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Videoextensometric measuring of deformation processes in automotive steel sheets at two strain rate levels

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Abstract

Videoextensometry is a new experimental technique for non contact strain measurement, which enables measuring of longitudinal and transversal strain components on a planar surface of a loaded object. Experimental equipment uses a CCD camera (640 × 480 pixels) for monitoring the process on a surface area of 20 × 10 mm^2. The special software calculates the displacement of contrast dots prepared on the specimen surface. The paper presents results obtained experimentally on two steel grades for automotive steel sheet during tensile testing at different strain rates in the quasi static loading range. Non contact strain measuring is used for monitoring the strain development and strain localization.

Key words: microalloyed steel, interstitial free steel, deformation

1. Introduction

For complicated parts of the car body mainly steel sheets made of interstitial free (IF) steels are used. Advantageous plastic properties are achieved by minimizing of carbon and nitrogen contents lower than 0.005 %. Microalloyed steels (HSLA – High Strength Low Alloyed) are widely used in car industry, because of their good strength which results in reducing the car weight. Alloying by max. 0.15 % with Al, Ti, Nb, V or combination of elements results in fine-grained ferrite-pearlite microstructure [1–5].

External factors affect material characteristics during mechanical loading. Strain rate is one of the factors, increasing strain rate causes the increasing the yield point R_y, tensile strength R_m, and the deformation characteristics change [6].

For this reason, it is necessary to know the material behaviour and material characteristics during the forming process due to the increased strain rate. As the measuring of the material characteristics at the high speeds is complex, new methods of modification tests for material characteristics are being researched.

The aim of this work is to investigate the effect of the loading rate 1.3 mm min^{-1} and 130 mm min^{-1} on the plastic properties and their homogeneity of two grades of steel sheets using a videoextensometry method for scanning the strain distribution during tensile test, mainly at R_m and just before fracture.

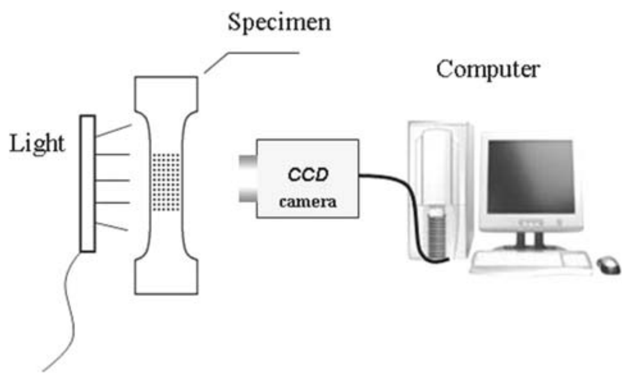

Fig. 1. The principle of videoextensometry measuring.

Videoextensometry is a non contact method for strain measuring, which enables the scanning of both longitudinal and transverse strain components from the surface of the test specimen [7, 8].

Experimental equipment consists of CCD (Charge Coupled Device) camera and a computer (Fig. 1),

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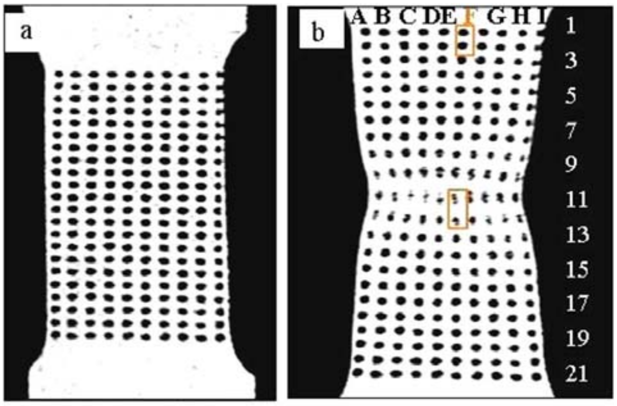

Fig. 2. Specimen with raster (a), before fracture with investigation places (b).

T a b l e 1. Mechanical properties of investigated materials

Materials	Mechanical properties		
	R_y (MPa)	R_m (MPa)	A (%)
HR 45	369	464	18
XSG	185	300	35.8

which process the camera signal by appropriate software. Suitable contrast marks (dots) are dashed on the scanned surface of the specimen (Fig. 2), the specimen is appropriately illuminated during the measurement in such manner to obtain the best contrast between the specimen surface and dashed dots [9].

The PC program records the position of the gravity centre of individual dots during test and enables the saving of picture sequences simultaneously. When scanning has finished, evaluation of the strain components can be then completed and final results from co-ordinates of gravity centres of individual dots are calculated [10].

The method enables the scanning of the deformation in two directions by one camera system [11, 12]. The deformation kinetics development is recorded during videoextensometry measuring.

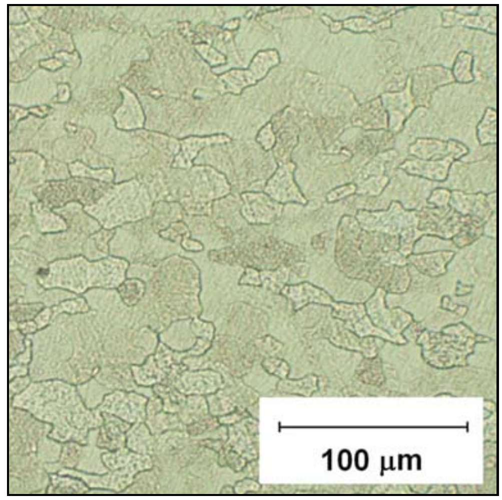

Fig. 3. Steel XSG – microstructure.

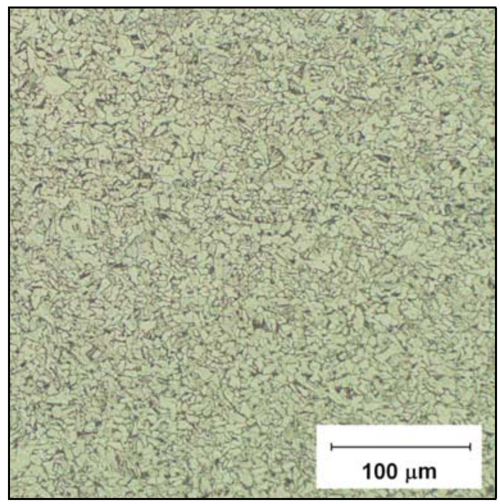

Fig. 4. Steel HR 45 – microstructure.

2. Experimental material and methods

Two steel grades, namely, an IF steel XSG and a microalloyed HR 45, were used for the investigation as 1.5 mm thick cold rolled sheets. Tensile specimens were made and tested in the transversal orientation to the rolling direction. Mechanical properties are in Table 1, chemical compositions in Table 2.

The microstructure of steels (Figs. 3 and 4) pre-

T a b l e 2. Chemical composition (%) of investigated materials

Mat.	C	S	N	Mn	P	Si	Al	Ni	Sn	Nb	V	Ti
XSG	0.001	0.0105	0.0017	0.082	0.011	0.006	0.055	0.013	0.003	0.001	0.002	0.040
HR 45	0.156	0.004	0.003	0.654	0.013	0.010	0.035	0.015	0.005	0.001	0.002	0.001

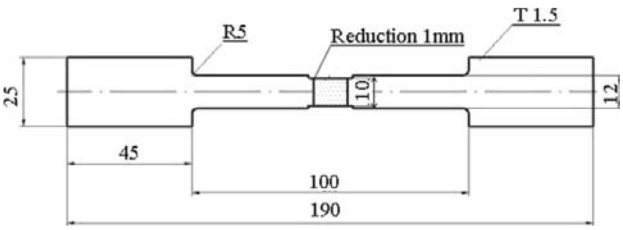

Fig. 5. Specimen geometry.

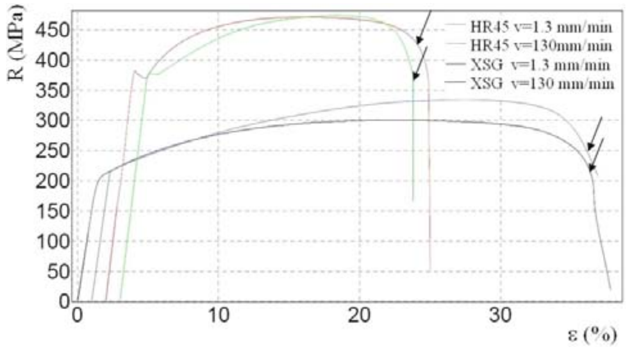

Fig. 6. Tensile stress-strain diagrams of loading rate 1.3 mm min^{-1} and 130 mm min^{-1}.

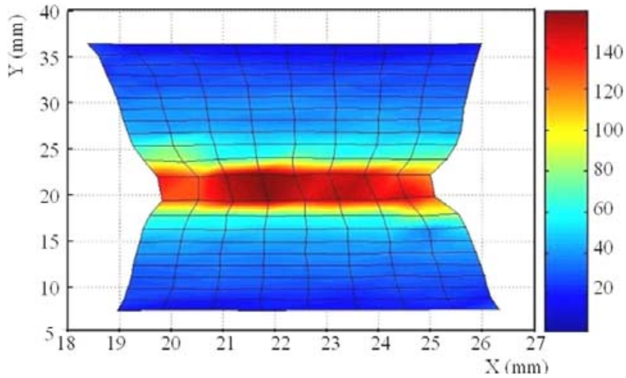

Fig. 7. Strain field map ε_L nearly before fracture for steel XSG, loading rate 1.3 mm min^{-1}.

pared by a standard way, classic shaping, polishing and etching in 2 % nital, were observed by OLYMPUS light microscope. Microstructure of XSG grade consists of ferrite (Fig. 3).

Due to the absence of interstices the XSG steel has a low yield point, high ductility, high index of normal plastic anisotropy and high strain hardening exponent. These steels are not susceptible to an ageing process and they are suitable for complicated car body parts. IF steel is used mainly for extremely deep drawing. High plasticity is achieved by the reducing of carbon content to a value C $<$ 0.005 % and by a micro-alloying with Ti, Nb, or combination Ti + Nb, which completely bind elements C, N on a stable precipitates [9].

HR 45 grade is a micro-alloyed steel (HSLA) with ferrite-pearlite fine-grained microstructure (Fig. 4). Micro-alloyed elements are bound to carbon and nitrogen. The solubility of the TiC, VC, NbC carbides, AlN, TiN nitrides and Ti(C, N) carbo-nitrides in austenite and ferrite and the hardening mechanisms are important for the micro-alloying effect.

Tensile testing was performed on standard test specimens (Fig. 5). The width of the specimen was reduced in the centre of the specimen from both sides by approx. 0.5 mm each side over a length of 20 mm. This causes the deformation process focuses in this area. The deformation process was recorded by CCD camera with a resolution of 640 × 480 pixels. A scanned area on the specimen surface was covered with a grid of 9 × 22 dots with a step of 1.0 mm between dots. Specimens were loaded under loading rate of 1.3 mm min^{-1} and 130 mm min^{-1}, respectively. After the testing the longitudinal strain components ε_L (parallel to the loading direction) were evaluated. The detailed strain analysis was made just before fracturing, see marked points in the stress-strain diagram (Fig. 6).

3. Results and discussion

After reaching the maximum load the strain begins to be localized. This phenomenon is allied with big deformation changes in the area slip band.

Strain components were calculated from formula (1):

$$\varepsilon_L = \frac{dv}{dy}, \qquad (1)$$

where ε_L is strain in longitudinal direction, v is displacement in loading direction Y.

Local deformation in the area of breaking for steel (XSG) is $\varepsilon_L = 160$ % by loading rate 130 mm min^{-1}, and $\varepsilon_L = 140$ % by loading rate 1.30 mm min^{-1} (Figs. 7 and 8). Local deformation in the area of breaking for steel (HR 45) is $\varepsilon_L = 100$ % by loading rate 130 mm min^{-1} and $\varepsilon_L = 90$ % by loading rate 1.3 mm min^{-1} (Figs. 9 and 10).

The effect of the loading rate on strain homogeneity was investigated using two loading rates: 1.3 mm min^{-1} and 130 mm min^{-1}. The grid for strain measurement consisted of 9 columns and 22 lines of dots. Two different places, namely dots 1–2 and 11–12 in F column (Fig. 2b) were chosen for comparing the strain rate conditions.

The local strain rate increases during the tensile test, the values depend on the place – close to the fracture initiation or on the periphery of the scanned area. The increase of the strain rate be-

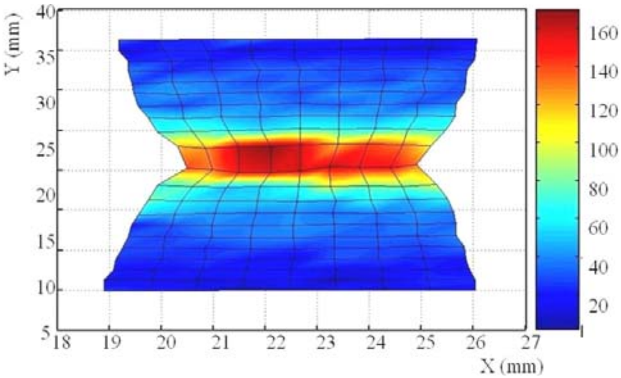

Fig. 8. Strain field map ε_L nearly before fracture for steel XSG, loading rate 130 mm min^{-1}.

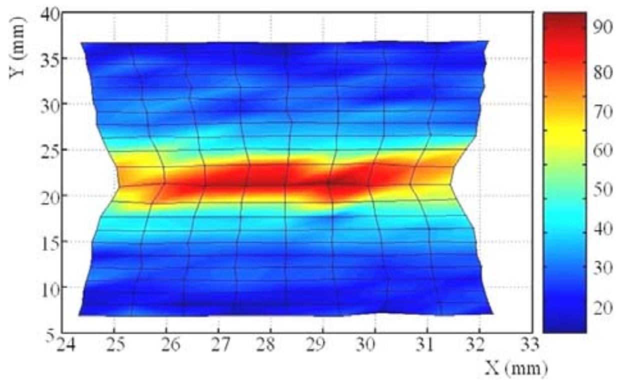

Fig. 9. Strain field map ε_L nearly before fracture for steel HR 45, loading rate 1.3 mm min^{-1}.

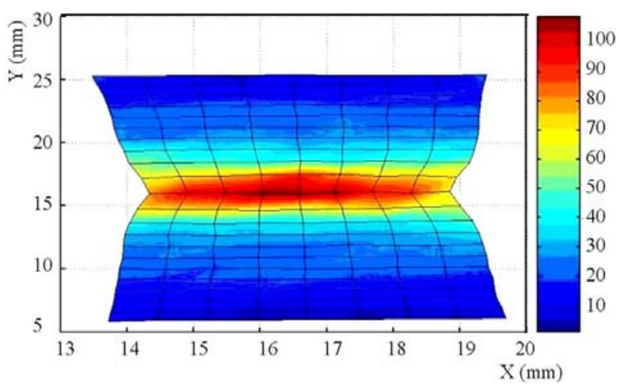

Fig. 10. Strain field map ε_L nearly before fracture for steel HR 45, loading rate 130 mm min^{-1}.

ginning from the area of regular homogeneous deformation between R_y and R_m up to fracture is 20 times for the HR 45 grade (ductility = 18 %) and loading rate of 1.3 mm min^{-1} in the place close to the fracture initiation and 2.7 times for the periphery of scanned area (Figs. 11 and 12). In case of

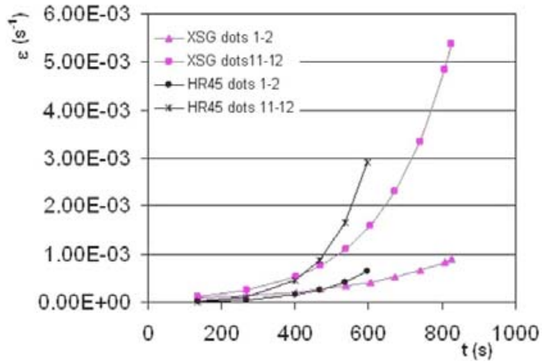

Fig. 11. The development of strain rate by loading rate 1.3 mm min^{-1} steel HR 45 and steel XSG of dots 1–2 and 11–12.

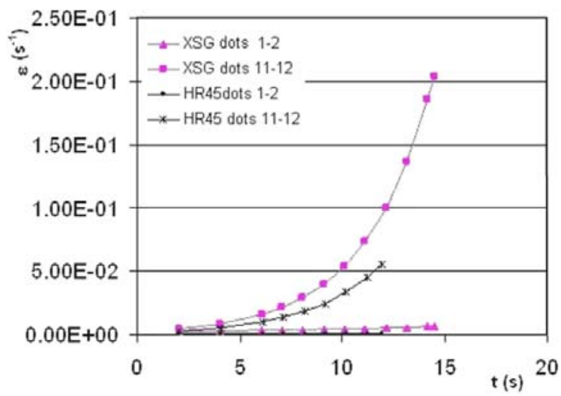

Fig. 12. The development of strain rate by loading rate 130 mm min^{-1} steel HR 45 and steel XSG of dots 1–2 and 11–12.

130 mm min^{-1} the increase is 18 and 1.17 times, respectively.

For the XSG grade (ductility = 35.8 %) the increase of the strain rate during deformation process is 45 times in the place close to the fracture initiation and 10.5 times for the periphery of scanned area for the 1.3 mm min^{-1} loading rate. In case of 130 mm min^{-1} the increase is 44.5 and 2.4 times, respectively (Figs. 11 and 12).

4. Conclusions

The non contact strain measurement technique – videoextensometry – was applied for the analysis of both the strain kinetics and strain distribution on two cold rolled steel sheets under two loading rates: 1.3 and 130 mm min^{-1} on the tensile machine.

1. For both investigated steels the strain analysis was made just before fracture as strain field maps.

2. Maximum local deformation in the area close to the fracture line is ε_L = 90–110 % for HR 45 grade and

ε_L = 140–150 % for XSG grade, regardless of loading rate.

3. Fracture was initiated in the specimen centre in the deformation band.

4. Strain rate increases at the periphery of scanned area during loading by 2.7 times for loading rate of 1.3 mm min^{-1} and by 1.17 times for loading rate of 130 mm min^{-1} for HR 45 grade. For XSG grade the corresponding values are 10.5 times by the low and 2.4 times by the high loading rate, respectively.

5. Strain rate increases in the area close to the fracture line by 20 times for loading rate of 1.3 mm min^{-1} and by 18 times for loading rate of 130 mm min^{-1} for HR 45 grade. For the XSG grade the strain rate increases by 45 times for both loading rates.

Acknowledgements

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