Advances in Science and Technology Research Journal
Volume 10, No. 32, Dec. 2016, pages 248–253
DOI: 10.12913/22998624/65759

Research Article

FORMABILITY OF THIN SHEETS FROM ALUMINUM ALLOYS

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Received: 2016.08.15
Accepted: 2016.10.26
Published: 2016.12.01

ABSTRACT
In this contribution there have been evaluated properties of four types of sheets made from aluminium alloys. In the case of each of the examined sheets there has been checked its shearing ability via the influence of punch-die clearance change on the quality of blanking edge. Quality of blanking edge is characterized by a ratio of plastic zone height to the total thickness of the sheared material. Formability during the drawing process was measured with earring test. Results are presented by the earring coefficient (unequal height) of the cups.

Keywords: formability, aluminum alloys sheets, uniaxial tensile test, earring test

INTRODUCTION

Formability refers to the ability of sheet metal to be formed into a desired shape without necking or cracking. Necking is localized thinning of the metal that is greater than the thinning of the surrounding metal. Necking precedes cracking [7, 12, 14, 15]. From the metallurgical perspective, the formability of a particular metal depends on the metal's elongation, which is the total amount of strain measured during tensile testing. A metal with a large elongation has good formability because the metal is able to undergo a large amount of strain (work) hardening [2, 4, 8, 11].

Finally, the formability of a metal also depends on the state of stress on a metal during forming. The state of stress depends on the shape of the component and the process used to form of the component. Forming limit diagrams are used to predict whether the forming strains to which a metal will be exposed will result in necking or cracking [1, 5, 6, 9].

Material properties that have a direct or indirect influence on formability and product quality are ultimate tensile strength, yield strength, young's modulus, elongation, hardness, the strain hardening exponent and the plastic strain ratio. All these parameters can be determined by testing a samples cut from the blank [3, 10, 13].

The properties of four types of sheets, made from aluminum alloys, have been evaluated in this paper. In the case of every tested sheet, there has been verified its shearing ability, by means of the effect of changes of punch-die clearance on the blanked edge quality. The blanked edge quality is characterized by a ratio of plastic zone height to the total thickness of the sheared material. Formability during the drawing process was evaluated with earring test. Results are presented by the earring coefficient (unequal height) of the cups.

EXPERIMENTAL PROCEDURE

Sheets from aluminum alloys where used for the experiment to evaluate the formability. The tested sheets H11, H22, H24 with thickness 0.80 mm and sheet T6 with thickness 1.00 mm are described in Table 1.

Uniaxial tensile test was carried out on the device TIRA test 2300. For this test conditions and the shape of the sample indicate standards STN EN 10002-1+AC1 and STN 42 0321. Samples were taken for a tensile test to determine mechanical properties of the material under zero-, 45-, and 90-degree angle in relation to the direction of rolling. From uniaxial tensile test there were measured and calculated

Table 1. Designation of heat treatment of aluminum alloys

Designation according to the method of processing	Description	Designation of the material according to EN AW	Designation of the material according to DIN
H11	Deformation lightly hardened	EN AW 5754	$AlMg_3$
H22	Deformation hardened and partly annealed 1/4 hard	EN AW 5754	$AlMg_3$
H24	Deformation hardened and partly annealed 1/2 hard	EN AW 5754	$AlMg_3$
T6	After solution annealing and subsequent aging	EN AW 6082	$AlMgSi_1$

mechanical properties – yield of point, tensile strength and elongation.

An experimental cutting tool and a ZD 40 hydraulic press were used for blanking. Blanks were cut at two different punch-die clearances, namely 0.01 mm and 0.08 mm. Plastic zone height was measured at five different locations at both clearances settings. It was measured by an Olympus Bx FM microscope. Pictures of the samples were taken by an Olympus E 410 camera.

Because of the examination of technological formability there was earring test realized on the examined sheets. From the materials there were made circle blanks of diameter of 55 mm, 5 pieces made from each material. The blanks were drawn in drawing tool with mechanical blank holder. For the drawing of the cups there was used single-action hydraulic press. Measures of the experimental tool:

- punch diameter: 33.00 mm,
- die diameter: 34.80 mm, 35.20 mm,
- punch radius: 4.75 mm,
- die radius: 2.20 mm,
- die clearance: 0.9, 1.1 mm.

The heights of the cup´s walls were measured in eight directions according to the direction of rolling in a case of each sample (Fig. 1). From the measured values there was evaluated the degree of earring ΔH (1) and the earring coefficient Z (2).

Degree of earring:

$$\Delta H = \frac{1}{2}(H_0 - 2H_{45} + H_{90}) \tag{1}$$

where: H_0, H_{45}, H_{90} are cup heights in the direction 0°, 45°, 90° in relation to the direction of rolling.

The degree of earring represents the average heights of ears. The earring of cups is characterized as unfavourable property of deep drawing sheets, which is result of surface anisotropy.

Earring coefficient:

$$Z = \frac{H_{max} - H_{min}}{H_{min}}.100 \tag{2}$$

where: H_{max}, H_{min} are maximal and minimal cup heights.

RESULTS AND DISCUSSION

Results of the uniaxial tensile test demonstrate visible differences in the values of mechanical properties. Behaviour of mechanical properties according to the direction of rolling are stated in Figure 2.

From the results it is evident that the materials H11 and H22 had comparable values of strength properties. Material H24 has low strength properties, the ratio of $R_{p0.2}/R_m$ is ex-

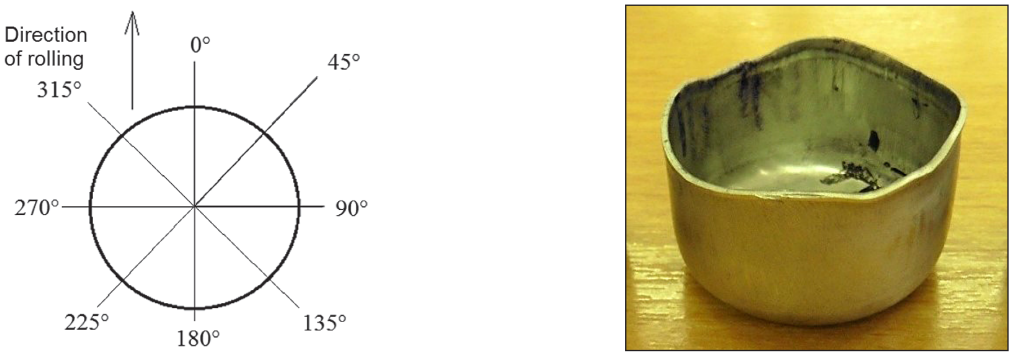

Fig. 1. The directions of the measurement height of cups wall (left) and the cup of the material H24 (right)

actly 0.96. Material T6 has almost three times larger strength properties than H24 and the ratio of $R_{p0.2}/R_m$ that is exactly 0.91.

In the case of all the examined materials, the largest drawability is in the direction of 45° according to the direction of the rolling and the smallest drawability is in the direction of the rolling. This fact can be used when designing the technology of drawing of the cups from these materials. Areas of the cups which are drawn the most (for instance: corner areas of four-wall cups), will be placed in the direction of 45° according to the direction of the rolling of the sheet and so on.

Punch-die clearance has the largest effect on blanked edge quality. Therefore, its magnitude, regularity and stability become very important factors as the tool wears. According to the results of the plastic zone height measurements (Table 2), the plastic zone area decreases proportionally with clearance increasing. The largest value of the plastic zone height was observed in the case of the material H11, and the smallest in the case of the material H22 (Fig. 3).

In general, there exists a rule for metal materials that the sheets with fine formability have

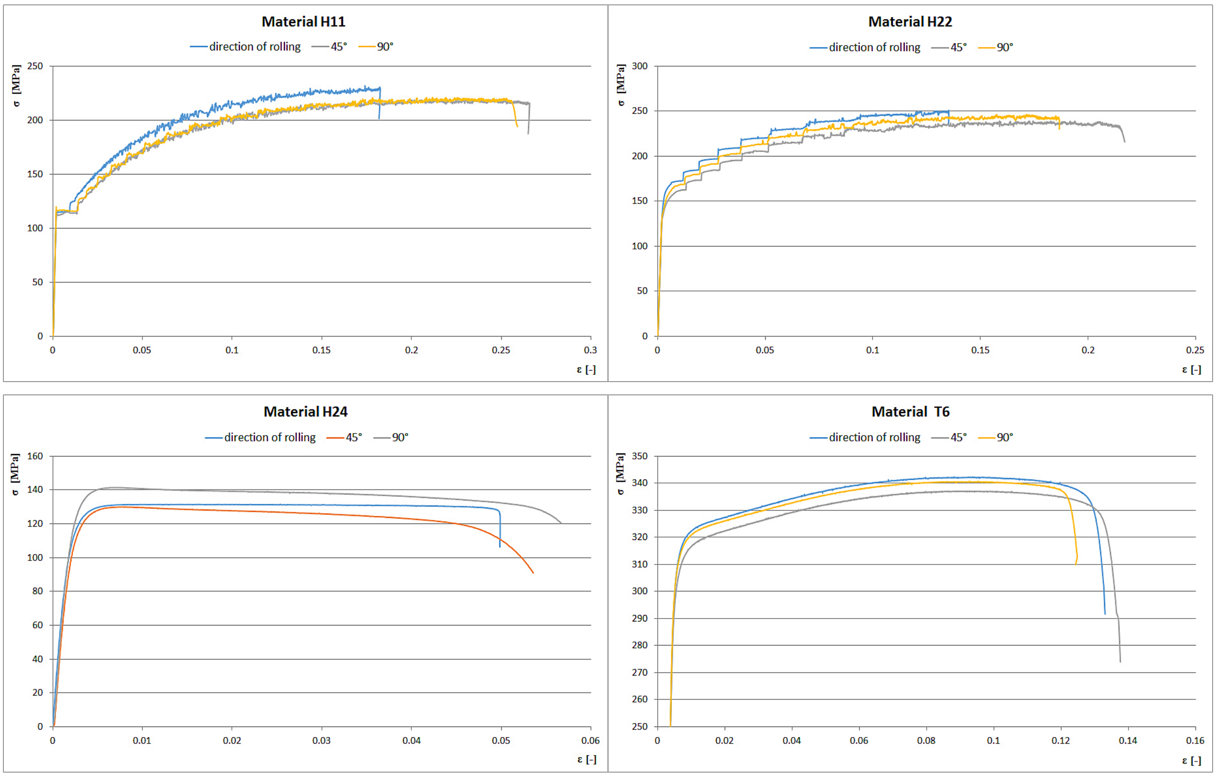

Fig. 2. Uniaxial tensile characteristics of tested materials

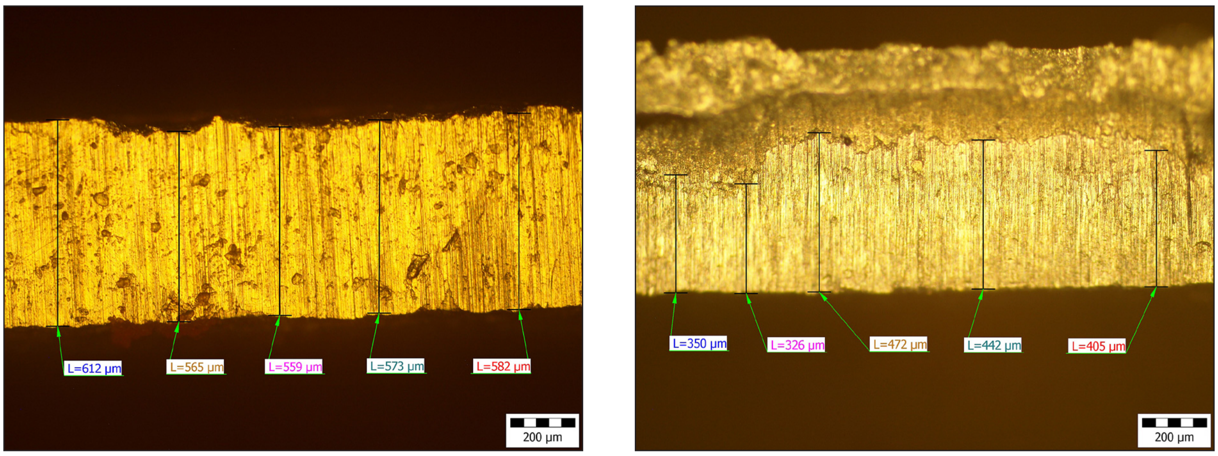

Fig. 3. Plastic zone height of material: H11 blanked with 0.01 mm clearance (left) and H22 blanked with 0.08 mm clearance (right)

low value of the ratio of $R_{p0.2}/R_m$. From the results of the uniaxial tensile test it is evident that materials H11 and H22 have this ratio lower than 0.653. In the case of the materials H24 and T6 is this ratio very high (higher than 0.914). Despite that the values of the ratios of yield of point to the tensile strength did considerably differ, measured values of size of the razor cut differ considerably less than in the case of the steel sheets. From the comparing of the stated ratio with the height of plastic zone of the shear of tested materials, we can deduce that the higher value of index h_v/a_0 was achieved at the lower value of the ratio $R_{p0.2}/R_m$ (Table 3).

In Figure 4 there are listed comparisons of the degree of earring ΔH, earring coefficient

Table 2. Plastic zone height of the sheet blanked for two different punch-die clearances – 0.01 and 0.08 mm

Sheet material	Clearance [mm]	Plastic zone height [mm]					
		h_{v1}	h_{v2}	h_{v3}	h_{v4}	h_{v5}	Average h_v
H11	0.01	0.673	0.635	0.611	0.638	0.623	0.636
	0.08	0.556	0.576	0.556	0.583	0.577	0.569
H22	0.01	0.543	0.544	0.588	0.639	0.559	0.544
	0.08	0.331	0.368	0.332	0.451	0.394	0.375
H24	0.01	0.543	0.553	0.534	0.480	0.471	0.517
	0.08	0.493	0.396	0.412	0.423	0.432	0.431
T6	0.01	0.512	0.403	0.588	0.614	0.532	0.535
	0.08	0.463	0.499	0.496	0.477	0.488	0.485

Table 3. Relative plastic zone height h_v/a_0 dependence on sheet material index R_e/R_m

Material	Sheet thickness a_0 [mm]	$R_{p0.2}/R_m$ ratio	Clearance [mm]	h_v [mm]	h_v/a_0
H11	0.80	0.625	0.01	0.636	0.795
			0.08	0.569	0.711
H22	0.80	0.653	0.01	0.544	0.680
			0.08	0.375	0.468
H24	0.80	0.962	0.01	0.517	0.646
			0.08	0.431	0.538
T6	1.00	0.914	0.01	0.535	0.535
			0.08	0.485	0.485

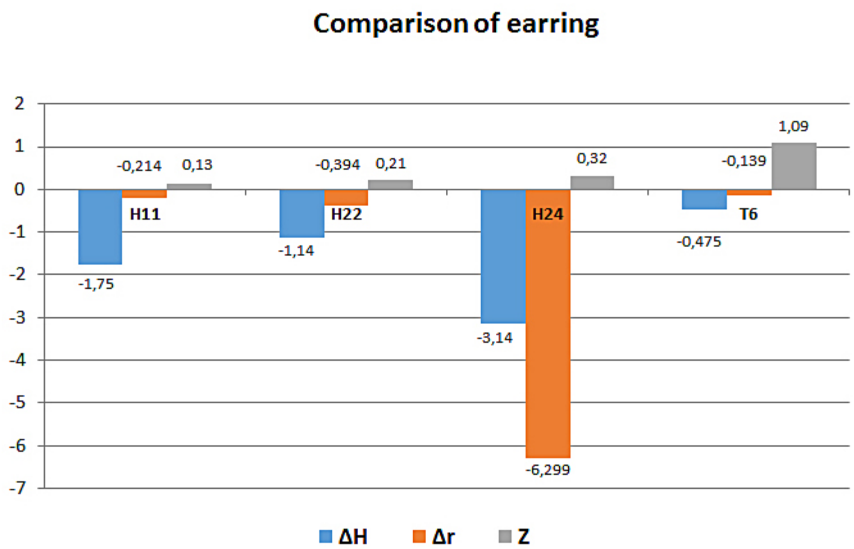

Fig. 4. Comparison of the degree of earring ΔH, earring coefficient Z and areal anisotropy coefficient of normal anisotropy Δr

Z and areal anisotropy coefficient of normal anisotropy Δr, in the case of the examined materials. From the measured results we can assert that material H24, which has very low values of yield of point and tensile strength and has the lowest drawability of the examined materials, shows the highest earring. What can be considered as an interesting finding, coming from the comparison of these four sheets, is the fact that during the drawing of the cups, made from all the four sheets, there were without any problems drawn cups from the same diameters of blanks, despite that the sheets differed considerably in their strength and plastic properties.

CONCLUSIONS

In this contribution there have been examined the properties of four types of the sheets made from aluminium alloys. These sheets were produced in different ways and that caused the different hardening of the original material and therefore also the change of its strength and plastic properties. Basic mechanical and plastic properties were stated by the uniaxial tensile test on the samples according to the corresponding standards. From the measured strength and plastic properties we can state arose anomaly on the sample of the material H24, on which, even after half-reinforcement by over-rolling, came to the decrease of the hardness and considerable increase of the ratio of yield of point to tensile strength. The decrease of the drawability of this material is an expected consequence of its reinforcement.

Blankability of aluminium sheets was verified at two punch-die clearances (0.01 and 0.08 mm). From the measured results it can be stated that plastic zone height is decreasing alongside with the decreasing plastic properties of the material. At larger punch-die clearance (0.08) there was measured lower value of the plastic zone height than at smaller punch-die clearance (0.01) in the case of all the examined materials. Relative plastic zone height, which we stated as a ratio of the plastic zone height to the total thickness of the sheared material, moved from 0.795 to 0.468. These values are considerably larger than during the shearing of the steel sheets. From the results it can be stated that the strength and plastic properties of the aluminium sheets have less of an influence on the plastic zone height than during the shearing of the steel sheets.

From the results of the earring test we can deduce that during the process of drawing of the cups from all the examined materials, the most obvious change of the plastic properties occurred by the increase of the degree of earring (ΔH) in the case of the material H24 which had the smallest drawability from the examined materials. That is why it will be needed in the future to verify the causes of this feature by examining the structural properties of the material.

Acknowledgements

The authors are grateful to APVV for support of experimental work under grant APVV-14-0834 and the project VEGA No. 1/0872/14.

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