M. MIHALIKOVA, J. JANEK

ISSN 0543-5846
METABK 46 (2) 107-110 (2007)
UDC - UDK 669.14–672.4:620.17=111

INFLUENCE OF THE LOADING AND STRAIN RATES ON THE STRENGTH PROPERTIES AND FORMABILITY OF HIGHER-STRENGTH SHEET

Received - Primljeno: 2006-07-26
Accepted - Prihvaćeno: 2006-12-15
Preliminary Note - Prethodno priopćenje

The paper analyses the influence of the loading rate in the interval from 1 to 1000 mm/min, which corresponds to the tensile machine working range, on the strength properties and the formability characteristics obtained on standard and notched test bars made of H340 LAD steel strips. The combination of the loading rate and the test bar type made it possible to obtain the relationships of monitored variables in the strain rate interval from 10^{-4} to 10 s^{-1}. In this interval, the strength properties of the tested strips thick 1, 1,5 and 1,8 mm exponentially increase, but formability does not change up to the strain rate of 1 s^{-1}.

Key words: *steel strips, loading rate, strain rate, strength properties, formability*

Utjecaj brzine zatezanja i deformacije na vrijednost čvrstoće i deformabilnost visoko čvrstih traka. Članak analizira utjecaj brzine zatezanja u intervalu 1 do 1000 mm/min, koji odgovara rasponu vlačnih strojeva na vrijednosti čvrstoće i karakteristike deformabilnosti istražene na standardnim i epruvetama sa zarezom izrađenim iz traka čelika H340 LAD. Kombinacija brzine zatezanja i vrste epruvete je omogućila ustroj ovisnosti promjenljivih veličina u intervalu brzine deformacije 10^{-4} do 10 s^{-1}. U tom intervalu vrijednost čvrstoće ispitivanih traka debljine 1, 1,5 i 1,8 mm se eksponencijalno povećava, ali se defomabilnost i do brzine deformacije s^{-1} ne mijenja.

Ključne riječi: *čelične trake, brzina zatezanja, brzina deformacije, vrijednosti čvrstoće, deformabilnost*

INTRODUCTION

Cold formability of material is influenced by all factors participating in the forming process. The crucial factors include the sheet material, whose formability is the most often evaluated according to its yield point, tensile strength and their ratio, elongation, uniform deformation, their combination, etc. [1]. In the forming process, these material characteristics are significantly influenced by the strain rate and the intensity of its influence on the material characteristics depends on the internal structure of the material [2, 3]. The study of the influence of high strain rates on the material characteristics using a standard tensile test is very difficult in terms of both the technical equipment and the interpretation of the measured results. Therefore possibilities to determine the material characteristics using modified tests are looked for [4 - 6].

The presence of a notch on the test bar also influences the material characteristics as a result of a stress change, and its effect is expressed using a coefficient, which must be taken into account [7]. Besides the above-mentioned, at the given loading rate the notch causes the localization of deformation and hence the strain rate in the notch area increases by an order [5].

M. Mihalikova, Faculty of Metallurgy Technical University of Košice, Košice, Slovakia, J. Janek, SCA Hygiene Products, Gemerská Hôrka, Slovakia

EXPERIMENTAL MATERIAL AND METHODS

The influence of the loading rate and the notch on the mechanical properties during uniaxial loading was observed on microalloyed steel strip H340 LAD, whose chemical composition is the following: C < 0,12 %, Mn < 1 %, Si < 0,04 %, P < 0,025 %, S < 0,01 %, Al > 0,015 %, Nb < 0,08 %, Ti < 0,1 %, V < 0,10 %.

The material was supplied as cold rolled sheets cut in length with the thickness of 1, 1.5, 1.8 mm.

Table 1. **Basic mechanical properties of tested steel**
Tablica 1. **Osnovna mehanička svojstva ispitivanog čelika**

Thicknes / mm	R_e / MPa	R_m / MPa	A_{50} / %
1,0	353	440	23,0
1,5	352	440	23,4
1,8	344	424	26,0

The microstructure of steel is predominantly ferritic, while fine pearlitic grains are precipitated at the ferritic grain boundaries (Figure 1.). The structure nature did not change with the strip thickness; the only difference was the ferritic grain size, which had a slight impact on mechanical properties, as shown in Table 1. The influence of the loading rate on the mechanical properties of the tested steel was determined using tensile tests made on a tensile

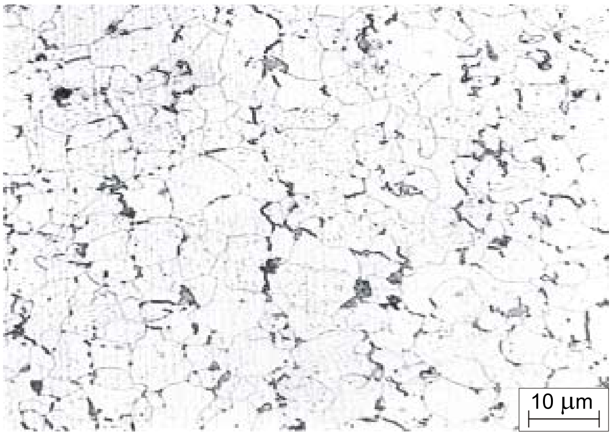

Figure 1. **Microstructure of the tested steel**
Slika 1. **Mikrostruktura ispitivanog čelika**

testing machine INSTRON 1185 at the loading rates of 1, 10, 100 and 1000 mm/min. Samples for the tensile tests were taken from the sheets in the rolling direction and tensile tests bars were made, as shown in Figure 2. and Figure 3. During the tensile tests, the force - elongation

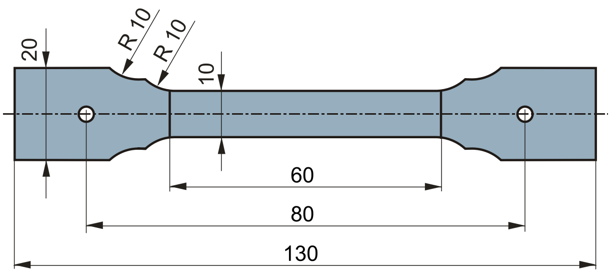

Figure 2. **Tensile test bar**
Slika 2. **Ispitivana epruveta**

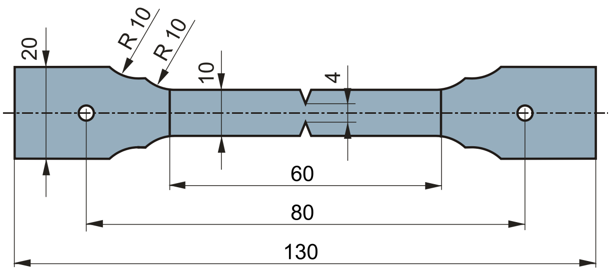

Figure 3. **Tensile test bar with V-notch on both sides**
Slika 3. **Ispitivana epruveta sa V zarezom s obe strane**

diagrams were recorded using a PC and basic mechanical properties were evaluated.

RESULTS OF TESTS AND THEIR ANALYSIS

The aim of the paper is to evaluate the influence of the strain rate and the notch effect on the basic mechanical properties of hot dip galvanized steel strips H340 LAD with the thickness of 1, 1,5 and 1,8 mm, intended for the manufacture of heavy-loaded pressings in the automotive industry. Figures 4. to 6. show the graphs of documented results of the influence of the loading rate on the basic

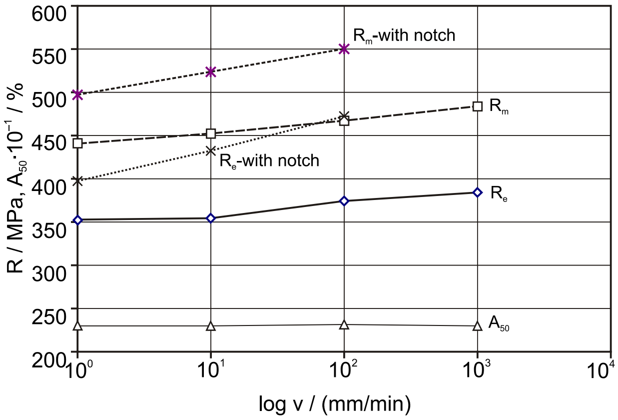

Figure 4. **Influence of the loading rate on the mechanical properties of the tested sheet thick 1 mm**
Slika 4. **Utjecaj brzine zatezanja na mehanička svojstva ispitivane trake debljine 1 mm**

mechanical properties, determined on classical flat test bars and on test bars with V-notches on botch sides with the notch depth of 3 mm and radius of 0,2 mm.

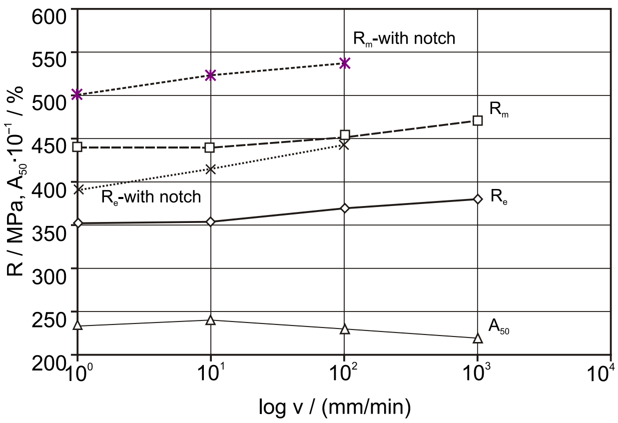

Figure 5. **Influence of the loading rate on the mechanical properties of the tested sheet thick 1,5 mm**
Slika 5. **Utjecaj brzine zatezanja na mehanička svojstva ispitivane trake debljine 1,5 mm**

The measured results indicate that with increasing the loading rate the resistance of steel against plastic deforma-

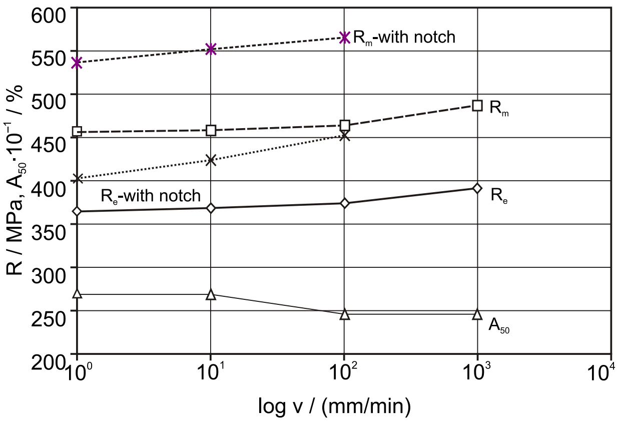

Figure 6. **Influence of the loading rate on the mechanical properties of the tested sheet thick 1,8 mm**

Slika 6. **Utjecaj brzine zatezanja na mehanička svojstva ispitivane trake debljine 1,8 mm**

tion increases, which means that the yield point R_e and the tensile strength R_m increase.

The R_e and R_m values of the notched test bars are higher than these values measured on flat (classical) test bars and are dependent on the thickness (but also on the structure) of the tested sheet (Table 2.).

Table 2. shows that with increasing the loading rate the differences between values of the yield point and the tensile strength of the classical test bars and the notched test bars increase. This is due to the notch effect, since the notch changes the stress state and strengthens the material [7] and localises deformation, therefore at the same loading rate the strain rate around the notch is higher by an order than mean strain rate of the classical test bar (in this case L = 60 mm) [5].

The mean strain rate for classical bars can be calculated from the formula $\dot{\varepsilon} = v/L$, where v is the loading rate and L is the deformed length. The determination of the mean strain rate in the notch is very problematic. Using formulas for the notch opening from the COD test, measuring the notch shape before the tensile test and after the failure, as well as verifying using a video camera the mean strain rate in the notch at the loading rates of 1, 10 and 100 mm/min could be determined. Thus, it was possible to construct the relationship between the strength properties (R_e, R_m) of the tested sheets and the strain rate in the interval from 10^{-4} to 10 s^{-1}, which are documented in Figure 7. In the strain rate interval from 0,028 to 0,28 s^{-1} (Figure 7.), R_e and R_m values were experimentally determined on classical and notched test bars. The nature of the $R_e - \dot{\varepsilon}$ or $R_m - \dot{\varepsilon}$ relationships determined on classical test bars (L = 60 mm) and on notched test bars do not change and these relationships can be described as follows:

$$R_e\dot{\varepsilon} = R_e\dot{\varepsilon}_0 + A \cdot \log\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)^n$$

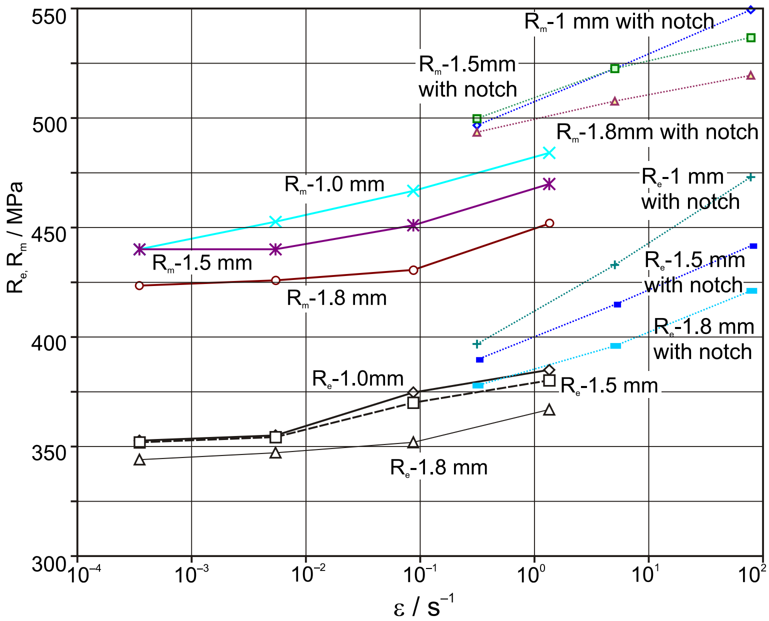

Figure 7. **Influence of the strain rate ε on the yield point R_e and the tensile strength R_m of the tested sheets**

Slika 7. **Utjecaj brzine deformacije ε na granicu razvlačenja R_e i vlačnu čvrstoću R_m ispitivanih traka**

or

$$R_m\dot{\varepsilon} = R_m\dot{\varepsilon}_0 + B \cdot \log\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)^m,$$

where:

- $R_e\dot{\varepsilon}$, $R_m\dot{\varepsilon}$ - the yield point and tensile strength, respectively, at the strain rate of $\dot{\varepsilon} < 10$ s^{-1},
- $R_e\dot{\varepsilon}_0$, $R_m\dot{\varepsilon}_0$ - the yield point and tensile strength, respectively, at the strain rate of $\dot{\varepsilon}_0 \approx 10^{-3}$ s^{-1},
- A, B, n, m - material constants expressing the sensitivity of the structure on the strain rate.

Table 2. **Influence of a notch on the yield point R_e and the tensile strength R_m**

Tablica 2. **Utjecaj zareza na granicu razvlačenja R_e i vlačnu čvrstoću R_m**

h / mm	1,0			1,5			1,8		
v / (mm/min)	1	10	100	1	10	100	1	10	100
ΔR_e / %	12	21	26	11	17	19	10	14	19
ΔR_m / %	13	15	26	13	18	19	16	19	20

Higher yield point and tensile strength values determined at the strain rate of 0,084 s^{-1} on the notched test bars when compared with the classical test bars should be attributed to the notch effect. Figure 8. documents the influence of the notch effect ($R_{notch} = k{\cdot}R$) for the tested sheet thickness, which indicates that the notch effect is more significant at a higher sheet thickness.

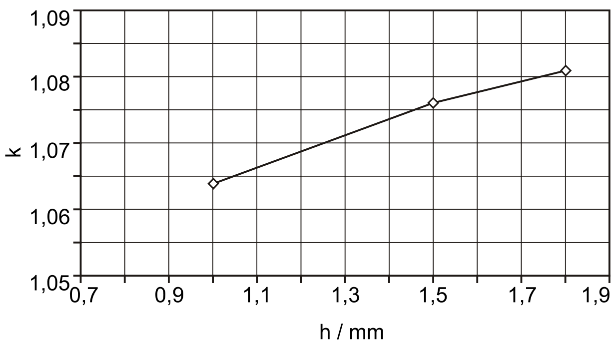

Figure 8. **Relationship between the thickness of the tested sheet and the notch coefficient**
Slika 8. **Odnos između debljine ispitivanih traka i koeficijenta zareza**

For evaluation of the cold formability of sheets, the basic characteristics include, besides R_e, R_m and A, also the R_e/R_m ratio, which controls the local loss of plastic stability due to the sheet non-homogeneity (structure, thickness tolerance, defects, etc.), but also due to the processing technology. The R_e/R_m ratio is dependent on the sheet grade, as well as on the product type. Since the aim of the paper was, *inter alia*, to determine the influence of the strain rate on the formability of the tested sheet, we also analyzed the influence of the strain rate on the R_e/R_m ratio (Figure 9.). Figure 9. shows that the R_e/R_m ratio practically does not change up to the strain rate of 1 s^{-1} (while taking into account the notch coefficient), while this rate is a maximum achievable in practice. The tested sheets reach a more significant increase of the R_e/R_m ratio at the strain rate of 10 s^{-1}, i.e. at such a strain rate there is a risk of loss of plastic stability of the tested sheets.

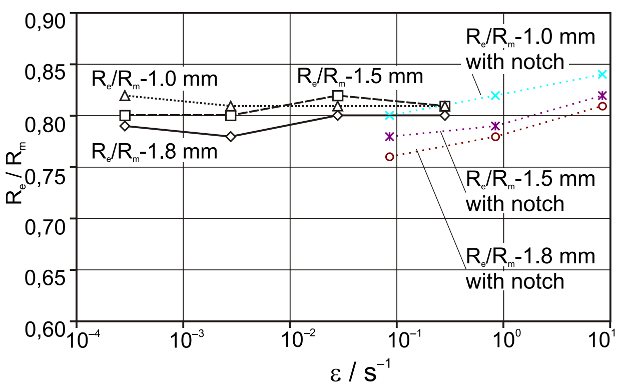

Figure 9. **Influence of the strain rate $\dot{\varepsilon}$ on the R_e/R_m ratio of the tested sheets**
Slika 9. **Utjecaj brzine deformacije $\dot{\varepsilon}$ na odnos R_e/R_m ispitivanih uzoraka**

CONCLUSION

The results of the tensile test at the loading rates from 1 to 1000 mm/min show the following:

1. With increasing the loading rate in the interval from 1 to 1000 mm/min, the resistance of the tested steel against plastic deformation increases. The yield point and tensile strength values of notched test bars are higher than that of standard test bars and the intensity of their growth increases with increasing the loading rate.
2. The differences of yield point and tensile strength values determined at the same loading rates on standard and notched test bars enable to determine the strain rate in the notch, as well as the strengthening due to the notch. At standard loading rates of tensile machines, it is possible to achieve strain rates as many as 10 s^{-1} on notched test bars, i.e. strains under dynamic conditions.
3. At loading rates from 1 to 1000 mm/min and using standard and notched test bars, the strain rates from 10^{-4} to 10 s^{-1} were achieved. The obtained tests are in accordance with parametric equations describing the influence of the rate on the strength properties, shown in literature.
4. The analysis of the results shows that up to the strain rate of ca 1 s^{-1} the R_e/R_m ratio and the elongation of the tested steel practically do not change, i.e. it is possible to use the formability criteria determined at the tensile test up to this strain rate. With increasing the strain rate, it is necessary to take into account an increase of the natural deformation resistance.

The above-presented pieces of knowledge are important for practice, since in the manufacture of pressings high strain rates occur in critical points even during static loading.

REFERENCES

[1] A. Hrivňák et. al.: Technologická lisovateľnosť oceľových plechov. In: Materiál v inžinierskej praxi 98, Herľany 14. - 16.1.1998, p. 181.
[2] J. Micheľ, Materiálové inžinierstvo 3 (1996) 4, 22.
[3] R. W. K. Hon Eycombe, F. B. Pickering, Metallurgical Trans. 3 (1972), 1099.
[4] E. Čižmárová, J. Micheľ, Acta Metallurgica Slovaca 9 (2003) 2, 90 - 100.
[5] E. Čižmárová et. al., Metallurgy 41 (2002) 4, 285 - 290.
[6] J. Micheľ, M. Buršák, M. Mihaliková, Acta Metallurgica Slovaca 11 (2005) 1, 134 - 140.
[7] J. Janovec, J. Ziegelhelm: Růst úžitných vlastností u tenkých automobilových plechů. In: Technológie 99, STU Bratislva, 8. - 9.1999, p. 319.
[8] F. Trebuňa, M. Buršák: Medzné stavy-Lomy, SjF TU Košice, Grafotlač, Prešov, 2002, ISBN 80-7165-362-4.