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Evaluation of Limit Drawing Ratio of Selected Types of Steel Sheets

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ABSTRACT

High-strength steels have suitable mechanical properties to meet all the requirements of the end consumer while at the same time being economically suitable for the manufacturer and meeting strict environmental standards. The main use of these materials is in the automotive industry, where reducing the weight of cars and increasing passenger safety is required.

This article deals with the evaluation of the limit drawing ratio of two types of steel sheets - steel with transformation-induced plasticity TRIP RAK40/70 and deep-drawing steel DC06. The limit drawing ratio of the examined materials was evaluated by a deep-drawing cup test. In the experimental research, two cups with different diameters without and with the use of lubricant were produced and compared. The examined sheets had a thickness of 0.75 mm.

Keywords *– TRIP steel, deep-drawing steel, limit drawing ratio*

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I. INTRODUCTION

The development of materials for automotive production face pressure to achieve several conflicting obstacles such as reduction in the weight of the vehicle, high ductility, weldability, joinability, sufficient rigidity or high strength of the materials to ensure passenger safety.

In addition, is also important to ensure simple installation of the components, the resistance of the surface in a high demanding environment, while maintaining aesthetic properties. Along with these requirements, today's cars must meet standards that push for fuel saving and air protection, all under strong economic constraints [1-3].

As a result, the choice of material is a key decision in the construction design in automotive production. High-strength steels (HSS) have been proven to meet the above requirements as they offer a balance between keeping costs low, weight and good mechanical properties [4, 5].

The research is now focused on advanced high-strength steels (AHSS) and ultra-high-strength steels (UHSS), which mostly consist of martensitic steels. The AHSS category includes dual-phase and TRIP (Transformation induced plasticity) steels. All these groups of materials have suitable mechanical properties to meet all strict environmental standards, the requirements of the end customer along with economic accessibility for the manufacturer [1,3, 4].

In this paper, we will evaluate deep-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 limit drawing ratio, which was designed by The International Deep Drawing Research Group (IDDRG).

II. MATERIALS FOR EXPERIMENT

In the experimental research were used two grades of steel sheets - steel with transformation-induced plasticity TRIP RAK40/70Z100MBO (Designation: M1) and deep-drawing steel DC06BZE75/75PHOL (Designation 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 [%]

Designation	C	Mn	P	S	Ti	Si	Al	Cr	Cu	Ni	Nb	Mo	Zr
M1	0.205	1.68	0.02	0.003	0.01	0.2	1.73	0.05	0.03	0.02	0.004	0.008	0.007
M2	0.02	0.25	0.02	0.02	0.3								

The values of mechanical properties of the examined sheets obtained by uniaxial tensile test according to STN EN ISO 6892-1 are given in Tab.2.

Tab. 2 Mechanical properties of experimental materials

	Material	Type	Thickness [mm]	Rp 0.2 [MPa]	Rm [MPa]	A80 [%]
M1	TRIP RAK40/70 Z100MBO	TRIP	0.75	443	766	26.3
M2	DC06BZE75/75PHOL	DDS	0.75	140	278	51.7

III. EVALUATION OF THE LIMITING DRAWING RATIO BY DEEP-DRAWING CUP TEST

To evaluate deep-drawability of experimental materials, we performed a deep-drawing cup test. The test was executed on a hydraulic tearing machine ZD 40 with a deep-drawing tool to examinate the drawability of thin sheet metals.

This test imitates the deep-drawing process and its results well describe the drawability of thin sheets as well as their behavior during deep-drawing. The experiment was performed to determine the limit drawing ratio (LDR) of the experimental materials. The tool for the deep-drawing cup test (Fig.1) has exchangeable functional parts - a die and a punch for testing different sheet metal thicknesses.

The limiting drawing ratio is defined as the ratio of the drawn part diameter to the limit diameter of the blank. The method for determining the limiting drawing ratio is because the dependence of the deep-drawing force F_t on the diameter of the initial blank is linear.

The point at which the regression line intersects the line of maximum force (force required to tear off the bottom - F_{max}) determines limit blank diameter D_m on the x-axis. To calculate a regression line, measurements of the deep-drawing force F_t for both materials were performed for each diameter of the blanks.

Figure 1 Deep-drawing tool for cup test

According to STN 42 0127, low-carbon cold-rolled steel sheets are divided into drawing quality groups listed in Tab. 3.

Tab. 3 Evaluation of sheet metal quality according to the limit diameter ratio

LDR	Category
≤ 0.45	Extra Deep Drawing Quality-Super (EDDQ-S)
0.45 ÷ 0.48	Extra Deep Drawing Quality (EDDQ)

0.48 ÷ 0.50	Deep Drawing Quality (DDQ)
0.50 ÷ 0.55	Drawing Quality (DQ)

Deep-drawing cup test was performed for both experimental materials (thickness of 0.75 mm for both materials) with and without use of lubricant. The punch diameters were 69.15 mm and 147.8 mm.

Deep-drawing cup test for punch diameter of 69.15 mm without the use of lubricant
In this test cylindrical cups were formed without lubrication from circular blanks with diameter of 119, 123, 128, 133, 138 a 144 mm (Fig. 2). Punch diameter was 69.15 mm. From each type of blank were drawn three cups.

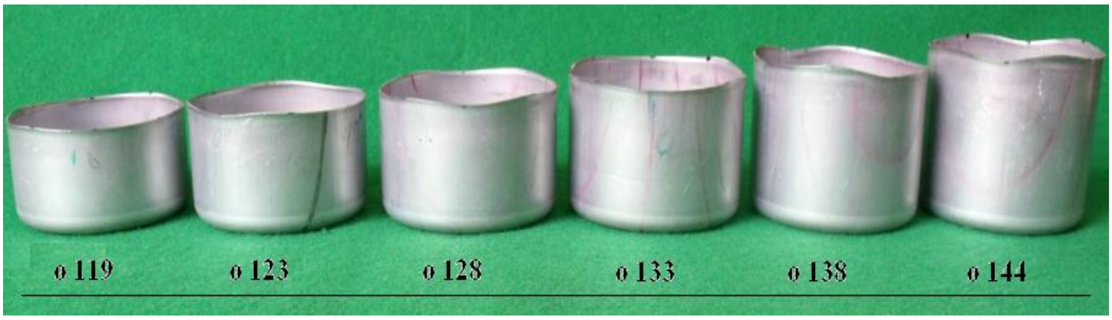
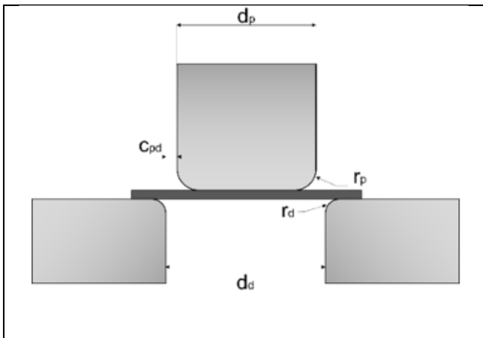


Figure 2 Cylindrical cups deep-drawn with 69.15 mm punch

Parameters of deep-drawing tool are given in Tab. 4.

Tab. 4 Deep-drawing 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

The measured maximum deep-drawing forces for the individual diameters of the blanks (F_{tmax}) and the bottom breaking force (F_{max}) for the samples of experimental material M1 and M2 are shown in Fig. 3. Limit blank diameter for M1 determined mathematically is D_{0max} = 143.94 mm. Limit drawing ratio in the first draw of examined material is LDR = 0.479.

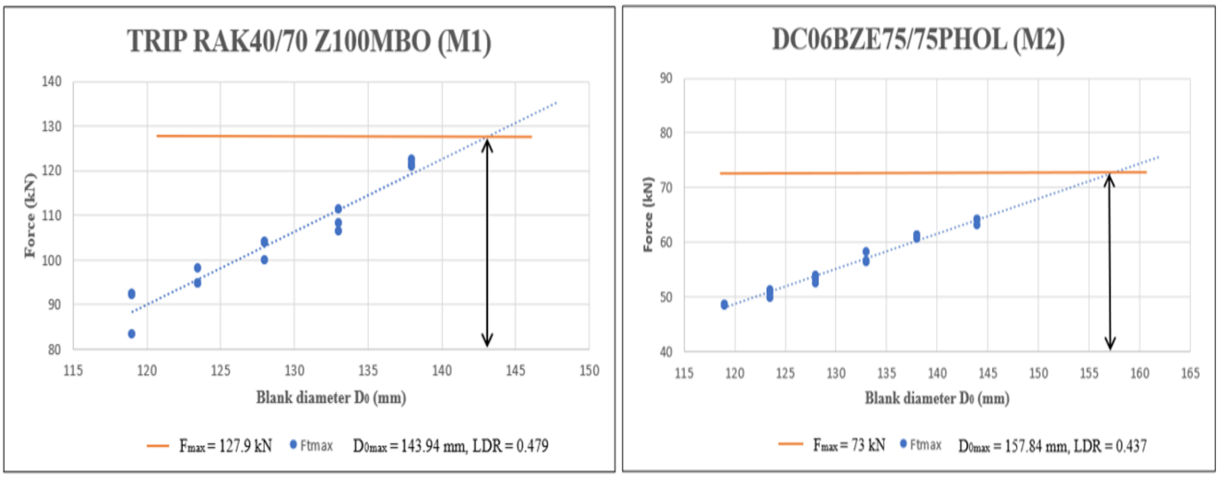


Figure 3 Limit blank diameter for M1 and M2 without lubrication

Limit blank diameter for M2 determined mathematically is D_{0max} = 157.84 mm. Limit drawing ratio in the first draw of examined material is LDR = 0.437.

Deep-drawing cup test with punch diameter 69.15 mm with the use of lubricant

In this experiment, a lubricant was used to reduce friction between punch and die and the test materials. The measured maximum deep-drawing forces for individual blanks (F_{tmax}) made of materials M1 and M2 are shown in Fig. 4. Limit blank diameter for M1 determined mathematically is D_{0max} = 154.28 mm.

Limit drawing ratio in the first draw of examined material is LDR = 0.447. Limit blank diameter for M2 determined mathematically is D_{0max} = 162.91 mm. Limit drawing ratio in the first draw of examined material is LDR = 0.423.

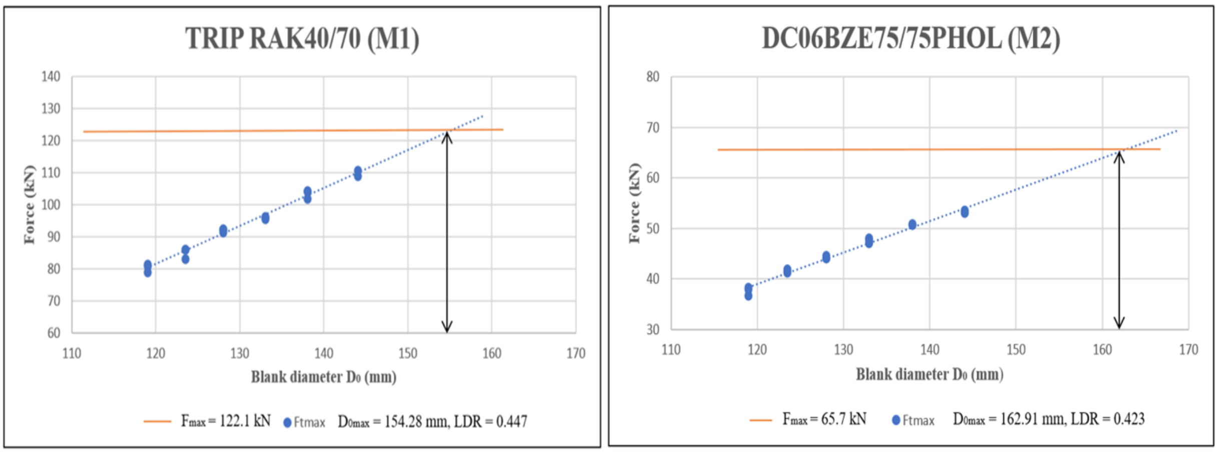


Figure 3 Limit blank diameter for M1 and M2 with lubrication

According to the scale for evaluating the quality of sheets depending on the size of the limit drawing ratio the examined sheets can be evaluated as is given in Tab. 5.

Tab. 5 Quality of material according to LDR

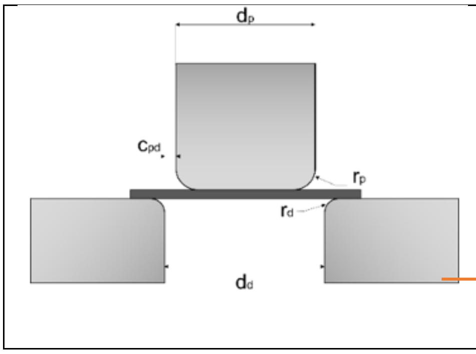
Material	LDR (without lubrication)	Quality category	LDR (with lubrication)	Quality category
M1	0.479	EDDQ	0.447	EDDQ-S
M2	0.473	EDDQ-S	0.423	EDDQ-S

With the use of a lubricant, the values of the LDR improved and for the M1 samples the category was also changed from EDDQ to EDDQ-S.

Deep-drawing cup test with punch diameter of 147.8 mm without the use of lubricant

In this test, cylindrical cups were drawn from circular blanks of 273, 300, 312, 333, and 345 mm diameter. The parameters of deep-drawing tools are shown in Tab. 6.

Tab. 6 Deep-drawing tools parameters



Parameters	Length [mm]
Die diameter - d_d	150
Punch diameter - d_p	147.8
Clearence between punch and diameter - c_{pd}	1.1
ı radius - ı	[illegible]
Die radius - r_d	8

F_{max} = 127.9 kN D_{0max} = 143.94 mm, LDR=0.479

The measured maximum deep-drawing forces from materials M1 and M2 are shown in Fig. 5. The TRIP steel samples (M1) was teared off a at diameter of 300 mm. For this reason, the test was also performed on blanks with diameter of 258 mm and 280 mm.

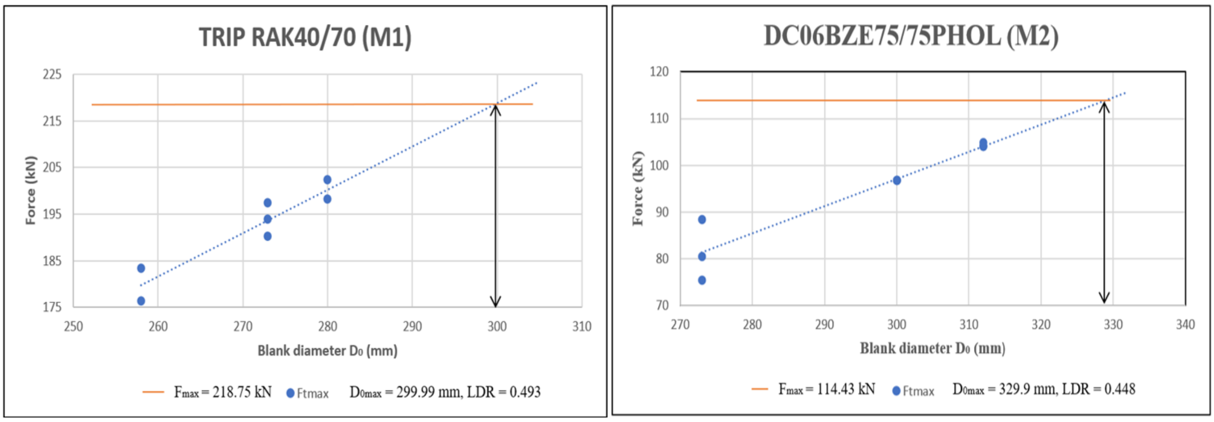


Figure 4 Limit blank diameter for M1 and M2 without lubrication

Deep-drawing cup test with punch diameter of 147.8 mm with the use of lubricant
In this experiment, a lubricant was used to reduce friction. The achieved maximum deep-drawing forces and maximum force (force required to tear off the bottom - F_{max}) of materials M1, M2 are shown in Fig. 6. Limit blank diameter for both materials was mathematically calculated.

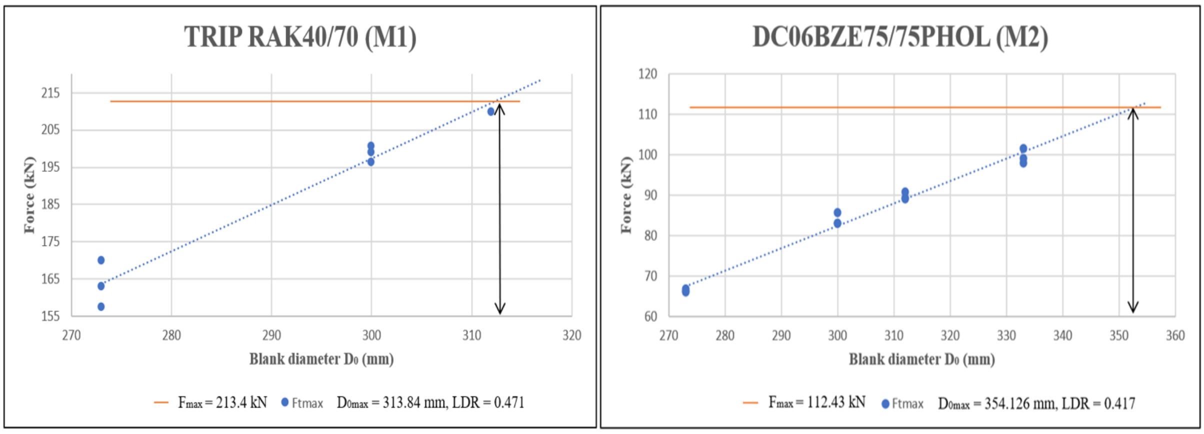


Figure 5 Limit blank diameter for M1 and M2 with lubrication

According to the scale for evaluating the quality of sheets depending on the size of the limit drawing ratio the examined sheets can be evaluated as is given in Tab.

Tab. 7 Quality of material according to LDR

Material	LDR (without lubrication)	Quality category	LDR (with lubrication)	Quality category
M1	0.493	DDQ	0.471	EDDQ
M2	0.448	EDDQ-S	0.417	EDDQ-S

With the use of a lubricant, the values of the LDR were improved for the samples made of M1 material by 4.5% and for the samples made of M2 material by 7%. For samples made of M1 material, the classification category was also changed from DDQ to EDDQ.

Fig. 7 shows a comparison of the LDR of the examined materials M1 and M2 without and with the use of lubricant and two different internal diameters of the punch.

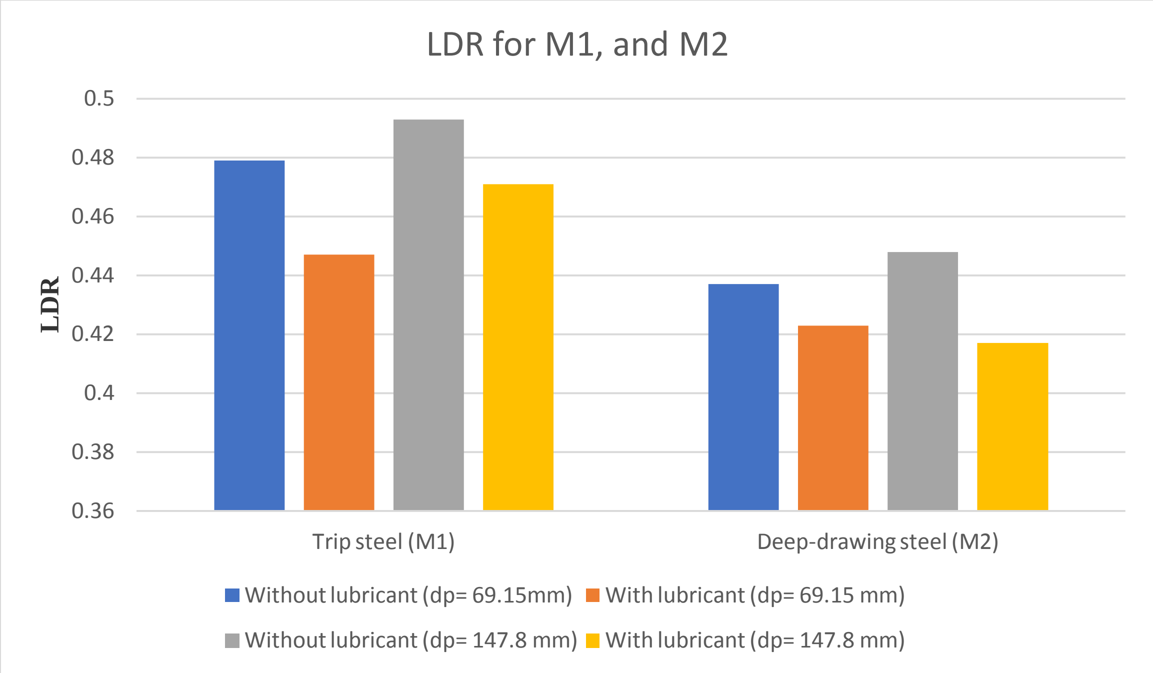


Figure 6 Comparison of LDR of materials M1 and M2

IV. CONCLUSION

In this paper, the limit drawing ratio of two types of steel sheets was evaluated – steel with transformation-induced plasticity TRIP RAK40/70 (M1) and deep-drawing steel DC 06 (M2). Limit drawing ratio of the cups with diameter of 69.15 mm and 147.8 mm was rated. Cups were drawn with and without lubricant.

The results of the deep-drawing cup test show that both examined materials have a lower LDR for both cups diameters when lubricant is used. At the same time, the use of a lubricant during deep-drawing changed the quality category of the TRIP steel. With a diameter of 147.8 mm the classification category was changed from DDQ to EDDQ.

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