EVALUATION OF HIGHT PURITY ALUMINIUM AFTER ASYMMETRIC ROLLING AT AMBIENT AND CRYOGENIC TEMPERATURES

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Abstract
Ultrafine grained materials are capable of superplastic elongation at strain rates faster than those currently employed for commercial superplastic forming operations. However, such operations require the material in the form of thin sheets. Asymmetric rolling (ASR), as one of severe plastic deformation (SPD) methods, was used to make ultra-fined grain materials with enhanced performance. This work show effect of the deformation paths on micro-hardness and mechanical properties changing during asymmetric rolling of pure aluminium. In our case, the asymmetric condition was introduced by using different diameters with a ratio of upper and bottom roll 2,4. The thickness of samples was reduced about 20% - 40% at ambient temperature and at cryogenic temperature. Asymmetric rolling at cryogenic temperature (ASR-C) provides greater strength tensile properties than rolling at ambient temperature (ASR-A).

Keywords: pure aluminium; asymmetric rolling; microstructure; mechanical properties

1 Introduction

It is known that strength and toughness of metallic materials can be improved through decreasing grain size. Many efforts have been devoted to developing new techniques for grain refinement. Severe plastic deformation (SPD) has recently appeared as the most promising method. With SPD, the grain size of metallic materials is refined to the submicrometer range, or even to nanometer range [1-4].

SPD can also be attained through asymmetric rolling. Due to asymmetric rolling, we can also gain benefits such as lower pressure distribution between rolls, rolling force, rolling torque and very thin materials thickness with high rolling precision. Experiments were performed in which the asymmetric rolling was used in terms of deformation texture. In aluminium alloys can deformation texture improve the ratio of plastic deformation [6-9]. The orientation of components in surface layer at high frictional resistance between the sheet and the roll is affected by geometrical parameters defined as the ratio of the sheet thickness of the contact length between the sheet and rolls [10-12]. Asymmetric rolling can be realised in several ways:

- the angular speed of two working rolls are different; this can be achieved by different rolls diameters at the same speed rotations **Fig. 1a**)
- different speed rotations with same diameters of the rolls **Fig. 1b**)

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- by one driven roll **Fig. 1c**)
- the different friction of the rolls **Fig. 1d**)

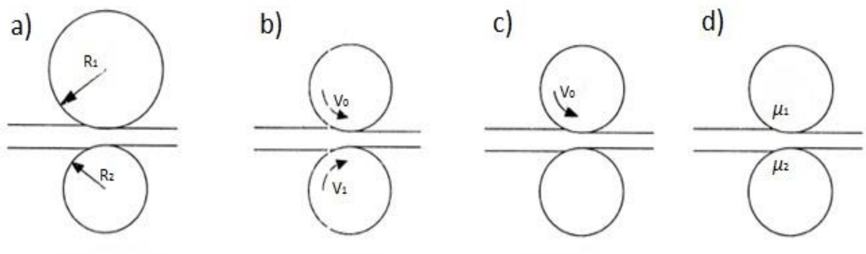

Fig. 1 Types of ASR:a) different rolls diameters; b) different rotations speed; c) one driven roll; d) different friction of the rolls [5]

Under these conditions, the material is submitted to an extra shear deformation in addition to compression deformation. With increased shear deformation as well as the compression, it has been suggested that high angle boundaries develop with increasing strain, and ultrafine grains are formed by continuous recrystallization [13-15].
Deformation at cryogenic temperature has emerged as a potential route to develop ultrafine grained (UFG) material with improved mechanical properties. The formation of UFG microstructures in various Al alloys has been investigated by many researchers [16-18] through various techniques such as asymmetric cryorolling, symmetric cryorolling, cryo-ECAP, etc. Yu et. al. [19] studied the effect of asymmetric cryorolling + ageing to produce UFG structure in Al 6061 and reported that both, tensile strength and ductility are increased due to the thickness effect and micro defect surrounding secondary phase particles. High strength is obtained to the development of UFG microstructure with high angle grain boundaries and high density of dislocations in the sample [19, 20].
Additional benefits of cryorolling over other SPD, is simple experimental setup and operation, high productivity, lower cost and less wastage. Increasing the number of passages of the cryorolled strip, is the density of dislocation increases to its highest steady state level, at maximum deformed conditions. Oversaturated dislocations rearrange themselves within deformed grains to develop dislocation substructures/subgrains, which subsequently produce ultrafine grained/nanocrystalline materials with reduced ductility, formability and strain hardening [21, 22].

2 Experimental material and methods

For asymmetric rolling was used as experimental material pure aluminium (99,999%). The samples were heat treated by homogenised annealing where the annealing temperature was 220°C within 30min. with air cooling. Microstructure after homogenised annealing have polyedric structure were average grain size was 50 μm.
Asymmetric rolling conditions were provided with different diameters of upper and lower roll with caliber ratio 2,4. Rolling mill has been modified such that the samples were kept in liquid nitrogen before and after rolling for the effective suppression of dynamic and postdynamic recovery. Before each passage, the samples were kept in liquid nitrogen for 5 minutes to achieve the homogenization of temperature throughout the sample.

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The samples were asymmetric rolled with thickness deformation ε = 20 and 40% in ambient and cryogenic temperature conditions. Static tensile test according to the standard EN ISO 6892-1 was made for determination of mechanical properties. Vickers micro-hardness was measured on the samples with the polished surface under a load of 981 mN for 5 seconds. Metallography analysis by SCAN microscope (TESCAN VEGA 3) was carried out to the definition of structural changes in depends on plastic deformation. Samples were prepared (polishing and etching) by Struers apparatus LectroPol-5. Polishing was performed at voltages 48V for a period of 30 seconds. For etching were voltages set at 7V for a period of 120 seconds. As electrolyte was used Electrolyte A2 l and A2 ll mixed together.

3 Result

The stress-strain curves in depend on thermal-deformation processing conditions are given in **Fig. 2**, were **Fig. 2a** is describing processing in ambient temperatures and **Fig. 2b** processing in cryogenic temperatures. From the measured data, it is evident that the UTS increases with the degree of deformation, on the other hand, elongation has an opposite progress. Elongation decreases with the higher degree of deformation from 21% of the initial state to 13% of 40% of deformation.

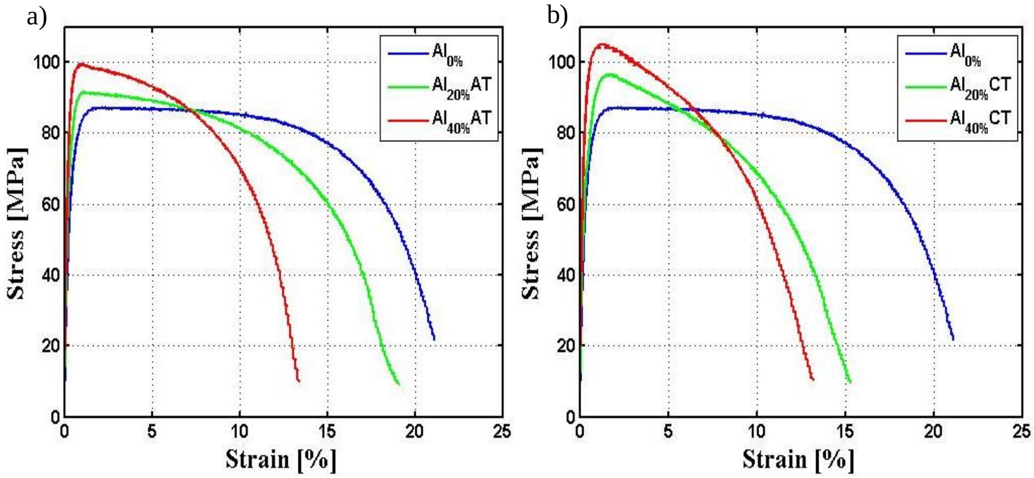

Fig. 2 Tensile diagram of pure aluminium for : a) ASR-A; b) ASR-C

Higher UTS was measured on samples which were rolled at cryogenic temperature. After ASR-C, UTS increased consistently up to 40% deformation at 104 MPa. After ASR-A was UTS lower at 98 MPa. From the **Fig. 3** it is obvious that yield strength is not effected by the type of asymmetric rolling because curves have approximately the same values.

Fig. 4 shows the average micro-hardness values of pure aluminium samples after ASR at the various deformation levels. The results show that higher values of micro-hardness are after ASR-C for both types of deformation. After 40% of deformation in cryo condition was average value of micro-hardness 37,04 HV, in ambient temperature it was 34 HV.

In order to investigate the uniformity of microstructure and its evolution during asymmetric rolling and asymmetric cryorolling, the microstructure of both degrees of deformation was observed. **Fig. 5** and **6** show the microstructure of pure aluminium deformed at 20% (**Fig. 5**) and

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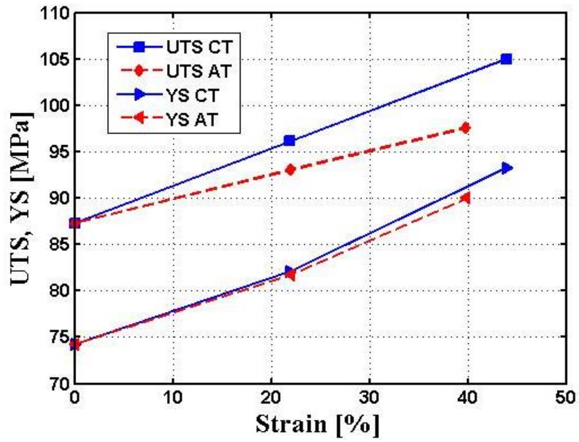

Fig. 3 Mechanical properties of pure aluminium after ASR

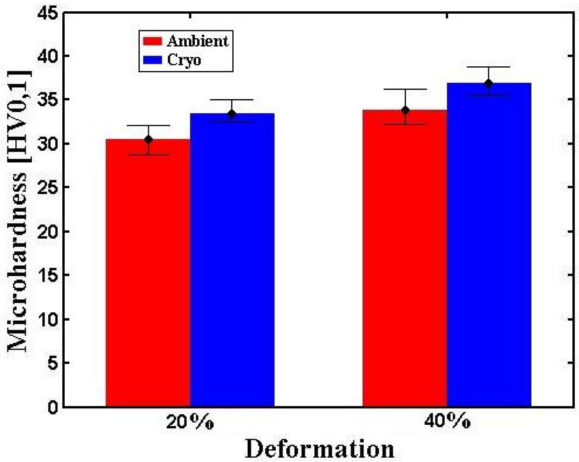

Fig. 4 Micro-hardness of pure aluminium after 20% and 40% deformation

40% (**Fig. 6**). The microstructure of 20% of deformation is slightly elongated. Also linearity is created. After ASR-C (**Fig. 5c**) microstructure became finer and more uniform than it is after ASR-A (**Fig. 5a**). Microstructure deformed at 40% by ASR-A (**Fig. 6a**) is more elongated, which is represented by an increase in grain size in the rolling direction up to 52,35 μm and a decrease in the normal direction to 33,33 μm. After ASR-C of pure aluminium is microstructure, even more, finer were grain size is 27,28 μm in the rolling direction and 14,29 μm in the normal direction. Average values of grain size of both directions are documented in **Tab. 1**.

Table 1 Average values of grain size after ASR

Deformation	ASR-A		ASR-C	
	rolling direction	normal direction	rolling direction	Normal direction
20%	≈42,9 μm	≈57,95 μm	≈23,07 μm	≈37,5 μm
40%	≈52,35 μm	≈33,33 μm	≈27,28 μm	≈14,29 μm

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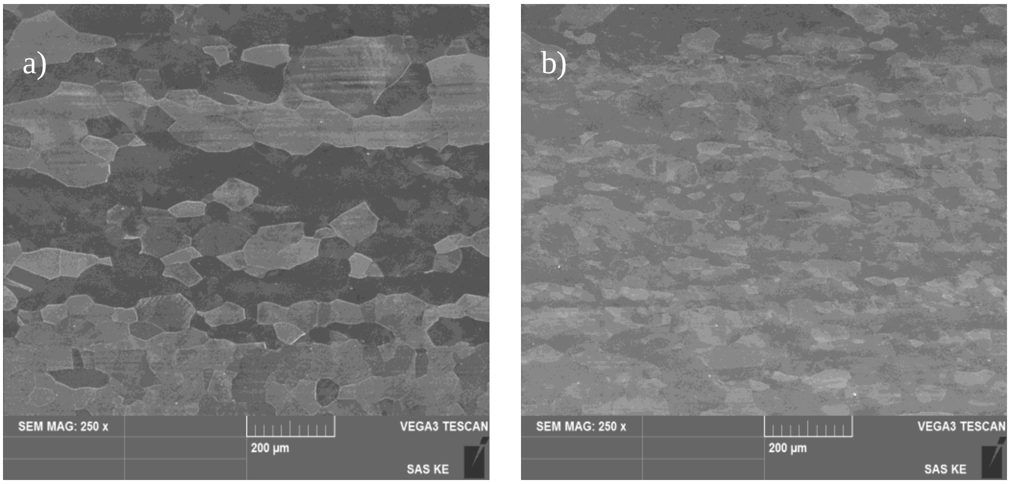

Fig. 5 Microstructure of 20% deformed pure aluminium after: a) ASR-A b) ASR-C

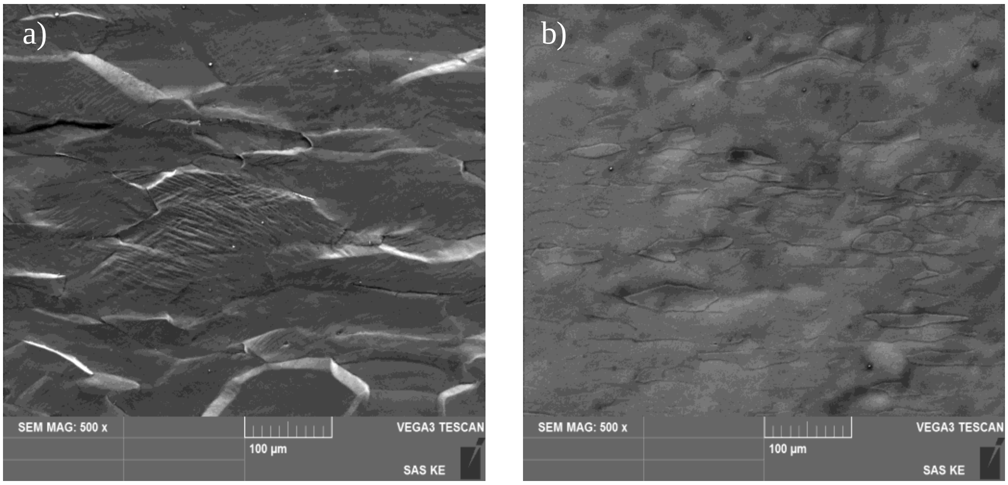

Fig. 6 Microstructure of 40% deformed pure aluminium after: a) ASR-A b) ASR-C

Conclusions

In this study was exploring the possibility of using asymmetric rolling to increase mechanical properties of pure aluminium as model material. Compared with the classic symmetric rolling, the asymmetric rolling can create an additional shear deformation and dramatically change the deformation stream of pure aluminium. Asymmetric cryorolling can increase the mechanical properties such as ultimate tensile strength and micro-hardness, compared with asymmetric rolling in ambient conditions. The progress of yield strength is almost identical, which means that the type of asymmetric rolling does not have a significant impact on it. Average values of micro-hardness for ASR-A was 34 HV, for ASR-C it was 37 HV. The metallographic analysis shows that ASR-C produces finer microstructure as ASR-A. With higher deformation degree the linearity is formed, and grains are more elongated in the rolling direction.

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