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Evaluation of Drawability of Selected Types of Steel Sheets

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ABSTRACT

Presented article deals with the evaluation of drawability of steel sheets. Drawability was evaluated by the normal anisotropy ratio and by mean ear height during deep-drawing with and without lubricant. In the experimental research, two types of steel sheets were examined – deep-drawing steel DC 06 and TRIP RAK40/70 steel with transformation-induced plasticity. The ratio of normal anisotropy of the examined materials was evaluated based on the tensile test results. Earing was evaluated by a cupping test on blanks with different size with punch diameter of 69.15 mm. Thickness of tested sheets was 0.75 mm.

Keywords *– TRIP steel, deep-drawing steel, ratio of normal anisotropy, earing*

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I. INTRODUCTION

Increasing interest in the environment and gradual depletion of fossil fuels are forcing the automotive industry to implement strict government regulations while meeting customer demands for improved fuel efficiency. Designers are forced to find new high-performance and lightweight materials in order to improve fuel efficiency while meeting aesthetic and safety requirements [1-3].

In addition to this, the development of materials for automotive production faces, among other things, the pressure to achieve several conflicting technological obstacles, such as high ductility, weldability, drawability, connectivity, sufficient rigidity or high strength of materials to ensure passenger safety [4, 5].

In this paper, we will evaluate drawability of high-strength steels compared to classic deep-drawing steels. The sheet metal quality evaluation criterion for deep-drawing will be the sheet quality evaluation scale according to the normal anisotropy, which was designed by The International Deep Drawing Research Group (IDDRG).

II. MATERIALS FOR EXPERIMENT

For experimental research were used two grades of steel sheets – deep-drawing steel DC06BZE75/75PHOL (marked M1) and steel with transformation-induced plasticity TRIP RAK40/70 Z100MBO (marked M2). The evaluated steel sheets M1, M2 were electrolytically galvanized on both sides, M1 with a zinc amount of 75 g/m^2 and M2 with a zinc amount of 100 g/m^2. The chemical composition of the examined sheets is given in Tab.1.

Tab. 1 Chemical composition of materials [%]

	C	Mn	P	S	Ti	Si	Al	Cr	Cu	Ni	Nb	Mo	Zr
M1	0.02	0.25	0.02	0.02	0.3								
M2	0.205	1.683	0.018	0.003	0.009	0.2	1.73	0.055	0.028	0.018	0.004	0.008	0.007

III. EVALUATION OF MATERIAL FORMABILITY BY UNIAXIAL TENSILE TEST

The uniaxial tensile test is currently the most widely used test in which the basic mechanical properties of the materials are obtained. The conditions and dimensions of the test samples are specified in the standards STN EN ISO 6892-1 and STN 42 0321. The common properties measured by the uniaxial tensile test of thin steel sheets include the yield strength, tensile strength and ductility.

To obtain the anisotropic properties of the materials, samples were taken for the tensile test in the direction of 0°, 45° and 90° with respect to the rolling direction. Three samples cut in each direction were used in tensile test for both materials.

Tab. 2 shows the quality of deep-drawing sheets on the basis of mechanical properties according to IDDRG and standard STN 42 0127.

Tab. 2 Evaluation of sheet metal quality according to the mechanical properties

$R_{P0,2}$ [MPa]	A_{80} [%]	r_m	n_m	IDDRG	STN 42 0127
<180	>40	≥ 1.65	≥ 0.23	EDDQ-S	VT
180÷200	38÷40	1.50 ÷ 1.65	0.21 ÷ 0.23	EDDQ	HT
200÷240	36÷40	1.30 ÷ 1.50	0.18 ÷ 0.21	DDQ	ST
>240	28÷36	0.90 ÷ 1.3	0.15 ÷ 0.18	DQ	MT

The values of mechanical properties obtained from the uniaxial tensile test for the material M1 are given in Tab. 3 and for material M2 in Tab. 4.

Tab. 3 Mechanical properties of M1

Direction [°]	$R_{p0.2}$ [MPa]	R_m [MPa]	A_{80} [%]
0°	138	277	53.0
45°	142	282	50.4
90°	141	277	51.7

Tab. 4 Mechanical properties of M2

Direction [°]	$R_{p0.2}$ [MPa]	R_m [MPa]	A_{80} [%]
0°	442	771	27.7
45°	441	762	25.4
90°	450	766	25.9

Normal anisotropy ratio

Evaluation of the normal anisotropy ratio was performed according to the standard STN 42 0401. Samples of materials M1 and M2 were tested in the directions 0°, 45° and 90° with respect to the rolling direction. Three samples were evaluated for each direction. The obtained values of the normal anisotropy ratio and planar anisotropy parameter Δr are given in Tab. 5 for M1 and for the material M2 in Tab. 6.

Tab. 5 Values of the normal anisotropy ratio and planar anisotropy parameter for M1

Direction [°]	$r_{avg.}$	r_m	Δr
0°	1.604	1.732	0.268
45°	1.598		
90°	2.127		

Normal anisotropy ratio has reached the minimum value in the direction of 45° and the highest value is in the direction of 90° for M1 with respect to the rolling direction of the sheet.

Tab. 6 Values of the normal anisotropy ratio and planar anisotropy parameter for M2

Direction [°]	$r_{avg.}$	r_m	Δr
0°	0.686	0.816	- 0.108
45°	0.870		
90°	0.838		

Normal anisotropy ratio reached the lowest value in the direction of 0° and the highest value is in the direction of 45° for M2 with respect to the rolling direction of the sheet.

According to the scale of sheet metal quality evaluation based on the value of the average normal anisotropy ratio (Tab. 2) qualitative evaluation of the examined sheets is given in Tab. 7.

Tab. 7 Qualitative evaluation of M1 and M2

Material	Des.	r_m	Quality category
DC 06BZE75/75PHOL	M1	1.732	EDDQ-S
TRIP RAK40/70 Z100MBO	M2	0.816	DQ

Earing evaluation

To evaluate drawability of the experimental materials, we performed a cupping test. The test was performed on a hydraulic machine ZD 40 with a tool to test the drawability of thin sheets. This test imitate the deep-drawing process and its results well describe their behavior during deep-drawing.

The test was performed to evaluate the earing of experimental materials. The tool for the cupping test (Fig.1) has exchangeable functional parts - a punch and a die for testing different sheet metal thicknesses.

Fig. 1 Tool for cupping test

According to the value of Δr, it is possible to determine the susceptibility of the sheet to form earing during deep-drawing. Ears are formed in sheet directions in which the value of the normal anisotropy ratio r is maximum. If:

- Δr > 0 – ears will form in 0° and 90° to the rolling direction
- Δr = 0 – ears will not form
- Δr < 0 – ears will form in 45° direction to the rolling direction

Earing of the cups was evaluated by the ear height expressed as a percentage and by mean ear height. The values of mean ear height were calculated from the relation (1).

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

Where: ΔH – mean ear height [mm]

H_o, H_{45}, H_{90} – cup height in the direction of 0°, 45° and 90°, with respect to the rolling direction [mm] (Fig.2).

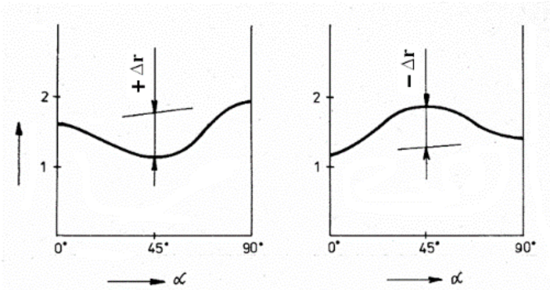

Fig. 2 Planar anisotropy Δr

The values of the ear height expressed as a percentage were calculated from the relation (2) :

$$Z = \frac{Hmax - Hmin}{Hmin}.100\ [\%] \qquad (2)$$

Where: Z – ear height expressed as a percentage [%]

H_{max}, H_{min} - maximum and minimum cup height [mm]

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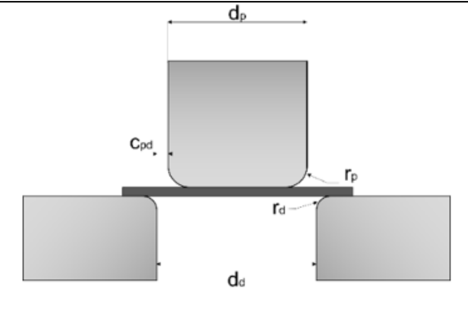
During cupping test, cylindrical cups were formed from circular blanks of diameters 119, 123, 128, 133, 138, and 144 mm. Parameters of experimental tool are in Tab. 8.

Tab. 8 Tool parameters



Parameters	Length [mm]
Die diameter - d_d	71.25
Punch diameter - d_p	69.15
Clearence between punch and die - c_{pd}	1.05
Punch radius - r_p	6
Die radius - r_d	6

From each blank diameter, three cylindrical flat-bottomed cups were drawn, on which the height was subsequently measured in eight places around the circumference of the cup (Fig. 3). In the direction of 0° twice, in the direction of 45° four times and in the direction of 90° twice.

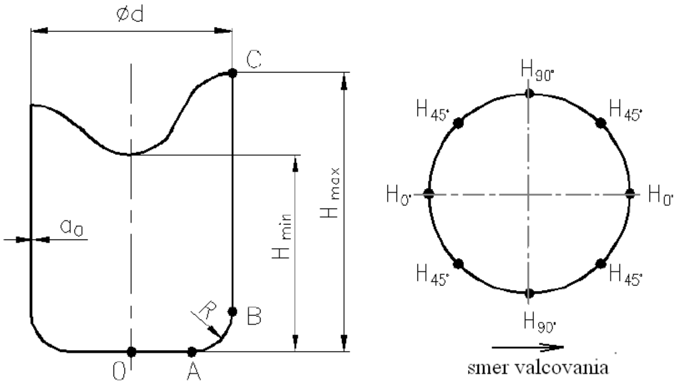


Fig. 3 Flat bottom cylindrical deep-drawn cup

The average values of the ears heights were calculated from the measured values for the individual directions. From these height averages, average values were figured for cups drawn from the same diameter of the blank. Subsequently, we calculated the mean ear height ΔH according to (1) and the ear height expressed as percentage Z according to (2). Tab. 9 contains the measured values for cups without the use of lubricant and Tab. 10 shows values with the lubricant, to reduce friction between the die and the materials.

Tab. 9 Measured values for M1 and M2 without lubrication

	Blank diameter [mm]	H_0 [mm]	H_{45} [mm]	H_{90} [mm]	ΔH [mm]	Z [%]
DC06-Y (M1)	119	37.3	36.5	37.36	0.805	2.29
	123	41.8	40.83	41.63	0.887	2.38
	128	46.19	45	45.88	1.053	3.69
	133	51.39	50.8	52.33	1.104	3.1
	138	55.08	54.1	55.19	1.149	3.04
	144	61.75	60.7	61.6	1.159	3.80
RAK40/70 (M2)	119	34.75	34.6	33.74	-0.311	2.99
	123	38.77	38.29	37.17	-0.312	4.31
	128	42.93	42.3	40.98	-0.317	4.76
	133	46.41	46.8	46.34	-0.435	1.01
	138	51.83	52,9	52.71	-0.625	2.05
	144	58.1	59.5	59.14	-0.856	2.37

Cups from low-carbon deep-drawing steel DC06-Y (M1) shows earing in the 0° and 90° directions with respect to the rolling direction, which is in agreement with the calculated value of planar anisotropy Δr = 0.268.

Tab. 10 Measured values for M1 and M2 with lubrication

	Blank diameter [mm]	H_0 [mm]	H_{45} [mm]	H_{90} [mm]	ΔH [mm]	Z [%]
DC06-Y (M1	119	35.78	34.8	35.45	0.815	2.81
	123	39.85	38.76	39.12	0.824	2.91
	128	44.02	42.6	43.16	0.981	3.32
	133	48.87	47.6	48.39	1.024	2.65
	138	54.58	52.8	53.65	1.3	3.34
	144	60.71	58.7	59.81	1.525	3.36
RAK40/70 (M2)	119	34.54	34.74	33.91	-0.52	2.45
	123	38.13	38.33	37.51	-0.61	2.19
	128	41.89	42.29	41.22	-0.74	2.59
	133	46.58	46.91	45.34	-0.95	3.47
	138	51.69	52.12	50.70	-0.93	2.80
	144	58.13	58.23	56.45	-0.94	3.15

Cups from TRIP steel (M2) shows earing in 45° direction with respect to the rolling direction which is again in agreement with the calculated negative value of planar anisotropy Δr = - 0.108.
Dependence of mean ear height ΔH on the blank diameter without lubrication and with lubrication is shown in Fig. 4.

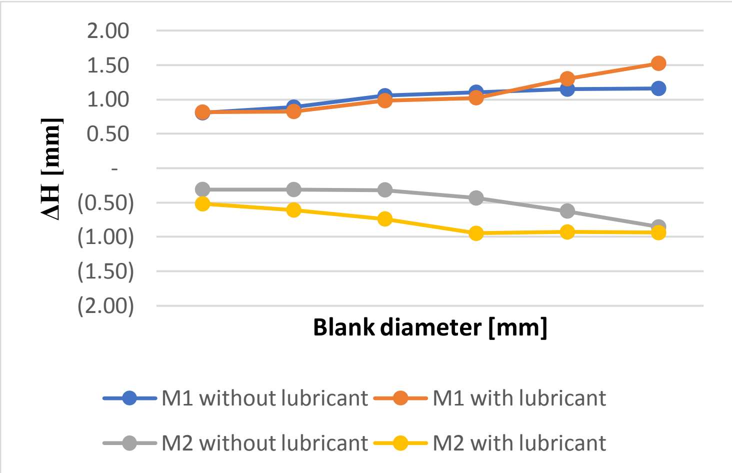


Fig. 4 Dependence of mean ear height ΔH on the blank diameter without and with lubrication

IV. CONCLUSION

In this paper, the deep-drawing properties of two types of steel sheets were evaluated - deep-drawing steel DC06 (M1) and steel with transformation-induced plasticity TRIP RAK40/70 (M2). Based on tensile test results has been evaluated normal anisotropy ratio. By the cupping test, mean ear height and ear height expressed as a percentage have been evaluated. Parameters were calculated on cups of 69.15 mm in diameter for both materials with and without the use of lubricant.

Based on the value of the normal anisotropy ratio, the examined material DC06 (M1) was classified to the EDDQ-S category and TRIP steel RAK40/ 70(M2) to the DQ category. The results of the cupping test show that the ΔH of the deep-drawing steel DC06 acquires positive values and TRIP of the steel RAK40/70 acquires negative values for the cups drawn with or without the use of lubricant.

As the diameter of the blank increases, the value ΔZ of deep-drawing steel DC06 increases during deep-drawing process with and without the use of lubricant. The value ΔZ of cups from TRIP steel RAK40/70 increases with a diameter of 119 - 128 mm and decreases from 133 - 144 mm during deep-drawing with or without the use of lubricant. Increase of the ΔH and ΔZ with increasing diameter we consider as an adverse effect.

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