

Analysis of the Influence of the Loading Rate on the Mechanical Properties of Microalloyed Steel

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Abstract

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The aim of this paper is to analyse the influence of the loading rate in the range 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 steel strips. The combination of the loading rate and the test bar type made it possible to obtain the relationship 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 thickness of 1, 1.5 and 1.8 mm increase exponentially, but formability does not change up to the strain rate of 1 s^{-1} .

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

Introduction

Cold formability of material is influenced by all factors participating during the forming process. The crucial factors include the sheet material, the formability, which is most often evaluated according to its yield point, tensile strength and its ratio, elongation, uniform deformation, its combination.⁽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 by means of a coefficient, which must be taken into account.⁽⁷⁾ Besides the information provided above, at the given loading rate, the notch causes the localization of deformation and hence the strain rate in the notch area increases by order.⁽⁸⁾

Experimental material and methods

The influence of the loading rate and the notch on the mechanical properties during uniaxial loading were observed on microalloyed steel strip, which chemical composition is the following: 0.12%C, 1%Mn, 0.04%Si, 0.025%P, 0.01%S, 0.015%Al, 0.08%Nb, 0.1%Ti, 0.10%V. The material was supplied as cold rolled sheets cut in length with the thickness of 1, 1.5, and 1.8 mm.

The microstructure of steel is predominantly ferritic, while fine pearlitic grains are precipitated at the ferritic grain boundaries (Figure 1). The nature of the structure did not change with the strip thickness; the only difference was the ferritic grain size,



Figure 1. Microstructure of the tested steel

Table 1. Basic mechanical properties of tested steel

Thickness [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

which had only 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 the tensile 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 test bars were made, as shown in Figures 2 and 3. During the tensile tests, the force – elongation diagrams were recorded using a PC and basic mechanical properties were evaluated.

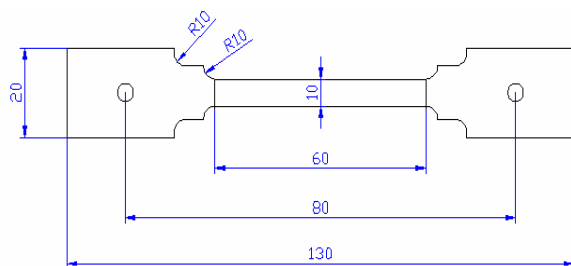


Figure 2. Tensile test bar

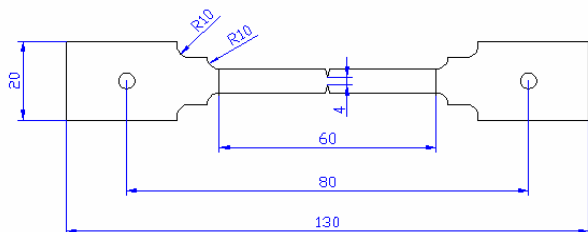


Figure 3. Tensile test bar with V notch on both sides

Results and Discussion

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 with the thickness of 1,

1.5 and 1.8 mm, intended for the manufacturing of heavy-loaded pressings in the automotive industry. Figure 4 shows the graphs of documented results of the influence of the loading rate on the basic mechanical properties, determined on classical flat test bars and on test bars with V-notches.

The measured results indicate that the resistance of steel against plastic deformation increases together with the increasing loading rate, 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 the differences between values of the yield point and the tensile strength of the classical test bars and the notched test bars increase with the increasing loading rate. This is due to the notch effect, since the notch changes the stress state and strengthens the material and localises deformation, therefore at the same loading rate the strain rate around the notch is higher by order than mean strain rate of the classical test bar (in this case L=60 mm).⁽⁵⁾

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

h [mm]	1			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

Note: $\Delta R_e = [\Delta R_{enotch} / R_e]100$; $\Delta R_m = [\Delta R_{mnotch} / R_m]100$

The mean strain rate for classical bars can be calculated from the formula $\dot{\epsilon} = v/L$, v being the loading rate and L being the deformed length. The determination of the mean strain rate in the notch is very problematic. The mean strain rates in the notch at the loading rates of 1, 10 and 100 mm/min could be determined by applying formulas for the notch opening from the COD test together with the notch shape measurements before the tensile test and after the failure as well as verifying using a video camera. 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

range from 10^{-4} to 10 s^{-1} , which are documented in Figure 5. In the strain rate interval from 0.028 to 0.28 s^{-1} (Figure 5), R_e and R_m values were experimentally determined on classical and notched test bars. The nature of the R_e - $\dot{\epsilon}$ or R_m - $\dot{\epsilon}$ relationship determined on classical test bars ($L=60 \text{ mm}$) and on notched test bars does not change and these relationship can be described as follows:

$$R_e \dot{\epsilon} = R_e \dot{\epsilon}_0 + A \cdot \log \left(\frac{\dot{\epsilon}}{\dot{\epsilon}_0} \right)^n \quad (1)$$

$$\text{or } R_m \dot{\epsilon} = R_m \dot{\epsilon}_0 + B \cdot \log \left(\frac{\dot{\epsilon}}{\dot{\epsilon}_0} \right)^m \quad (2)$$

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

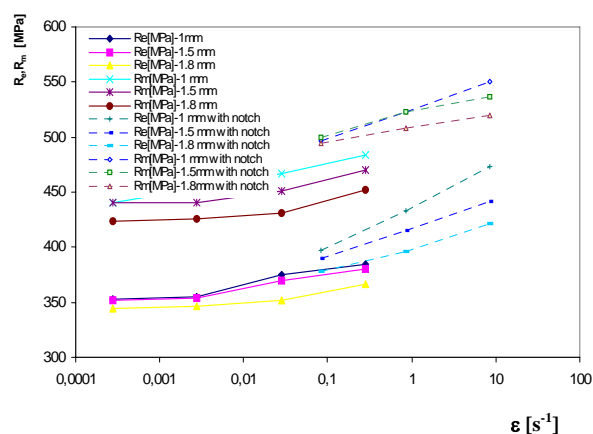


Figure 4. Influence of the strain rate $\dot{\epsilon}$ on the yield point R_e and the tensile strength R_m of the tested sheets.

Higher yield point and tensile strength values were determined at the strain rate of 0.084 s^{-1} on the notched test bars when compared with the classical test bars and should be attributed to the notch effect. Figure 6 documents the influence of the notch effect ($R_{\text{notch}} = k \cdot R$) for the tested sheet thickness, which indicates that the notch effect is more significant at a higher sheet thickness.

For evaluation of the cold formability of sheets, the basic characteristics include 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, 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 to determine the influence of the strain rate on the formability of the tested sheet. The influence of the strain rate on the R_e/R_m ratio was also analysed (Figure 5). Figure 6 shows that the R_e/R_m ratio practically does not change up to the strain rate of 1 s^{-1} (when taking into account the notch coefficient), while this rate is a maximum achievable in practice.

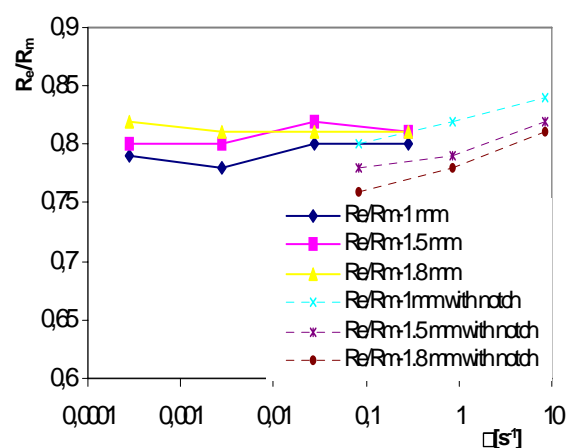


Figure 5. Influence of the strain rate $\dot{\epsilon}$ on the R_e/R_m ratio of the tested sheets.

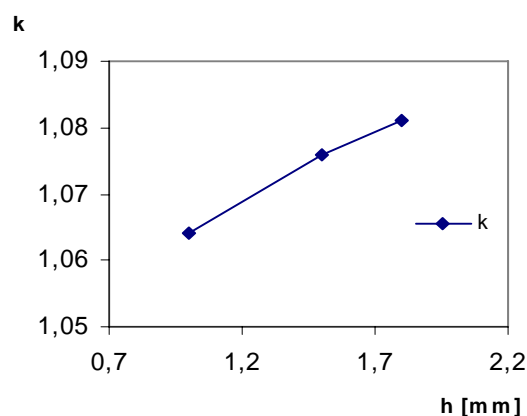


Figure 6. Relationship between the thickness of the tested sheet and the notch coefficient.

Conclusion

The results of the tensile test at the loading rates from 1 to 1000 mm/min are shown as follows:

1. With the increasing 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 those of standard test bars and the intensity of their growth increases together with the increasing loading rate.

2. The differences of yield point and tensile strength values determined at the same loading rates on standard and notched test bars allow 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 as many as 10 s⁻¹ strain rates 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, 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.

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