Int J Mater Form (2009) Vol. 2 Suppl 1:891–894
DOI 10.1007/s12289-009-0625-3
© Springer/ESAFORM 2009

EFFECT OF ASYMMETRICAL ROLLING AND ANNEALING ON THE MECHANICAL RESPONSE OF AN AA1050-O SHEET

Fábio J. P. Simões[1*], Ricardo J. Alves de Sousa[2], José J. A. Grácio[2], Frédéric Barlat[2,3], Jeong Whan Yoon[2,4]

[1]CDR-SP - Centre for Rapid and Sustainable Product Development , Polytechnic Institute of Leiria, Leiria, Portugal.
[2]Department of Mechanical Engineering, Center for Mechanical Technology and Automation, University of Aveiro, 3810-193 Aveiro, Portugal.
[3]Graduate Institute of Ferrous Technology, Pohang University of Science and Technology, Pohang, South Korea.
[4]Alcoa, Inc., Alcoa Technical Center, 100 Technical Drive, Alcoa Center, PA 15069-0001, USA.

ABSTRACT: The asymmetrical rolling process has been studied as a way to promote intense shear deformations across the sheet thickness. These shear deformations may lead, given the proper conditions, to the development of shear texture components ({001}<110>, {111}<110> and {111}<112>) and also grain refinement. In this work, a 1050-O sheet is asymmetrically rolled and annealed. Conventional rolling is also performed, for comparison purposes. Shear texture components are obtained for the asymmetrically rolled specimens, and seem to be retained after annealing. Differences in mechanical response between asymmetrical and conventionally rolled specimens, as well as texture evolution after heat treatment processing are inferred based on experimental tensile and shear tests. Numerical simulations are used to help explain the differences found on experimental tests. It is proven that it is difficult to spread shear texture through the entire sheet thickness from a general asymmetric rolling process. Based on the fact, future research is discussed at closure.

KEYWORDS: asymmetrical rolling, crystallographic texture, mechanical response, grain refinement

LIST OF SYMBOLS

ε_w – strain on the sheet's transverse direction
ε_t – strain on the sheet's thickness direction.
r – plastic anisotropy ratio, or Lankford coefficient
r_{45} - plastic anisotropy ratio, or Lankford coefficient, obtained for a tensile test performed at 45° from rolling direction.

1 INTRODUCTION

The increasing environmental concerns regarding fuel efficiency and emissions have been leading to a weight reduction trend in transportation industries, especially aerospace and automotive. Aluminium alloys are one of the materials sought in order to achieve this purpose. These materials have the advantage of corrosion resistance and low density, but their reduced formability, when compared to steels, has prevented their use.

Formability is closely related to plastic anisotropy, or r value, defined as $r=\varepsilon_w/\varepsilon_t$. Higher r value means the sheet is able to deform with less thickness reduction, thus reducing necking and promoting formability. It is known that crystallographic texture is one of the main factors influencing plastic anisotropy [1,2]. Aluminium alloys are generally processed by rolling, originating β fiber textures – Brass ({011}<211>), S ({123}<634>) and Copper ({112}<111>). These textures usually evolve to Cube texture ({001}<100>) after recrystallization [3], causing r values to decrease, especially for r_{45}. {111}|| ND texture components, usually found on recrystallised steels, are said to be the most favourable for the formability of sheets. These texture components are difficult to be achieved in Al alloys using conventional processing methods, despite the fact some good results have been obtained in a particular condition [4]. On the other hand, imposing shear deformations has been shown to have the potential to generate some of those specific texture components, namely {001}<110>, {111}<110> and {111}<112> [5].

Asymmetrical rolling, in which different velocities are imposed to sheet surfaces, is one of the processes that can produce severe shear deformation. It can be achieved by using different roll diameters, different roll speeds, or still using a stationary block [6]. Choi *et al* [7] first used

---

*Corresponding author:
CDR-SP, INDEA, Campus 5,
Rua das Olhalvas, 2414-016 Leiria, Portugal
fabio.simoes@estg.ipleiria.pt

asymmetrical rolling to produce intense shear deformation throughout the entire sheet thickness, as opposed to superficial shear deformation already observed for conventional rolling , aiming to obtain the desired shear texture components.

Studies available provide significant background concerning rolling conditions and their impact on the formation of shear texture components ([5, 8-11]), The main motivation is to obtain a preferred texture, in order to improve *r* values and hence, formability. Shear texture components are shown to be retained even after heat treatments. This indicates the possibility of obtaining annealed sheets with increased *r* values, due to the presence of shear textures components, at the expense of the typical cube texture components. Moreover, a proper strength / formability combination can be provided by tuning the annealing conditions. However, no information on the actual mechanical response of asymmetrically rolled sheets is available, or even a comparison with conventionally rolled sheets in similar conditions. Therefore, the present study intends to evaluate the mechanical responses of asymmetrically rolled and annealed aluminium sheets, and compare those with conventionally rolled sheets. Asymmetrical and conventional rolling experiments are carried out and the results for mechanical response and texture evolution after rolling and annealing are discussed. Numerical assessments, aiming to evaluate the influence of pre-determined near – ideal textures on the mechanical responses of the material, are performed using a polycrystal plasticity model. Simulations are used to support a reasonable explanation for differences in mechanical response after the asymmetric rolling process. Finally, the benefits and possible improvements of the asymmetric rolling process are also discussed.

2 EXPERIMENTAL PROCEDURE

2.1 ROLLING

The initial material used in this work is a 1050-H111 8 mm thick sheet. It was first heat treated at 350 1C for 1 h, then rolled down to 0.65 mm by two different procedures, asymmetric (ASR) and conventional (CR) rolling, using a house-built rolling mill having two rolls of equal diameter (180 mm), each driven by a separate motor. Each roll velocity can be independently controlled by software, thus allowing different roll speeds.

The asymmetric rolling process was performed with no lubrication, in order to maximize the shear deformation. The upper / lower roll speed ratio was set to 15/11 rpm. and the specimen was rotated 180º about the TD axis after each rolling pass. For the sake of comparison, conventional rolling was carried out using 15/15 rpm roll speed ratio under a normal lubrication condition, keeping the same specimen position during every rolling pass. The thickness reduction imposed on each rolling pass (RPP), in both specimen sets (ASR and CR) was 50%. This RPP is a maximum value, since some variations occurred during rolling.

2.2 MECHANICAL TESTING

For mechanical evaluation, shear and tensile specimens were cut from the sheet and divided into two groups, for both asymmetric and conventional processes: as rolled and heat treated at 250ºC for 2h, followed by furnace cooling (HT). Both shear and tensile tests were performed along rolling direction. Surface and full thickness texture analyses were carried out to access texture gradients.

3 RESULTS

3.1 SHEAR TESTS

Figure 1 shows the shear test results for ASR and CR specimens. As rolled specimens show high yield stress and low elongation. It can be noticed only a slight difference concerning the mechanical responses of ASR and CR specimens. After HT, CR specimens show both higher yield and flow stresses. ASR specimens seem to show higher strain hardening rate after yielding.

3.2 TENSILE TESTS

Figure 2 shows the RD tensile tests of ASR and CR specimens. As rolled specimens display similar mechanical responses, though ASR specimens display slightly higher maximum stress. After HT, mechanical response is different among ASR and CR specimens. The most noticeable difference is the yield stress, which is more than two times greater for ASR specimens. Maximum stress is also greater, but uniform strain is lower.

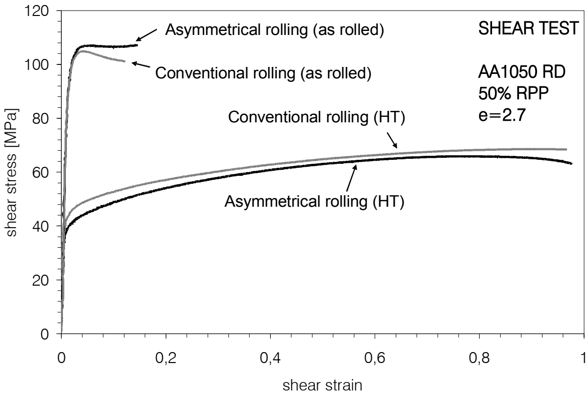


Figure 1: *RD Shear tests of CR and ASR specimens. As rolled and after HT.*

3.3 CRYSTALLOGRAPHIC TEXTURE

Surface texture measurements were performed with an X-ray goniometer. For full thickness texture, the samples were measured on the Rigaku Geigerflex Pole Figure Unit with Mo radiation and a Zr filter using the transmission method. This procedure was chosen since it allows accessing the material's average texture, providing an indirect way to identify texture gradients along the sheet thickness, when combined with surface texture measurements.

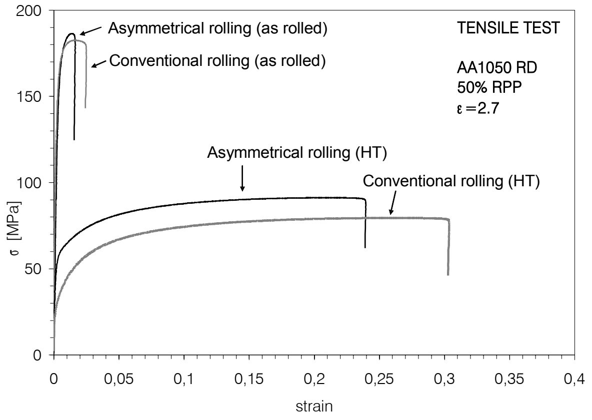


Figure 2: *RD Tensile tests of CR and ASR specimens. As rolled and after HT.*

Table 1 shows the surface texture evolution for ASR and CR specimens, measured in the two states, as rolled and HT. Shear texture components, especially the rotated Cube (shear1, {001} <110>) component, appear in all cases. Shear texture components seem to be stable even after annealing treatments. Only a slight difference in texture between CR and ASR specimens can be found: the larger spread observed on ASR specimens, especially toward other shear texture components, such as shear3 ({111} <110>). In order to complete the information provided by this figure, the through-thickness texture measurement was also performed, for the HT1 specimens.

Table 2 shows the ODF sections φ2=0º and φ2=45º obtained from the full thickness texture measurements (transmission method) of ASR and CR specimens after HT. The main difference between CR and ASR specimens is the relative amount of Cube component, higher on CR specimens. CR specimens also show a higher volume fraction of Brass and Goss orientations. Shear texture components are relatively weak in both specimens, but the ASR specimen seems to have slightly higher volume fraction of the shear4 component ({112} <110>). The shear1 ({001} <110>) component does not appear.

4 NUMERICAL ASSESSMENTS

In order to investigate the influence of shear texture components on the mechanical response of a 1050 aluminum sheet, numerical simulations using a polycrystal plasticity model were carried out. The model is based on the upper bound Taylor assumption and utilizes the notion of interacting slip systems and no rate sensitivity is considered. The implementation details can be found in [14].

A set of grains having crystal orientations around ideal components were subjected to tensile and simple shear boundary conditions. An orientation spread of + /- 15 degrees for each Euler angle was used to generate the grain orientation input data. The spread was generated in a simple linear way, since the main purpose of this procedure was to smooth the simulation curves.

Table 1: *Surface φ2=0º and φ2=45º ODF sections for ASR and CR specimens rolled with 50% RPP. Conditions: as rolled and after HT.*

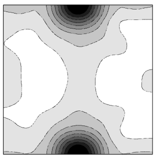
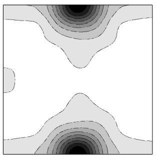
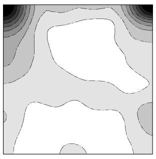
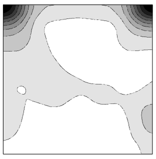
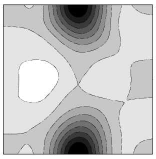
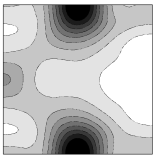
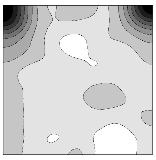
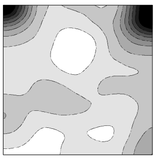
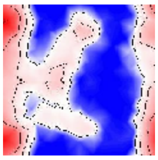
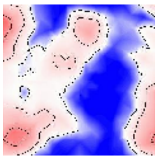
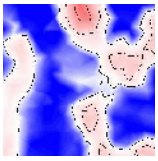
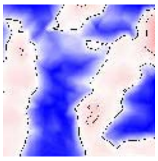
		as rolled	after HT
CR	φ2=0º		
	φ2=45º		
ASR	φ2=0º		
	φ2=45º		

Table 2: *Through thickness ODF's for ASR and CR specimens rolled using 50% RPP, after HT.*

	CR	ASR
φ2=0º		
φ2=45º		

The predicted mechanical response for each set of grains is depicted in Figure 3. In the case of the tensile solicitation, the shear 2 component presents the highest stress level, followed by shear 4 and copper. Cube displays the lowest stress response, as well as lower strain hardening. For simple shear, it is possible to observe that the Cube component provides the highest stress level, as well as very different strain hardening behaviour when compared to other orientations. Nevertheless, its response is not monotonic.

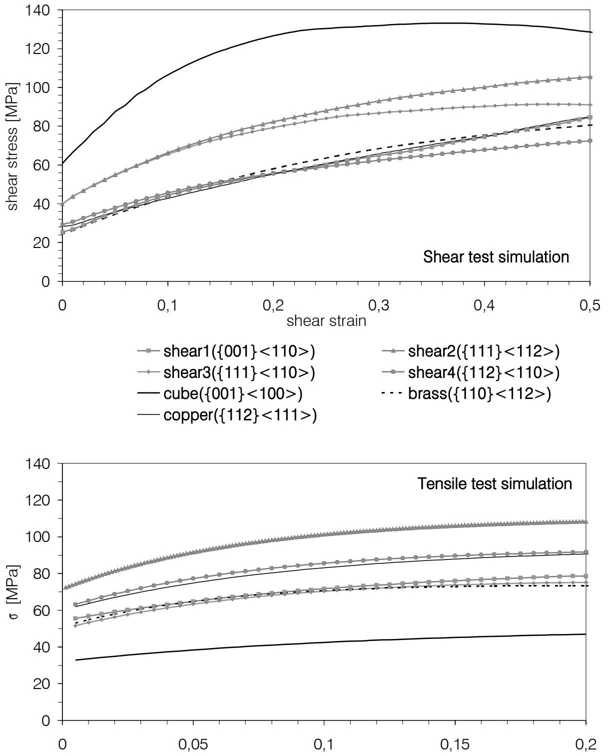


***Figure 3:** Simulation of shear and tensile response of a set of grains having ideal orientations.*

5 DISCUSSION

Figure 1 and Figure 2 are plots of, respectively, the shear and tensile response of asymmetrical and conventionally rolled specimens, after HT1 As observed before, the yield strength in tension of asymmetrically rolled sheets is higher than conventionally rolled sheets. Shear tests lead to a different conclusion: in this case, conventionally rolled sheets present higher shear stress when compared with asymmetrically rolled specimens. Taking into account the analysis of the simulated tensile and shear responses for ideal major orientation components (Figure 3), the difference in mechanical response can be explained by the different responses of individual texture components.

The higher volume fraction of the cube component on conventionally rolled specimens can be one of the factors responsible for their higher stress level, when compared to asymmetrically rolled ones. Simultaneously, the same high volume fraction of the cube component has the opposite effect on the tensile response of the material. Moreover, the shear components, and especially {111}<112> tend to raise the stress level for tensile test. In the case of shear solicitation, their influence is not as important as the cube component.

6 CONCLUSIONS

Asymmetric rolling is an important process for texture optimization towards improved anisotropy. In this work, it was found that ASR specimens present differences in mechanical response relatively to conventionally rolled specimens, for the processing and annealing conditions considered. However, shear texture components were not spread throughout the entire sheet thickness, and thus additional optimizations of the processing route must be studied, especially concerning the reversing of the rolling direction [5, 13].

REFERENCES

[1] Bunge, *Texture Analysis in Materials Science*, Butterworths, London, 1982.

[2] K.C. Chan, Earring in cup drawing of textured materials, *Scripta Metallurgica et Materialia* 32: 229–234, 1975.

[3] Doherty RD. Recrystallization and texture, *Progress in Materials Science* ;42(1–4):39–58, 1997.

[4] Engler O, Kim HC, Huh MY. Formation of {111} fibre texture in recrystallised aluminium sheet, *Materials Science and Technology,* 17:75–86, 2001.

[5] Kim S-H, Ryu J-H, Kim K-H, Lee DN, The evolution of deformation texture and grain refinement in asymmetrically rolled aluminum sheets, *Materials Science Research International,* 8(1):20–5, 2002.

[6] Huh MY, Lee KR, Engler O. Evolution of texture and strain states in AA 3004 sheet during rolling with a dead block. *International Journal of Plasticity,* 20(7):1183–97, 2004.

[7] Choi C-H, Kim K-H, Lee DN. The effect of shear texture development on the formability in rolled aluminum alloy sheets. *Materials Science Forum,* 273–275:391–6, 1998.

[8] Kim, K-H and Lee, DN. The deformation textures and lankford values of asymmetrically rolled aluminum alloy sheet. In 12th ICOTOM NRC-CNRC, 755-760, 1999.

[9] Kim, K-H and Lee, DN. Analysis of Deformation Textures of Asymmetrically Rolled Aluminum Sheets. *Acta Materialia* 49:2583–2595, 2001.

[10] Sakai, T, Hamada, S, Saito, Y. Improvement of the r-value in 5052 aluminum alloy sheets having through-thickness shear texture by 2-pass single-roll drive unidirectional shear rolling. *Scripta Materialia* 44:2569–2573, 2001.

[11] Jin, H, Lloyd, DJ. The reduction of planar anisotropy by texture modification through asymmetric rolling and annealing in AA5754. Materials Science and Engineering A 399(1-2):358-367, 2005.

[12] Alves de Sousa, RJ. Development of a General Purpose Nonlinear Solid-Shell Element and its Application to Anisotropic Sheet Forming Simulation. PhD Thesis, University of Aveiro, 2006.

[13] Lee, DN, Kim, K-H. Effects of asymmetric rolling parameters on texture development in aluminum sheets. In *Innovations in processing and manufacturing of sheet materials*, edited by Demeri, MY, Warrendale, PA, TMS, pages 219–235.