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The Influence of the Strain Rate on the Material Properties of the Zinc-Coated Sheet

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Abstract

In this paper the influence of the strain rate on the material properties of the zinc-coated sheet of the thickness (1; 1.5; 1.8) mm made from low-alloyed steel ZINKODUR 340 was analyzed. Increasing the strain rate is one of the possible ways to increase cold mechanical work in products. The tensile test is the most useful method for determining the material characteristic such as ductility. This contribution analyzes the influence of loading rate in range from 1 to 1000mm/min on material characteristics of tested steel during the tensile test. Strain rate is one of the most significant factors, which affected material behavior during the forming and resultant properties of wrought products. Intensity of this influence is function of internal composition of the steel.[2-5]

Key words: low alloyed steel, cold forming, ductility

Introduction

The increase of strain rate during the cold forming is one of the possible ways to increase the productivity. It is necessary to know the characteristics of material during the increase of strain rate because of their necessity for determination of deformation resistance and limiting state of material.[1, 7]

The aim of this contribution is to analyze the influence of the strain rate on mechanical properties of low alloyed steel of different thickness. Main result of this work is determination of the influence of loading rate in the range from 1 to 1000mm/min on the yield strength, ductility and contraction during cold forming and observation of material failure on the fracture areas.[4]

Experimental Material and Methods

The influence of strain rate on the material properties was observed on the low alloyed steel ZINKODUR 340. The chemical composition and basic mechanical properties of this steel are listed in the Tables 1 and 2.

Table 1. Chemical composition of the steel ZINKODUR 340

Steel grade according to company standard	Chemical composition [%]								
	C max	Mn max	Si max	P max	S max	Al min	Nb max	Ti max	V max
ZINKODUR 340	0,12	1,00	0,04	0,025	0,010	0,015	0,08	0,10	0,10

Table 2. Mechanical properties of the steel ZINKODUR 340

Steel grade according to company standard	Rp0,2 min [MPa]	Rm min [MPa]	Amin[%] Lo=80mm
ZINKODUR 340	340	410	20

Modern progressive technological method via the oxygen converter and strait chemical composition performance is used to produce tested material ZINKODUR 340. The steel is killed and continuously casted into the slabs.(5)

Material was supplied after the cold rolling in form of the sheets of different thickness 1; 1,5 and 1,8mm.(4) The optical microscope OLYMPUS with 500x and 1000x zoom was used for the observation of the microstructure and zinc surface of the steel, Figures. 1 and 2. It is steel with low content of the carbon (0,10%C) and this fact is supported by microstructure of the steel, which is mostly ferrite. The middle size of the grain was determined in accordance with standard STN 42 0462, d_m=0,0062mm.

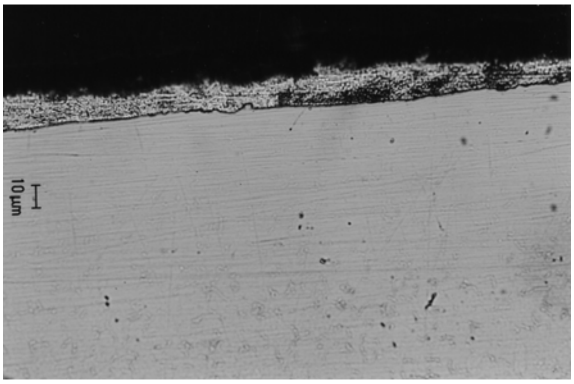

Figure 1. Non-deformed zinc layer

Figure 2. Base material

The tensile tests were carried out on the universal testing machine INSTRON 1185 (1, 10, 100, 1000 mm/min) for determination of the mechanical properties. Specimens were carried out from the material in the direction of rolling. Samples with and without notch were made for the tensile test, Figures. 3 and 4, respectively

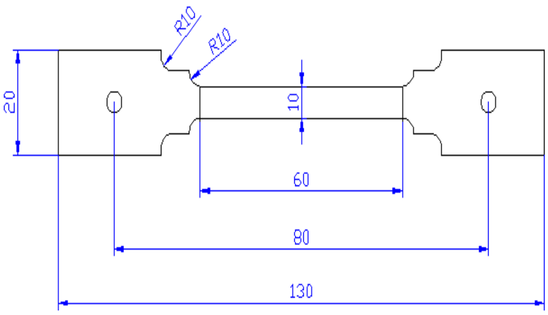

Figure 3. Test sample for tensile test

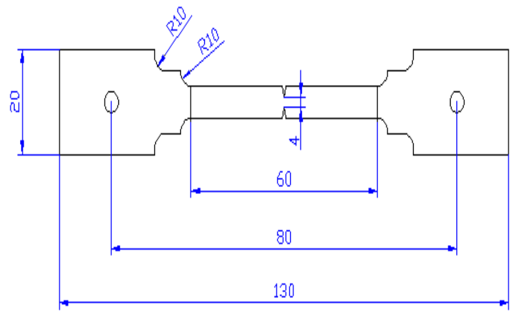

Figure 4. Test sample with notch

Results

During the tensile test with different rate the mechanical properties were registered (R_e, R_m, A_{50}, Z). Specimens with different thickness (1; 1.5; 1.8mm) were tested by tensile test using different loading rate (1; 10; 100; 1000 mm/min). Results are interpreted in Figure 5.

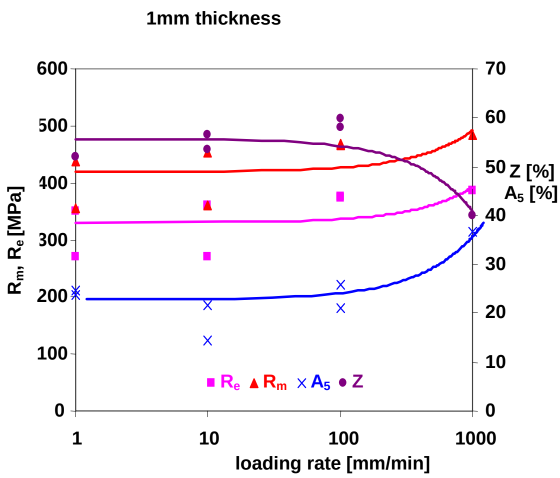

Figure 5. R_e, R_m, A_5, Z in dependence of loading rate

Mechanical properties of the samples with notch were measured in the same way and obtained values are interpreted by Figure 6.

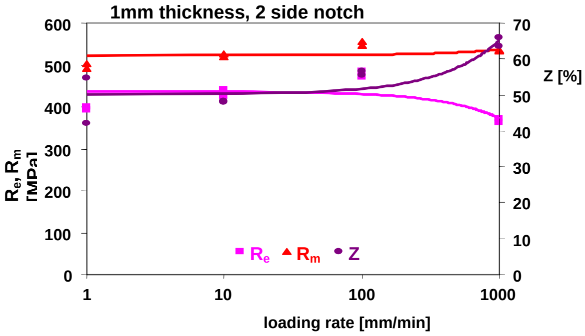

Figure 6. R_e, R_m, A_5, Z in dependence of loading rate

From the analysis of obtained values it is clear that basic mechanical properties of tested steel ZINKODUR 340 change with increasing rate. Strength properties increase, too, see Figure. 5 With increasing loading rate, values increase in range Re = 12 – 30% and Rm 2 – 26%. Values of ductility increase from 23 to 35% while value of the contraction decrease from 10 to 23%.

In the case of the samples with V-notch on both sides (Figure.6), it was found that the strength increased till the loading rate reaching the value 100mm/min. When the loading rate was 1000 mm/min the values of these characteristics are R_e = 20-34% and R_m = 7.5 – 24%.

Deformation characteristics (A_{50},Z) change with increasing strain rate, ductility increase is in the range of 10 – 23% and decrease of the contraction in the range of 16 – 20%.

The ratio Re/Rm is one of the possible ways to evaluate the plastic behavior of the material during the cold forming of thin steelsheets. Perfect plasticity is obtained when Re/Rm is <0,6 and delimited plasticity can be obtained when Re/Rm is >0,8 (Figure. 7)

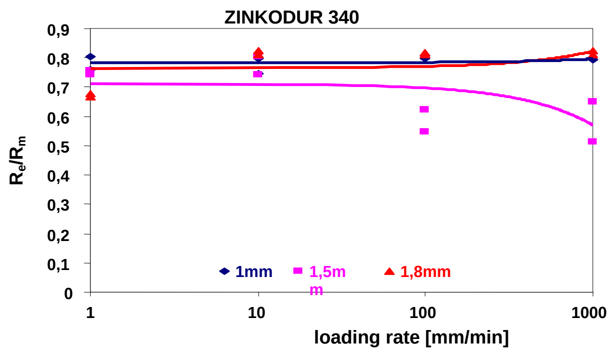

Figure 7. R_e/R_m in dependence of the loading rate

For the sample with notch it can be concluded that with increasing sheet thickness, value of the ratio Re/Rm decreases from 0,78 to 0,47 and with increasing loading rate, this value decreases too. For the sample without notch value of this ratio only slips with increasing thickness and loading rate. In the Figure. 8 there is fracture area with 200x magnification. In the Figure. 9 there is fracture area with 2000x magnification and value of used loading rate was 1000mm/min.

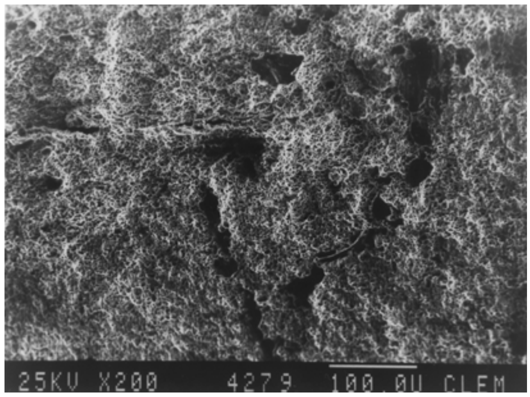

Figure 8 Fracture -Loading rate 1000 mm/min

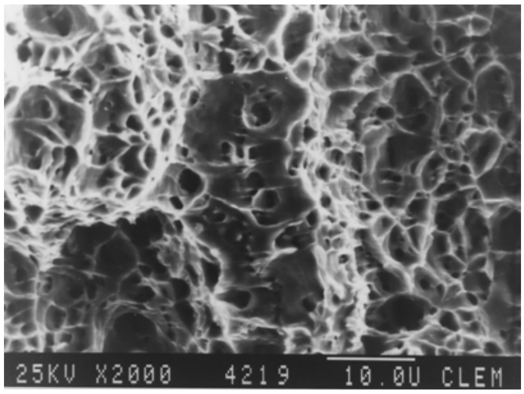

Figure 9. FractureLoading rate 1000 mm/min

Discussion

Increase of strain rate causes the increase of resistance against dislocation motion which causes critical yield stress. Till the deformation rate reaches its critical value, strength properties of material increase. Intensity of the rate influence on strength properties is a function of internal material composition. The fewer barriers against the dislocation motion provided material more sensible on deformation rate.

Increase of the strain rate till its critical values can either positively or negatively influence plastic behavior of the material. Definitely, increase of the strain rate cause increase of material toughness as the integral function of strength and strain characteristics.

The influence of the strain rate on material characteristics of tested steel is in accordance with literature knowledge. Discuss problem is determination of dependence between all the characteristic obtained by tensile test.

From the experimental results it is clear that the resistance against the plastic deformation increase with increasing strain rate (increase of the deformation resistance), but its capability of plastic deformation increase till the strain rate reaches the value of $8s^{-1}$. This critical value is limited by increasing value of the ratio Re/Rm. For tested steel sheet this ratio reaches the value of 0,8. The strain rate for nowadays cold-forming procedure is about $1s^{-1.}$

Conclusions

The aim of this work was the observation of loading rate influence (1 to 1000 mm/min) on mechanical properties of material by the tensile test. Experiments were realized on low alloyed steel ZINKODUR 340 of different thickness 1; 1.5; 1.8mm.

- Strength properties of this steel are influenced by loading rate and their values increase from 10 to 30%. Changes of ductility and contraction values only moderate in the range of the loading rate 1 to 100 mm/min but when the strain rate reach $0{,}32s^{-1}$ they start to tumble.

- Total and plastic energy consumed for destruction of the specimen decrease with increasing loading rate but Re/Rm doesn't change. In the case of the specimen with notch, total energy increases, plastic energy doesn't change and value of the ratio R_e/R_m decreases because of the loading rate changes. Forming keeps constant in both cases.

- The specimens faulted by plastic fraction realized by cavity mechanism during observed changes of the loading rate. In the case of the loading rate value of 1000 mm/min it can be observed indication of intergranular plastic failure.

- Loading rate (in the range from 1 to 1000 mm/min) does not influence strength and deformation characteristics in noticeable way. So it can be concluded that final products of this steel can be formed with loading rate 1000mm/min. This fact cause decrease of the time of forming and increase of the productivity.

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