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# THE INFLUENCE OF THE LOADING RATE ON THE MECHANICAL PROPERTIES OF DRAWING STEEL SHEET

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*Preliminary Note - Prethodno priopćenje*

The paper analyzes the influence of the loading rate in the interval from 1 to 1000 mm/min on the mechanical properties of drawing steel sheet H260LAD with the gauge of 1 mm, 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). The paper presents knowledge that using a modified notch toughness test it is possible to achieve the pressability (formability) characteristics corresponding to dynamic strain rates even under the static loading.

***Key words:*** *steel strip, drawing, tension, bending, strain rate*

**Utjecaj brzine opterećivanja na mehanička svojstva vučenog čeličnog lima.** U radu se analizira utjecaj brzine opterećivanja u intervalu od 1 do 1000 mm/min na mehanička svojstva vučenog čeličnog lima H260LAD debljine 1 mm koji se koristi u proizvodnji autodijelova tako da se podvrgne istezanju i savijanju. Opisuju se aspekti karakteristika materijala pri istezanju i savijanju. Testiranje na savijanje se izvodilo na epruvetama sa zarezom (prilagođen test na savijanje na udar). Rad nam demonstrira saznanja da je uporabom prilagođenog testa na zareznu žilavost moguće dobiti takve karakteristike oblikovnosti koje odgovaraju zahtijevanim brzinama dinamičkog deformiranja čak i pri statičkom opterećenju.

***Ključne riječi:*** *čelični lim, vučenje, istezanje, savijanje, brzina deformacije*

## INTRODUCTION

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.

The influence of the strain rate on the material characteristics is systematically observed and the knowledge is generalized [1 - 4]. 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.

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 - 7]. 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 [8 - 10], with a certain modification, can be included among such tests.

The paper is aimed at analyzing the influence of the loading rate in the tensile test and the notch toughness test on the material characteristics of drawing steel. It is also aimed at the aspects of the determination of material characteristics using these testing methods and their utilization in evaluating the pressability.

## MATERIAL AND EXPERIMENTAL METHODS

Experiments were made on light-gauge steel strip with the gauge of 1 mm, made of galvanized microalloyed steel H260LAD. Such steel strips have higher strength properties, but also good plasticity even at a low carbon content, due to microalloying with Nb (Nb < 0,005 %) and Zr (Zr < 0,01 %) combined with controlled hot rolling, and they are used to manufacture loaded pressings for the automotive industry. The microstructure of the tested sheet consists of the ferritic matrix with the grain size of ca 0,01 mm,

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in which the precipitates of microalloying elements are uniformly distributed.

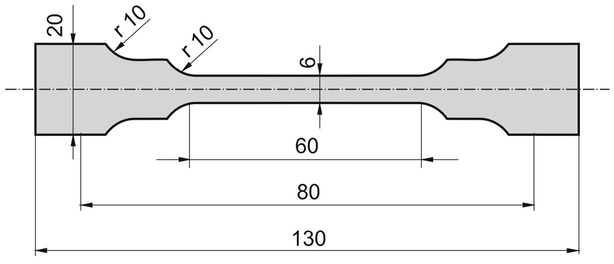


Figure 1. **Shape and dimensions of the tensile test specimen**
Slika 1. **Oblik i dimenzije epruvete za ispitivanje na vlak**

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, as shown in Figure 1. and Figure 2.

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 by using a fixture also modified bending tests (notch toughness test) were carried out. Based on experience, the distance of supports in the modified bending test was 27 mm, the mandrel shape was identical with that of the Charpy hammer mandrel. The depth of the V notch was 0,5 × specimen height.

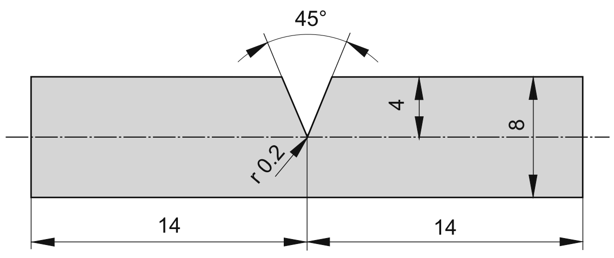


Figure 2. **Shape and dimensions of the modified bending test (modified notch toughness test) specimen**
Slika 2. **Oblik i dimenzije epruvete za prilagođeno testiranje na savijanje (prilagođen pokus na zareznu žilavost)**

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 pressability of the tested sheet at selected loading rates.

## TEST RESULTS AND ANALYSIS

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 3. and Figure 4. The results show that the strength properties of the tested steel strip increase with an increasing loading rate (Figure 3.).

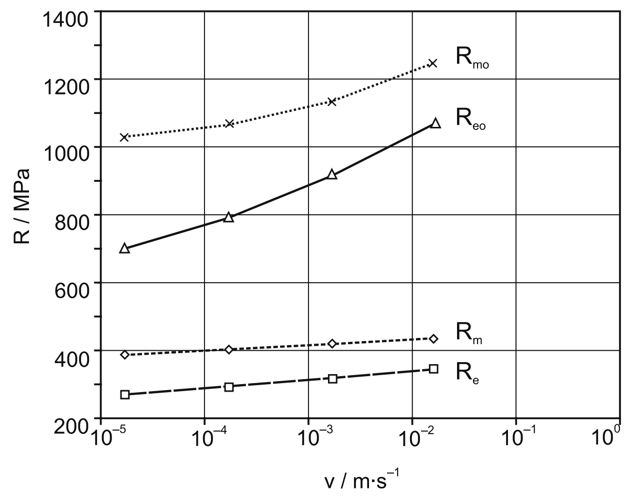


Figure 3. **Dependence of mechanical properties on the loading rate in the tensile test**
Slika 3. **Utjecaj mehaničkih svojstva o brzini opterećivanja u prilagođenom pokusu na savijanje**

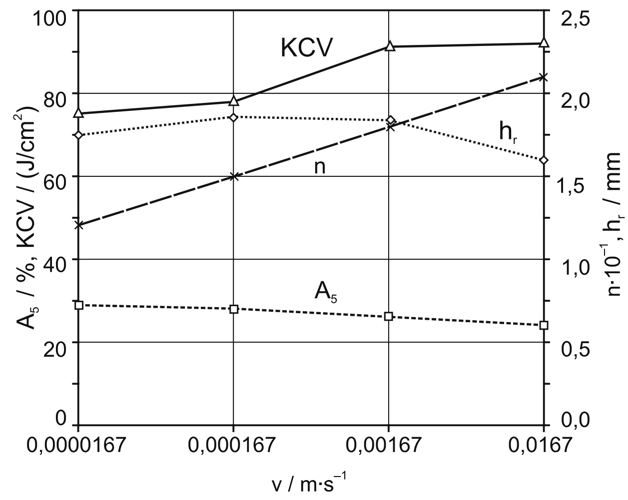


Figure 4. **Dependence of mechanical properties on the loading rate in the modified bending test**
Slika 4. **Ovisnost mehaničkih svojstava o brzini opterećivanja u prilagođenom pokusu na savijanje**

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 by using the following formula:

$$R_v = R_{vo} + k \cdot \log (v/v_0) \qquad (1)$$

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 $v_0 = 1,67 \cdot 10^{-5}$ s$^{-1}$,

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

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:

$$R_{ov} = R_{ov0} + k \cdot \log (v/v_0)^n \quad (2)$$

Hence the sensitivity of the tested steel to the loading rate is expressed using material characteristics $k$ and $n$.

The influence of the loading rate in the evaluated interval on the elongation $A_5$ is not significant (Figure 5.). The strain hardening exponent n increases with an increasing loading rate ($n_v = k \cdot \log (v/v_0)$) and the stable plastic strain

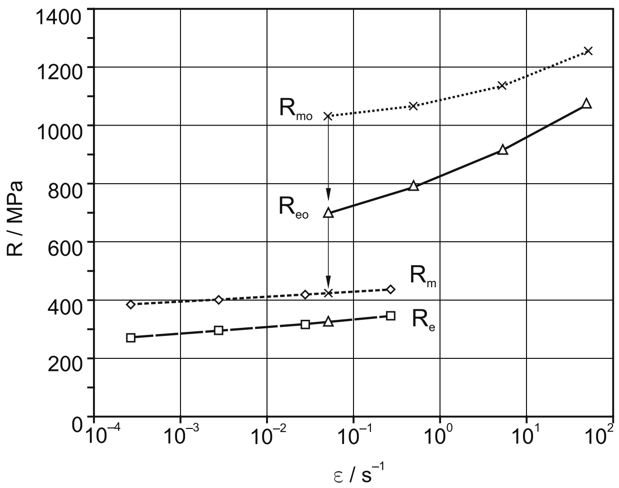


Figure 5. **Dependence of strength properties on the strain rate ε in the tensile test and the modified bending test**

Slika5. **Ovisnost svojstava čvrstoće, o brzini deformiranja ε u pokusu na vlak i prilagođenom pokusu na savijanje**

deflection $h_r$ in the modified bending test is maximum at the loading rate of 10$^{-1}$ m/s. The relationship between the notch toughness KCV and the loading rate $v$ is similar.

The loading rate v is a relative variable, which depends on the deformed length. The mean strain rate $\varepsilon$ in the tensile test can be calculated easily ($\varepsilon = v/L_o$, where $L_o$ is the deformed length). However, it is more difficult to calculate the strain rate in the notch in the bending test and this loading rate is higher by an order than in the tensile test. The influence of the strain on the strength properties [2 - 4, 6] can be described with parametric equations:

$$R_\varepsilon = R_\varepsilon + k \cdot \log (\varepsilon/\varepsilon_0) \quad (3)$$

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

$$R_\varepsilon = R_\varepsilon + k \cdot \log (\varepsilon/\varepsilon_0)^n \quad (4)$$

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

Figure 4. 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 values of strength and plasticity properties determined by 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 $h_r$.

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 6. shows the influence of the strain rate on the $R_e/R_m$ ratio, the strain hardening exponent and the stable plastic strain deflection $h_r$.

It results from Figure 5. that the yield point at the strain rate interval up to 1 s$^{-1}$ can be described using Equation (3) and at the strain rate interval from 1 to 10$^2$ using Equation (4). The results indicate that using the modified bending test, while taking into account the correction (see Figures 5. and 6.) due to the loading method and the notch effect, it is possible to determine material characteristics corresponding to characteristics measured in the tensile test.

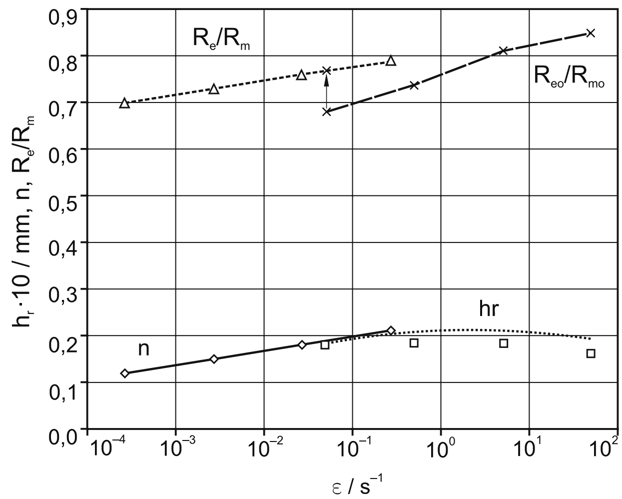


Figure 6. **Dependence of the $R_e/R_m$ ratio, the strain hardening exponent $n$ and the stable plastic strain deflection $h_r$ on the strain rate ε in the tensile test and the modified bending test**

Slika 6. **Ovisnost omjera $R_e/R_m$, eksponenta otvrdnjavanja deformiranjem $n$ i deflekcije $h_r$ o brzini deformiranja ε u pokusu na vlak i prilagođenom pokusu na savijanje**

An advantage of this test is that at the static loading we can achieve loading rates higher by an order.

Classical material pressability characteristics include, among others, the $R_e/R_m$ ratio and the strain hardening exponent. The influence of the strain rate on these characteristics of the tested steel is documented in Figure 6., which shows that with an increasing strain rate the $R_e/R_m$ ratio increases in the whole strain rate range from $10^{-4}$ to $10^2$ $s^{-1}$. The strain hardening exponent $n$, or the uniform strain deflection $h_r$, also increases, but only up to the strain rate of ca 1 $s^{-1}$. After exceeding this strain rate, $h_r$ decreases, while the reduced $R_{eo}/R_{mo}$ ratio = 0,85.

## CONCLUSIONS

The paper analyses the influence of the loading rate ranging from 1 to 1000 mm/min on the mechanical properties of drawing steel H260LAD 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 $2{,}3 \cdot 10^2$-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 $10^{-4}$ to $10^2$ $s^{-1}$, the yield point and the yield point/strength ratio of the tested steel significantly increase. The strain hardening exponent, or the equivalent stable plastic strain deflection, increases with an increasing strain rate up to ca 1 $s^{-1}$ and after exceeding this rate it decreases,
- with the increase of the strain rate up to ca $10^2$ $s^{-1}$, the notch toughness of the tested material increases, which means that the energy consumption during pressing increases,
- from the practical point of view, for assessment of pressability of the tested steel traditional criteria can be used up to the strain rate of ca 1 $s^{-1}$, which represents the upper limit of strain rates, currently used in pressing.

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