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THE EFFECT OF FORMING HISTORY AND STRAIN RATE ON FORMING LIMIT DIAGRAMS

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ABSTRACT

Metal sheets produced from higher strength steels are now extensively used in the automotive industry. Products formed from these materials are used mainly for parts expected to resist high impact loading. This report presents FLD's determined at punch velocities from $2.08*10^{-4}$ *m/s up to 22.5 m/s. A special experimental stand, able to produce striking velocities up to 50 m/s, had to be built for these measurements. Limiting strains for selected materials are evaluated at different stress states. The effect of the forming history was evaluated on specimens already deep drawn and then loaded by high velocity impact till fracture. Different punch velocities, magnitude and direction of the first draw have influenced the limiting strains. Higher strength steel TRIP steel RAK 40/70 was used for the experiments. The research results should be used in the motorcar industry for design, manufacturing and crash test simulation.*
Keywords: strain rate, steel sheets, forming limit diagrams, deep drawing.

1. EXPERIMENTAL METHOD AND EQUIPMENT.

The most frequent and basic method used to establish mechanical properties of materials is the tensile test, standardized by different national and international standards (e.g, ČSN –EN 10002-01). This test is used to determine limiting strains only in one stress state (uniaxial tension) and therefore it gives partial information for the purpose of metal forming. During the production of stamped parts the material is subject to different stress states and it is therefore necessary to determine the respective limiting strains. For this, forming limit diagrams (FLD) are commonly used.
The method used to determine the effect of the strain rate on forming limits is basically a modified test used at the Department of Manufacturing Engineering in Liberec for determining the FLD. The prepared shaped specimens determining the different stress states are formed in a special die

see Fig.1. The punch nose has the shape of a half sphere and it is powered by the energy of pressurized air; the "air gun" is able to accelerate the punch up to the velocity of 180 km/h.
This equipment is used to determine forming limit diagrams with a striking velocity up to 108 km/h without any problems. For higher velocities it is necessary to use a bottom stop that will absorb the excess energy, which has not been consumed for forming the specimen. For our laboratory experiments punch velocities, $v_2 = 64$ km/h, $v_3 = 81$ km/h were used.
Forming limit diagrams determined at higher velocities should better correspond to ram velocities of mechanical presses used today for deep drawing in the automotive industry. The velocities were also selected with respect to the velocities used for crash testing.

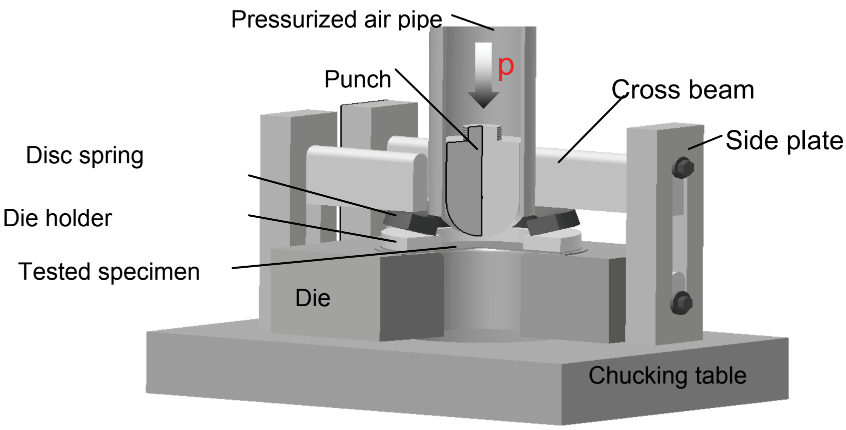


Figure 1 - Experimental die set.

The same experimental method has been used to find out the effect of former forming on the forming limits at higher punch velocities. The only difference is in the shape of used specimens; instead of flat blanks, specimens formed by a half spherical punch were used. The punch velocity was $v = 2.08*10^{-4}$ m/s, the magnitude of pre forming was selected as 1/3 of the height of the spherical segment which has been formerly used to reach the limiting strains, during the conventional FLD test.
Two methods of forming were used. Fig.2 shows the arrangement of the tests. In the first case the direction of movement of the punch is the same as the direction of movement of the punch for forming the specimen.

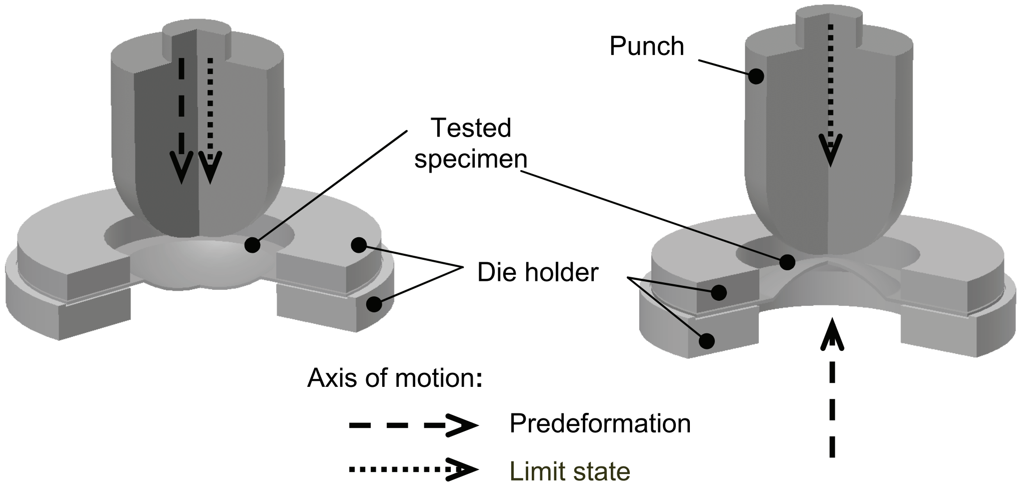


Figure 2 - Variants of tests (VAR A, VAR B)

2. MATERIAL USED FOR EXPERIMENTS.

The material used for experiments was RA-K 40/70. This material belongs to the group of higher strength TRIP steels (transformation induced plasticity) which are used mainly for manufacturing of crash resistant elements in the car body. Basic mechanical properties of the experimental material are given in table 1.

Table 1. Basic mechanical properties of RA-K 40/70 steel.

direction	$R_{p0,2}$ [MPa]	s	R_m [MPa]	s	A_{50} [%]	s	A_g [%]	s	r [-]	s
0°	459,01	2,54	760,83	3,08	27,79	0,71	20,71	0,69	0,784326	0,00183
45°	462,8	3,84	763,7	4,33	29,1	0,91	22,93	0,56	0,731719	0,00118
90°	461,12	6	762,7	3,8	28,75	2,22	23,2	0,73	0,914894	0,00367
x_s	461,43		762,73		28,69		22,44		0,790665	

3. EXPERIMENTAL RESULTS

In the following Fig.3 are plotted forming limit curves that were received experimentally at different striking velocities of the punch. Fig.4 presents the graphical results of measurements according to variants A and B (VAR A, VAR B). The difference between these two variants is in the initial position of the specimens; for A the spherical cup on the specimen has been formed in

the direction of the following impact of the punch, in the variant B the punch strikes on the top of the sphere, that means against the direction of previous deformation.
The key to the different curves in Fig.3 is as follows:

-The results from regression analysis after previous deformation of the specimens by $v_1 = 2.08 * 10^{-4}$ m/s

- FLD resulting from a standard test, punch velocity $v_1 = 2.08 * 10^{-4}$ m/s

- FLD for punch velocity $v_2 = 64$ km/hod

- FLD resulting from regression analysis on specimens previously deformed as

- Corresponding points, representing values of limiting strains and initial strains

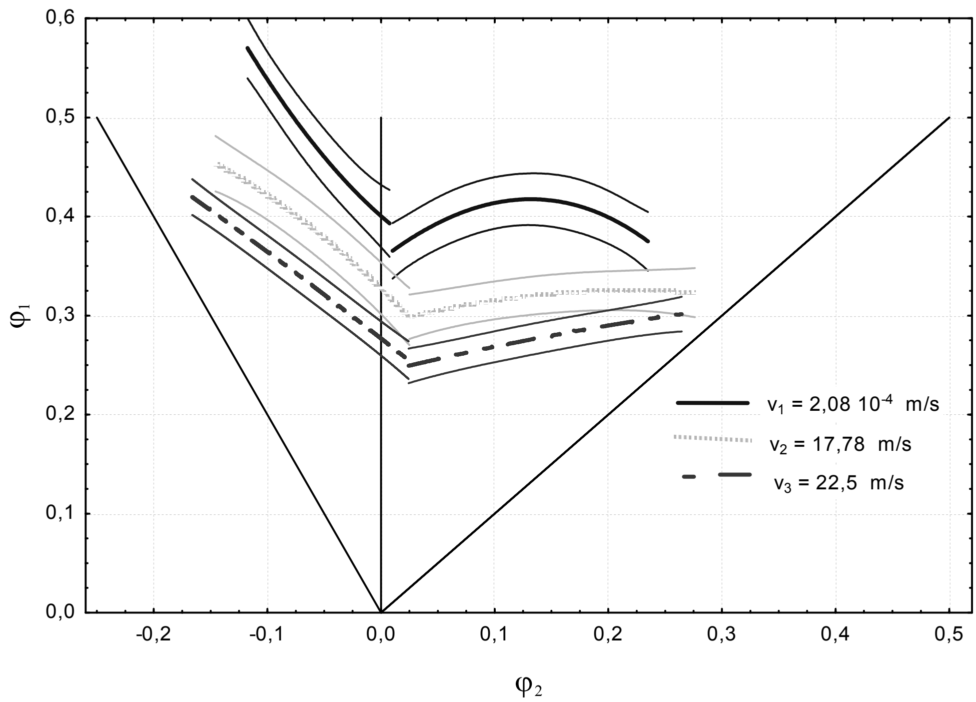
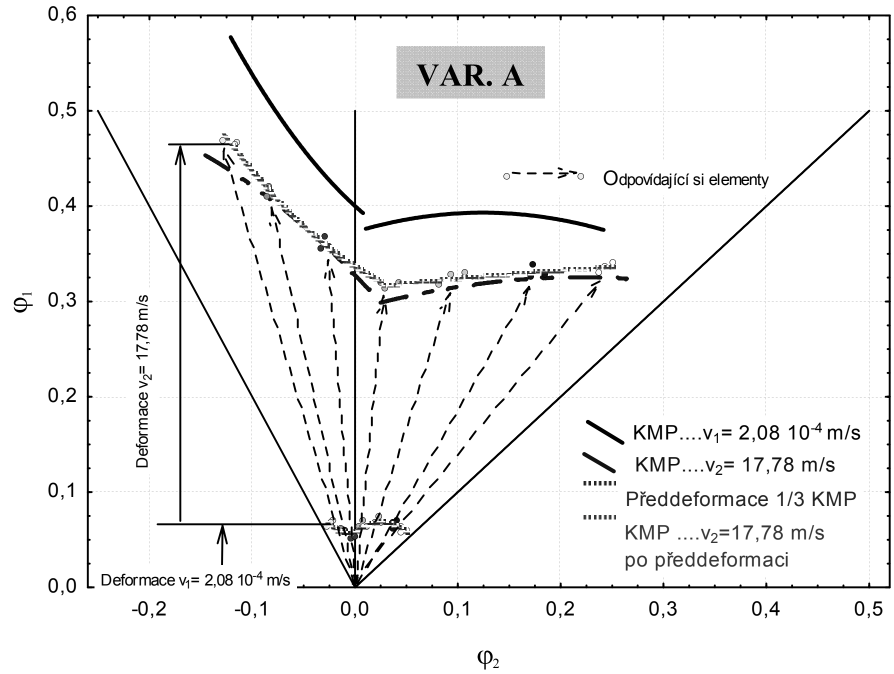


Figure 3 - FLD for different punch velocities



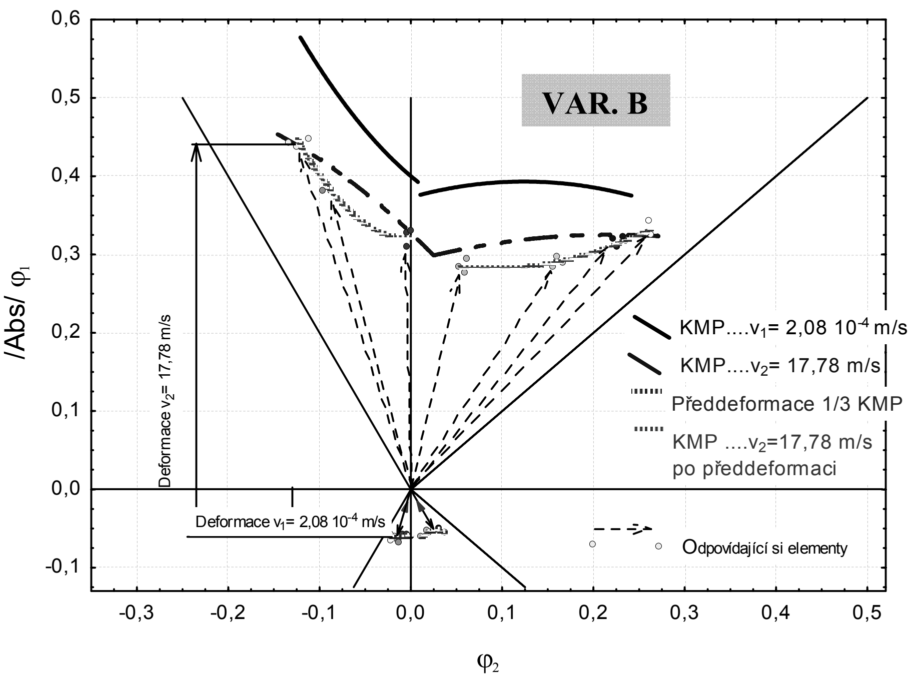


Figure 4 - FLD for v_2 = 64 km/h, material RAK 40/70, previous straining according to Var. A and Var. B

4. ANALYSIS OF RESULTS

From the experiments it is quite clear that with the increasing striking velocity of the punch (and that means growing strain rate) the limiting strains decrease. In the range of experimental velocities the forming limit curve shifts to lower values of limiting strains in an inverse proportion to the strain rate. The shift in the direction of lower strains φ_1 as a result of higher strain rate may reach up to 40%.

The effect of forming history is more complicated. The forming limit curves shift to higher values after forming in the same direction as was the direction of previous shaping of the specimen. The reason is that with the increasing magnitude of the first slow deformation (by the velocity v_1), the effect of higher striking velocity of the punch in the next step is eliminated. The result is that the FLD, lowered by higher strain rate increases its limits after forming according to VAR A.

Experiments according to VAR B (previous forming was done against the direction of movement of the striking punch) resulted in lower values of the limiting strains.

This is not always so, together with the described experiments on TRIP steels, some specimens made of complex phase steels were also tested and then the limiting strains were shifting to higher values even for VAR B. Such behaviour could be explained by the Bauschinger effect, but further research in this area is prepared.

As a result of the experiments we may state that to increase the load-carrying capacity of those stamped products, which have the greatest influence on crash tests results, it would be useful to form them in such a way that some compressive stresses will remain in them. As the cold forming of higher strength steels is usually possible only by simple forming operations as bending, this may be reached only for small bending radii. For larger area auto body stampings from thin sheets this will practically never be reached. On the other hand, in parts produced by hydro forming compressive stresses will remain.

5. CONCLUSIONS

The aim of this paper is to show the considerable effect of strain rate and forming history on the forming limit diagrams. From the comprehensive evaluation of the received results it is clear that with increasing strain rate the limiting strains decrease. This also corresponds to literature /3/. The evaluation of the strain history is not so simple. The paper includes results only for a limited range of experiments (striking punch velocity ´17.78 m/s and depth of cup 1/3 of the maximum) and one material only. It is certain that previous forming in the same direction always increases the forming limits reached by higher punch velocities. In the reverse direction it is necessary to consider the type and thickness of material.

At present the results are being used as reference points for the numerical simulation of crash tests. The results should help to analyse the behaviour of metal sheets during impact loading. In the future there may be some restrictions in the method of forming; the manufacturing engineer together with the designer can purposely decide about the shape of the product and method of forming with respect to maximum impact resistance. This will substantially increase the requirements on metal forming technology but at the same time it should increase the safety of the car body and safety is now a priority in the motorcar industry.

6. REFERENCES

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EFEKT ISTORIJE DEFORMISANJA I BRZINE DEFORMISANJA NA DIJAGRAM GRANIČNE DEFORMABILNOSTI

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REZIME

Limovi proizvedeni od čelika povišenih mehaničkih osobina se sve intenzivnije koriste u auto industriji. Od ovih limova izrađuju se odgovorni delovi koji su u eksploataciji izloženi velikim opterećenjima.
Ovaj rad prezentuje određivanje krive granične deformabilnosti (FLD) pri brzini žiga od $2.8*10^{-4}$ m/s do 22,5 m/s. Za tu svrhu konstruisana je specijalna eksperimentalna stanica na kojoj je moguće postići brzine i do 50 m/s. Određene su granične deformacije za različita naponska stanja. Uticaj istorije deformisanja je istraživan na uzorcima koji su predhodno duboko izvlačeni, a zatim opterećeni visokim brzinama, sve do loma. Ustanovljeno je da granična deformacija zavisi od brzine žiga i veličine i pravca prvog dubokog izvlačenja. Za eksperimentalna istraživanja korišćen je čelični lim TRIP RAK 40/70. Dobijeni rezultati mogu biti korišćeni u auto industriji prilikom projektovanja procesa konstrukcije i izrade odgovarajaćih delova od lima.