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RESEARCH OF STRAIN DISTRIBUTION AND STRAIN RATE CHANGE IN THE FRACTURE SURROUNDINGS BY THE VIDEOEXTENSOMETRIC METHODE

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Preliminary Note – Prethodno priopćenje

The paper deals with the strain distribution and the strain rate of material in the surroundings of its fracture. Three steels applied in the automotive industry (DP - dual phase steel, microalloyed steel HR 45 and IF - interstitial free steel) were used as the experimental material. The videoextensometric technique was used for sensing with CCD camera and computer. During the test, software records the coordinates of the centres of gravity of individual points, from which the respective strain values are then obtained. For individual steel grades, strain field maps in the fracture surroundings were plotted. The change in the strain rate in the fracture surroundings and at places more distant from the fracture was observed.

Key words: videoextensometry, automotive steels, strain field maps, strain rate

Istraživanje promjena raspodjele i brzine deformacije u okolini prijeloma sa videoekstenziometričkom metodom. Članak daje raspodjelu i brzinu deformacije materijala u okolini prijeloma. Za experimentalne materijale rabljena su tri čelika iz automobilske industrije (DP – dvofazni čelik, mikrolegirani čelik HR 45 i IF – neinstersticijskij čelik). Za istraživanje je primjenjena videoekstenzometrička metoda s CCD kamerom i računalom. Tijekom opita bilježi se koordinate težišta pojedinačnih vrhova iz kojih se dalje dobiju vrijednosti deformaciji. Za pojedinačne vrhove čelika ustrojene su deformacijske karte u okolini prijeloma. Istraživana je izmjena brzine deformacije kako u okolini prijeloma, tako i na mjestina udaljenim od prijeloma.

Ključne riječi: videoextenzometrička metoda, automobilski limovi, deformacijske karte, brzina deformacije

INTRODUCTION

Steels applied in the automotive industry can be classified under the AHSS category, which includes dual-phase (DP) steels, complex-phase (CP) steels and transformation-induced plasticity (TRIP) steels. The UHSS category mainly includes martensitic steels. The above-mentioned steel groups are well pressable, show an excellent combination of strength, service life and absorption of strain energy, strain hardening and good weldability [1]. Microalloyed (HSLA – High Strength Low Alloyed) steels show a fine ferrite-pearlite structure with a small addition (max. 0,15 %) of one element or the combination of elements of the Al, Ti, Nb, V group. The microalloying elements are bound to carbon and nitrogen, while the nature of microalloying effects is connected with the dissolubility of TiC, VC, NbC carbides, AlN, TiN nitrides and Ti(C, N) carbonitrides in austenite and ferrite and with the hardening mechanisms. Such designed steels enable car designers to implement the ideas of reduction of the weight of a structure and increase of safety of passengers in case of an accident [1].

The material characteristics of steel sheet in the forming process are also significantly influenced by external factors. The strain rate is a significant external factor and the intensity of its influence on the behaviour of material during the forming process, and hence on the material characteristics, is a function of its internal structure. With increasing the strain rate, the critical slip stress increases, the yield point intensively increases, the ultimate tensile strength increases and the material deformation characteristics change. Therefore it is necessary to know the behaviour of material in the forming process at increased rates, as well as its material characteristics. Measuring the material characteristics using the tensile test at high strain rates is very difficult and therefore possibilities to evaluate the material characteristics using modified tests are looked for [2, 3].

In the paper, the behaviour of three automotive steel sheets was observed. The steels were loaded with static uniaxial stress at the loading rate of 1,3 mm/min. The strain distribution at the R_m value and immediately before fracture was sensed using the videoextensometric technique.

There are several non-contact strain-sensing methods. They are based on the illumination of the sensed surface with white and laser light. The signal obtained

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from sensing the surface can be processed in various ways. The videoextensometric technique is a non-contact strain-sensing method, which makes it possible to sense longitudinal and transversal strains from the surface (mostly flat) of a test specimen [4-6]. The experimental equipment consists of a CCD camera and a computer, which processes the signal from the camera. Suitable contrast dots are put on the sensed surface. During sensing, the test specimen is illuminated with a diffuse light source, in order to obtain the best possible contrast between the test specimen surface and the dots. During the test, software records the centres of gravity of individual points and can also store the sequence of images. In processing a great number of points, the stored images are evaluated using the Image-pro software in such a way that the evaluation is only made after completion of sensing. The result of the test is the coordinates of the centres of gravity of individual points, from which the respective strain values are then obtained.

This technique makes it possible to sense strains in two directions simultaneously using one camera system, and hence to give information of the areal distribution of the both strain components. By sensing the surface during the whole test, the strain development kinetics is recorded [6].

MATERIAL AND EXPERIMENTAL METHOD

For the static tensile test, test specimens made of three cold-rolled sheets of the following grades were used: IF steel with the thickness of 1,7 mm, microalloyed steel (HR 45) with the thickness of 1,8 mm, and DP steel with the thickness of 1,7 mm. The mechanical properties of steels are shown in Table 1. The test specimens were taken perpendicularly to the rolling direction.

Table 1 **Mechanical properties of used materials**

Materials	Mechanical properties		
	$R_{p\,0,2}$ / MPa	R_m / MPa	A / %
HR 45	369	464	18
IF	185	300	36
DP	415	631	24

The steel structures (Figure 1, 2 and 3) were observed using the OLYMPUS light microscope. Figure 1 shows the microstructure of the steel IF, consisting of pure ferrite. The properties of steel depend on the ferrite grain size. As a result of the absence of interstitial elements, IF steels have a low yield point, a high elongation, a high normal anisotropy coefficient, and a high strain hardening exponent. The steels are resistant to ageing and are suitable for large body pressings with complex shapes. High plasticity is achieved by decreasing the carbon concentration to C < 0,005 % and by microalloying with Ti, Nb, or the combination of Ti + Nb, which completely bind the interstitial C, N elements into stable precipitates [7].

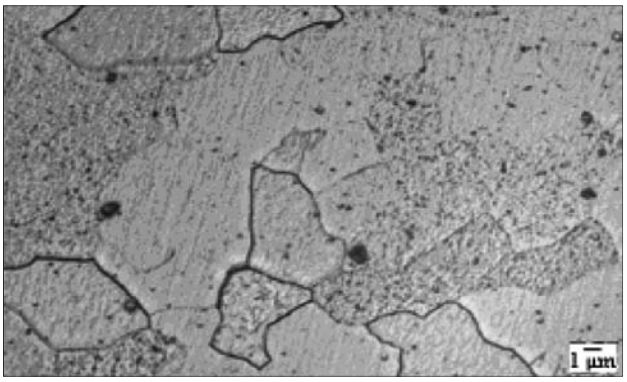

Figure 1 Steel IF microstructure

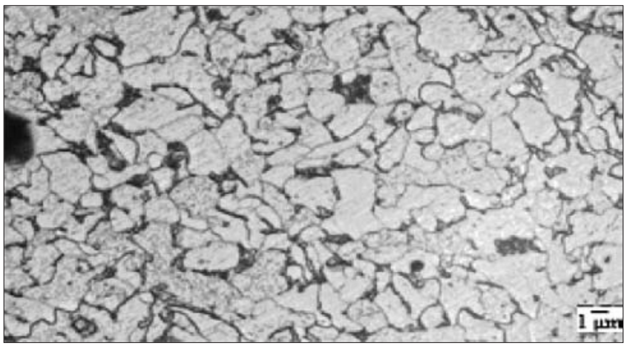

Figure 2 Steel DP microstructure

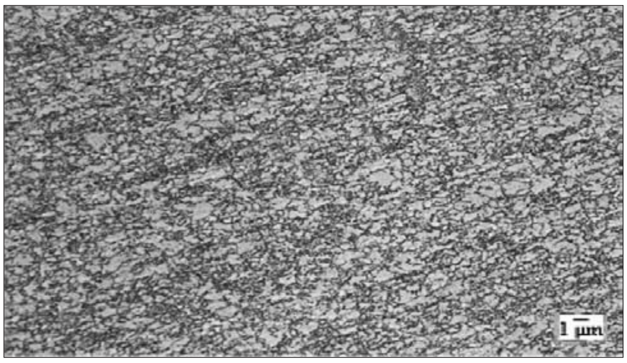

Figure 3 Steel HR 45 microstructure

Dual-phase steels (DP steels), which fall under the group of advanced high-strength steels (AHS) steels, have, in comparison with conventional steels, a significantly better strength-elongation combination and very good formability. In DP steels, the martensite portion in the ferrite matrix is the crucial hardening parameter, at the optimum combination of the percentage of soft ferrite and hard martensite islands Figure 2 [8].

HR45 steel falls under the group of microalloyed (HSLA – High Strength Low Alloy) steels. HSLA steels have a fine ferrite-pearlite structure, Figure 3, with a small addition (max. 0,15 %) of the combination of Al, Ti, Nb, V elements [8,9].

For the static tensile test, flat test specimens were used a CCD camera with the resolution of 640 multiply 480 pixels was used for recording. To sense the strain, the grid of 9 multiply 22 points with the spacing of 1,0 mm was put in the reduced area of the specimen. The test specimens were statically loaded with the rate of 1,3 mm/min. During the tensile strength, the surface of the test specimen was sensed using the CCD camera. Longitudinal strain ε_L (parallel with the loading direction) and transversal strain ε_T (perpendicular to the rolling direction) at immediately before fracture were evaluated.

After the ultimate tensile strength, strain localization takes place, which is connected with great strain changes in the slip band area. To calculate strain, the following equations were used (1, 2):

$$\varepsilon_L = \frac{dv}{dy} \tag{1}$$

$$\varepsilon_T = \frac{du}{dx} \tag{2}$$

where ε_L – strain in the longitudinal direction, v – displacement in the Y direction (Y direction = loading direction), ε_T – strain in the transversal direction, u – displacement in the X direction.

We were focused on the strain state at the ultimate tensile strength value and immediately before the crack formation. Strains are recorded in strain field maps, which show the ability of material to distribute plastic strains within an area.

To observe the effect of the strain rate, the grid of points in 9 columns 22 rows was used Figure 4. We observed the effect of change in the strain rate in the points 1-2 in the column F, specimen centre, and in the points 11-12 in the same column. In the column F, we expected the greatest material deformation and the crack initiation.

When comparing Figure 8 for the material IF, DP and HR 45 we can state that in the fracture formation area (specimen centre) the material strain rate increases by 2 orders in all the materials when compared with the edge (dots 1-2) of the observed area. Of the observed materials, IF steel is the most sensitive and the microalloyed steel is the less sensitive to the strain rate.

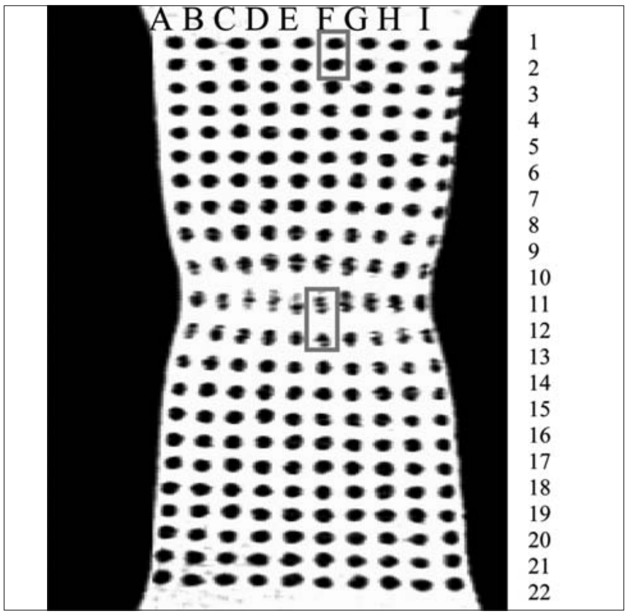

Figure 4 Dots position

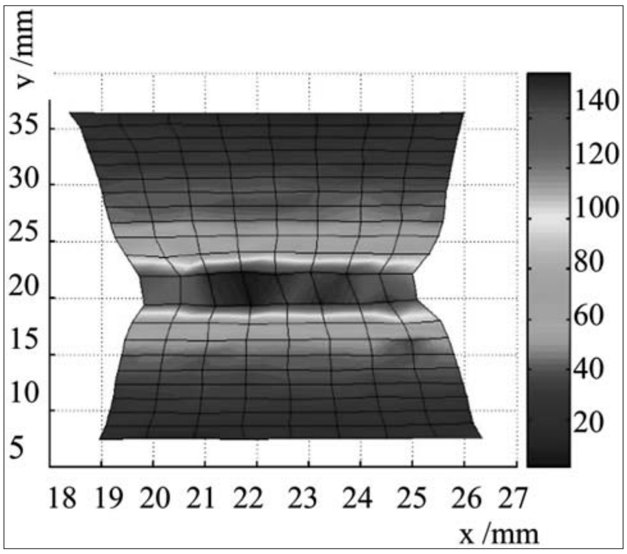

Figure 5 Strain field map ε_y nearly fracture for steel A (IF)

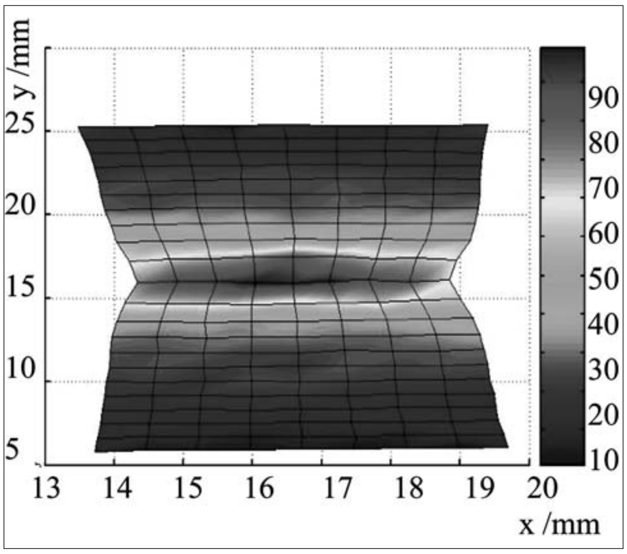

Figure 6 Strain field map ε_y nearly fracture for steel HR 45

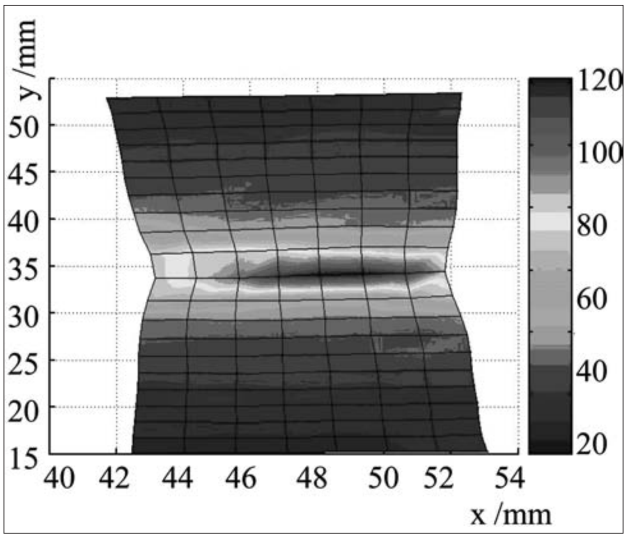

Figure 7 Strain field DP map ε_y nearly fracture for steel DP

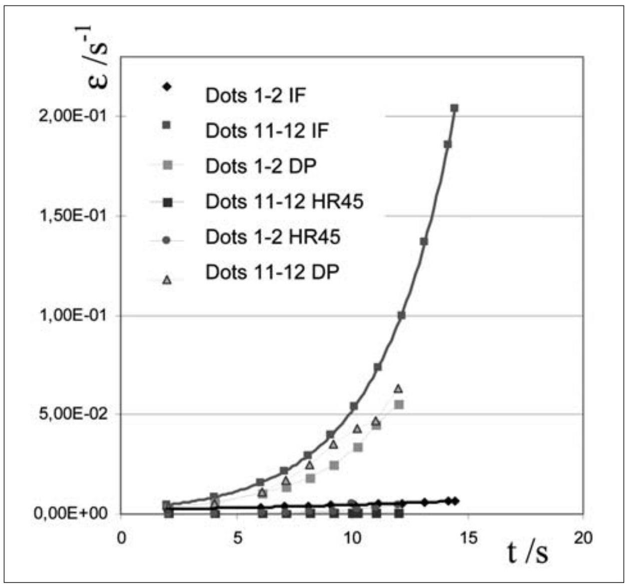

Figure 8 The development of strain rate steels IF, DP, HR 45 of dots 1 - 2 and 11 - 12

CONCLUSIONS

The videoextensometric technique was applied to three automotive steels, which proved to be a suitable experimental tool to study the strain kinetics and distribution.

For the steels, particular strain field maps were plotted and local strain values were determined at the immediately before fracture.

Local fracture strains differ in individual steels, and their values range from ε_L = 100 % for Al, 120 % for DP to 140 % for IF steel.

Plastic deformation is localized to the centre of bands where fracture initiation and deformation of the test specimens takes place.

The increase in the loading rate results in the increase in the strain rate by 2 orders in the specimen centre.

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