample. Fig. 7 is an EBSD IQ (image quality) map of Sample C after 10% rolling strain, which based on the contrast of Kikuchi bands. Boundaries with the misorientation of $56^\circ \pm 5^\circ$ and $38^\circ \pm 5^\circ$ along $\langle 1\,1\,\bar{2}\,0\rangle$, which were expected for $\{1\,0\,\bar{1}\,1\}$ contraction twinning and $\{1\,0\,\bar{1}\,1\}$–$\{1\,0\,\bar{1}\,2\}$ double twinning, were highlighted in green and red respectively. Although the Kikuchi bands contrast was usually poor in these thin twinning regions, fragments of typical $\{10\bar{1}1\}$ and $\{10\bar{1}1\} - \{10\bar{1}2\}$ twinning orientation relationship could still be found at most of twin boundaries. Trace analyses also showed that the shape of thin twins invariably coincided well with $\{1\,0\,\bar{1}\,1\}$ trace in the IQ map, as shown in Fig. 7, it could thus be concluded that thin twins in Sample C belong to $\{1\,0\,\bar{1}\,1\}$ or $\{10\bar{1}1\} - \{10\bar{1}2\}$ type.

Similar shearing bands were observed in Mg–Th, Mg–Ce alloys which were cold-rolled with multiple passes reported by Couling et al. [3]. He insisted that these shearing bands evolved from $\{10\bar{1}1\} - \{10\bar{1}2\}$ twins, and the deviation from ideal direction of such twins, which was about 60° inclined to RD, could be attributed to the discreteness of perfect basal texture. Considering the inevitable increasing tendency of basal texture in the rolling process of magnesium alloys [1–3], such assumption would not be compellent. In our present work, however, it was observed that extensive twins were produced in original grains, which may act as impede of dislocation slip within original grains, as shown in Fig. 5(b). As a result dislocations piled up at theses twinning boundaries, causing rather high stress concentration, twinning distortion could occur and towards the direction of observed shearing band under macro stress. This process could be replayed in Fig. 6(c).

3.3. Influence of grain size and texture on the formation of shearing bands

Since Samples A and C has similar equal-axial microstructure with a mean grain size of 20 μm, the different texture may attribute to the different formation mechanism of shearing bands in these samples. It could be expected in the present work that sharper basal texture could promote mechanic twinning, making it the most important element in the formation of shearing bands, while weaker texture may facilitate DRX near original grain boundaries, producing fragmentation morphology and making DRX the most efficient ways in shearing bands formation.

However twinning was not involved in Sample B, which has the strongest basal texture among these samples. It was reasonable

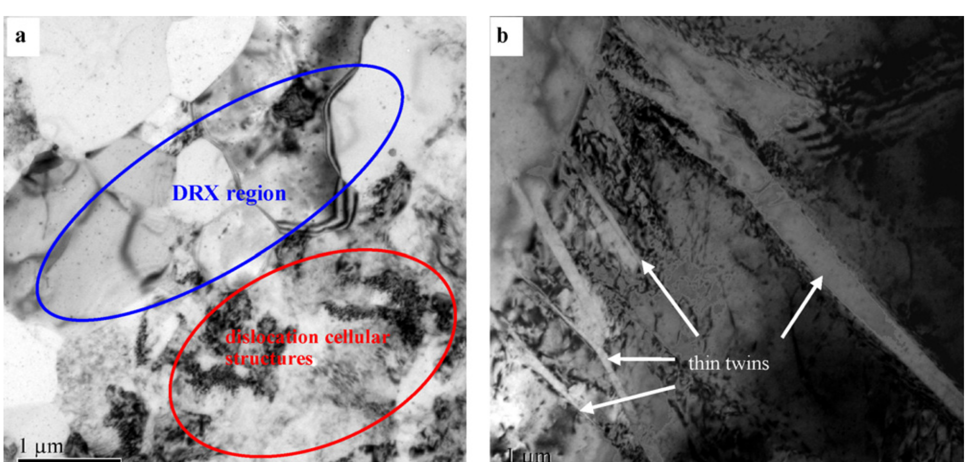

Fig. 5. (a) Dynamic recrystallized grains nucleating at original boundaries in Sample A and (b) dislocations accumulating at twinning boundaries in Sample C.

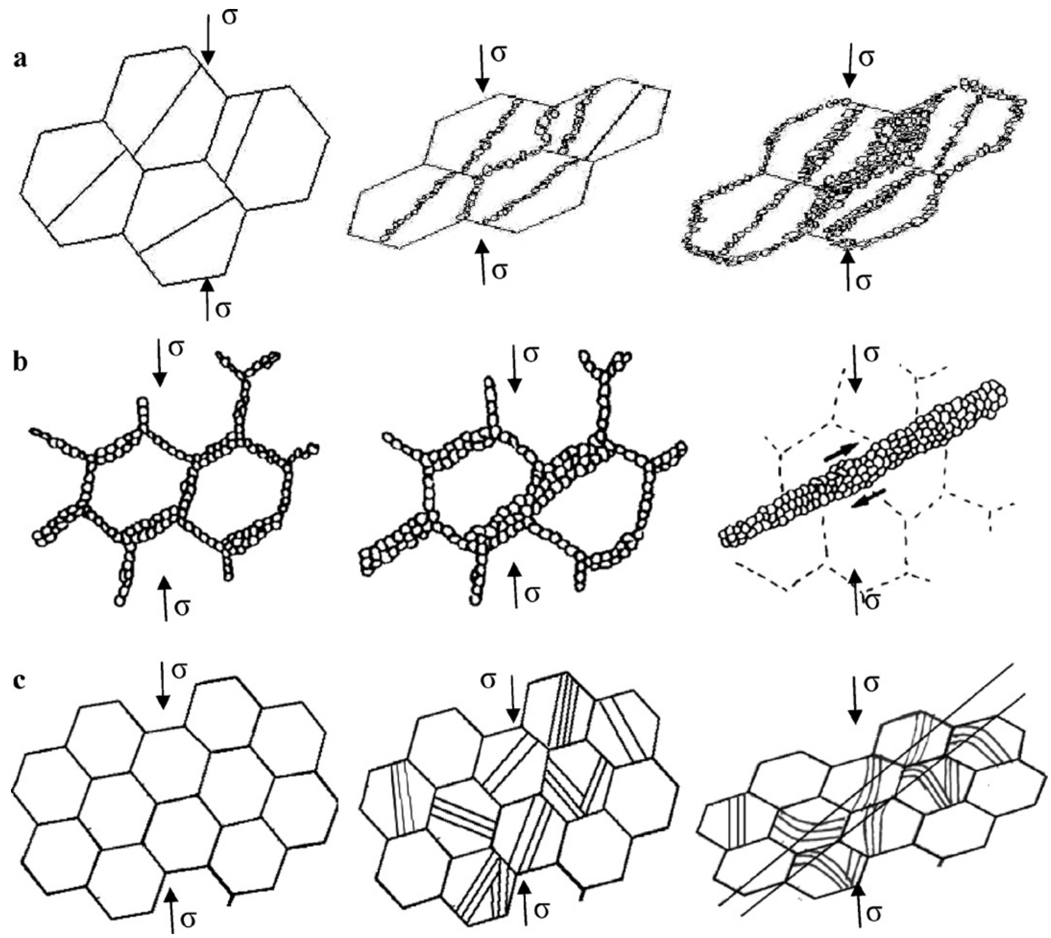

Fig. 6. Forming process of shearing bands in (a) Sample A, (b) Sample B and (c) Sample C.

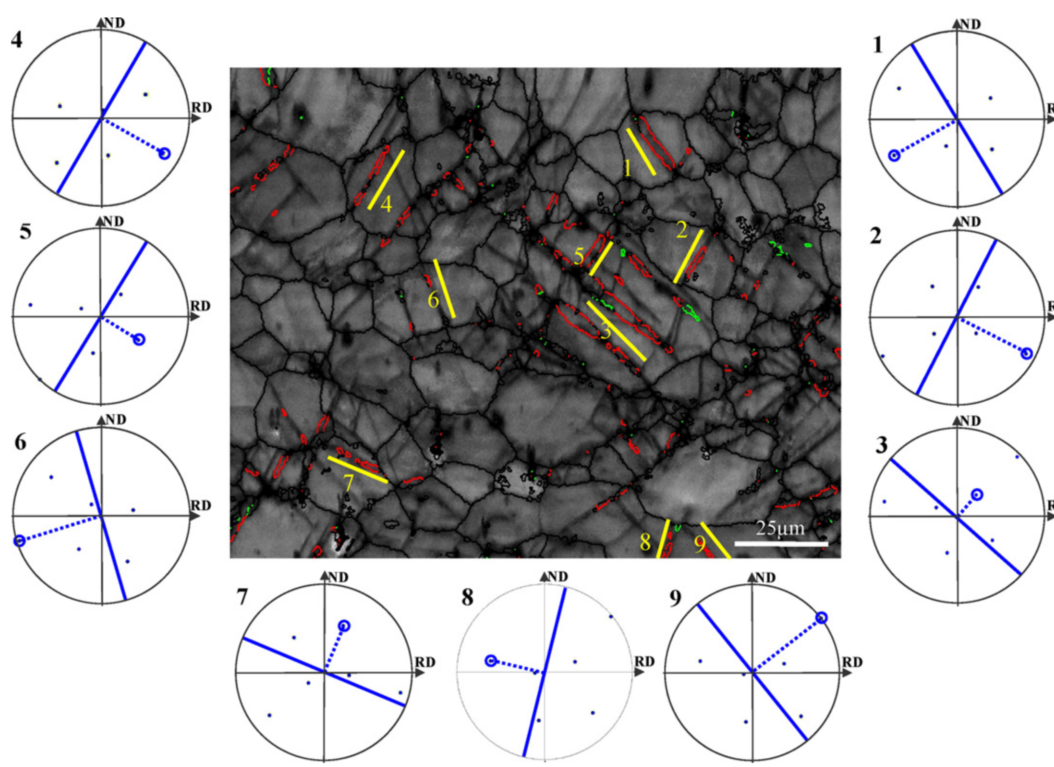

Fig. 7. $\{1\,0\,\bar{1}\,1\}$ trace analyses in EBSD IQ map of Sample C after 20% rolling strain.

to think that small grain size effectively arrested the activation of twinning in Sample B. This may be due to the easy activation of non-basal slip system under the influence of plastic compatibility stress of grain boundaries. Since the process of twinning was retarded by the small grain size effect [9], DRX was made the principal element in the formation of shearing bands in this alloy.

As clearly seen in the present work, shearing bands were inevitable in the rolling process of magnesium alloy, probably due to the macro-stress state. However, which mechanism dominates in the shearing bands formation depends on the initial state of materials, such as grain size and texture. Sharper basal texture could promote mechanic twinning, while weaker texture and small grain size may facilitate DRX, making them the most important element in the shearing bands formation.

4. Conclusion

Dynamic recrystallization and twinning are two major elements in the formation of shearing band in magnesium alloys. Which one dominates in the formation process depends on the grain size and basal texture of magnesium alloys. It could come to a conclusion that sharper texture will increase the influence of twining, while small size will promote the recrystallization in shearing bands formation.

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References

[1] J.A. del Valle, M.T. Pere-Prado, O.A. Ruano, Materials Science and Engineering A 355 (2003) 68–78.
[2] M.T. Perez-Prado, J.A. Del Valle, J.M. Contreras, O.A. Ruana, Scripta Materialia 50 (2004) 661–665.
[3] S.L. Couling, J.F. Pashak, L. Sturkey, Transaction of the ASM 51 (1958) 94–107.
[4] E.W. Kelley, W.F. Hosford, Transaction of the Metallurgical Society of AIME 242 (1968) 5–13.
[5] W.H. Hartt, R.E. Reedhill, Transaction of the Metallurgical Society of AIME 239 (1967) 1511–1517.
[6] B.C. Wonsiewcz, W.A. Backon, Transaction of the Metallurgical Society of AIME 239 (1967) 1422–1431.
[7] S.E. Ion, F.J. Humphreys, S.H. White, Acta Metallurgica 30 (1982) 1909–1919.
[8] Z. Zhang, M.P. Wang, N. Jiang, S.M. Li, Materials Science and Engineering A 527 (2010) 6467–6473.
[9] M.A. Meyers, O. Vohringer, V.A. Lubarda, Acta Materialia 49 (2001) 4025.