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MECHANICAL PROPERTIES OF MATERIAL AFTER ROLLING AND HEAT TREATMENT

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Abstract

In this work asymmetric and conventional rolled 1050 aluminum alloy sheet was investigated. Three different types of rolling were studied: conventional rolling, asymmetric rolling continues and asymmetric rolling reverse. The influence of crystallographic orientation of the grains and dislocation structure developed during plastic deformation on the mechanical behavior of the material was analyzed using X-ray diffraction and transmission electron microscopy. The visco-plastic self consistent model was used to quantify the effect of crystallographic texture on the stress-strain curves obtained in tensile tests performed on the rolled samples before and after heat treatment.

Keywords: *Asymmetric rolling, tensile strength, Lankford coefficient - R.*

INTRODUCTION

Stripe rolling can be either symmetric (or conventional) or asymmetric. When the linear velocities, radii and surface friction coefficients of upper and lower parts of working cylinders are equal, the rolling is conventional.

Asymmetrical rolling occur when any rolling parameters is distorted, for instance, difference in work rolls radii, rolls velocity or different friction parameters acting on both surfaces of the strip.

Differently from conventional rolling, in asymmetric rolling the neutral points do not have a position on a vertical line, they are shifted according the asymmetry conditions. Modeling the mechanical behavior of polycrystalline materials from the responses of their single crystals has been a challenging task. Polycrystals consist of grains which, due to mutual interaction, cannot deform freely as single crystals. The compatibility process of deformation between neighbor grains leads to the development of local accommodation stresses and to the differences between macroscopic and microscopic imposed strain/stress states.

Different mathematical models have been proposed to correlate the strain/stress in the polycrystal and in each grain.

The viscoplastic model assumes that the shear strain rate in each slip system ($\dot{\gamma}^s$) depends on the resolved shear stress (τ^s) by the power law 0 0:

$$\dot{\gamma}^s = \dot{\gamma}_c^s \left(\frac{\tau^s}{\tau_c^s} \right)^{\eta} \qquad (1)$$

where $\dot{\gamma}_c^s$ and τ_c^s are the reference shear rate and critical resolved shear stress on the system, respectively, and η is the inverse strain rate sensitivity coefficient of the material.

EXPOSITION

The asymmetric and conventional rolling of the material was performed on the house built device. The machine has identical upper and lower cylinders with diameter 180 mm, powered with independent DC electrical motors. The rotation speeds of the rolls were controlled by computer using dedicated software. In conventional rolling experiments was used 15 rpm for both rolling cylinders speed. The asymmetric rolling was carried out using 5rpm and 15rpm for, respectively, lower and upper rolls.

For all rolling experiments, the thickness reduction per pass was 15%, which corresponds (after 2, 4 and 6 passes) to 28%, 48% and 62% of total thickness reduction.

Conventional rolled (CR) samples were always rolled in the same direction. Asymmetric rolling was performed in to different sequences: asymmetric rolling continues (ASRC) and asymmetric rolling reverse (ASRR). In ASRC, the rolling direction (RD) was not changed. In ASRR, the samples were rotated 180o around RD after each pass. In order to keep high the value of friction coefficient between rolls and sample surfaces, no lubrication was used and the working surfaces of rolls were cleaned periodically.

The mechanical behavior in tensile test after rolling and heat treatment was tested using universal testing machine. For the three investigated orientations, higher value of flow stress before necking (which occurs at lower strains than for asymmetric rolled samples) are observed for conventional rolled samples. Moreover, the ASRC and ASRR samples present similar $\sigma - \varepsilon$ curves but different uniform strain values (Table 1).

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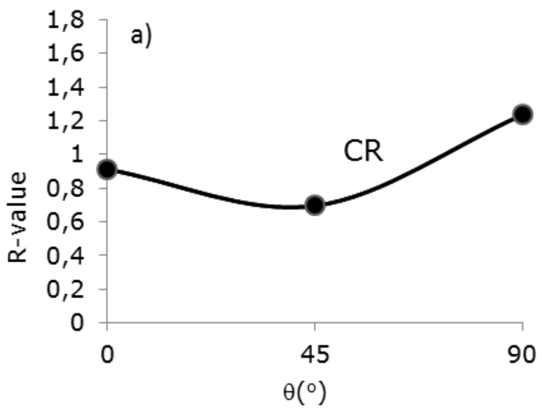
Table 1. Yield stress (σ_0), maximum stress ($\sigma_{\max}$) and uniform deformation (ε_u) at 0^o of rolled and heat treated samples

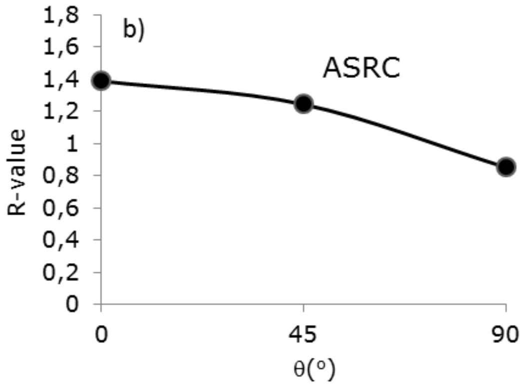
	Rolling	σ_0 (MPa)	$\sigma_{\max}$ (MPa)	ε_u
0^0	CR	55	100	0.16
	ASRC	43	103	0.22
	ASRR	45	95	0.18
45^0	CR	50	95	0.15
	ASRC	35	93	0.21
	ASRR	35	95	0.24
90^0	CR	55	102	0.16
	ASRC	40	104	0.23
	ASRR	38	103	0.26

Differences in the distribution of the strain along the length, width and thickness were also observed during the tensile test (Fig. 1 and

Table 2). Namely, the CR samples present highest average thickness reduction. The most favorable anisotropic strain behavior (highest normal $\overline{R}$ and lowest planar ΔR values) was presented by ASRC samples. More specifically, an increase of 34% and 57% was observed in the normal anisotropy coefficient ($\overline{R}$) value for ASRC, when compared with CR and initial material, respectively. Improvement, but with lower magnitude, of $\overline{R}$ was also measured for ASRR samples (10% and 29%). The planar anisotropy coefficient (ΔR) after ASRC was -0.12, which corresponds to a decrease in the absolute value of ΔR equal to 68% and 66%, respectively. An increase of this parameter was observed for ASRR (30% and 40%).

These results show that asymmetric rolling (in particular ASRC) can be used to improve the anisotropic behavior of aluminum sheets through the change of crystallographic orientation of the grains.





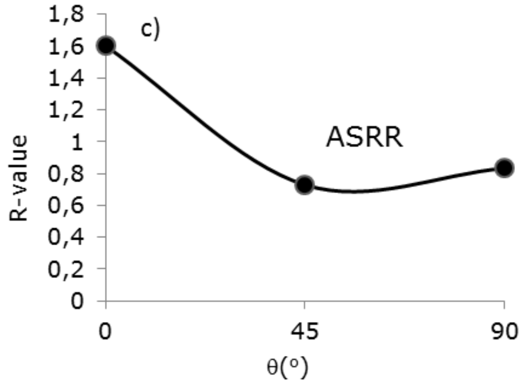


Fig. 1. *Anisotropy coefficient of rolled and heat treated samples a) CR; b) ASRC; and c) ASRR*

Table 2. Anisotropy coefficient of rolled and heat treated samples

Specimen	θ( )	R	Normal ($\overline{R}$)	Planar (ΔR)
CR	0	0.91	0.88	0.38
	45	0.70		
	90	1.23		
ASRC	0	1.39	1.18	-0.12
	45	1.24		
	90	0.85		
ASRR	0	1.60	0.97	0.49
	45	0.73		
	90	0.83		

Another important difference showed by $\sigma - \varepsilon$ curves is the strain hardening evolution during the tensile test. Indeed, all rolled samples present higher flow stress values (for the same strain amount) than the initial material. However, due to a reduction of the ε_u for all orientations and rolling types, this increase of flow stress did not result in any significant increase of $\sigma_{\max}$.

The influence of crystallographic texture for these strain hardening differences was investigated analyzing the of $\sigma - \varepsilon$ curves simulated using the equation (1) and <M> values extracted from pole figures measured for rolled and heat treated samples.

$$\sigma(\varepsilon,\theta) = \sigma(\varepsilon,\theta)_{ref} \frac{< M(\varepsilon,\theta) >}{< M(\varepsilon,\theta)_{ref} >}$$

The results from these calculations show that the differences in the initial crystal orientations after CR, ASRC and ASRR have almost no influence on the flow stress and cannot explain the observed differences.

The quality of the results computed with the VPSC model was evaluated for $\theta=0^o$ using two methods: comparing the <M> values calculated from the experimental textures before and after the tensile tests; and comparing the pole figures simulated with the model, and the texture measured after tensile test at 0^o. For both methods a good agreement is observed, showing that VPSC model can be used to analyze the influence of crystallographic texture on $\sigma - \varepsilon$ curves.

CONCLUSION

The asymmetric rolling of 1050 aluminum sheets was investigated. Three different types of rolling were studied: conventional rolling (CR), asymmetric rolling continues (ASRC) and asymmetric rolling reverse (ASRR). The influence of crystallographic orientation of the grains and the dislocation structure developed during the plastic deformation on the mechanical behavior of the material in uniaxial tensile test where analyzed using X-ray diffraction and transmission electron microscopy. The visco-plastic self consistent (VPSC) model was used to quantify the effect of crystallographic texture on the stress-strain curves obtained by tensile tests performed on the rolled samples before and after heat treatment.

After heat treatment, the asymmetric rolled samples showed an increase of normal anisotropy coefficient, when compared with conventional rolled or initial material. For ASRC, a decrease of planar anisotropy coefficient was observed. These results show that asymmetric rolling can be used to improve the formability of 1050 aluminum alloy sheets.

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