UTILIZATION OF HS CAMERAS FOR ANALYSIS DEFORMATION LIMIT STATES OF STEEL SHEETS

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Abstract

Knowledge of deformation limit states is the basic presumption for the proposal of all forming operations at stampings production. Deformation limit states of given material are greatly influenced by forming temperature, stress state and strain rate. Regarding the fact that common types of steel sheets are not formed under higher temperatures, size of limit deformation depends mainly on the stress state and the strain rate. For the technical community is the dependence of deformation limit states on the stress state commonly marked as forming limit diagram (FLD) and there are many experimental and numerical methods how to obtain so-called forming limit curve (FLC). Problem about strain rate on the deformation limit state is not so frequently discussed and in mostly cases it is just focused only on the research zone for uni-axial stress state. In this paper is evaluated influence of strain rate on the deformation limit state of TRIP steel at different stress states (from uni-axial up to bi-axial stress state). At experiment there is used pneumatic device which was designed and assembled at TU of Liberec and which makes possible to achieve the impact velocity of punch up to 30 m·s-1. Deformation analysis of tested samples was carried out by modern contact-less system ARAMIS in combination with high-speed (HS) cameras Photron SA3 which enables to scan processes under frequency up to 100 kHz. Results of experiments are presented by forming limit diagrams for chosen strain rates and by examples of deformation distribution on tested samples.

Keywords: Plastic Deformation, Stress, Strain Rate, Deformation Limit State, Optical Analysis, HS Cameras

1. INTRODUCTION

Beside basic mechanical properties of the formed material is so-called forming limit diagram (FLD) another material characteristic which determines deformation ability for given material under chosen temperature-rate conditions. Nowadays there are a lot of methods for determination FLD of formed material, however the most common method for determination FLC (forming limit curve) is still so-called Nakazima test. Principle of this test rests in stretching shaped samples by means of semi-spherical punch with diameter 100 mm. Advantage of this method is possibility to measure both left and right part of FLC. Regarding the fact that it is the most used method for determination FLC is the methodology how to perform test and evaluate deformation limit states for the tested material given by standard ISO/DIS 12004-2. Conditions to perform this test are in the given standard chosen regarding possibilities of common testing devices and there is also effort for easy evaluation of deformation limit state for tested material. Here the punch velocity is set on the value 1 mm/sec and achieved strain rates fully correspond to common strain rates that are used in real press-shops at forming. However for common methods of pressing where is strain rate deeply under the critical strain rate is measurement error acceptable and FLC measured like this are generally accepted at proposal and design of formed parts. Nevertheless it is important to take into account that proper lay-out for formed part is not only subject about trouble-free production but it is necessary to solve also problems about parts behavior during operating. Mainly at stampings designed into the car industry is necessary to make control of parts by so-called Crash tests where is part loaded by high strain rates and has to fulfill strict safety precautions [1].

2. METHODOLOGICAL BASE AND EXPERIMENTAL PART

Within the frame of experimental measurements there was carried out the static tensile test and tests for determination strain rate influence on the limit deformation of TRIP steel RA-K 40/70 under different stress states. For experiment was chosen three stress states (uni-axial tensile stress state, so-called plain strain stress state and equi bi-axial stress state). Results of measurement limit deformation for given strain rates are presented by FLCs (forming limit curves).

2.1. Static tensile test

The static tensile test is basic test for determination material mechanical properties and enables to get information about deformation abilities of the tested material [2]. In Table 1 are summarized measured mechanical properties for TRIP steel 40/70 for directions 0°, 45° and 90° regarding the rolling direction. Graphical illustration of measured results from the static tensile test is shown in Fig. 1.

Table 1 Mechanical properties of the tested material (TRIP steel RA-K 40/70, thickness 1.5 mm)

Rolling direction	**Yield strength** R_e [MPa]	**Ultimate strength** R_m [MPa]	**Uniform ductility** A_g [%]	**Total ductility** A_{50mm} [%]	**Strength coefficient** C [MPa]	**Strain-hardening exponent** n [1]	**Normal anisotropy coefficient** r [1]
0°	459.2	760.8	20.7	27.8	1423.1	0.2589	0.7843
45°	462.1	763.7	22.9	29.1	1421.4	0.2611	0.7317
90°	461.7	762.4	23.2	28.8	1433.5	0.2653	0.9148

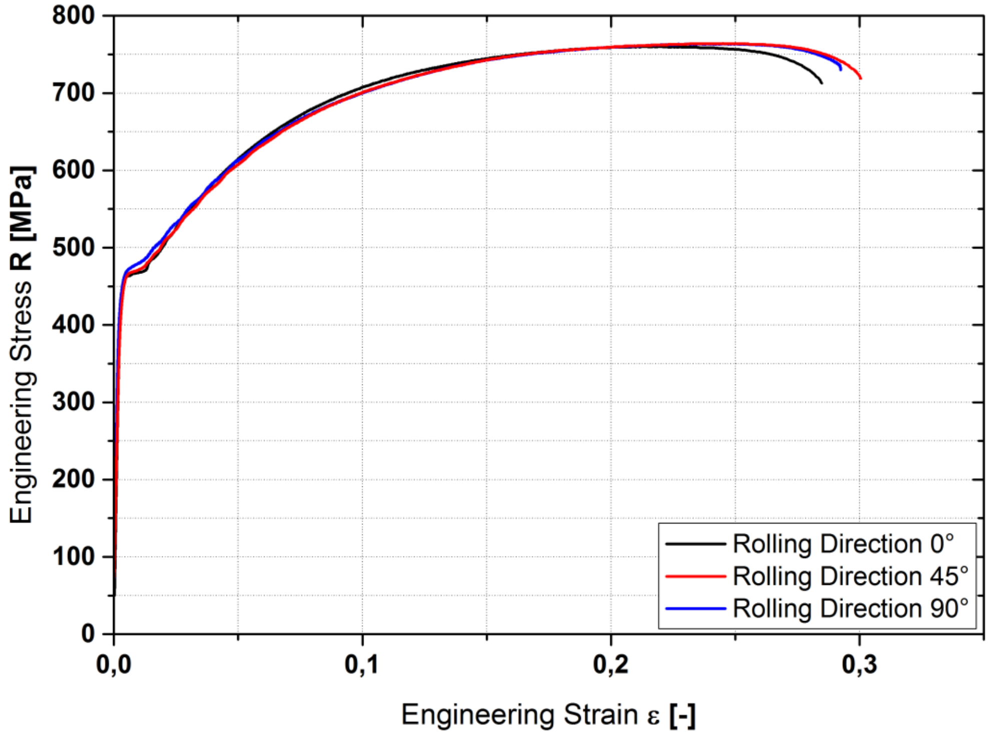


Fig. 1 Results from the static tensile test – material: RA-K 40/70

2.2. Nakazima test

To determinate deformation limit states there was used so-called Nakazima test whose principle is shown in Fig. 2 (left). Dimensions of testes samples from material RA-K 40/70 was chosen so that they characterized required stress states at testing. Uni-axial tensile stress state was achieved at sample with width 30 mm, plain strain stress state was achieved at sample with width 105 mm and equi bi-axial stress state was achieved at “full” blank with diameter 210 mm. Positions of points for limit deformation in FLC with these geometries of testing samples is schematically shown in Fig. 2 (right).

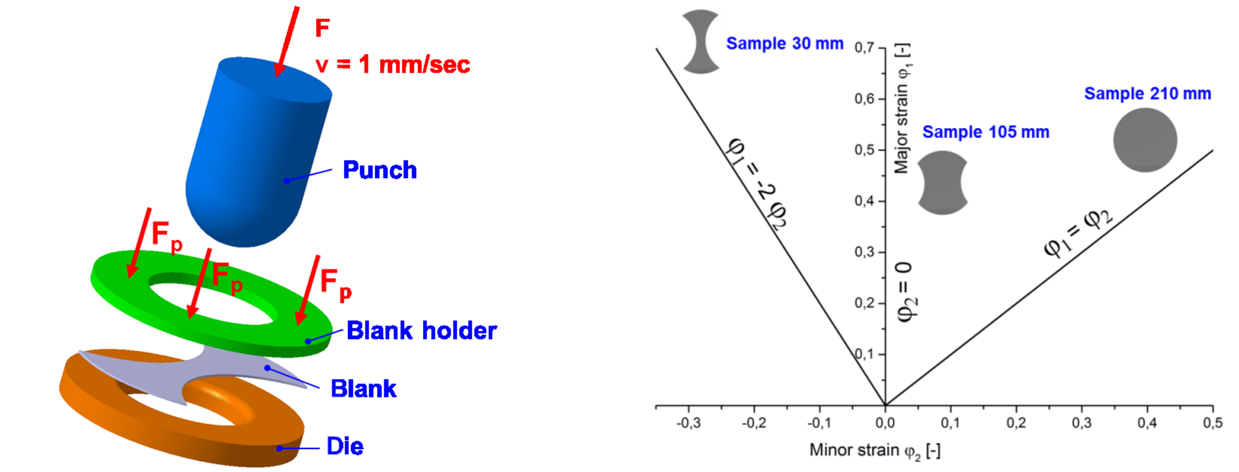


Fig. 2 Principle of Nakazima test (left) and shapes of testing samples (right).

Deformation of testing samples was measured by means of the contact-less optical system ARAMIS with data scanning frequency 12 Hz (12 frames per second). Methodology to carry out and evaluated test was chosen acc. to standard ISO/DIS 12004-2 [3]. Example of major strain φ_1 [1] distribution on the testing sample with width 30 mm measured by system ARAMIS is shown in Fig. 3 (left). Example of computation (or more precisely determination) deformation limit state acc. to ISO/DIN 12004-2 is shown in Fig. 3 (right).

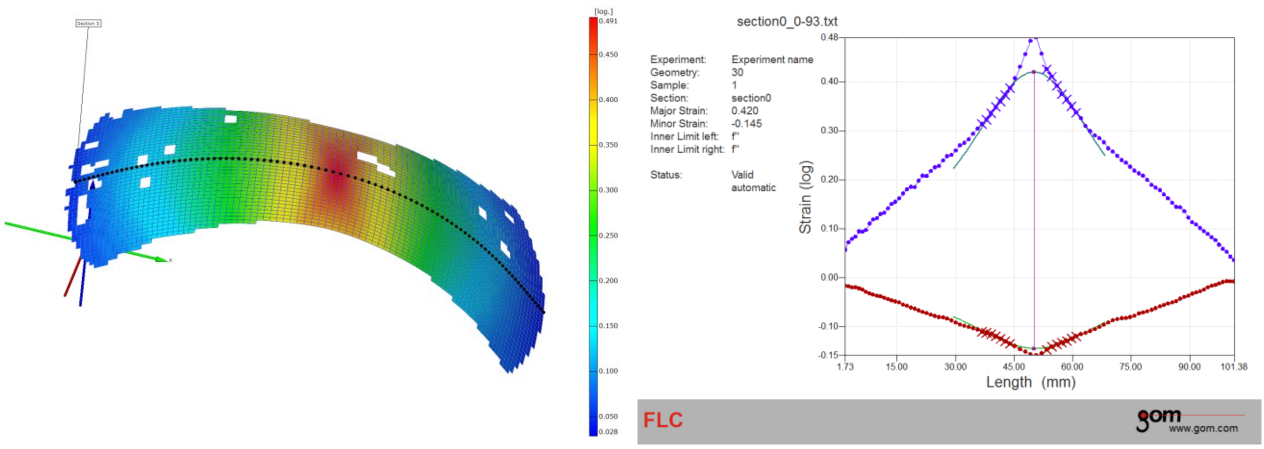
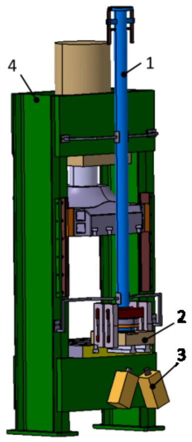


Fig. 3 Example of major strain φ_1 [1] distribution on the testing sample with width 30 mm (left) and principle of computation the deformation limit state acc. to ISO/DIS 12004-2 (right)

From the knowledge of distribution and size of deformation on testing samples for individual images it is possible to compute the strain rate. Regarding the fact that every from used geometries of testing samples (30 mm, 105 mm and 210 mm) revealed different deformation progress, it was necessary to change velocity of the semi-spherical punch to be able to keep the same strain rate. Velocity of the semi-spherical punch was chosen so that the strain rate for every testing sample corresponded to the value 0.02 s^{-1}. Results from measurement values of limit deformation at the strain rate 0.02 s^{-1} are shown in Fig. 7.

2.3. Tests of limit deformation under high strain rates

To measure deformation limit states of sheets under high strain rates was at the Department of Engineering Technology (TU of Liberec) designed and made pneumatic devices which makes possible to achieve punch velocity up to 30 $m \cdot s^{-1}$. Thus achieved strain rates at the maximal punch velocity vary from 100 s^{-1} up to 350 s^{-1} in dependence on tested material. Own design solution of this device is patented with number P 302418. Such device consists of clamping jig to grip sheet sample and separate pneumatic “cannon” makes possible to accelerate punch on the required impact velocity. Arrangement of own workplace for these high strain rates tests is evident from Fig. 4, where it is possible to see the clamping jig with pneumatic “cannon” placed on the hydraulic press CBA 300/60. Principle how to grip sheet sample in this clamping jig is evident from Fig. 5. Blank holding force is done by the belleville spring which has the maximal blank holding force 1.8 MN under compression of 7 mm. Thus clamping of sample into jig is possible only by compression of that belleville spring by hydraulic press on the required value and subsequent assemblage of jig under loading. Jig design is solved so that after its assemblage and clamping tested sheet there is no possible to unloaded belleville spring which ensures blank holding force. After assemblage of this testing jig it´s possible to manipulate with it already outside the press without necessity to set blank holding force again.



1- pneumatic accelerator
2- clamping jig
3- HS camera Photron SA3
4- press CBA 300/63

Fig. 4 Arrangement of workplace for high strain rates tests of deformation

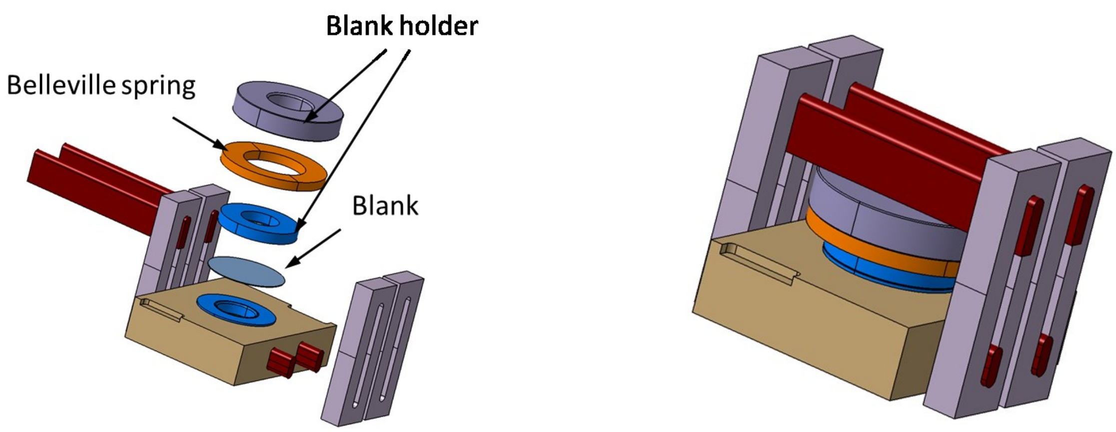


Fig. 5 Principle of sheet sample clamping in the jig

At analysis of deformation limit states under high strain rates was came on analogically as in the case of the Nakazima tests. Shapes and dimensions of tested samples were identical and for evaluation size of deformation there was again used the contact-less optical system ARAMIS. However regarding high strain rates there was necessary (for scanning whole process) to use high-speed (HS) cameras Photron SA3. At selection the basic data scanning frequency (in this case frames per second – fps) at 2 kHz were images clouded. At adjustment the data scanning frequency at 3 kHz was quality of scanned images already sufficient but there was not fulfilled condition about maximal deformation difference 0.05 between individual images. At the data scanning frequency 5 kHz there were already both conditions fully fulfilled and scanned images was possible to processed by system ARAMIS. Similarly to the Nakazima test there was from the first measured result for sheet sample with width 30 mm determined true strain rate on the tested sample. From analysis of obtained data there was computed value of such strain rate corresponding to 180 s^{-1}. Impact punch velocity for every other tested samples with the different geometry was chosen so that to fulfill condition to have the same strain rate as in the reference sample (width 30 mm). The change of impact punch velocity was done by changing value of pressure in the pneumatic “cannon”. Values of deformation limit states for individual samples were measured in the same way as in the case of Nakazima test acc. to evaluation methodology summarized in ISO/DIN 12004-2. Example of major strain φ_1 distribution and procedure how to obtain limit deformation on sample with diameter 210 mm under high strain rate (180 s^{-1}) is shown in Fig. 6. Results of measurement under high strain rate loading for individual deformation geometries are recorded into so-called forming limit diagram (FLD) which is shown in Fig. 7. To determinate influence of the different strain rate on deformation limit states are in Fig. 7 shown results for both carried out tests under strain rates as following: 0.02 $s^{-1}$and 180 s^{-1}.

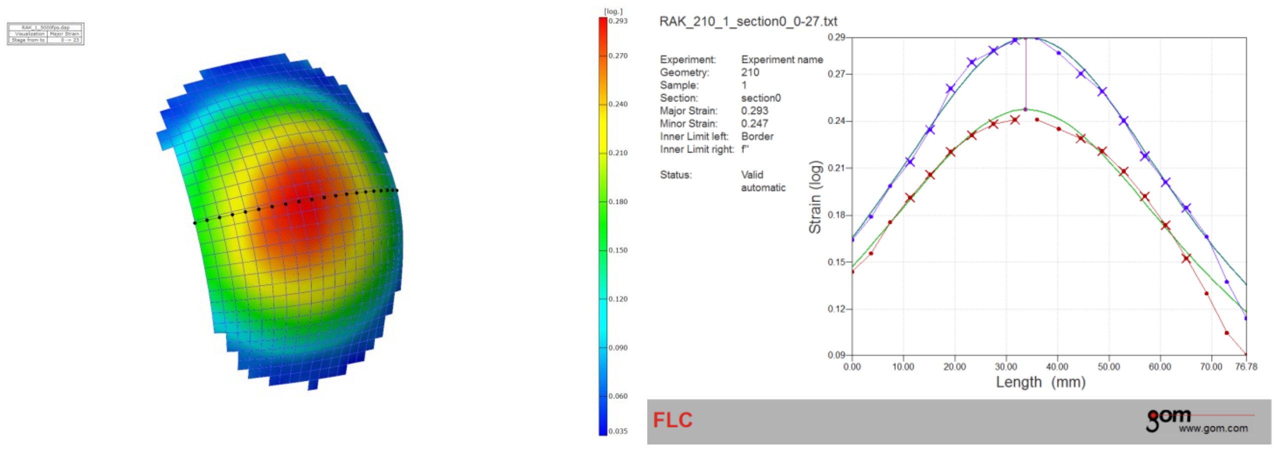


Fig. 6 Example of major strain φ_1 distribution on tested sample with diameter 210 mm (left) and principle of computation the deformation limit state acc. to ISO/DIS 12004-2 (right)

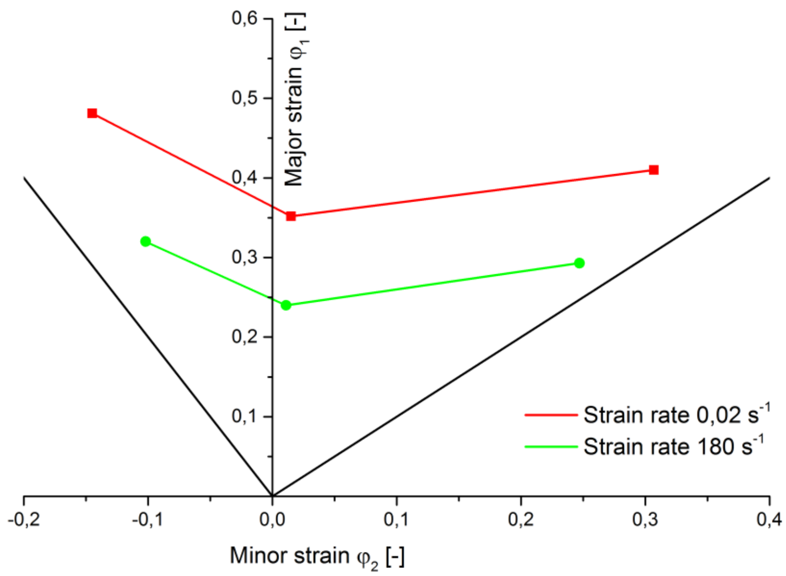


Fig. 7 Influence of strain rate on the limit deformation – material: RA-K 40/70

CONCLUSION

In the paper is evaluated the influence of strain rate on the limit deformation of TRIP steel RA-K 40/70 under different stress states. In the first case was the limit deformation of tested material achieve by means of Nakazima test under the common strain rate 0.02 s^{-1}. In the second case was such limit deformation achieved under the quite high strain rate 180 s^{-1} by the high-velocity pneumatic device (see Fig. 8). From results of tests (which are summarized in Fig. 7) it is obvious that with increasing strain rate from the initial 0.02 s^{-1} up to 180 s^{-1} there is decrease of material plastic properties at every monitored stress states approx. by 30 %. Tested material TRIP RA-K 40/70 is designed mainly for production safety reinforcements in cars and it is necessary to take into account changes in plastic properties of this material under different strain rates. Measured values can found their application during design of formed parts mainly in the automotive industry where are put very strict claims for their safety through the whole car running time.

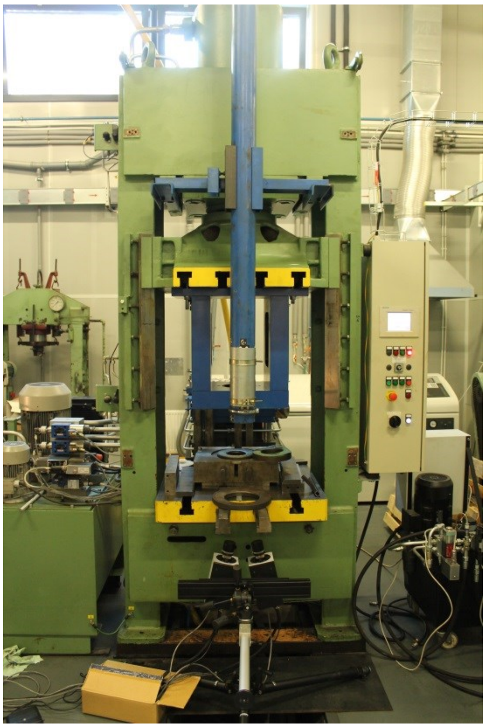
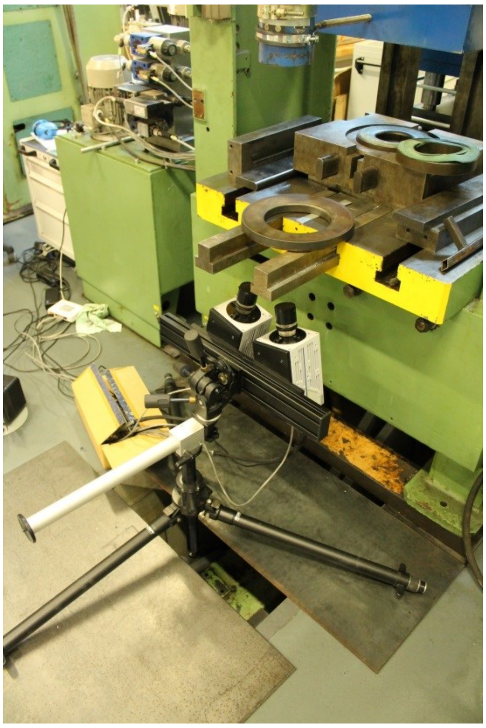



Fig. 8 Used pneumatic “cannon”(left) and position of HS cameras for high strain rate testing (rigth)

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