THE INFLUENCE OF COLD ROLLING PROCEDURES ON THE DEVELOPMENT OF DEFORMATION AND RECRYSTALLISATION TEXTURES

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Abstract

Studies of deformation and recrystallisation structures are usually carried out in the mid-layer of metal sheets, where a near homogenous plane strain deformation condition prevails during rolling. However, in the later years the awareness of the importance of surface textures and structures has increased due to demand for thinner, less material consuming products and better surface finish. In order to study the relevant surface-region-effects it is necessary that the laboratory rolling experiments simulate the industrial processes. Comparison of surface textures in industrially and experimentally cold rolled sheets have shown that both the development of the surface texture and recrystallised grain size are strongly dependent on the experimental cold rolling procedures. Parameters such as lubrication and rolling speed have to be controlled in order to simulate industrial cold rolling processes. However more strain hardening materials seems to be less sensitive to the shear deformation, probably due to different flow patterns.

Introduction

When working with twin roll cast (TRC) commercial purity aluminium, the surface becomes of special interest to study. A well known problem with TRC materials is the very coarse grained surface structure associated with recrystallisation annealing. In order to understand the mechanisms responsible for this phenomenon the effect of surface deformation mode becomes an important aspect. Previous investigations [1] have shown how the surface texture and structure can vary with experimental rolling parameters. This work is meant as a complementary work studying the effects of alloying content and starting texture, and giving a better description of the recrystallisation texture and structure. The investigations are therefore carried out with three different alloys, two alloys with almost identical chemical composition but different starting texture and two alloys with identical starting texture but different alloying composition.

Experimental procedure

Three twin roll cast AlFeSi alloys have been investigated. TRC1(0.03 wt%Si and 0.40 wt%Fe) cast on a Harvey/Hunter caster and TRC2(0.13 wt%Si and 0.45 wt%Fe) and TRC3(0.78 wt%Si and 0.53 wt%Fe) cast on a SCAL caster. The Harvey/Hunter caster has rolls with a diameter of 600 mm and a typical arc of contact of 30 mm while the SCAL caster has rolls with diameter of 900 mm and an arc of contact of 70 mm. The total caster rolling gap strains are for the SCAL and the Harvey/Hunter casters estimated to about 0.7 and 0.25 respectively. It has to be stated that the solidification rate and strain varies through the sheet thickness and consequently different micro-structures are found in the surface and mid-layer regions of the as cast sheets.

All three TRC materials were laboratory cold rolled at various rolling speeds to a strain of 3. The laboratory rolling was performed with and without lubricant(oil) for all grades. Thereafter all variants were given a simulated batch annealing, i.e. heated from room temperature to T=400°C at a rate of 100°C/hour, held there for 3 hours and then air cooled. A commercial grade of the TRC1 sheet has also been investigated. This TRC1 alloy was cold rolled to a strain of 2.2 by Hydro Aluminium`s rolling mill at Karmøy.

Macro textures were analyzed by pole figures and 3-dimensional ODFs, f(g). Here g denotes the orientation, given in the form of three Euler angles($\phi_1\Phi\phi_2$). The ODFs were produced from four incomplete pole figures ({111}, {200}, {220}, {311}), which were measured by means of an automatic Siemens D5000 X-ray texture goniometer and corrected with respect to background intensity and defocusing errors. They were calculated by the series expansion method[2] and ghost corrected according to the positivity method[3]. Pole figures and ghost corrected ODFs are presented in the form of iso-density lines normalised to random intensity in stereographic projection or in constant ϕ_2 sections in 5° steps in Euler space. Samples were taken from the surface and mid-layer of the sheets in the as cast, in the cold rolled and in the recrystallised state.

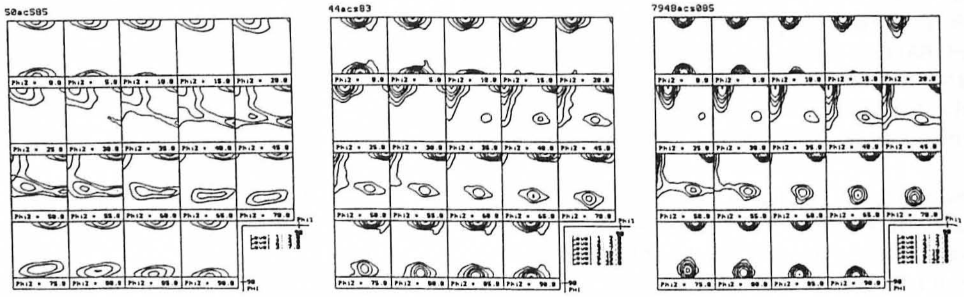
Micro textures and grain sizes were measured by the high sensitivity SINTEF EBSP system type J40 connected to a Jeol 6400 SEM microscope. Scans were done in surface layer (10-30 μm below the surface) of the longitudinal transverse section in the rolling direction in order to achieve grain sizes and orientation distributions. For every condition more than 200 grains was measured.

Results and discussion

The texture found in the surface of as cast sheets are shown in Figure 1. The shear texture{100}<110> is dominant for all alloys, but a significantly weaker texture is found in the TRC1 alloy which was exposed to the least strain through the rolling gap.

Effect of surface friction on rolling textures

The effect of lubrication in laboratory rolling is illustrated in Fig.2a-f. Rolling with high contact friction (i.e. dry rolls) resulted in a shear texture ({001}<110>) in the surface region as shown in Fig.2a-c while well lubricated rolls resulted in a relatively uniform β-fibre texture over the sheet thickness with the surface textures as given in Fig.2d-f. In the dry roll case the strength of the shear texture is influenced by the alloy composition and the rolling speed. Note that in the low alloyed AA1050-variants (TRC1 and TRC2) the initial as cast shear texture is further strengthened by cold rolling to a strain of $\varepsilon = 3$, an approximate doubling of the peak strength in both cases. The more highly alloyed TRC3 (AA8111-variant) behaved quite differently, in this case the initial shear texture was considerably weakened as a result of rolling, instead a more normal β-fibre texture developed during cold rolling (Fig.2c). Also the rolling speed affects the



TRC1 TRC2 TRC3

Figure 1. Texture in the surface of as cast TRC sheets.

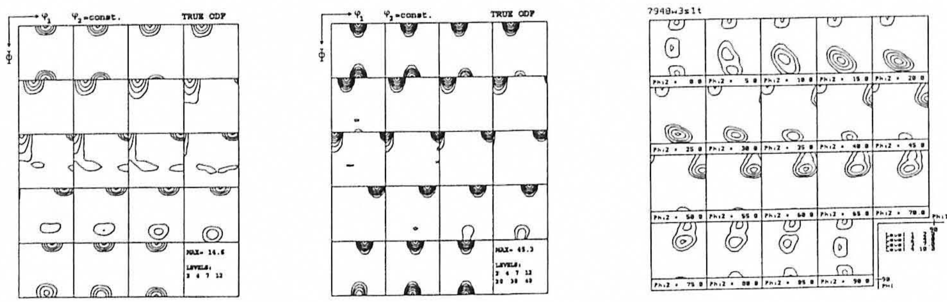
strength of the shear texture. This is illustrated in Fig.3 showing that by increasing the speed from about 4 m/min to 13 m/min the peak strength of the shear texture component decreased from about 40 to 12.

When performing the laboratory rolling with well lubricated rolls at a relatively high speed a β-fibre type texture developed also in the surface region (Fig.2d-f). This surface texture is little different from that found in the center(Fig.4). A slightly weaker Bs or stronger Cu component is found in the surface. The development of this strong Cu component is associated with the strong initial shear texture, see Ref. 4,5,6,7. During homogenous plane strain deformation the initial shear texture requires a relatively small rotation in order to end up in the stable Cu orientation. It is also found that the mid-sheet-texture is marginally affected by the surface friction as illustrated in Fig.4a and b. An important point, however, is that in the well-lubricated case laboratory rolling results in nearly the same surface texture as that found by rolling in a commercial mill (Fig.5a). Industrial rolling results in a slightly more uniform β-fibre as illustrated in Fig.5b and c.

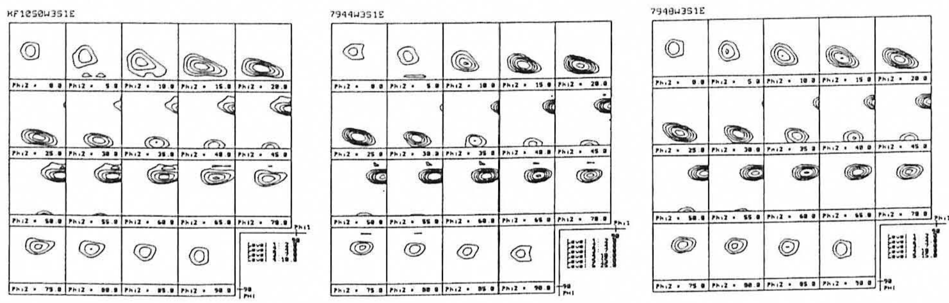
The effects due to alloy content and rolling speed, illustrated in Fig.1a-f and Fig. 3 respectively, can both be interpreted in terms of the effect of work hardening on the surface strain distribution. By increasing the alloy content or the strain rate, the material work hardens more strongly, and the deformation becomes more homogeneously distributed.

Recrystallisation structures and textures

The recrystallised grain sizes in the surface of the investigated variants are listed in Table I. These results show that the recrystallised grain size depends on both the cold rolling procedure and the surface deformation mode. A significant increase of the average grain size as well as in the spread in the size distribution is observed comparing the dry-rolls-case to the oiled-rolls-case. This is illustrated in Fig.6 which shows the grain size distribution in the surface of the TRC2 material cold rolled to a strain of 3 and given a simulated batch annealing for both the dry-rolls-case and the oiled-rolls-case. The difference in grain size between the dry-rolls-case to the oiled-rolls-case may be due either to differences in stored energy or to the absence of cube nuclei, i.e. very potential nuclei, in the first case, see also Ref. 8.

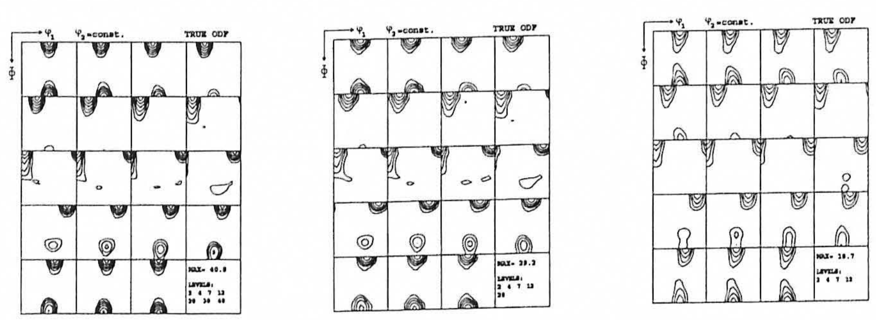


a) b) c)



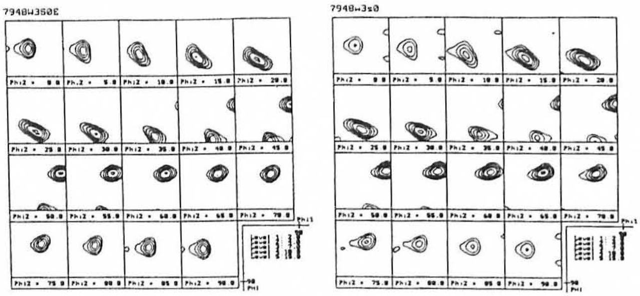
d) e) f)

Figure 2. The texture in the surface of the a) and d) TRC1, b) and e) TRC2 and c) and f) TRC3 materials cold rolled to strain of 3, a-c without lubricant and d-f with well lubricated rolls.



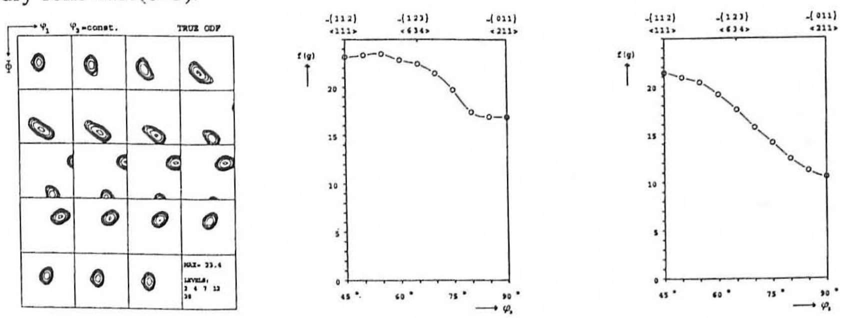
a) b) c)

Figure 3. The surface texture in TRC1 material cold rolled without lubricant with rolling speeds of a)3.8 m/min, b)9.4 m/min and c)12.6 m/min.



a) b)

Figure 4. The texture in the middle of the TRC3 material for a) the oiled-rolls-case and b) the dry-rolls-case(ε=3).



a) b) c)

Figure 5. a) The surface texture in the TRC1 material after industrial cold rolling (ε=2.2), b) the same texture presented in a β-fibre plot and c) the β-fibre in the middle of the TRC1 alloy cold rolled with lubricant (ε=2.2).

Table I The average grain size and largest grain size measured for the TRC materials

Alloy	Dry-rolls-case		Oiled-rolls-case		Industrially rolled	
	D_{mean}[μm]	D_{max}[μm]	D_{mean}[μm]	D_{max}[μm]	D_{mean}[μm]	D_{max}[μm]
TRC1	15.8	95.7	31.6	137	36.2	194
TRC2	37.5	323	87.2	472		
TRC3	11.5	104	16.1	191		

As was expected, the recrystallisation texture in the dry-rolls-case and the oiled-rolls-case are quite different, Fig.7a-f. As for the dry-rolls-case, Fig.7a-c, a retained shear texture and a rare texture component, a displaced S component reported by Hirsch [6], were found for the TRC1 and TRC2 grades. The TRC3 grade had a more common ND rotated cube component. Several

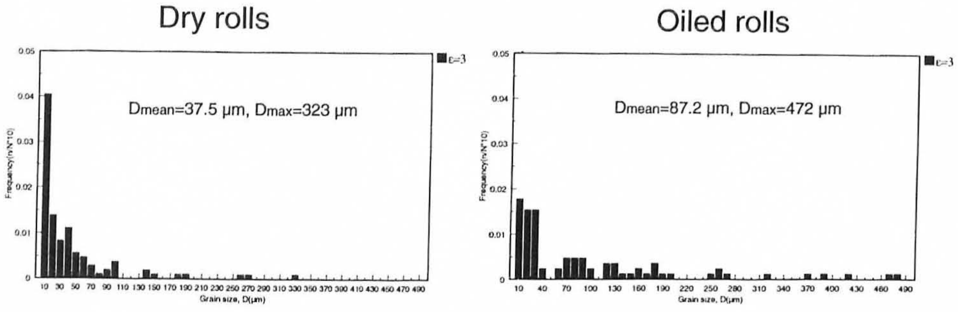


Figure 6. The grain size distribution in the surface of the TRC2 material for the dry-rolls-case and the oiled-rolls-case.

authors [7,9] have associated this texture with the presence of a strong Cu component and a very good 40°<111> relationship to this Cu component. However, in this case the strength of the Cu component is relatively weak (Fig.2e). On the other hand, in the TRC2 oiled-rolls-case the surface texture is characterised by a very strong Cu component (Fig.2a) while recrystallisation gives a strong cube texture, see also Ref.8.

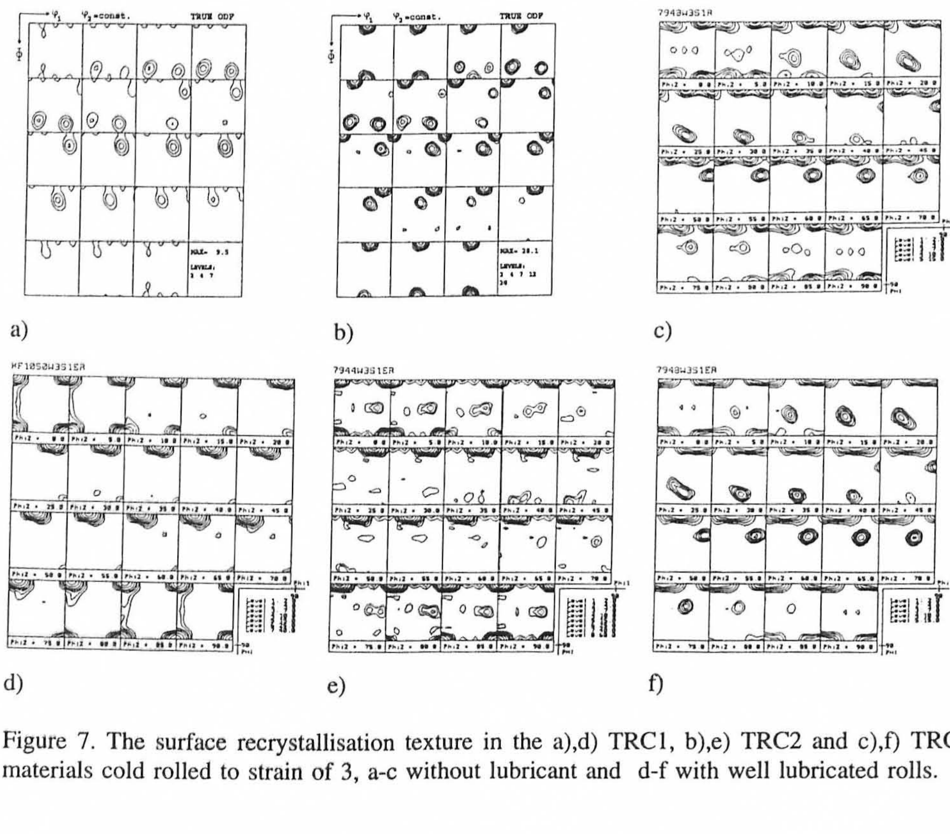
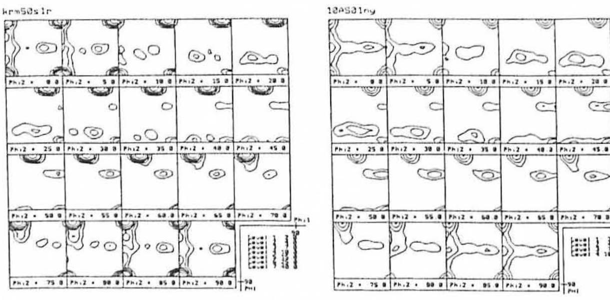
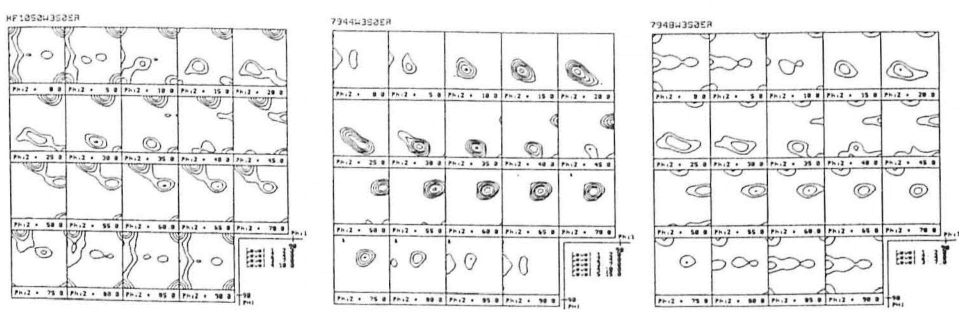


Figure 7. The surface recrystallisation texture in the a),d) TRC1, b),e) TRC2 and c),f) TRC3 materials cold rolled to strain of 3, a-c without lubricant and d-f with well lubricated rolls.



a) b)

Figure 8. The recrystallisation texture in the a) surface and b) middle of the industrially cold rolled TRC1 material,(ε=2.2).



a) b) c)

Figure 9. The recrystallisation textures in the middle of the a) TRC1, b) TRC2 and c) TRC3 materials, cold rolled with well lubricated rolls (ε=3).

The recrystallisation textures in the surface of the material rolled with well lubricated rolls, Fig.7d-f, were of a more familiar type. The cube orientation was the most important component, with an increasing intensity in the order TRC3, TRC1 and TRC2. A comparison with the industrially cold rolled variant of the TRC1 material, Fig.8a, illustrates that laboratory rolling and a commercial mill give sheet qualities which upon annealing both give strong cube textures.

The recrystallisation textures in the middle of material cold rolled with well lubricated rolls are shown in Fig.9a-c. The textures seemed to be equal in the mid-layer both for the oiled-rolls-case and the dry-rolls-case, with cube, P{110}<111> and a retained β-fibre for the TRC1 and TRC3 variants and only a retained β-fibre for the TRC2 variant. It should be noticed that the textures in the middle of the TRC1 material after cold rolling, both industrially (Fig.8b) and experimentally are more or less identical.

Conclusions

The shear texture in the surface of laboratory cold rolled sheets is a result of high friction and heterogenous strain distribution. This can be avoided by properly lubrication of the rolls and high rolling speed.

The microstructure and texture in the recrystallised material are also strongly dependent upon the rolling procedure. High friction, which promotes surface shear, results in a corresponding shear texture after recrystallisation, while the near homogenous plane strain surface deformation conditions of industrial rolling and well lubricated laboratory rolling give sheets which recrystallise into a strong cube texture.

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