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THE INFLUENCE OF THE SURFACE ROUGHNESS ON THE DRAWING PARAMETERS OF ALUMINUM-ALLOY AUTO-BODY SHEETS

VPLIV HRAPAVOSTI POVRŠINE NA VLEČNE LASTNOSTI ALUMINIJEVIH PLOČEVIN ZA AVTOMOBILSKO KAROSERIJO

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The drawing characteristics of aluminum-alloy sheets for automotive body sheets were investigated. Optimal deep drawing properties were obtained from the AlMg4.5Zn1.5MnCu alloy which exhibited the highest forming-limit values. The roughness of the sheet surface was found to improve the drawing capability. Roughness parameters vary in range R_a=0.6 to 3.3µm and R_t=4 to 14.68µm, depending on the micro-craters' forming process. High roughness values are obtained by the photo-etching method, which produces a uniform surface roughness and micro-craters grid.

Key words: auto-body, alloy AA5xxx, drawing, surface, roughening.

Raziskane so vlečne sposobnosti aluminijevih pločevin za avtomobilske karoserije. Optimalne globokovlečne sposobnosti so dosežene pri zlitini AlMg4.5Zn1.5MnCu, ki ima najboljše mejne oblikovalne lastnosti. Hrapavost površine poveča vlečno sposobnost. Parametri hrapavosti so v razponih R_a od 0,6 do 3,3 µm in R_t od 4 do 14,68 µm, odvisno od procesa oblikovanja mikrokraterjev. Veliko hrapavost se doseže s postopkom fotojedkanja, ki ustvari enakomerno hrapavost in mrežo mikrokraterjev.

Ključne besede: avtomobilska karoserija, zlitina AA5xxx, vlečenje, hrapavost

1 INTRODUCTION

Aluminum sheets should have a high level and uniformity of mechanical properties as well as surface quality. The selected groups are evaluated on the basis of criteria that unite many influential factors, which are significant in the final sheet-forming processes. Some criteria are particularly important in the production of automotive-body elements because of "one operation" manufacturing on highly automated equipment. The development of materials involves both steel and aluminum[1-3]. Steel sheets are used in greater quantity than aluminum sheets, however, the share of aluminum sheets grows steadily because aluminum offers the possibility of reducing the weight of the automotive body. Alloys such as: AA2xxx, AA5xxx and AA6xxx are typical for automotive-body elements. The development of these materials is still increasing rapidly, both in terms of chemical composition and methods of production and processing[4-7]. The 5xxx alloy types that satisfy the "30-300" criteria, with a high content of Mg, increased content of Zn and low contents of Mn and Cu were investigated with the purpose of determining their behavior during the forming of sheets with a surface produced by standard rolling technology and sheets with surfaces, with a "statistical" and an "uniform" distribution of elements on the surface, as result of roughening.

2 EXPERIMENTAL DETAILS

The tests were performed on 1.25 mm final-gauge sheets from three different as annealed 5xxx **alloys (Table 1**). The chemical composition of the basic alloy, AlMg4.5Mn, is standardized, while the chemical composition of the other two alloys should improve the strength and plasticity of the basic AlMg4.5Mn alloy. The sheets are manufactured entirely in the laboratory (casting, cold rolling, and heat treatments). For the purpose of testing the influence of roughness on the sheets' behavior during the drawing process, the laboratory-produced sheets were subjected to different types of surface roughening process: shot-peening, photo etching of the micro-channels and micro-craters' grid. The testing included the checking of three different types of surface roughness: direct surface roughness called "fine-ground" and produced by cold rolling; statistically oriented surface roughness produced by shoot-peening and uniformly distributed surface roughness produced by photo-etching. The testing consisted of: hardness tests; uniaxial tensile tests; Erichsen penetration-ductility tests IE_{27}; cylindrical-cup drawing tests (β=2); biaxial-hydraulic ("bulge") tests with a 100 mm of die diameter; measurements of amplitude parameters that represent the vertical characteristic of surface deviations (R_a, R_t). Forming-limit diagrams are determined using the method of visio-plasticity (coordinate grid of 3 mm circles; microscopically measured strains).

Table 1: Chemical compositions of the investigated alloys
Tabela 1: Kemična sestava raziskanih zlitin

TYPE OF ALLOY	Chemical composition % (wt)					
	Mg	Zn	Cu	Mn	Fe	Si
AlMg4.5Mn	4.23	0.02	0.015	0.42	0.26	0.13
AlMg4.5MnZnCu	4.03	0.34	0.16	0.43	0.24	0.22
AlMg4.5Zn1.5MnCu	4.00	1.31	0.18	0.21	0.22	0.21

3 RESULTS AND DISCUSSION

Mechanical properties

The mechanical properties of the 1.25 mm final-gauge annealed sheets are shown in terms of the content of the main alloying elements (Mg+Zn+Cu+Mn) in **Table 2**. The addition of Zn and Cu, as in the case of AlMg4.5Zn1.5MnCu, increases the hardness and strength by 25% and 20% respectively. The elongation is also increased by 9%. Sheets have the lowest strength and the highest elongation in the direction of 45° to the rolling direction. The anisotropy of the yield stress, tensile strength and elongation increases with the presence of Zn and Cu. Values of **r** in the plane of the sheets are given in **Table 3**. The highest r value is in the 45° direction for all the investigated sheets. The increasing of alloying elements' content increases the **r** value only in this direction. These changes cause an increasing earring, with ears in the 45° direction in all alloys. The results obtained by testing of the biaxial stretching are also given in Table 3. The sheet formability increases with increasing the alloying elements' content. The limiting stretching depth IE_{27} and the limiting "bulge" height also increase with increasing the content of the alloying elements. All three alloys show a similar forming-limit curve shape, with the curves moving to the higher strain values with increasing the alloying elements' content (**Figure 1**).

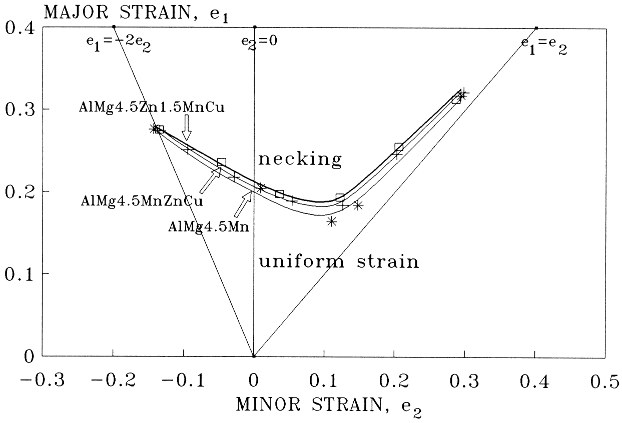

Figure 1: Forming-limit curves of the investigated alloys. The e_1 and e_2 are the true strains (major and minor strain in the plane of the sheet).
Slika 1: Mejne preoblikovalne krivulje raziskanih pločevin. e_1 in e_2 sta realni napetosti (največja in najmanjša napetost v ravnini pločevine)

Sheet-surface roughness

The micro-shape of the selected sheet surface roughness types is shown in **Figures 2a-d**. After cold rolling, the numerous scrapes parallel to the rolling direction represent the surface roughness called "ground" (**Figure 2a**). With shot peening (**Figure 2b**), statistically distributed micro-holes and micro-peaks of on irregular shape are produced. The sheet surface with the uniform grid of continuous micro-channels (dark areas) and micro-peaks (bright areas) is shown in **Figure 2c**. Uniformly distributed micro-bridges shape the regular grid of prismatic micro-holes (dark areas) in **Figure 2d**. Quantitative parameters of sheets surface roughness, R_a and R_t, are given in **Table 4**. The surface roughness produced by shot peening is three to five times greater than that produced by the grinding process. The sheets with a regular grid of prismatic micro-craters have the highest level of roughness, which is close to the "lasertex" roughness values[7].

Table 2: Hardness and tensile properties of 1.25mm thickness sheets in the annealed state
Tabela 2: Trdota in raztržne lastnosti žarjene 1,25 mm debele pločevine

TYPE OF ALLOY	Mg+Zn+Cu+Mn	HB	Rp0,2 (MPa)			Rm (MPa)			A_5 (%)		
	%		0°	45°	90°	0°	45°	90°	0°	45°	90°
AlMg4.5Mn	4.68	60	124	120	125	257	248	257	25	26	25
AlMg4.5MnZnCu	4.96	69	143	140	142	285	280	283	26	28	26
AlMg4.5Zn1.5MnCu	5.70	75	154	146	154	306	296	306	27	29	27

Table 3: r-value; earring; limiting IE_{27} and "bulge" height of the investigated sheets
Tabela 3: Velikost r, mejni IE_{27} in višina kalote raziskanih pločevin

TYPE OF ALLOY	r_0	r_{45}	r_{90}	r_m	Δr	z (%)	IE_{27} (mm)	H_{bulge} (mm)
AlMg4.5Mn	0.78	0.87	0.78	0.825	-0.18	0.8	9	29
AlMg4.5MnZnCu	0.78	0.89	0.76	0.83	-0.24	3.5	10.3	32
AlMg4.5Zn1.5MnCu	0.78	0.90	0.78	0.84	-0.24	2.0	9.8	33

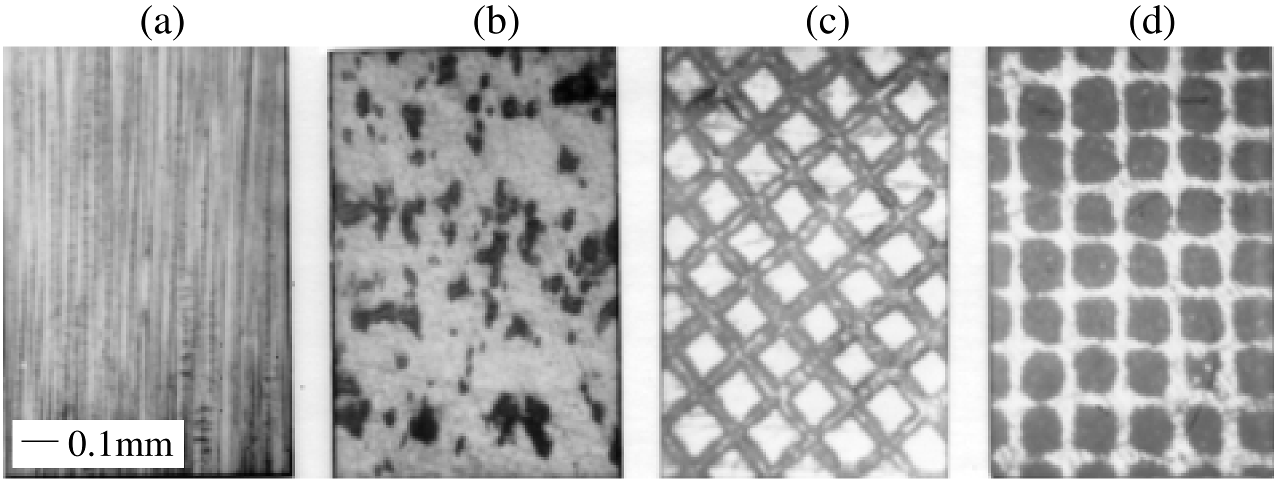

Figure 2: Surface roughness of sheets, produced by: a) rolling with fine-ground rolls; b) shot peening; c) photo etching of micro-channels' grid; d) photo etching of micro-craters' grid

Slika 2: Hrapavost površine pločevine, pripravljene z: a) valjanjanjem s fino brušenimi valji, b) peskanjem, c) fotojedkanjem mreže mikrokanalov in d) foto jedkanjem mreže mikrokraterjev

Table 4: Influence of the surface-roughness type on punch stretching parameters (compared with results obtained for the case of punch stretching with a quasi-solid lubricant)

Tabela 4: Vpliv vrste hrapavosti površine na parametre razteznosti (primerjava z rezultati doseženimi z uporabo kvazi trdnega maziva)

Type of Surface Roughness	R_a µm	Rt µm	Lubricant	IE_{27} (mm)	Diameter of fracture zone (mm)	F_{max} (N)
fine-ground	0.62	4.21	oil	9.05	13	11.996
shot-peened	2	14.5	oil	9.65	10.5	11.786
micro-craters' grid	3.3	14.68	oil	9.82	9.6	11.454
fine-ground	0.62	4.21	wax	10.5	7.6	11.212
"lasertex" roughening process[7]	R_a=1.18; R_{pm}=3.25; $R_{z\text{-}DIN}$=6.15					

Biaxial stretching and deep drawing of roughened sheets

The influence of roughening on the drawing parameters is determined through tests of biaxial stretching with a hemispherical punch and deep drawing. **Table 4** presents the obtained results. The roughening of the sheet surface increases the IE_{27} value and decreases the maximum drawing force and fracture area. In other words, the fracture zone moves near to the top of the formed bulge. These changes lead to the achievement of good lubrication conditions as in case of using the

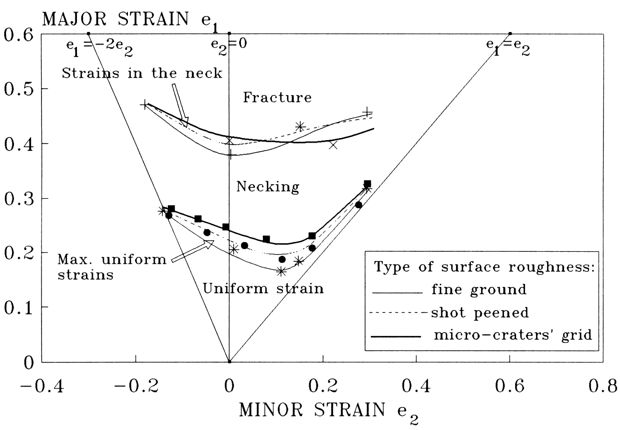

Figure 3: Influence of the surface-roughness type on the forming limit curves of AlMg4.5Zn1.5MnCu sheets

Slika 3: Vpliv vrste površinske hrapavosti površine na krivulje mejne preoblikovalnosti pločevine iz zlitine AlMg4.5Zn1.5Cu

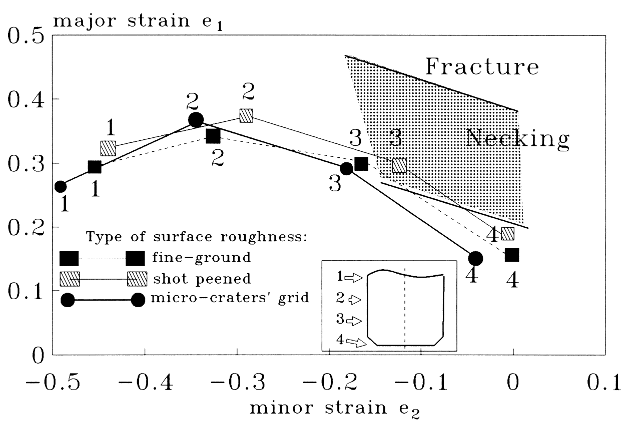

Figure 4: Influence of the surface roughness on the strains along the wall of the deep-drawn cup of AlMg4.5Zn1.5MnCu sheet

Slika 4: Vpliv hrapavosti površine na napetosti vzdolž stene globoko vlečene čaše iz pločevine iz zlitine AlMg4.5Zn1.5Cu quasi-solid lubricant (wax, see **Table 4**). Roughening of the sheets' surface moves the forming limit curves to higher strain levels (**Figure 3**). The "micro-craters' grid" type of sheets' surface roughness gives the best results. The influence of the sheets surface roughness on the strains along the wall of the deep-drawn cup is presented in **Figure 4**. Surface roughness, called the "micro-craters' grid", significantly removes the "e_1-e_2" strain combination from the forming-limit curve on the left side of the FLD. This removal is particularly noticeable in the area near the plain strain state (at the most critical area between the wall and the bottom of the cup).

4 CONCLUSION

The obtained results have shown the importance of the chemical composition of alloys intended for stretch forming and deep drawing. The most favorable values are obtained with AlMg4.5Zn1.5MnCu alloy sheets. The properties of these sheets correspond to the "30-300" demand with a low level of anisotropy. The roughening process that creates the uniform "micro-craters' grid" enables the improvement of the deep-drawing and stretch forming capability of the sheets. It gives drawing parameters close to those obtained with quasi-solid lubricants. The improvement of friction conditions during the sheets drawing decreases the drawing stress and stabilizes the process of deep drawing with a flat punch.

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