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Influence of the cutting gap on the quality of the cutting surface when cutting of aluminium sheets

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ABSTRACT

In recent years, aluminium sheets have been increasingly used in the design of machine structures, in the automotive and aircraft industries. The paper deals with the influence of cutting conditions on the quality of the cutting surface when cutting thin sheets of aluminium alloys. Three grades of $AlMg_3$-based aluminium sheets and one $AlMgSi_1$-based aluminium sheets were selected for experimental verification of the cutting gap impact on the cutting surface quality. The cut-outs were cutting in an experimental cutting tool at two different cutting gaps. The quality of the cutting surface was evaluated based on microscopic observation of the surface and comparison of the size of the plastic area to the overall sheet thickness.

Keywords - aluminium sheet, cutting, cutting surface quality

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I. INTRODUCTION

Aluminium and its alloys are now widely used in industry due to their low weight and enough strength properties which can be changed by mechanical or thermo-mechanical processing. Therefore, aluminium alloys have been used in recent years in the construction of car bodies, where they meet precisely the condition to reduce weight and thus reduce emissions. Some car manufacturers have already presented so-called "All-aluminium" body [1-3]. Aluminium alloys have lower mechanical properties (yield strength, tensile strength) than steel-based materials (steel sheets), but only one-third of weight [4].

Although aluminium alloys have a substantially lower hardness in most cases, this does not automatically mean that the processing conditions, whether machining or forming, will make processing considerably simpler than steel materials. In fact, however, in the processing of aluminium alloys (by machining or forming), under certain conditions, the quality of the surface can be lower after machining, respectively after forming [4-6].

The basic operation at processing aluminium sheets and profiles is the shearing operation. This shearing is often done by cutting. Due to the different properties of aluminium alloys, it is necessary to optimize the cutting process conditions to achieve the maximum service life of the cutting tools at the desired quality of the cutting surface [7,8]. The quality of the cutting surface during cutting depends on the properties of the materials, the design of the cutting tool and the technological conditions during cutting. It is generally known that the cutting gap has a decisive influence on the quality of the cutting surface [9,10]. Research in this area was aimed at achieving a high-quality cutting surface for various types of materials. Most often, these studies focused on steel sheets where the cutting surface was functional [11-13]. The widespread use of aluminium alloy sheets and the increased quality requirements of these sheets led us to investigate the effect of cutting conditions on the quality of the cutting surface.

II. EXPERIMENTAL MATERIALS

Four types of aluminium sheets marked H11, H22, H24 and T6 were selected for the research of the influence of cutting conditions on the quality of the cutting surface of the cut-outs. Three grades of aluminium sheets examined were based on $AlMg_3$ alloy (H11, H22, H24) and one based on $AlMgSi_1$ (T6). Sheets H11, H22 and H24 had thickness a_0 = 0.8 mm and T6 sheet had thickness a_0 = 1.0 mm. Specification for experimental research of used aluminium sheets is given in Table 1.

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$_1$

Uniaxial tensile test was carried out on the device TIRA test 2300 (Figure 1). The 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 mechanical properties – yield strength, tensile strength and elongation.

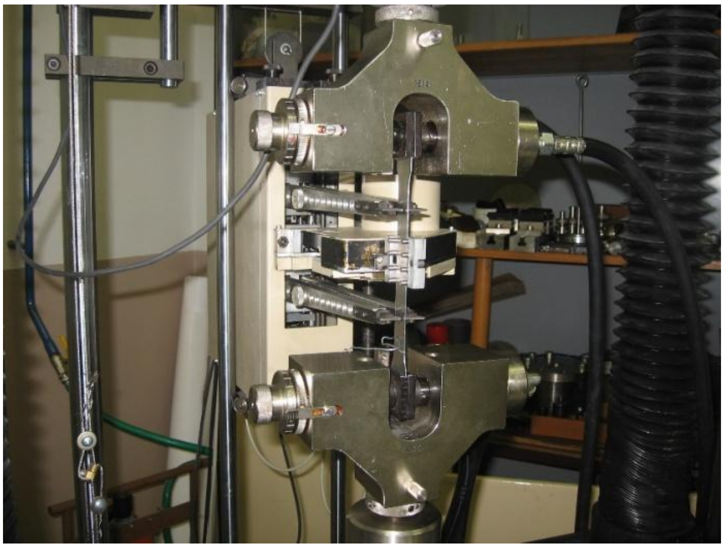


Fig. 1 Uniaxial tensile test equipment

Fig. 2 shows examples of the samples damaged after tensile test. The tensile test damage way was similar for all aluminium sheets used. The measured mechanical properties of the examined materials are given in Table. 2.

T6 - 0° T6 - 45° T6 - 90°

Fig. 2 Method of tested samples damage from sheet T6

Table 2 Measured properties of sheets tested by uniaxial tensile test

Direction [°]	**Sample designation**	**$R_{p0,2}$ [MPa]**	**R_m [MPa]**	**A_{80} [%]**
0°	H11	137	220	24.10
0°	H22	166	252	14.82
0°	H24	131	136	10.43
0°	T6	311	339	14.72
45°	H11	111	218	26.07
45°	H22	164	246	18.43
45°	H24	132	137	4.15
45°	T6	312	341	14.59
90°	H11	145	229	19.32
90°	H22	170	255	16.74
90°	H24	144	147	6.55
90°	T6	319	347	12.88

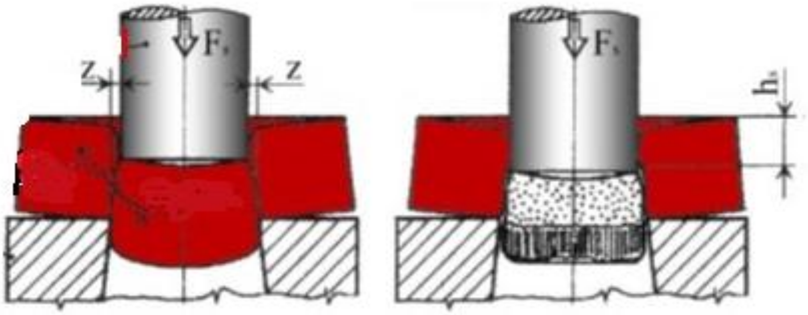
From the measured mechanical properties, it can be stated that the highest strength properties have material T6 (sheet based on $AlMgSi_1$). The yield strength of this material was measured in the range of 311-319 MPa. The tensile strength was measured between 339-347 MPa. The yield strength and tensile strength showed low surface anisotropy. Elongation was measured in the range of 12.88-14.72%. It was the lowest in the direction perpendicular to the rolling direction.

From the measured mechanical properties of materials H11, H22 and H24 (sheet based on $AlMg_3$) it can be stated that the material H22 has the highest strength properties. The yield strength of this material was measured in the range of 164-170 MPa. The tensile strength was measured in the range of 246-255 MPa. The yield strength and tensile strength showed low surface anisotropy. Elongation was measured in the range of 14.82-18.43%. The lowest elongation was measured in the rolling direction. The lowest values of tensile strength were measured for the material H24 (137-144 MPa), which does not correspond to the material condition. This material showed little difference between yield strength and tensile strength (difference of only 3 to 5 MPa). Its elongation was low (4.15 to 10.43%), which corresponded to the method of its production.

III. METHODOLOGY OF VERIFICATION OF CUTTING GAP INFLUENCE ON THE QUALITY OF THE CUTTING SURFACE WHEN CUTTING ALUMINIUM SHEETS

Based on the existing knowledge of the influence of cutting conditions on the quality of the cutting surface, we have selected the condition of the cutting gap effect in the experiments for this article. According to several researches, it is exactly the cutting gap that has a decisive influence on the quality of the cutting surface and the accuracy of the cut-outs. The effect of the cutting gap on the quality of the cutting surface is illustrated in Fig. 3.

An experimental cutting tool and a ZD 40 hydraulic press were used for blanking. Cut-outs were cutting at two different punch-die gaps, namely 0.01 mm and 0.08 mm. Height of plastic area was measured at five different locations at both gaps' settings. It was measured by an Olympus Bx FM microscope. Pictures of the samples were taken by an Olympus E 410 camera.



F_s - cutting force, z - cutting gap, h – height of plastic area

Fig. 3 Cutting gap at cutting and its effect on the cutting surface

The following formula was used to calculate the size of the cutting gap:

$$z = 0{,}32.\ C.\ a_0.\ \sqrt{\tau_S} \qquad [\text{mm}] \qquad (1)$$

where: C – coefficient (in the range from 0.005 to 0.035),
a_0 – material thickness [mm],
τ_S – shear strength limit [MPa].

Based on the shear limit strength, cutting gaps for cutting in experimental cutting tool of 0.01 mm and 0.08 mm were calculated and determined. For a sheet with thickness of 0.8 mm (1.0 mm), this represents 1.25% and 10% (1% and 8%) of the thickness of the cutting materials.

The samples that were cutting on the ZD 40 hydraulic press had two different cutting gaps in the tool (Fig. 4). The shape of the cutting samples and the method of creating the cutting gaps is shown in Fig. 5. On the sides of samples 1 and 3 (Fig. 5), the cutting gap between punch and die was 0.08 mm. The second value of the cutting gap was set to 0.01 mm and was on the sides of the samples marked 2 and 4.

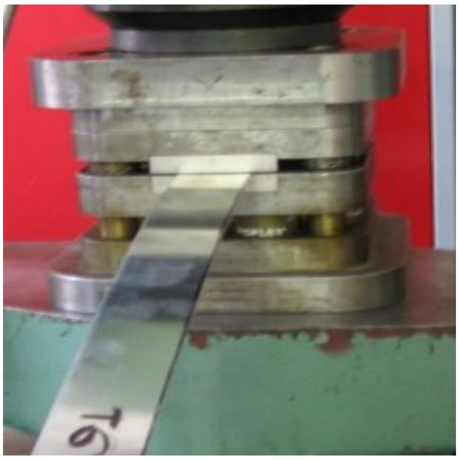


Fig. 4 Experimental cutting tool

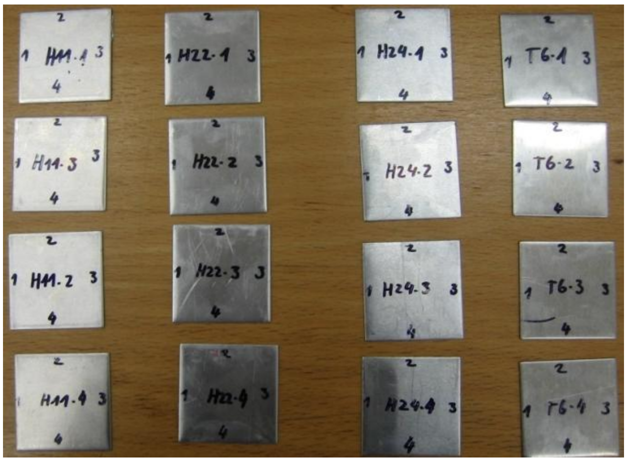
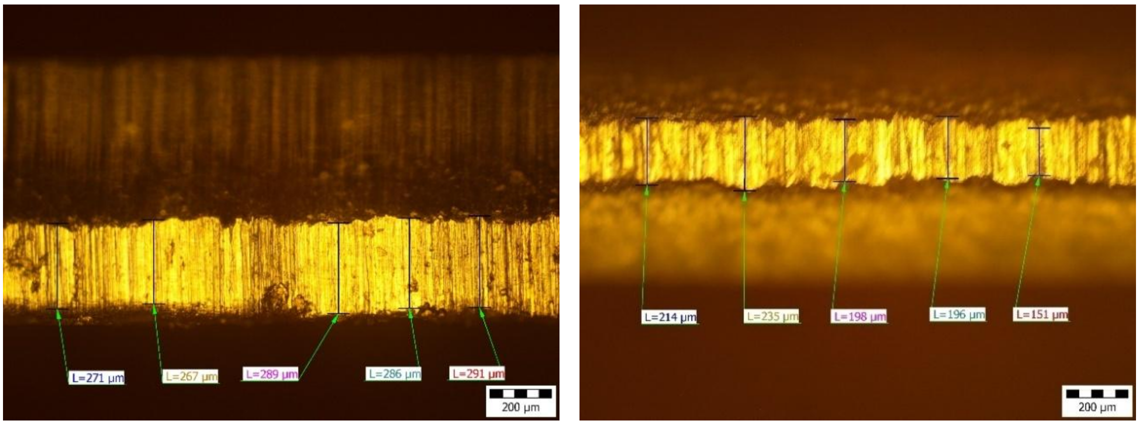


Fig. 5 The shape of cutting samples with marked sides

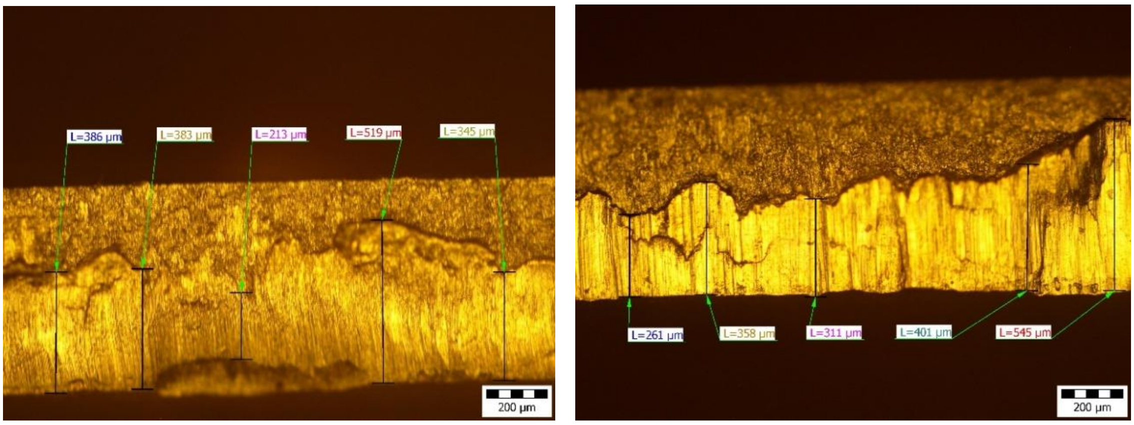
IV. RESULTS AND DISCUSSION

Cutting sheets samples from individual materials are shown in Fig. 5. Cutting surfaces on all sides of the samples were evaluated. From pages 1, 3 and 2, 4, the mean values of the plastic area "h" zone were calculated from ten measurements. From the measured values of the plastic area "h" area (Figures 6 to 9), the relative plastic area values h/a_0 were calculated for all aluminium alloy's sheets examined and compared with each other.



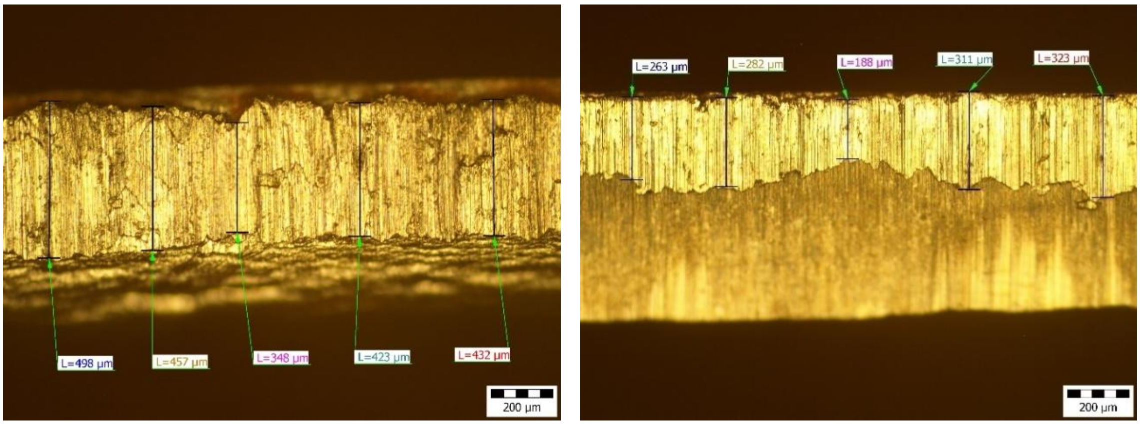
a) z = 0.01 mm b) z = 0.08 mm

Fig. 6 Shape of cutting surfaces of material H11



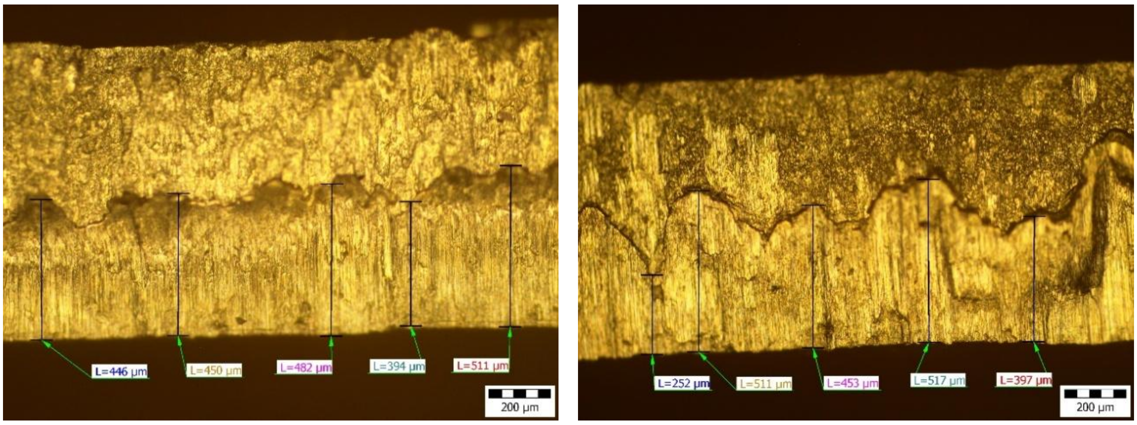
a) z = 0.01 mm b) z = 0.08 mm

Fig. 7 Shape of cutting surfaces of material H22



a) z = 0.01 mm b) z = 0.08 mm

Fig. 8 Shape of cutting surfaces of material H24



a) z = 0.01 mm b) z = 0.08 mm

Fig. 9 Shape of cutting surfaces of material T6

The average values of the height of plastic area in relation to the cutting gap for the examined materials are given in Table 3. The results of the experiments show that with a larger cutting gap, a lower height of plastic area was achieved for all materials. This has been established for all examined materials. Despite repeated experiments, the examined aluminium alloys sheets did not unambiguously confirm the effect of elongation of the cutting material on the size of the height of plastic area. Paradoxically, the lowest values of the plastic area were measured for H11, which had the highest elongation values in the tensile test. For sheet H24, which had the lowest elongation, the values of the plastic area were higher. With cutting gap of 0.01 mm, the height of plastic area of H24 was up to 48% of the material to be cutting on average. $AlMgSi_1$ alloy T6 material, which showed the highest yield strength and tensile strength in the tensile test, had relatively high values of the plastic area $h/a_0 = 0.43$ and 0.38, representing 44%, respectively 38% of thickness of the cutting material. Based on the obtained results, we can conclude that when cutting aluminium alloys sheets, the values of the plastic area are higher than when cutting steel sheets. This is especially evident with larger cutting gaps (8 to 10% of the material cut).

Table 3 Height of plastic area depending on the cutting gap for the examined materials

Material	**Material thickness a_0 [mm]**	**Cutting gap z [mm]**	**Relative height of plastic area h/a_0**
H11	0.80	0.01	0.41
H11	0.80	0.08	0.35
H22	0.80	0.01	0.47
H22	0.80	0.08	0.42
H24	0.80	0.01	0.48
H24	0.80	0.08	0.39
T6	1.00	0.01	0.43
T6	1.00	0.08	0.39

V. CONCLUSION

With respect to another mechanism of cold plastic deformation and another mechanism of hardening of aluminium alloys sheets, from the experiments it can be concluded that the values of the height of plastic area are higher than those of steel when cutting sheets. The values of the height of plastic area are less dependent on the mechanical properties of the materials cut. With sharp cutting edges of punches and dies, the achieved quality of the cutting surface is suitable for further production.

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