Acta Polytechnica **54**(4):281–284, 2014
doi:10.14311/AP.2014.54.0281

IMPACT OF STRAIN RATE ON MICROALLOYED STEEL SHEET FRACTURING

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Abstract. The strain rate is a significant external factor, and its influence on material behavior in the forming process is a function of its internal structure. This paper presents an analysis of the impact of the loading rate from 1.6 x 10-4 m s-1 to 24 m s-1 on changes in the fracture properties of steel sheet used for bodywork components in cars. Experiments were performed on samples taken from HC420LA grade strips produced by cold rolling and hot dip galvanization. Material strength properties were compared on the basis of measured values, and changes to the character of the fracture surface were observed.

Keywords: strain rate, microalloyed steel, fracture surface.

1. Introduction

High-strength low-alloy steel (HSLA) is a type of alloy steel that provides enhanced mechanical properties [1, 2]. Increasing the strain rate increases the resistance of the material against deformation, but also increases the tendency toward brittle fracture. An increasing strain rate results in changes to the microstructure and substructure of a deformed material.

In practical terms, this means that it is necessary to know the impact of the strain rate on the mechanical properties of a specific material. This forms the basis for calculating the deformational resistance, and also the processes taking place during forming.

It is quite complicated to predict the impact of the strain rate on the properties of a material. This is related to the fact that the intensity of the impact of the strain rate is a function of the internal structure of a material, and it is also very difficult to interpret test results at high rates.

An increasing strain rate also increases the critical flow stress. The yield strength grows strongly, the tensile strength increases, and the deformation characteristics of the material are changed [3, 4]. At the same time, the values of the forming criteria derived from these characteristics are also changed [5–7].

2. Experimental material and methods

Experiments were performed on samples taken from the cold rolled strips and then hot dip galvanized HC420LA grades intended for the production of stampings in the automotive industry. The chemical composition of the tested steels is shown in Table 1.

The microstructure of the tested material is polygonal ferritic, with small amounts of fine pearlitic grains precipitated at the boundaries of the ferritic grains (Fig. 1).

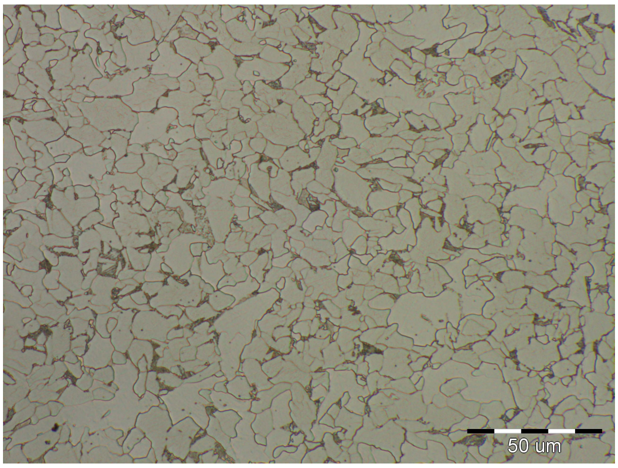

Figure 1. Steel HC420LA – microstructure.

The tested material was 1.0 mm in thickness. Samples of the material were taken in the rolling direction, and flat test specimens were produced for the tensile test. The tensile test was carried out on the INSTRON 1185 tensile testing machine, at a loading speed of 1–1000 mm/min. Dynamic tests were carried out on the PSW-type pendulum impact tester at a maximum speed of 24 m/s.

3. Results and discussion

According to [3, 4], an increasing strain rate increases the resistance of the tested steel to plastic deformation, and there is an increase in the yield strength and tensile strength (Fig. 2). The relation between stress (R) and the strain rate $\dot{\varepsilon}$ can be described by the following equation [4]:

$$R_{\mathrm{m}\varepsilon} = R_{\mathrm{m}\varepsilon 0} + A \log \dot{\varepsilon}/\dot{\varepsilon}_0,$$

where A is the material constant factor expressing the sensitivity of the material to the strain rate,

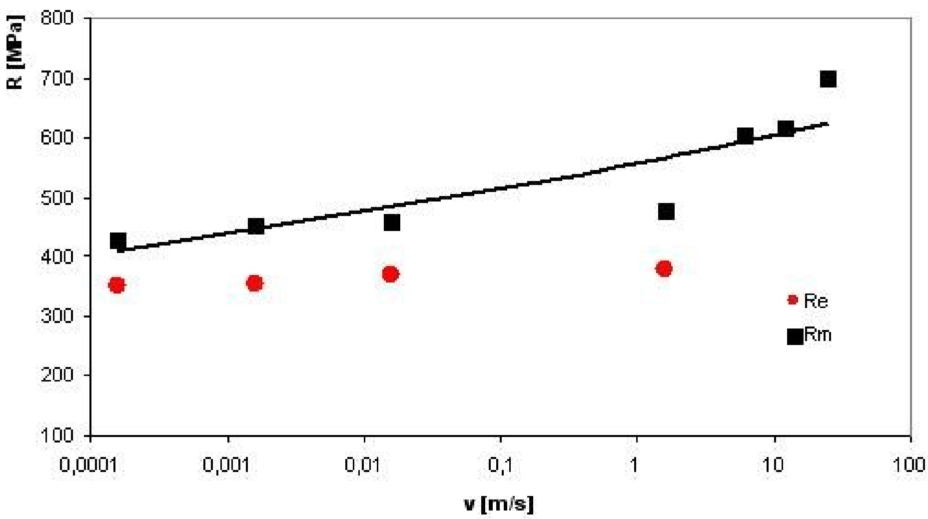

FIGURE 2. Effect of loading rate on the yield stress R_e and the tensile ultimate strength Rm of HC420LA steel.

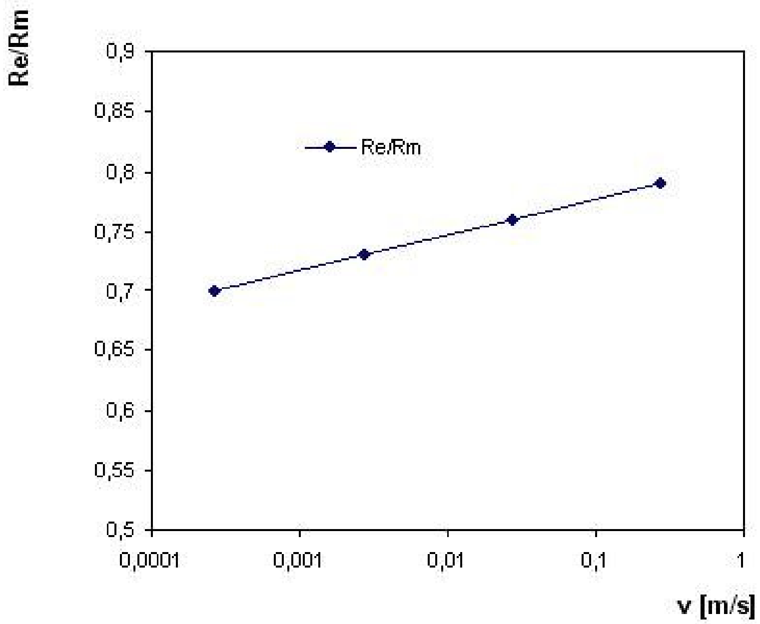

FIGURE 3. Influence of loading rate on R_e/R_m.

$R_{m\varepsilon}$ expresses the ultimate tensile strength values at strain rate $\dot{\varepsilon}$, and $R_{m\varepsilon 0}$ expresses the ultimate tensile strength values at the lowest strain rate.

One of the characteristics of thin sheet formability is the R_e/R_m ratio. This ratio grows with increasing strain rate, as shown in Fig. 3. This increases the risk of local plastic instability. Typical deep drawing sheets have a ratio of about 0.6. Sheets tested under a static load had R_e/R_m ratio $= 0.72$. This ratio increased with increasing loading speed (Fig. 3). The paper [8] states that the formability (plasticity) of the tested steels decreased after an Re/Rm ratio > 0.82 was reached.

At a static loading speed of 1.6×10^{-4} m/s, a transcrystalline ductile failure with a dimple morphology can be observed on the fracture surface. The shape and symmetry of the dimples is related to the stress at the failure spot. The size and the layout of the dimples depends on the grain size. At low rates, see Fig. 4, there is a ductile failure with an equiaxial dimple morphology, where the dimples are deep.

The generation of a fracture surface is accompanied by significant plastic deformation associated with the increasing number of active slip systems at a higher strain rate. The fracture surface obtained at a loading speed of 1.6 m/s has similar characteristics (Fig. 5). On the fracture surface, an increased number of secondary cracks and voids are generated in the direction of the lines. The increase in plastic deformation is clear from the shape of the dimples. The dimples are

Material	C	Si	Mn	P	S	Al	Ti	Nb
HC420LA	0.1	0.5	1.6	0.025	0.025	0.015	0.015	0.09

Table 1. Chemical composition of the material (in percents).

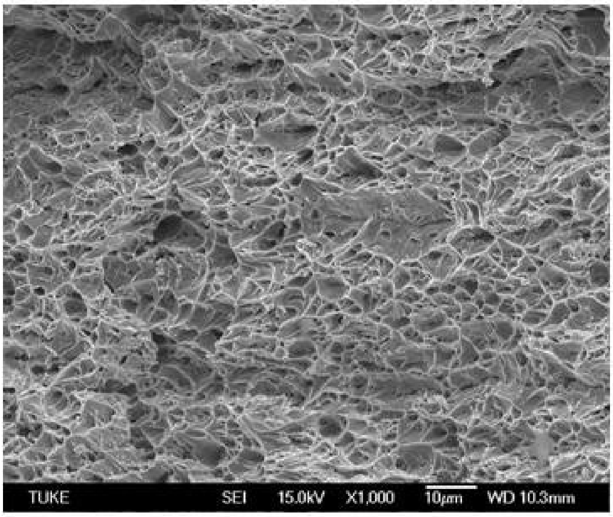

Figure 4. Fracture surface at a loading rate of 1.6×10^{-4} m/s.

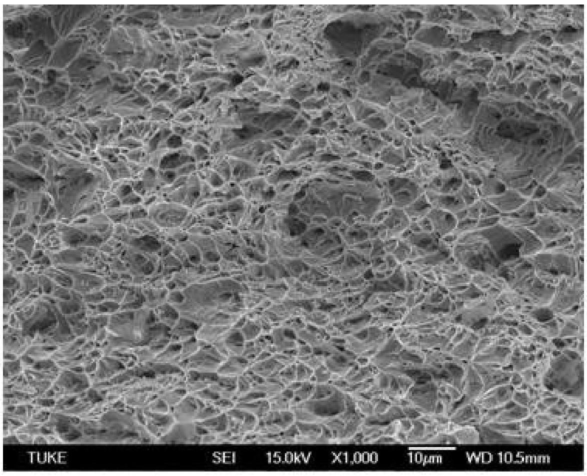

Figure 5. Fracture surface at a loading rate of 1.6 m/s.

elongated, with a strong presence of striation on the walls. Coalescence of cavities is seen more significantly in the direction perpendicular to the direction of the tensile stress. At a loading speed of 24 m/s, the angle of rupture increases (Fig. 6), an uneven surface is generated, and the dimples are shallower. At the void growth in the process of ductile failure, the coalescence bridges become narrow. Bridges break due to gradual stretching. Ductile fractures are formed in the phase of micro-defect nucleation, void growth and contraction of the bridges between the voids. The nucleation of micro-defects in ductile failure is generated by decohesion of the inclusions and other particles from the matrix.

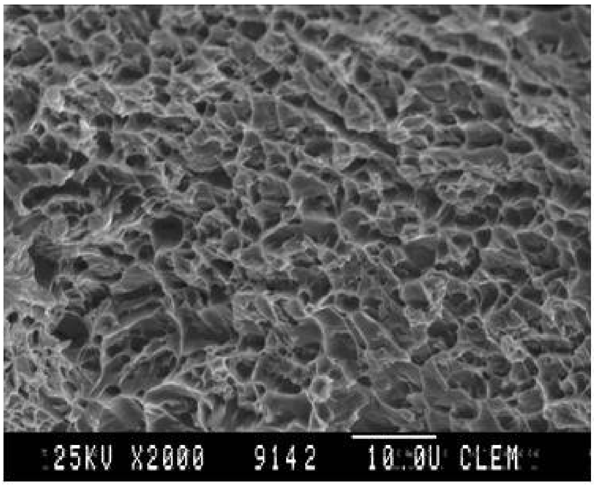

Figure 6. Fracture surface at a loading rate of 24 m/s.

Microscopic observation of the strain-strengthened steel structure confirmed that as the strain rate increases, the inhomogenity of the deformation plasticity also increases in the volume of deformed steel. It follows that the resulting properties of the strain-strengthened material are influenced by the strain rate.

4. Conclusion

This paper has presented an analysis of the impact of the strain rate of HC420LA steel sheet on changes in mechanical properties and the appearance of a fracture. On the basis of the results of tensile tests and dynamic tests in the loading speed range from 1.6×10^{-4} m/s to 24 m/s for the tested steel, it can be stated that:

- At an increasing strain rate up to about $3\,\mathrm{s}^{-1}$, there is no deterioration in the material characteristics of deep drawing, but deformation resistance increases.
- The limit state characterizing the drop in formability as a result of increasing the loading speed can be determined by the $R_\mathrm{e}/R_\mathrm{m}$ ratio. For the tested sheet, this ratio was around 0.82.
- For the HSLA steel of HC420LA grade tested here, ductile failure is generated by the void mechanism.
- At all rates, the material fails due to transcrystalline ductile fracture with a dimple morphology.
- As the strain rate increases, the plastic deformation becomes more significant and there is greater number of voids that are oriented in the direction of the lines, and the dimples become shallower.

The localization of plastic deformation in deep drawing automobile sheet metal is considered to be one of the most important indicators of compressibility sheets. The results of these experiments are recommended for practical applications regarding the exhaustion plasticity of materials and the behavior of materials during dynamic processes. When using and including these experimental findings in practical applications, it is necessary to support the analysis by measurements of the substructure of the material and by implementing EBSD analysis.

Acknowledgements

This study has been supported by the VEGA 1/0549/14 grant project.

References

[1] Wang, H.R., Wang, W., Gao, J.O.: Precipitates in two Zr-bearing HSLA steel plates. Materials Letters, 64 (2), 2010, p. 219–222. doi:10.1016/j.matlet.2009.10.053

[2] Huh. H., Lim, J.H. et al.: High speed tensile test of steel for the stress-strain curve at the intermediate strain rate. International Journal of Automotive Technology, 10 (2), 2009, p. 195–204. doi:10.1007/s12239-009-0023-3

[3] Čižmárová, E., Micheľ, J. et al.: Influence of strain rate on properties of microalloyed S-MC steel grades, Metalurgija, 41 (4), 2002, p. 285–290.

[4] Mihaliková, M., Janek, J.: Influence of the loading and strain rates on the strength properties and formability of higher-strength sheet. Metalurgija, 46 (2), 2007, p. 107–110.

[5] Német, M., Mihaliková M.: The effect of strain rate on the mechanical properties of automotive steel sheets, Acta Polytechnica, 53 (4), 2013, p. 384–387.

[6] Niechajowicz, A., Tobota, A.: Application of flywheel machine for sheet metal dynamic tensile tests. Archives of Civil and Mechanical Engineering 8 2008, p. 129–137.

[7] Buršák, M., Mamuzič, I., Micheľ, J.: Contribution to evaluation of mechanical properties during impact loading. Metalurgija, 47 (1) 2008, p. 19–23.

[8] Micheľ, J., Buršák, M.: The influence of strain rate on the plasticity of steel sheets. Komunikacie, 12 (4), 2010, p. 27–32.