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STRAIN STATE EFFECT ON THE SURFACE RELIEF APPEARANCE IN THE DEFORMED Al-Mg ALLOY SHEETS

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ABSTRACT
The Al-Mg alloy sheets containing 6.8 wt.% Mg were tested under different stretching conditions (uniaxial, plain-strain and balanced biaxial) in order to make some surface roughness created by type "A" or type "B" surface markings appearance. The presented results indicate that the stretcher-strain surface appearance was influenced in a great deal by changing the stress state, i.e. the stretching strain path. The harmful stretcher-strain lines appearance is mostly related to dynamic strain aging (DSA) and it can be suppressed in equibiaxial stretching conditions.
Keywords: Al-Mg alloys, surface markings, strain state.

1. INTRODUCTION
Considerable efforts devoted to introduce aluminum alloys in the manufacturing of auto bodies [1-4] with the basic motivation of weight saving, ensuring fuel consumption and pollution reduction, or even improvement of certain safety and driving performances [4].
The Al-Mg alloys have favorable formability performances due to the effective solution hardening and high strain hardening ability, which enable a stable behavior in the complex forming operations [5,6]. However, the solute Mg atoms can induce also some harmful surface appearance at the auto body parts. Namely, the dynamic strain aging (DSA) developed due to the dislocation reactions with solute Mg atoms, is the main source of unstable plastic flow during stretching of Al-Mg alloy sheets. This unstable flow in alloys with more than 2% magnesium [7] which appeared in uniaxial tension is known as a yield point or Lüders elongation.
This inhomogeneous deformation occurs within the first few percent of straining when the stress is constant. After that – at higher strains, the DSA is manifested as a discontinuous or serrated yielding. Both Lüdering and serrated yielding during uniaxial stretching was thought to cause the appearance of specific surface relief known as "A" ("flamboyant") and "B" ("parallel bands") type surface markings, respectively [8]. Those markings and the appropriate parts of the flow curves are shown in Fig. 1. The "A" stretcher markings are the most harmful as the appropriate roughness valleys developed within the first percent of straining can be more than 100 μm in depth [8]. The roughness created by "B" markings appearance is rather limited to 10 μm [9]. Thus, the "A" type stretcher markings are the main problem which reduces the application of a high strength Al-Mg alloy sheets and restricts its production to the inner panels of car bodies.

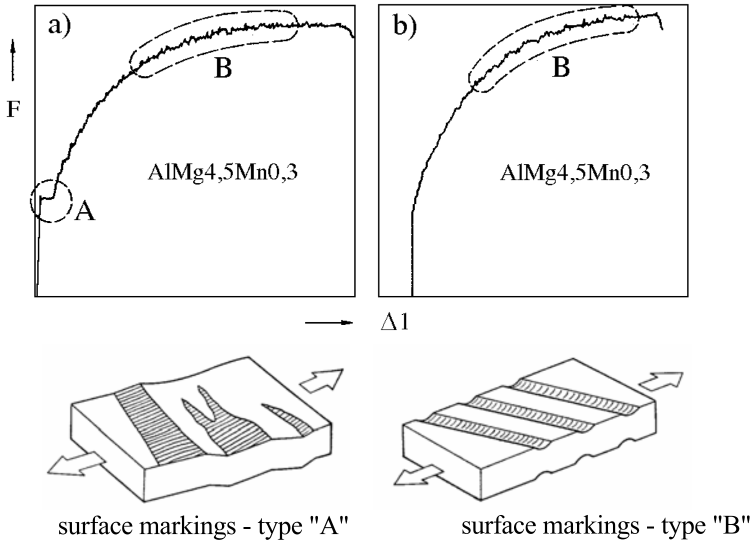


Figure 1. Uniaxial stress-strain curves with Lüders elongation (a) or only with serrated yielding range (b) and the sketches of appropriate surface markings – type "A" and "B".

As the auto body parts are produced by complex press forming operations, the strain path influence on the surface appearance is of the great importance. Fig. 2 shows a specific surface relief effects at a fender made in "ZASTAVA" car. The stretcher-strain lines are not uniform over the whole fender, but it seems dependent on the imposed stress state (the biaxiality degree varying over the fender during the pressing operation).

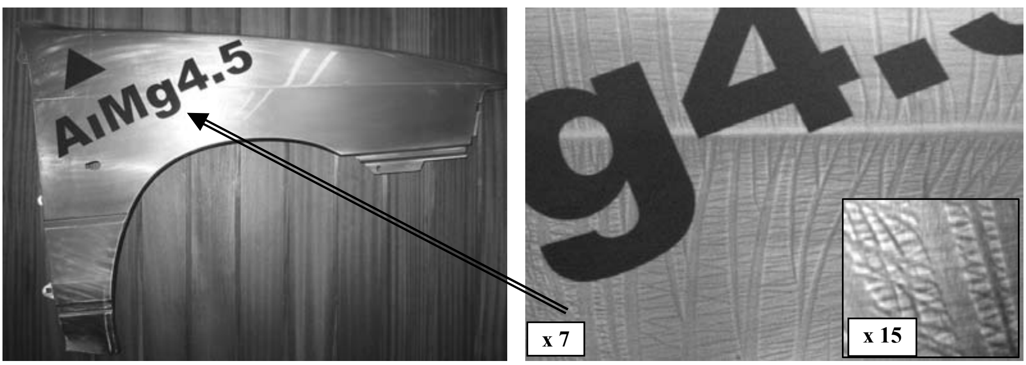


Figure 2. Macro photographs of the surface appearance at the fender made of AA5182 type alloy sheet. [10]

The objective of this work is considering the induced surface roughness development on the applied stress states or the produced specific strain paths in the range of uniaxial and equibiaxial stretching of highly alloyed Al-Mg sheet material.

2. EXPERIMENTAL

Material. The as-received Al-Mg sheet was 3.0mm thick, in fully annealed condition, with a chemical composition given in Table 1. The material was subsequently 70% cold rolled (to 0.9 mm) and annealed at 320°C for 3h in an inert gas atmosphere

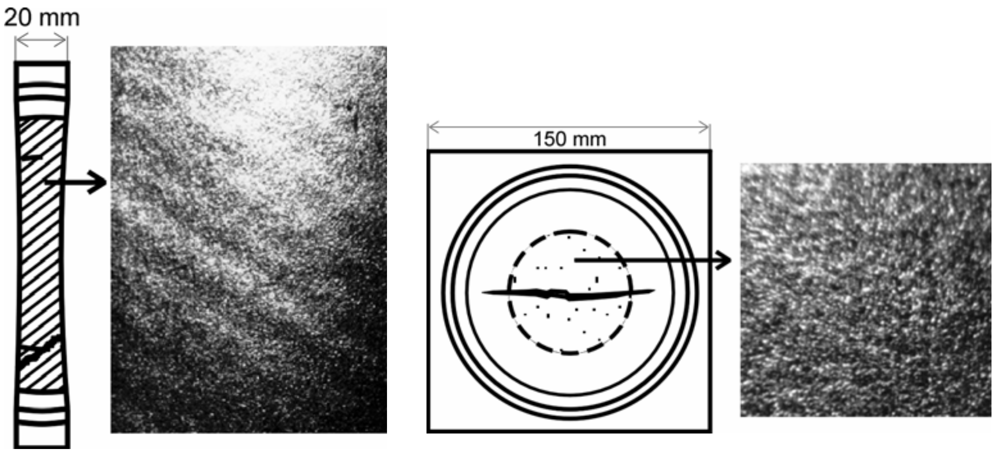
Table 1. Chemical composition of the tested material in wt%

Mg	Mn	Si	Fe	Zn	Ti	Cu	Pb	Cr	Ni	Al
6.8	0.5	0.1	0.2	0.03	0.054	0.001	0.002	0.001	0.005	rest

Stretching and surface relief observation. Rectangular blanks of various widths (from 150mm to 20mm) were firmly clamped in the longer direction, and stretched in a "Hille" sheet-metal testing machine over a 75mm diameter, unlubricated, hemispherical punch. Dependently on the ratio of specimen width vs. punch diameter different stress states were induced in the tested material, as was proposed earlier by A.K. Ghosh [11]. The surface relief of the stretched blanks was observed by optical microscope

3. RESULTS AND DISCUSSION

During biaxial stretching the surface appearance seems to change dependently on the degree of biaxiality. At the surface of nearly uniaxially stretched samples a net of parallel bands can be seen, which are rather "B" type (Fig. 3a). It should be noted that in those samples the very harmful "A" type ("flamboyant" type) surface markings could not be recognized. However, the surface banding completely disappeared in the case of equibiaxially stretched samples (Fig. 3b).



a) b)

Figure 3. Macro photographs and appropriate sketches of the samples surface markings after stretching in near uniaxial (a) and equibiaxial tension (b)

More complex surface appearance was detected in the samples stretched in the near plain – strain condition (Fig. 4). Banding out of the punch contact is rather "B" type (macro photograph 1), as in case of uniaxial stretching. In the area of punch contact the band configuration appeared to be parallel to the shorter side of the blank (macro photograph 3). The transition of ~ 60° aligned bands to the parallel net in the area of contact is shown in macro photograph 2.

Similar results reported recently [12] in respect to the biaxial stretching and surface appearance in some Al-Mg alloys with 5.5%Mg and 0.3% Cu sheet material. It was assumed that the dislocation pinning effect brought by the presence of Mg atoms is relaxed in a great deal in balanced biaxial stretching, when multiple slip occurs easily, as the sessile dislocations formed easily and the deformation proceed more homogenously.

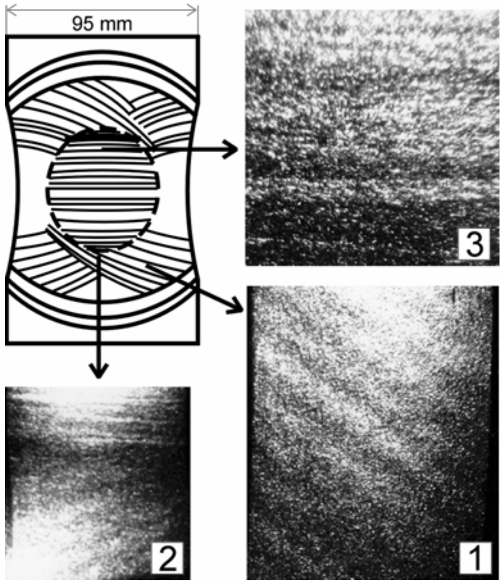


Figure 4. Macro photographs and appropriate sketches of surfaces markings in case of stretching in plain-strain conditions.

On the other hand quite same results [13] were treated by the basic assumption that the mechanism of dislocation interactions with solute atmospheres can not explain why the macroscopic markings appear in band pattern. It was suggested that is difficult to suppose that several millions of rows of atoms behave similarly, but quite different from the adjacent sever million rows of atoms.

4. SUMMARY

Al-Mg6.8 type sheets were tested under different stretching conditions (uniaxial, plain-strain and balanced biaxial) in order to make some surface relief appearance. The presented results indicate that the stretcher-strain surface appearance can be influenced in a great deal by changing the stress state, i.e. the stretching strain path. It seems that the harmful stretcher lines disappear in equibiaxial stretching.

The harmful surface appearance is mostly related to dynamic strain aging (DSA) due the reactions of Mg atoms with mobile dislocations, and the surface stretcher strain appearance was supposed to be controlled by the control of the DSA. However, some latest investigations indicate that the problem could be more complex, and need a further research.

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