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Effect of prestrain on mechanical behavior of aluminum alloys

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Abstract. Sheet metal forming involves many times large plastic strain and strain path changes. It is well known that the plastic behavior of metals is strain path sensitive. In monotonic loading, the microstructure as well as the crystallographic texture evolve during deformation leading usually to a gradual material hardening that tends to saturate at large strains. Such evolution can be interrupted if a severe change of strain path occurs. The simplest way to change drastically the strain path is through reverse loading, namely, by loading the material in opposite direction to the previous one. In this case, the material behavior can show one or more characteristics, such as the Bauschinger effect, transient hardening, softening or hardening. This work investigated the effects of the prestrain on the mechanical response of the material subjected to reverse simple shear. The prestrain is produced by rolling, either symmetric or asymmetric, and different amounts of equivalent strain. Three routes of rolling are used, namely, symmetric, asymmetric continuous, and asymmetric reverse [1]. The Bauschinger effect slightly decreases with the prestrain increase for the initial material. After rolling, the Bauschinger effect is insensitive to the rolling route, and it is also insensitive to the amount of the rolling prestrain.

Introduction

Aluminum alloys are very good choices for many applications from the aerospace industry to packaging, due to their advantageous strength-to-weight ratio and their high recyclability without loss of their properties. However, the forming operation of aluminum alloys faces some challenges, due to the low formability at room temperature and high springback. The latter mainly due to the low stiffness compared with steels. It is also well known that a high influence on the mechanical behavior of aluminum alloys subject to plastic deformation is related to their texture. An easy way to change the texture of the material is by rolling. Moreover, asymmetric rolling allows the creation of different texture components by controlling the rolling route. Another important factor during forming operation is the strain path changes. An abrupt change in strain path can cause a Bauschinger effect, a transient behavior, permanent softening, or higher hardening rate compared to monotonic loading. The effects of strain path changes were extensively studied over the years by experimental and numerical methods [2-8]. Moreover, many researchers stated that the Bauschinger effect is associated with the amplitude of springback and is an indispensable parameter that should be considered for an accurate prediction of springback [9,10]. The aim of this study is to analyze the influence of the amount of prestrain in the Bauschinger parameter for a large range of values.

Material and Experimental methods

Material.

The material used in this study is an aluminum-silicon-magnesium alloy AA6022-T4 with an initial thickness of 2 mm and chemical composition given in Table 1. The material has a strong cube texture typical for recrystallized aluminum sheets as can be seen in Fig. 1. A complete characterization of this material can be found in [1,11].

Table 1. Chemical composition of the material as-received wt. %.

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others	Al
0.8-1.5	0.05-02	0.01-0.11	0.02-0.1	0.45-0.7	0.1	0.25	0.15	0.15	Balance

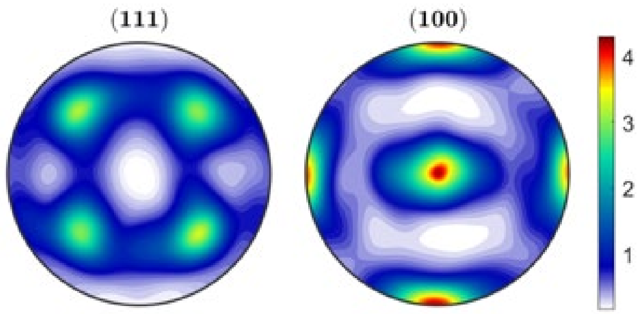

Fig. 1. Pole figures {111},{100} of the initial material.

Asymmetric rolling.

The in-house asymmetric rolling mill presented in Fig. 2 was used for rolling. The diameters of the rolls are 180 mm and the length is 300 mm. Detailed description of this mill can be found in [1]. The asymmetry was introduced by imposing different speeds for the upper and bottom rolls of the mill. For symmetric rolling, the angular speed of both rolls was 15 rpm. For asymmetric rolling, a ratio of 1.36 of the rolls' speeds was produced by the angular speeds of 15 rpm and 11 rpm.

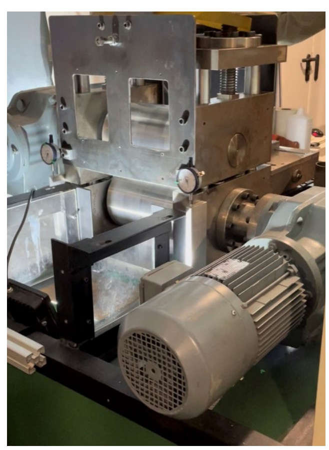

Fig. 2. Asymmetric rolling mill.

The total thickness reduction was 50%, and was obtained in 4 passes, with a thickness reduction of 15% per pass. Regarding asymmetric rolling, two types of strain paths were produced by the rotation of the sheet between two subsequent passes. Namely, (1) asymmetric continuous (ARC) when no rotation of the sheet occurred between two subsequent passes, and (2) asymmetric reverse route (ARR) when rotation of 180º around the rolling direction (RD) occurred between two subsequent passes. The rolling route produces a forward or a reverse shear deformation in sheet thickness, corresponding to ARC and ARR respectively. An illustration of the rolling route is presented in Fig. 3.

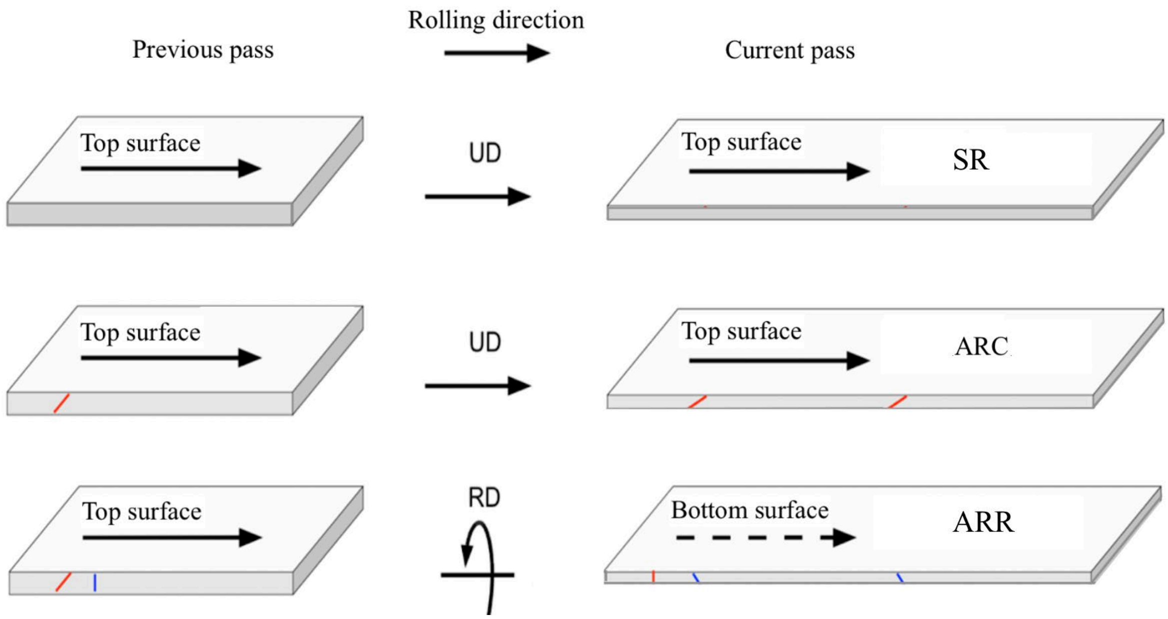

Fig. 3. Rolling routes: SR - symmetric rolling, ARC - asymmetric rolling continuous, ARR - asymmetric rolling reverse.

Simple shear test.

The study of the Bauschinger effect on sheet metals by tension-compression test is difficult due to the buckling that occurs during compression. Thus, to avoid buckling, an easy way is to promote reverse loading in simple shear tests. The as-received material was tested in simple shear and reverse loading at 10%, 20% and 30% shear prestrain. The rolled material was tested in reverse shear for a shear prestrain nearby 10%. The in-house simple shear device was used for these tests. The sample geometry is a rectangle with 34x13 [mm^2], corresponding to length and width, respectively. The thickness is variable according to the rolling. The shear deformation area is 34x3 [mm^2]. The strain measurements were made by Digital Image Correlation using the GOM system and the software ARAMIS 5M. The setup of the simple shear test can be seen in Fig. 4.

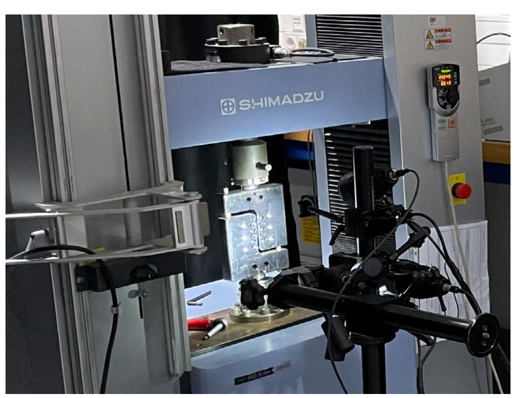

Fig. 4. Setup of the simple shear test.

Bauschinger Parameter

The Bauschinger coefficient was calculated as proposed by Hou et al. [12]

$$\beta = \frac{\tau_{p2}}{\tau_{p1}} \tag{1}$$

Where τ_{p1} and τ_{p2}, denoting the flow stress at the end of prestrain and the yield stress of reloading respectively, are schematically represented in Fig 5.

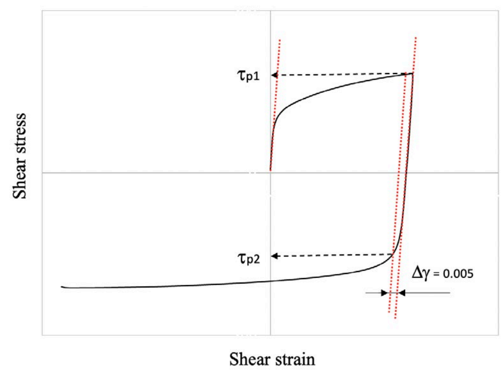

Fig. 5. Schematic representation of Bauschinger parameter calculation.

Thus, if β = 1, means that Bauschinger effect does not occur. If β decreases, means that the Bauschinger effect is more pronounced and opposite if β increases.

Results and Discussion

Initial material.

The initial material was tested in reverse shear for three amounts of prestrain, namely 10%, 20% and 30 % shear strain. The results are presented in Fig. 6 and are in agreement with data existing in the literature [3]. Namely, it can be noticed the existence of the Bauschinger effect, no plateau and a higher strain hardening that led to an overshooting of the monotonic shear stress-shear strain curve.

It can be observed from Fig. 7 that the Bauschinger coefficient increases with the increase of pre-strain amount for initial material, which means that the Bauschinger effect is reduced with the increase of pre-strain.

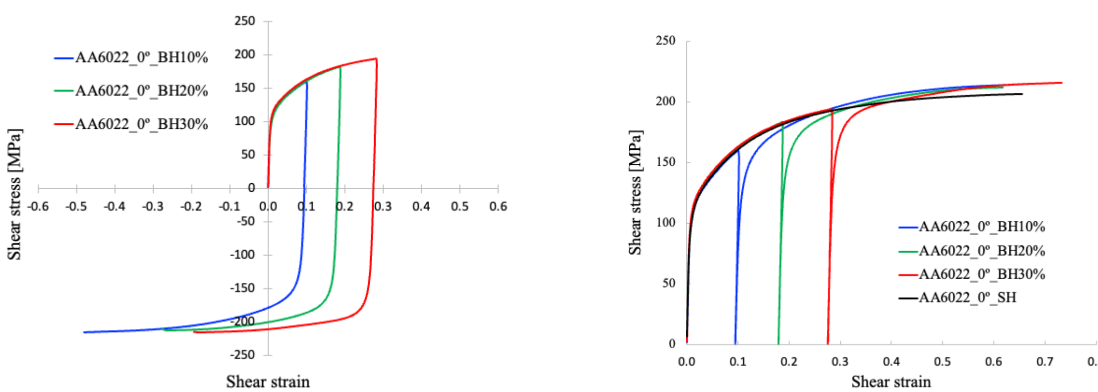

Fig. 6. Simple shear and reverse shear of AA6022-T4: a) reverse shear; b) monotonic and revere shear transformed to the first quadrant.

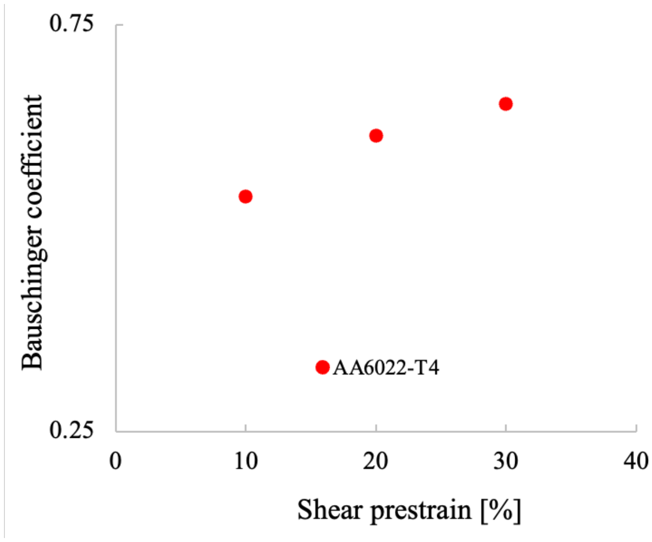

Fig. 7. Evolution of Bauschinger coefficient with the prestrain for material before rolling.

After rolling.

The shear stress-shear strain curves after each pass of rolling are presented in Fig. 8. It can be observed that after each pass the curves are superimposed which means that the material behavior is not affected by the rolling route. After rolling, the material has the same response as the initial material when submitted to reverse loading, showing the Bauschinger effect without plateau. It is worth to mention that the difference in the prestrain deformation is introduced by the difficulty in controlling the test when DIC is used. The Bauschinger coefficient seems to stabilize with the increase of prestrain as can be seen in Fig. 9, where the β is plotted versus equivalent strain corresponding to prestrain, and it is produced by shear or rolling + shear. The values after rolling are very close to the one obtained for the initial material after 30% prestrain. This trend is observed for all three routes. A very small difference in β between the rolling routes can be observed with the lowest value corresponding to ARC and the highest to ARR. The material processed by SR has the lowest variation of β between the rolling passes, only 2%, while for ARC and ARR this variation is about 5% and 4%, respectively. The saturation of the Bauschinger effect observed in figure 9 is related to the dislocation density. In theory, the short-term and long-term Bauschinger effects are caused by the dislocation in the pile-up that can travel backwards upon reversal loading. Their reverse motion is assisted by the back-stress, leading to a drop in the flow stress. Those dislocations also tend to recombine with other dislocations, leading to a lower dislocation hardening level. After a large accumulated strain, more dislocation will be pinned in the forest structures and thus become non-reversible, leading to a less significant Bauschinger effect.

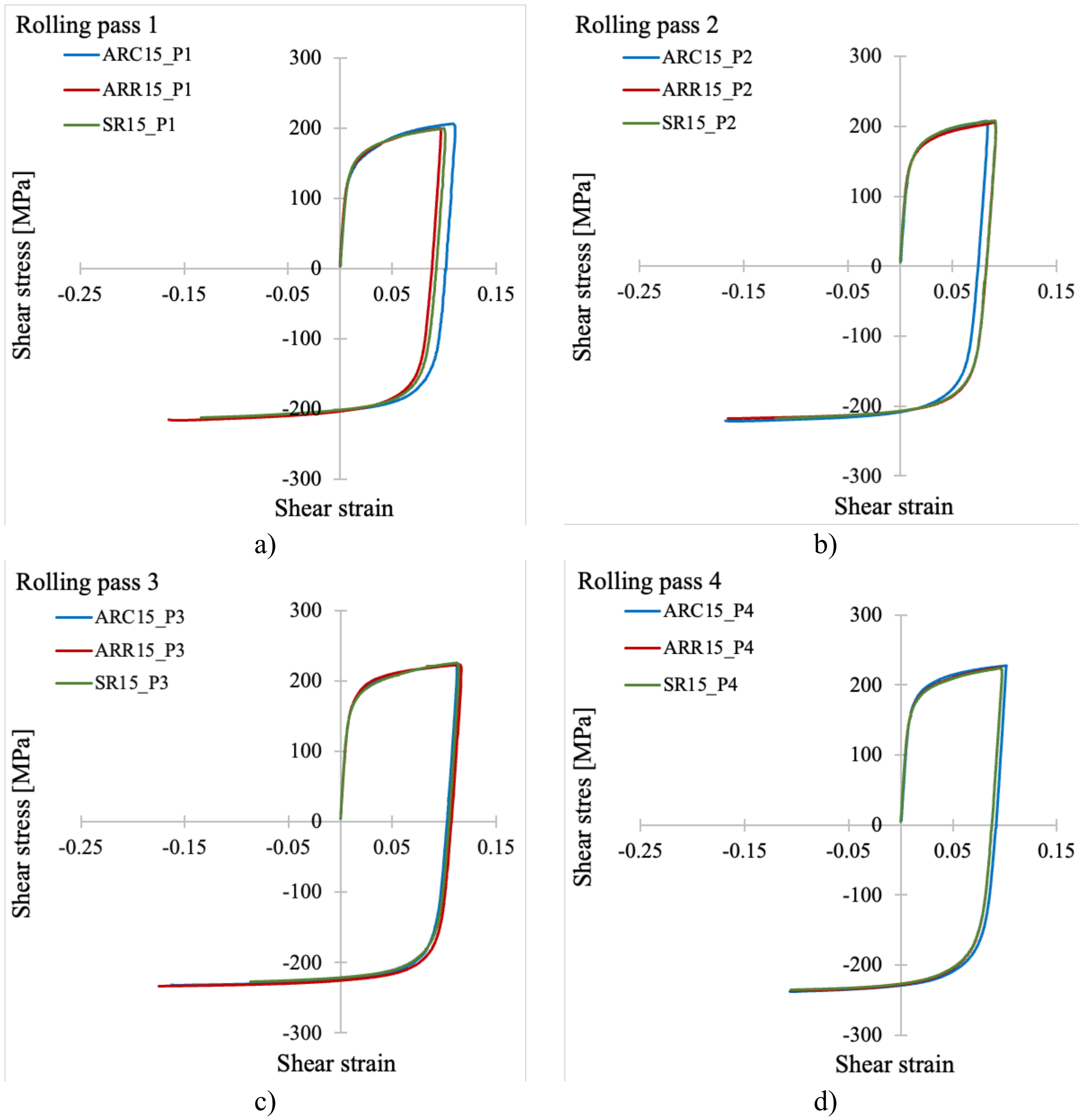

Fig. 8. Shear stress-shear strain after ARC, ARR and SR: a) pass 1; b) pass 2; c) pass 3 and d) pass 4.

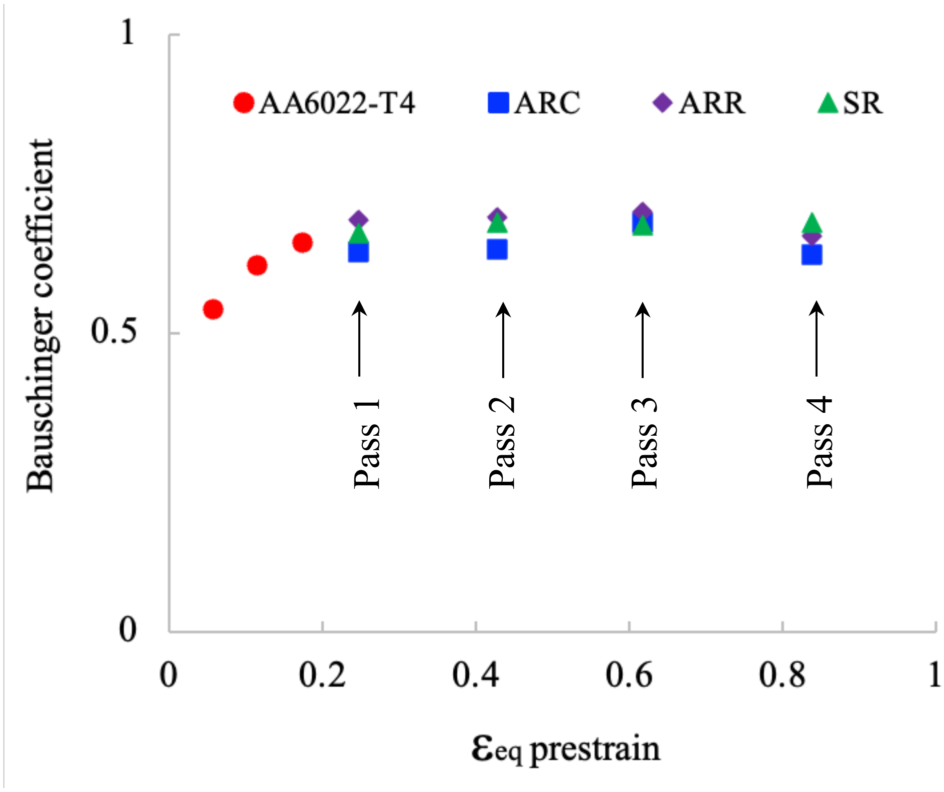

Fig. 9. Evolution of Bauschinger parameter with rolling pass.

Summary

The dependence of the Bauschinger effect on the prestrain quantity was investigated by reverse simple shear test. A large equivalent plastic prestrain was produced by three types of rolling, i.e. symmetric, asymmetric continuous, and asymmetric reverse, rolled in 4 passes. The Bauschinger effect seems to be almost insensitive to the rolling route. The results show an initial increase of the Bauschinger parameter with the increase of prestrain amount followed by a stabilization after approximately 20% equivalent prestrain. These results suggest that the contribution of the Bauschinger effect determined for low prestrain level can be used for the prediction of springback even for large plastic deformation. Nevertheless, it is worth mentioning that other sources of springback should be considered since recent results obtained in V-bending and U-bending tests for the material processed by the same conditions show that the springback after rolling increases.

Acknowledgments

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