# PROCESS FORMABILITY OF STEELS USED IN AUTOMOTIVE INDUSTRY

**E. Spisak, J. Hudak, M. Tomas**
*Department of Technologies and Materials,*
*Faculty of Mechanical Engineering, Technical University in Kosice*
*Slovak Republic*

*e-mail: Miroslav.Tomas@tuke.sk*

*Contribution deals with process formability evaluation of TRIP and HSLA steels, that were compared to typical deep drawing quality steel DC06. Process formability evaluation was performed by cupping test. Limit drawing ratio was used as a process formability criterion and drawing forces were measured during cupping test. There was used experimental-mathematic method for limit drawing ratio identification. HSLA steel H220PD with thickness 0,80 mm, TRIP steel RAK40/70 with thickness 0,75 mm and drawing quality steel DC06 with thickness 0,85 mm were used as experimental materials.*

**Keywords**
*deep drawing, process formability, AHSS steel, limit drawing ratio*

## 1. Introduction

The term formability of metals is a complex property involving plastic characteristics of formed materials (mechanical properties, coefficient of normal anisotropy, strain-hardening exponent, etc.) and specific conditions of forming process (stress and strain state, structural-technological parameters of the forming tools, friction, etc.). It is a criterion of natural resistance of the material at a specific stress system forced by forming process. [Mielnik 1991]

The term complex formability can be generally expressed by:

$$F_Y = f_1 \text{ (metal material) x } f_2 \text{ (process)}, \qquad (1)$$

where $f_1$ – function of basic formability (material), $f_2$ – function of external factors (process).

In general, when talking about the basic formability concerning the material, we refer to the material formability, or plasticity, and when talking about the mechanical working related to particular conditions of the forming process, we refer to the process formability, or technologic formability. [Mielnik 1991, Spisak, 2009, Bilik, 2010]

Basic plasticity assessment is executed by characteristic values of the basic indirect plasticity tests (tension, pressure). The results of the tests are quantitative indicators of plasticity, by which it is possible to evaluate the plastic properties of the material.

Technological tests, unlike the basic tests are carried out in very similar conditions close to the real conditions of technological methods. The results of the tests are quantitative indicators of material plasticity, taking into account the stress and strain state and specific conditions of particular test.

One of the most wide-spread technological tests is the Cup test, which corresponds to deep-drawing of cylindrical pressings. The Cup test can be considered as a comprehensive test where various types of cups bottom can be drawn – flat or hemispherical. These correspond to the limit cases of deep drawing – stretching (hemispherical bottomed cup) and deep drawing from flange (flat bottomed cup) – by which different stress strain state occurs during process.

During the Cup test of flat bottomed cup both main types of deformation (tension, pressure) occur. They can act in the processes of deep drawing, whereas the compressive stress dominates – tangential compression in the flange. The Cup test can be used for the determination of limit drawing ratio. The principle of the limit drawing ratio determination is the knowledge that dependance of limit drawing ratio on drawing force is linear [Pollakova 1996, Hrivnak 2004].

Category of cold rolled steel sheets for automotive industry should by divided into few groups: [Hrivnak 2004, Kvackaj 2006, Parilak 2005]
- textured low carbon steel sheets killed with aluminium;
- interstitial-free steel sheets – IF;
- bake hardenable steel sheets – BH;
- dual-phase steel sheets – DP;
- high strength low alloyed steel sheets – HSLA;
- transformation-induced plasticity steel sheets – TRIP.

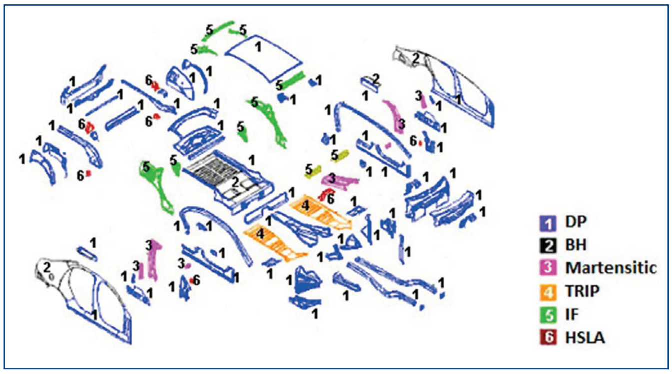


**Figure 1.** *Use of various kinds of steel in the car's body [Parilak,2005] [worldautosteel.org]*

Properties of mentioned steel sheets are controlled by both proper chemical concept and strengthening mechanisms (strengthening of solid solution by interstitial and substitution elements; dislocation strengthens; strengthening by grain boundaries, precipitation strengthens; transformation strengthens). The most dominant effect to steel properties shows transformation strengthening, even final steel properties depend on several strengthening effects altogether [Kvackaj, 2006, Parilak, 2005].

Possible use of various kinds of steel in car's body according to ULSAB concept is shown at Figure 1. As it is shown, each kind of steel is used for different car's body part (outside body, inside body, deformation zones, etc.). There are used different technologies for steel sheets processing whereby dominated are flat forming processes – deep-drawing, stretching, bending and cutting. Most complicated stress and strain state occurs at forming processes (deep-drawing, stretching). That is why the paper deals with process formability evaluation of Advanced High Strength Steels – high strength low alloyed steel and TRIP steel. These results are compared to process formability results of typical deep drawing steel DC.

## 2. Methods of experiment

### *2.1 Material*

Experimental works were done using followed steels sheets:
- high strength low alloyed steel sheet H220PD, initial thickness $a_0$ = 0,8 mm;
- transformation-induced plasticity steel sheet RAK40/70, initial thickness $a_0$ = 0,75 mm;
- drawing quality steel sheet DC06, initial thickness $a_0$ = 0,85 mm.

Steel sheets were galvanized, for H220PD and RAK40/70 zinc quantity was 100 g/m$^2$ (Z100MBO), for drawing quality steel sheet zinc quantity was 75 g/m$^2$ (BZE75/75PHOL).

Chemical composition of experimental materials is shown at Table 1. Mechanical properties, planar anisotropy of mechanical properties, normal anisotropy ratio and strainhardening exponent are shown

| | C | Mn | P | S | Ti | Si | Al | Cu | Ni | Nb | Mo | Zr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **H220PD** | 0,004 | 0,415 | 0,042 | 0,004 | 0,037 | 0,1 | 0,035 | 0,011 | 0,017 | 0,026 | 0,005 | 0,001 |
| **RAK40/70** | 0,204 | 1,683 | 0,018 | 0,003 | 0,009 | 0,2 | 1,73 | 0,028 | 0,018 | 0,004 | 0,008 | 0,007 |
| **DC06** | 0,020 | 0,250 | 0,020 | 0,020 | 0,300 | | | | | | | |

***Table 1.*** *Chemical composition of experimental materials [%]*

| | Direct. | $R_{P0,2}$ [MPa] | $R_m$ [MPa] | $A_{80}$ [%] | $PR_{P0,2}$ [%] | $PR_m$ [%] | $PA_{80}$ [%] | r | $r_m$ | Δr | n | $n_m$ | Δn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **H220PD** | 0° | 219 | 385 | 34,5 | | | | 1,172 | | | 0,235 | | |
| | 45° | 225 | 368 | 37,4 | 2,76 | –4,29 | 8,24 | 1,782 | 1,640 | –0,285 | 0,231 | 0,231 | 0,001 |
| | 90° | 238 | 382 | 35,8 | 8,38 | –0,69 | 3,67 | 1,823 | | | 0,229 | | |
| **RAK40/70** | 0° | 442 | 771 | 27,7 | | | | 0,686 | | | 0,295 | | |
| | 45° | 441 | 762 | 25,4 | –0,24 | –1,27 | –8,54 | 0,870 | 0,816 | –0,108 | 0,294 | 0,290 | –0,008 |
| | 90° | 450 | 766 | 25,9 | 1,80 | –0,72 | –6,64 | 0,838 | | | 0,278 | | |
| **DC06** | 0° | 145 | 292 | 50,8 | | | | 1,888 | | | 0,261 | | |
| | 45° | 151 | 298 | 47,9 | 4,25 | 2,09 | –5,75 | 1,464 | 1,753 | 0,576 | 0,255 | 0,258 | 0,005 |
| | 90° | 149 | 290 | 48,0 | 2,99 | –0,77 | –5,52 | 2,193 | | | 0,259 | | |

***Table 2.*** *Material formability parameters of experimental materials*

at Table 2. Presented material properties were measured according to standards: STN EN ISO 6892–1 – Tensile test, ISO 10113:2006 – Determination of plastic strain ratio, ISO 10275:2007 – Determination of tensile strain hardening exponent.

### *2.2 Process formability tests*

Cup test was realised to determination of limit drawing ratio of experimental materials. Cup test was realised under limit contact conditions: without lubricant and with plastic foil as a lubricant. There were drawn two nominal dimensions of cup diameter Ø 70 mm a Ø 150 mm.

Circular blanks used in cup test were cut by laser. Blanks diameter range for cup Ø 70 was 119, 123, 128, 133, 138, 144 mm and for cup Ø 150 it was 258, 273, 280, 300, 312, 333, 345 mm. Experimental drawing dies dimensions were follow:

| | **Ø 70** | **Ø 150** |
|---|---|---|
| – die diameter $D_{te}$ | 71,25 | 150,0 |
| – punch diameter $d_{tk}$ | 69,15 | 147,2 |
| – clearance $t_m$ | 1,05 | 1,4 |
| – punch radius $r_{tk}$ | 6 | 6 |
| – die radius $r_{te}$ | 6 | 8 |

During cup test the curves of drawing and blankholding forces were measured. Recording of drawing and blankholding forces was done using experimental measuring system created from follow subsystems (Figure 2):

1. double-action hydraulic press Fritz Müller BZE 100;
2. experimental drawing die;
3. flat bottomed circular cup;
4. measuring subsystem for record drawing and blankholding forces: force transducers (Figure 3 a), displacement transducer (Figure 3 b), frequency measuring amplifier (Figure 3 c), notebook.

Limit drawing ratio was determined mathematically [Polláková, 1996, Hrivňák, 2004]. For the individual diameters of blanks maximum drawing forces were evaluated which linearly increase with growing blank diameter. This linear relation between maximum drawing force and blank diameter was solved using regression analysis and regression line was calculated, from which after substitution of cup breaking force the limit drawing diameter was computed. Limit drawing ratio was then calculated

$$m_{limit} = \frac{d_{tk}}{D_{0\,max}} \qquad (2)$$

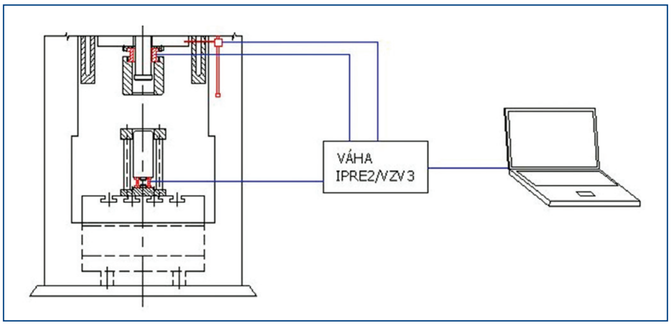


***Figure 2.*** *Experimental measuring system scheme*

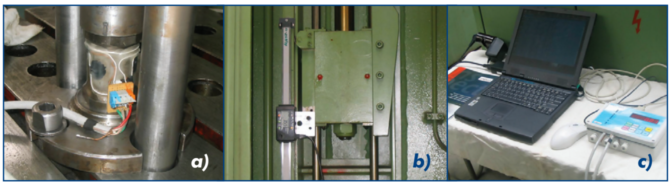


***Figure 3.*** *Experimental measuring system components – a) force transducer, b) displacement transducer Mitutoyo SD-60, c) frequency measuring amplifier IPRE2/VZV3*

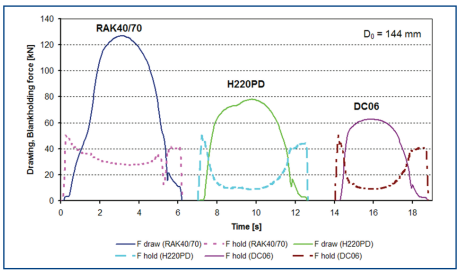


***Figure 4.*** *Drawing and blankholding forces (cup Ø 70 mm, blank D0 = 144 mm, without lubricant)*

Specific blankholding pressure during deep drawing process was chosen for HSLA steel H220PD and deep-drawing steel DC06 on the level of 1 MPa/mm$^2$. In case of TRIP steel RAK40/70 it was necessary to increase holding pressure to 2,5 MPa/mm$^2$ because the waves under the blankholder were created during the process due to the considerably higher material ultimate strength.

Drawing and blankholding forces during the deep drawing of cup with diameter Ø 70 mm from the blank diameter Ø 144 mm for each experimental materials are shown on the Figure 4.

## 3. Reached results

In regard to scope of experimental work (3 material qualities, 2 friction conditions and 2 cup diameters) are in the Table 3 and on the Figure 5 presented measured values of the maximum drawing forces and the way of limit drawing ratio evaluation only for steel TRIP, cup diameter Ø 70 mm and lubricant pvc foil.

| Blank diameter | Maximum drawing force | Averaged drawing force | Breaking force | Cup |
|---|---|---|---|---|
| $D_0$ | Ft max | Ft max average | F break | |
| [mm] | [kN] | [kN] | [kN] | |
| 119 | 81,4 | | | |
| 119 | 79,2 | 80,6 | | Good |
| 119 | 81,1 | | | |
| 123 | 86,1 | | | |
| 123 | 86,1 | 85,4 | | Good |
| 123 | 83,9 | | | |
| 128 | 91,6 | | | |
| 128 | 92,5 | 92,2 | | Good |
| 128 | 92,4 | | | |
| 133 | 95,7 | | | |
| 133 | 96,0 | 95,9 | | Good |
| 133 | 96,1 | | | |
| 138 | 104,4 | | | |
| 138 | 104,1 | 103,5 | | Good |
| 138 | 101,9 | | | |
| 144 | 110,7 | | | |
| 144 | 109,0 | 109,9 | | Good |
| 210 | 122,6 | | | |
| 210 | 121,6 | | 122,1 | Broken |

***Table 3.*** *Maximum drawing forces during cup test of TRIP steel RAK40/70 – cup Ø 70 mm, PVC foil as lubricant*

Evaluated values of limit drawing ratios for each experimental material, cup diameter and contact conditions are presented in the Table 4. Graphic illustration of the change of limit drawing ratio in relation to material properties yield point $R_{P0,2}$ and tensibility $A_{80}$ is shown on the Figure 6 and Figure 7.

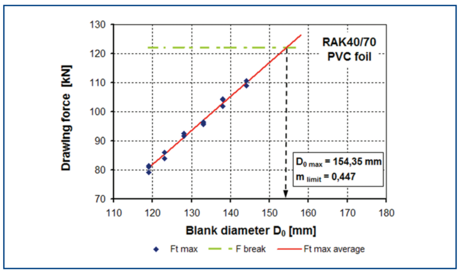


***Figure 5.*** *Principle of limit drawing diameter calculation (material TRIP steel RAK40/70, cup Ø 70 mm, PVC foil as lubricant)*

## 4. Conclusion

On the basis of the realized experimental works can point out:

1. According to reached value of limit drawing ratios during the cup test without using lubricant, which presents the most unfavourable case of the contact conditions, it is possible to classify the experimental materials on: deep-drawing steel DC06 (m = 0,448 – 0,437) by level EDDQ-S, HSLA steel H220PD (m = 0,451 – 0,443) on the edge of levels EDDQ and EDDQ-S and TRIP steel RAK40/70 (m = 0,493 – 0,479) by level DDQ.
2. Using of consistent lubricant pvc foil beneficially affects limit drawing ratio during the deep drawing from flange for experimental steels. Limit drawing ratio is lower by using of pvc foil for deep-drawing steel DC06 about 0,021 (cup Ø 70), or 0,023 (cup Ø 150), for HSLA steel H220PD about 0,019, or 0,018 and for TRIP steel RAK40/70 about 0,032, or 0,022 compared to the values reached at deep drawing without lubricant.
3. Limit drawing ratio is also affected by the dimensions of drawing die, for cup diameter Ø 150 mm were reached less beneficial values of limit drawing ratio compared to cup diameter Ø 70 mm

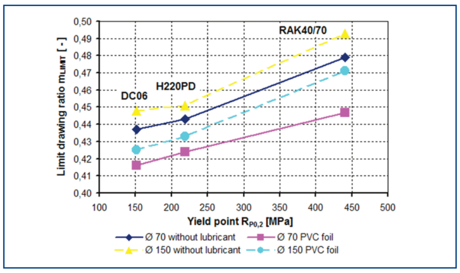


***Figure 6.*** *Dependency of limit drawing ratio on yield point RP0,2*

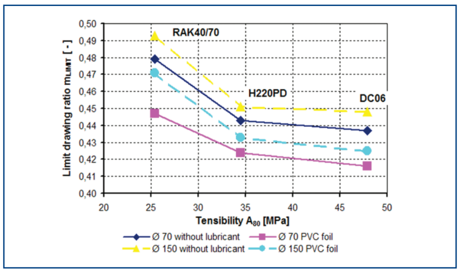


***Figure 7.*** *Dependency of limit drawing ratio on tensibility A80*

| | Cup diameter Ø 70 | | Cup diameter Ø 150 | |
|---|---|---|---|---|
| Material | Without lubricant | PVC foil | Without lubricant | PVC foil |
| DC06 | 0,437 | 0,416 | 0,448 | 0,425 |
| H220PD | 0,443 | 0,424 | 0,451 | 0,433 |
| RAK40/70 | 0,479 | 0,447 | 0,493 | 0,471 |

***Table 4.*** *Calculated limit drawing ratios*

for both limit cases of contact conditions. Grow of limit drawing ratio for deep-drawing steel DC06 is about 0,011 (without lubricant), or 0,009 (pvc foil), for HSLA steel H220PD about 0,008, or 0,009 and for TRIP steel RAK40/70 about 0,014, or 0,024.

4. Values of limit drawing ratios are proportional to the yield point and tensibility of the evaluated materials; the higher yield point and lower tensibility, the less beneficial value of limit drawing ratio.

**Acknowledgements**

The work was supported by Agency for support of research and development on the basis of Contract nr. APVV-0629-06 and Grant Agency VEGA, project nr. 1/0890/09.

**References**

**[Bilik, 2010]** Bilik, J., et al. Properties and formability of steel sheets DP 450. *Forging*, September 2010, no. 38, pp. 45-48. ISSN 1213-9289

**[Hrivnak 2004]** Hrivnak, A. and Evin, E. *Formability of steel sheets*. Kosice: Elfa, 2004. ISBN 80-89066-93–3

**[Kvackaj, 2006]** Kvackaj, T. Research of progressive steel not only for automotive industry. *Mechanical Engineering*, 2006, no. 5, 6, pp. 12–13. ISSN 1335 – 2938

**[Mielnik 1991]** Mielnik, E. M. *Metalworking science and Engineering*. New York: Mc Graw-Hill, Inc., 1991. ISBN 0-07-041904–3

**[Parilak, 2005]** Parilak, Ľ. , et al. Research of steels for automotive industry. *In: Workshop proceedings „MAT/TECH of automotive industry"*. Kosice, November 2005. Faculty of Mechanical Engineering Technical University of Kosice, pp. 78-84. ISBN 80-8073-400–3

**[Pollakova 1996]** Polláková, G. Experimental-mathematical determination of limit drawing ratio. *In: Conference proceedings "Steel Strips 96",* Opava, September 1996. Steel Strips Company, pp 285–290

**[Spisak 2009]** Spisak, E., et al. *Theory of conventional technologies*. Kosice, Faculty of Mechanical Engineering, 2009. ISBN 978-80-553-0201-0

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**Contacts:**

Ing. Miroslav Tomas, PhD.
Technical University in Kosice,
Faculty of Mechanical Engineering
Department of Technologies and Materials
Mäsiarska 74, 040 01 Kosice, Slovak Republic
tel.: +421 556 023 502, fax: +421 556 225 186
e-mail: Miroslav.Tomas@tuke.sk