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The influence of zinc layer heat treatment on the formation of ears of thin steel sheets

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--**ABSTRACT**--
The most widely used material meeting the conditions of good compressibility, corrosion resistance, paintability, weldability and cost-effectiveness are galvanized sheet metal. The automotive industry, where most car body parts are produced by deep drawing, is experiencing the largest increase in the consumption of galvanised sheet metal. Deep drawing is related to the anisotropy of the mechanical properties of the sheet metal, which is manifested by the different height of the yield around its perimeter, i.e. the formation of ears. The paper deals with the evaluation of the influence of zinc layer heat treatment on the formation of AHSS steel ears. Two types of AHSS steels were evaluated for which the creation of ears of the cup was assessed by the cupping test. The ears creation of the cups in the basic state (not affected by heat treatment) and the cups after annealing of the Fe-Zn layer were compared.

Keywords *– ears formation, thin steel sheets, Fe-Zn layer, cupping test*

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I. INTRODUCTION

The use of galvanised car bodies is now standard in car manufacturing. Galvanized sheet metal is resistant to corrosion. The 'body-in-white' of a car makes up about 80% of the body, all using galvanized steel, which makes it the ideal type of steel sheet to be used in areas where the likelihood of corrosion is high. It is an affordable type of steel sheet metal to be used, mainly because of its low production cost compared to other steel sheets and because it can be used directly.

The future of sheet metal in the automotive industry will largely depend on the future needs of the industry. With the current trend towards lean production and cost reduction, the most valuable for the industry will be the sheet metal forming process by drawing and deep drawing, which most closely meets the criteria.

The formability of sheet metal processed by drawing is often characterised by a drawing limit, which is determined by a cupping test. The yield strengths obtained by the cupping test are characterised as technological parameters for the formability of thin plates in general. They are determined under specific technological conditions of pressing, such as holding force, lubrication, changing friction ratios in the individual parts of the device caused by the size of the radius of curvature of the active parts of the device, or the holding force [1,2].

Sheets exhibit two types of anisotropy – surface (planar) and normal. Surface anisotropy expresses the non-uniformity of mechanical properties in different directions of the plane of the sheet. To detect the surface anisotropy, the results of tensile tests taken from the sheet at different angles with respect to the rolling direction are required. The surface anisotropy has an unfavourable effect during drawing of shape symmetrical cups not only because of the formation of ears that need to be removed, but also can cause thinning of the wall thickness of the cups and cause deviations in the circularity of the rolled cups [1-3].

The normal anisotropy expresses the non-uniformity of the properties obtained in the plane of the sheet with respect to the properties in the direction perpendicular to the plane of the sheet (in the thickness direction). Thus, it expresses the resistance of the sheet to thinning in deep drawing.

The qualitative expression of the normal anisotropy is the normal anisotropy coefficient r:

$$\boldsymbol{r} = \frac{\boldsymbol{\varphi_b}}{\boldsymbol{\varphi_a}} \qquad (1),$$

where: φ_b – actual deformation in the width direction,
φ_a – actual deformation in the thickness direction.

The degree of surface anisotropy of the normal anisotropy coefficient Δr is calculated according to the equation:

$$\Delta \boldsymbol{r} = (\boldsymbol{r_0} - 2\boldsymbol{r_{45}} + \boldsymbol{r_{90}})/2 \qquad (2).$$

According to the value of Δr, it is possible to determine the susceptibility of the plate to ear formation in deep drawing.

The ears are being formed in the direction of the sheet in which the value of the normal anisotropy coefficient "r" is at maximum. If $\Delta r > 0$, the ears will be formed in the directions of 0° and 90° with respect to the rolling direction, if $\Delta r = 0$ the ears are not being formed and if $\Delta r < 0$ the ears will be formed in the direction of 45° with respect to the rolling direction. The greater the absolute value of Δr, the larger the ears [2-5].

The value of Δr is related to the degree ΔH of ears creation calculated according to (3). The degree of ears creation represents the average height of cup. The ears creation of the cups is characterized as an unsuitable property of deep-drawn sheets, which arises due to surface (planar) anisotropy [1,4].

The degree of ears creation: $$\Delta H = (H_0 - 2H_{45} + H_{90})/2 \qquad (3),$$

where:

H_0 - the height of the cup in the 0° direction relative to the rolling direction [mm],
H_{45} - the height of the cup in the 45° direction relative to the rolling direction [mm],
H_{90} - the height of the cup in the 90° direction relative to the rolling direction [mm].

Coefficient of ears creation: $$Z = \frac{(H_{max} - H_{min})}{H_{\min}} . 100 \quad [\%] \qquad (4).$$

For the evaluation of the ear's creation of cylindrical cups, it is appropriate to use the ΔH degree of ears creation, especially because it indicates the average value of the height of cups. For the evaluation of asymmetric shaped cups, it is appropriate to use the coefficient of ears creation because it captures the percentage value of the ears for a given orientation of the cut in the device.

II. MATERIALS AND METHODS

Multiphase steel plates were used for the experiment:

- microalloyed steel H220 Z100MBO, thickness a_0 = 0.80 mm, marked "A",
- steel with transformation-induced plasticity TRIP RAK40/70 Z100MBO, thickness a_0 = 0.75 mm, marked "B".

The evaluated steel sheets "A" and "B" were galvanized on both sides, where the amount of zinc was 100 g/m^2 (designation Z100MBO).

The chemical composition of the experimental material obtained by the Belec Compact Port Spectrometer is (in %) for the materials are listed in Tables 1-2.

Tab. 1 Chemical composition for Material A

	C	Mn	P	S	Ti	Si	
A	0.004	0.415	0.042	0.004	0.037	0.1	
	Al	Cr	Cu	Ni	Nb	Zr	Mo
	0.035	0.031	0.011	0.017	0.026	0.007	0.005

Tab. 2 Chemical composition for Material B

	C	Mn	P	S	Ti	Si	
B	0.204	1.683	0.018	0.003	0.009	0.2	
	Al	Cr	Cu	Ni	Nb	Zr	Mo
	1.73	0.055	0.028	0.018	0.004	0.007	0.008

Uniaxial tensile test

The uniaxial tensile test was carried out on the TIRA test 2300 in accordance with STN EN ISO 6892-1, by which the main mechanical properties of the materials tested were obtained. The samples were taken at 0°, 45° and 90° angles with respect to the rolling direction. The number of samples taken in each direction was three.

The measured and calculated values of the experimental materials from the tensile test are shown in Tables 3-4.

Tab. 3 Mechanical properties and coefficient of normal anisotropy of steel A

Direction [°]	$Rp_{0,2}$ [MPa]	Rm [MPa]	A [%]	Δr
0°	219	385	34.5	-0.285
45°	225	368	37.4	
90°	238	383	35.8	

Tab. 4 Mechanical properties and coefficient of normal anisotropy of steel B

Direction [°]	$Rp_{0,2}$ [MPa]	Rm [MPa]	A [%]	Δr
0°	442	771	27.7	-0.108
45°	441	762	25.4	
90°	450	766	25.9	

Cupping test for cups with an internal diameter of 31mm and the effect of annealing temperature on the change in ears formation

In the cupping test, cylindrical flat-bottomed cups were drawing from circular cuts of 52-, 60- and 68-mm diameter. The test was evaluated from three test samples made from each test material and from the three test diameters of the cut. The experiment was carried out on microalloyed steel "A" and on steel with transformation-induced plasticity "B".

The experimental drawing device used for this test had the following parameters:

- diameter of the drawing punch d_{te} = 33mm,
- diameter of the die d_{tk} = 31mm,
- tensile blank gap t_m = 1mm,
- semi-diameter of curvature of the drawing punch r_{te} = 4.5mm,
- semi-diameter of curvature of the die r_{tk} = 6.0mm.

The cupping test was carried out for the contact friction limit conditions - drawing with the use of a lubricant.
The cups with an inner diameter of 31mm in the basic state (unaffected by heat treatment) were compared with the cups after annealing of the Fe-Zn layer. The samples were sheared from the annealed sheets and further heat treated at 550 °C for 10 and 60 seconds. The temperature of the samples was verified by contact thermocouple, after annealing the samples were air cooled. Subsequently, cups were drawn from the samples.
The heights of the cups were measured in the basic state and in the post-annealed state at 550 °C for 10 and 60 seconds for both materials examined.
The measured data were statistically processed and the ΔH degree of ears creation was calculated from these values (Tables 5-6).

Tab. 5 Values of cup heights and degree of ears creation for microalloyed steel A

With lubricant	Diameter of blank D_0 [mm]	H_0 [mm]	H_{45} [mm]	H_{90} [mm]	ΔH [mm]
A	**52**	15.40	15.66	15.46	-0.23
	60	22.49	22.91	21.98	-0.68
	68	30.64	31.82	30.23	-1.38
A 550 ^{0}C/10s	**52**	15.83	15.54	15.61	0.18
	60	22.57	22.99	22.29	-0.56
	68	30.73	31.94	30.53	-1.31
A 550 ^{0}C/60s	**52**	15.75	15.40	15.62	0.29
	60	22.27	22.84	22.14	-0.64
	68	30.19	31.89	30.8	-1.76

Tab. 6 Values of cup heights and degree of ears creation for steel with transformation-induced plasticity B

With lubricant	Diameter of blank D_0 [mm]	H_0 [mm]	H_{45} [mm]	H_{90} [mm]	ΔH [mm]
B	**52**	15.7	15.12	14.90	-0.14
	60	21.55	21.90	21.50	-0.37
	68	30.50	30.78	30.23	-0.45
B 550 ^{0}C/10s	**52**	15.15	15.6	15.11	0.07
	60	21.68	22.1	22.29	-0.34
	68	30.76	30.96	30.68	-0.24
B 550 ^{0}C/60s	**52**	15.8	15.14	15.7	-0.07
	60	21.72	22.3	21.59	-0.38
	68	30.9	30.71	30.14	-0.59

The dependence of the degree of ears creation on the diameter of the cut for cups with an inner diameter of 31mm in the basic state and after annealing at 550 °C with a dwell time of 10 and 60 seconds is shown in Fig. 1.

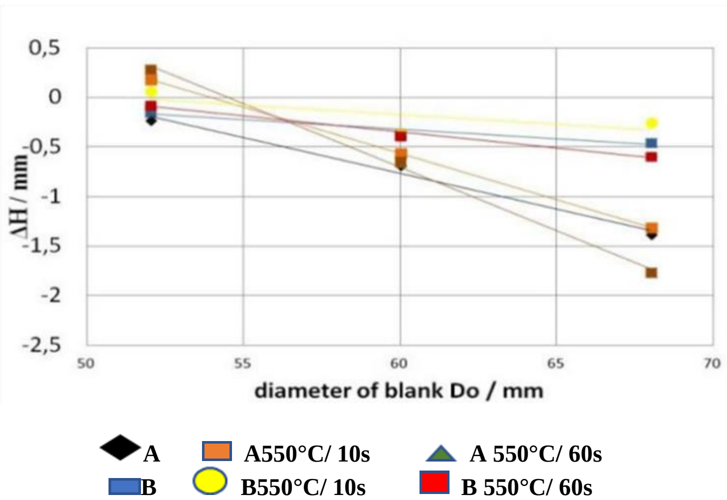

Fig. 1 Dependence of the degree of ears creation on the diameter of the cut

III. RESULTS AND DISCUSSION

The 31mm inner diameter cups drawn from "A" steel exhibit ears in the 45° direction with respect to the rolling direction, which is consistent with the calculated negative value of the coefficient of normal anisotropy $\Delta r = -0.285$. After annealing, higher absolute values of the degree of ears creation ΔH were obtained compared to the baseline condition. We consider this fact as an unfavourable consequence.

The cups drawn from the "B" steel exhibit ears also in the 45° direction with respect to the rolling direction, which agrees with the calculated negative value of the coefficient of normal anisotropy $\Delta r = - 0.108$. After annealing at T = 550 °C with a dwell time of 10 seconds, the absolute value of the degree of ears creation ΔH decreased, but the tendency for the height of the ears to increase with increasing diameter of the cut D_0 remained. At T = 550 °C with a dwell time of 60 seconds, the absolute value of the degree of ear creation ΔH increased and higher degrees of ear creation ΔH were achieved with increasing diameter of the D_0 cut compared to the baseline condition.

IV. CONCLUSION

Based on the measured and calculated values we may conclude:

- The degree of ears creation ΔH calculated by (3) agrees with the calculated sign of the normal anisotropy coefficient number Δr. After annealing at T = 550 °C with a dwell time of 10 seconds, the absolute value of the degree of ears creation ΔH decreased compared to the baseline condition. After annealing at T = 550 °C with a dwell time of 60 seconds, the absolute value of the degree of ears creation ΔH increased compared to the baseline. In this case, the heat treatment of the steel had a positive effect.
- From Fig. 1 shows that the value of the degree of ears creation ΔH decreases with the increase of the cut diameter D_0 of the microalloyed steel "A" and the steel with transformation-induced plasticity "B".

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