MICROALLOYED STEEL UNDER TENSION AND BENDING CONDITION

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Abstract: *The article deals with the influence of the loading rate in the interval from 1 to 1000 mm/min on the mechanical properties of drawing steel sheet, used for the manufacture of automotive parts, under tension and bending conditions. It describes the aspects of material characteristics under tension and bending conditions, while bending tests were made on notched specimens (a modified impact bending test). With an increasing strain rate up to the critical value, the resistance of material against strain increases and hence the yield point and the tensile strength increase, the deformation ability, the deformation homogeneity, the structure and the substructure after deformation, etc. are changed. The paper presents knowledge that using a modified notch toughness test it is possible to achieve the formability characteristics corresponding to dynamic strain rates even under the static loading.*

Keywords: MICROALLOYED STEEL, MECHANICAL PROPERTIES, DRAWING STEEL SHEET, BENDING, STRAIN RATE, PRESSABILITY CHARACTERISTICS

1. Introduction

The influence of the strain rate on the material characteristics is systematically observed and the knowledge is generalized. With an increasing strain rate up to the critical value, the resistance of material against plastic strain increases and hence the yield point and the tensile strength increase, the deformation ability, the deformation homogeneity, the structure and the substructure after deformation, etc. are changed. At a supercritical strain rate, which is higher than the maximum dislocation movement rate, a brittle failure occurs [1-4]. The sensitivity of steel to the strain rate depends on its structure; therefore it is necessary to assess the sensitivity of individual steel grades to the strain rate [5]. The experimental determination of the influence of the strain rate on mechanical properties, as well as the interpretation of obtained results, is very demanding even today. Possibilities of replacing the tensile test at various strain rates with simpler tests are looked for. The notch toughness test, with a certain modification, can be included among such tests [6 - 8].

The increase of the production rate of pressings enables the productivity increase. This route is the most utilized nowadays and the strain rates are gradually approaching to rates corresponding to dynamic loading.

2. Material and Experimental procedures

Experiments were made on light-gauge steel strip with the gauge of 1 mm, made of galvanized microalloyed steel. Such steel strips have higher strength properties, but also good plasticity even at a low carbon content, due to microalloying with (Nb<0.008%) and Ti (Ti<0.01%) combined with controlled hot rolling, and they are used to manufacture loaded pressings for the automotive industry Table 1. The microstructure of the tested sheet consists of the ferritic matrix (see Fig. 1), in which the precipitates of microalloying elements are uniformly distributed.

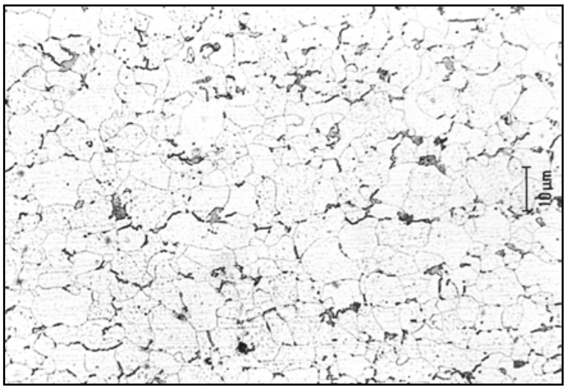


Fig. 1 *Microstructure of microalloyed steel.*

Table 1: *Chemical composition of tested steels*

%	C	Mn	Si	P	S	Al	Nb	Ti	V
steel	0,12	1,0	0,04	0,025	0,01	0,01	0,008	0,01	0,1

Samples were taken from the strip in the rolling direction and flat test specimens for the tensile test and test specimens for the modified bending test were made, (see Fig. 2 and Fig. 3).

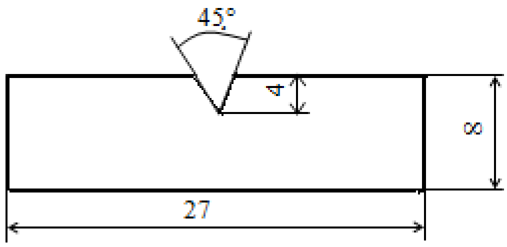


Fig. 2 *Shape and dimensions of the modified bending test (modified notch toughness test) specimen.*

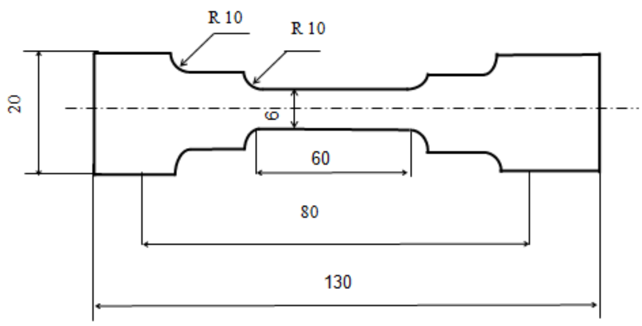


Fig. 3 *Shape and dimensions of the tensile test specimen.*

On the tensile machine INSTRON 1185, which makes it possible to record the loading diagram on a computer via a converter, tensile tests were carried out and using a fixture also modified bending tests (notch toughness test) were carried out (see Fig. 4). The distance of supports is in the modified. Bending test was 27 mm; the mandrel shape was identical with the of the Charpy hammer mandrel. The depth of the V notch was 0.5 x

Fig. 4 *Modified bending tests (notch toughness test).*

specimen height. The tests were carried out at four loading rates, namely 1, 10, 100 and 1000 mm/min. The following mechanical properties were evaluated: yield point, tensile strength, yield point in bending, ultimate bending strength, strain hardening exponent and stable plastic strain deflection (deflection from the force at the yield point up to the maximum bending force). These mechanical properties make it possible to determine basic characteristics for the assessment of the press ability of the tested sheet at selected loading rates. Table 2 shows mechanical properties microalloyed steel in static condition.

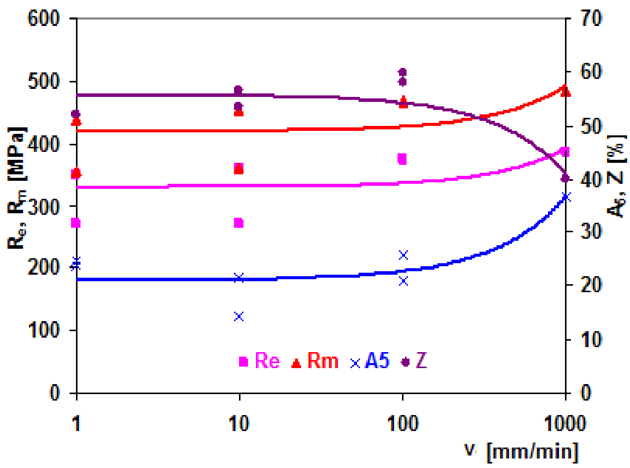
Table 2: *Mechanical properties of tested material in static condition.*

	Microalloyed steel
Thickness [mm]	1
Yield strength R_m [MPa]	410
Proof stress $R_{p0,2}$ [MPa]	340
Contraction A_5 [%]	20
Ductility Z [%]	49

3. Results and Discussions

3.1 Mechanical properties

The experimental results of the influence of the loading rate on the observed mechanical properties using the tensile test and the



bending test (modified notch toughness test) are shown in Figure 5.

Fig. 5 *Dependence of mechanical properties on the loading rate in the tensile test*

The results show that the strength properties of the tested steel strip increase with an increasing loading rate (Fig. 5).

The influence of the loading rate on the yield point R_e and the tensile strength R_m in the tensile test can be described using the following formula (1) [9,10]:

$$R_V = R_{vo} + k.\log v/v_o \qquad (1)$$

Where:

-R_v is the yield point or the tensile strength at the loading rate v

-R_{vo} is the yield point or the tensile strength at the loading rate $v_o = 1.67.10^{-5} s^{-1}$

-**k** is a material constant expressing the sensitivity of the tested steel to the loading rate.

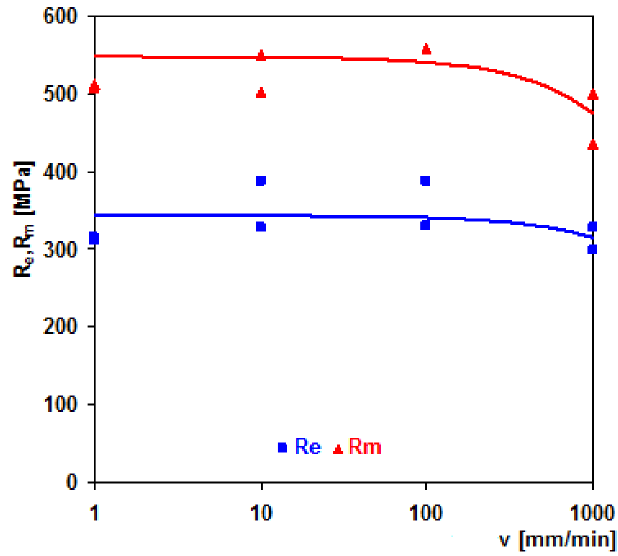


Fig. 6 *Dependence of mechanical properties on the loading rate in the modified bending test.*

Fig. 6 shows that in the modified bending test the course of the R_{eo}, R_{mo} – loading rate relationship is exponential, which means that the strain rate ε in this test is higher than 1 s^{-1}. Using calculations and microscopic measurements, the deformed area in the notch was determined and then the strain rate in the notch was calculated.

The relationship between the loading rate and the yield point in bending R_{eo} and the ultimate bending strength R_{mo} in the modified bending test is different from the tensile test and can be described as follows formula (2, 3) [9 -11]:

$$R\varepsilon = R\varepsilon + k.\log(\varepsilon/\varepsilon_o) \qquad (2)$$

at the strain rate up to 1 s^{-1}, and

$$R_\varepsilon = R\varepsilon + k.\log(\varepsilon/\varepsilon_o)^n \qquad (3)$$

at the strain rate from 1 to $10^2 s^{-1}$.

One-way load of the material with a higher mechanical tension than a certain limit value causes the breakdown of the breakage and its gradual growth until the cohesion of the material, the parts of which are separated to form new free surfaces - fracture surfaces

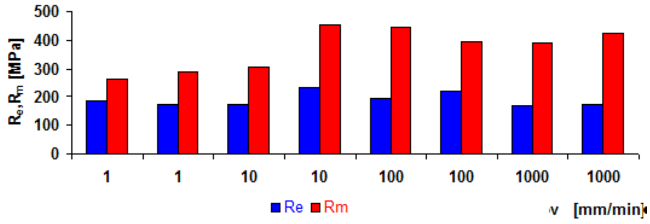


Fig. 7 Dependence Re, Rm, from the load speed at modified bend test

3.2 Fracture Analyses

In the fracture areas, we see a gradual, asynchronous loss of interatomic bonds under the effect of shear stresses. It is realized by skid movement of dislocations. The tested microalloyed steel is a ductile violation that arises from a hollow mechanism. Hole morphology is the result of a ductile material fracture

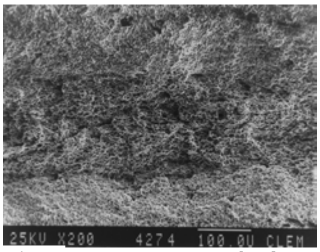


Fig. 8 *Fracture area at a load speed of 1mm/min 200x*

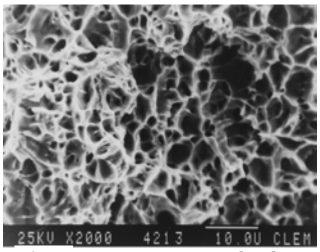


Fig. 9 *Fracture area at a load speed of 1mm/min 2 000x*

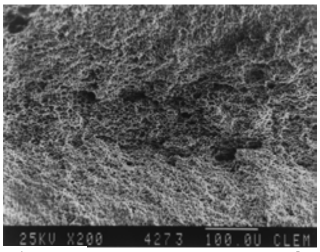


Fig. 10 *Fracture area at a load speed of 100 mm/min 200x*

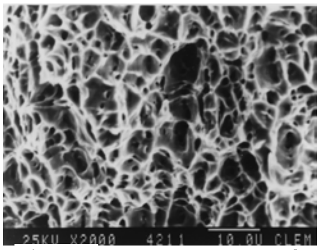


Fig. 11 *Fracture area at a load speed of 100mm/min 2 000x*

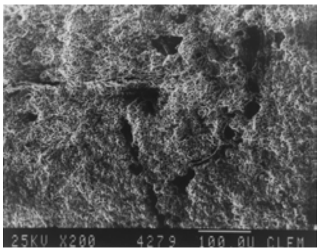


Fig. 12 *Fracture area at a load speed of 1000 mm/min 200x*

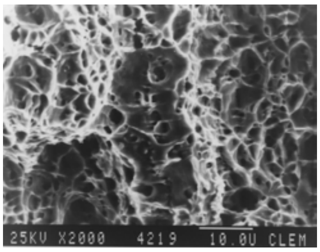


Fig. 13 *Fracture area at a load speed of 1000mm/min 2 000x*

Fig. 8, 9 at speeds 1 mm/min, the ductile fracture is an even morphological hole where the holes are deep. Cavity coalescence is visible in small magnifications. The fracture characteristic of (Fig. 10, 11) at a load speed of 100 mm / min is similar to that of 1 mm / min. More pronounced is the cavity coalescence in the direction perpendicular to the direction of the tension. At a load speed of 1 000 mm min, the angle of rupture is increased (Fig. 13), a fairly uneven surface is formed, the wells are smoother. (Fig. 12) we can see a large particle trap, because it did not manage to pass through the whole process of ductile morphology with a hole morphology.

At speeds load 1000 mm/min is visible indication (facets) intergranular ductile fracture.

The values of strength and plasticity properties determined using the modified bending test are, when compared with the tensile test, influenced by the loading method and the notch effect. This fact was taken into account in such a way that we put into line the values of the yield point and the strength values. A similar way was used for the strain hardening exponent n and the stable plastic strain deflection

On the basis of these considerations, Figure 5 shows the graph of the influence of the strain rate on the strength properties of the tested material in the tensile test and the modified bending test and Figure 7 shows the influence of the strain rate on the R_e/R_m ratio, the strain hardening exponent and the stable plastic strain deflection hr.

4. Conclusions

The paper analyses the influence of the loading rate ranging from 1 to 1000 mm/min on the mechanical properties of microalloyed steel under tension and modified bending conditions (modified notch toughness test). It results from the analysis that:

- the strain rate in the modified bending test is 2,3-times higher than that in the tensile test at the same loading rate, which means that using this test it is possible to determine material characteristics corresponding to dynamic strain rates at the static loading
- after making a correction resulting from the different loading and the notch effect, in the modified bending test it is possible to obtain the relationship between the material characteristics and the strain rate, corresponding to the uniaxial tension conditions
- with the increase of the strain rate in the interval from 100 to 1000 mm/min, the yield point and the yield point/strength ratio of the tested steel significantly increase.

- At the loading rates monitored, samples were broken by a ductile fracture, which is performed by a cavity mechanism. The result is the fracture morphology of the fracture surface. At 1000 mm / min load speeds, a hint of intercrystalline ductile violation is seen.

Load speed (1 to 1000 mm / min) affects strength and deformation characteristics only slightly, meaning that steel products can be formed at a high speed up to 1000 mm / min. This fact means shortening the production cycle and thus increasing the financial benefits.

5. Acknowledgement

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6. References

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