

Effect of deformation rate on low carbon steels mechanical properties

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Abstract. Study shows the influence of stretching rate on the tensile properties for two low carbon steels during cold plastic deformation. Studies were carried out at laboratory conditions at room temperature with a static tensile test, at stretching rates ranging from 5 to 30 mm / min. Influence of the stretching rate on the elongation (A), tensile strength (R_m), yield stress (R_e) and the ratio R_e/R_m were analysed by MATLAB software. For both steels, yield stress and tensile strength increase with the increase in stretching rate, while the elongation decreases for both steels. The ratio R_e/R_m for niobium microalloyed steel remains constant. It can be concluded that both steels are strain rate sensitive, and that only R_e/R_m ratio cannot be used to determine the strain rate sensitivity of the steel.

1 Introduction

Depending on the need to achieve a better surface quality, narrow dimensional tolerance and/or increasing the strength, subsequently after the hot deformation the cold plastic processing of steel is carried out [1-2].

The final mechanical properties of steel products depend on the parameters during the plastic processing of steel. Considering there are no recrystallization mechanisms during cold plastic deformation, the strengthening is mainly due to the increase in dislocation density [3]. Strain rate, or rate at which the deformation is carried out during forming the steel products, is one of the most important parameters during plastic deformation [2].

Therefore, it is essential to know whether the steel to be shaped is sensitive to strain rate or not. It has been shown that low-carbon steels have a high sensitivity to strain rate. Depending on the chosen strain rate and the degree of reduction, the final mechanical properties of the product can be influenced [4]. Studies show that increasing the strain rate in the case of low-carbon steels increases the yield stress and tensile strength, while elongation is reduced [5-7].

The strain rate sensitivity of the steels depends primarily on the homogeneity of the steel and the presence of obstacles for dislocations movement [2,6]. Accordingly, the steels with a lower content of the alloying elements and the larger grain size show a greater sensitivity to the increase in the strain rate. Studies on microalloyed steels show that these steels exhibit less or no sensitivity to changes in strain rate. They claim that if there is less obstacles to the dislocation movement the strain rate sensitivity is higher [2].

As the decrease in plasticity is possible due to the inhomogeneities of steel, most research shows the sensitivity of the steel to increase of strain rate through the R_e/R_m ratio, which is completely



dependent only on the material itself [5]. It is shown that increase of strain rate for low-carbon steels increases the R_e/R_m ratio [6,7]. Some studies show that this increase is more pronounced for steel with $R_e < 300$ MPa and $R_e/R_m > 0.82$, in which case it is recorded a significant drop in the elongations [6]. It is well known that with microalloying, due to the presence of precipitates as obstacles to dislocation movement, the significantly higher values in the yield stress and tensile strength are achieved [8-10]. Due to the assertion that strain rate sensitivity is largely dependent on steel homogeneity, more specifically on the obstacles to dislocation motion [2], it is expected that niobium microalloyed steel is less susceptible to changes in strain rate.

This study aims to examine the strain rate sensitivity of tensile properties of two low carbon steels, one with and another without the presence of niobium precipitate. The influence of stretching rate (i.e. strain rate) on the basic mechanical properties of the studied steels will be analyzed using the MATLAB software package.

2 Experimental material and methods

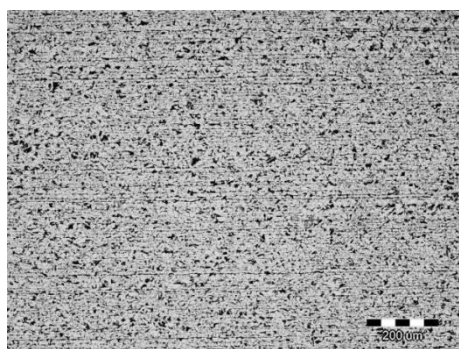
The influences of the increase in stretching rate on the tensile properties were carried out on two steels with the same base chemical composition, one of which is additionally microalloyed with niobium.

The chemical compositions of the tested steels are given in table 1.

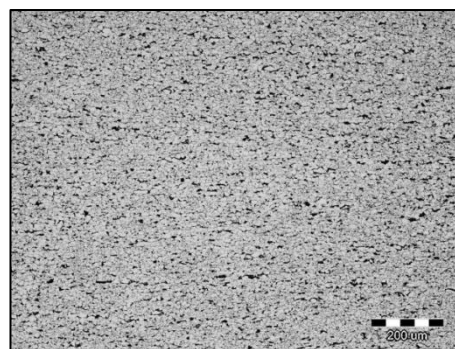
Table 1. Chemical composition of the tested steels.

Steel / Element (mas %)	C	Mn	Si	P	S	Al	Nb	N
Niobium microalloyed steel	0.12	0.78	0.18	0.011	0.018	0.02	0.048	0.008
Low carbon steel	0.13	0.77	0.18	0.010	0.019	0.02	-	-

The tests were carried out by static tensile test at room temperature, on the mechanical universal tensile testing machine Zwick 50kN. Tests were carried out at 4 different stretching rates ranging from 5 to 30 mm/min. Used stretching rates correspond to the strain rates in the range from $1.8 \cdot 10^{-3} \text{ s}^{-1}$ to $1.1 \cdot 10^{-2} \text{ s}^{-1}$. Samples of rectangular cross-section were taken in the direction of rolling from the 3 mm thick hot-rolled steel strips. Samples having original gage length of 45 mm, width 20 mm and thickness of 3 mm were prepared on CNC milling and turning machine. From previous research on the same steels [7], it is known that they have a fine grained ferrite-pearlite microstructure, figure 1.



Low carbon steel



Niobium microalloyed steel

Figure 1. Microstructure of the initial materials for low-carbon and niobium microalloyed steel

Tensile testing machine records force-elongation diagrams from which stresses and strains can be obtained. DIC method was used for determination of onset of plastic deformation during tensile testing. Using DIC the point of yielding was determined, and from force – elongation diagrams stress was obtained.

The analysis of the results was performed using the MATLAB software package, and the dependence of the mechanical properties on stretching rate was determined.

3 Results and Discussion

From the recorded force-extension graphs and from measured extension, values of yield stress, tensile strength and elongation were calculated, table 2.

Table 2. Average values of measure R_e , R_m and A at different stretching rates.

Steel / Element (mas %)	Stretching rate mm/min	R_e (MPa)	R_m (MPa)	A (%)
Niobium microalloyed steel	5	510	582	26.33
	10	537	589	26.31
	15	531	593	25.35
	30	540	615	24.30
Low carbon steel	5	394	538	31.18
	10	395	541	28.66
	15	413	546	27.00
	30	434	656	26.33

The stretching rate dependence of the yield stress is shown for the tested steels by figure 2.

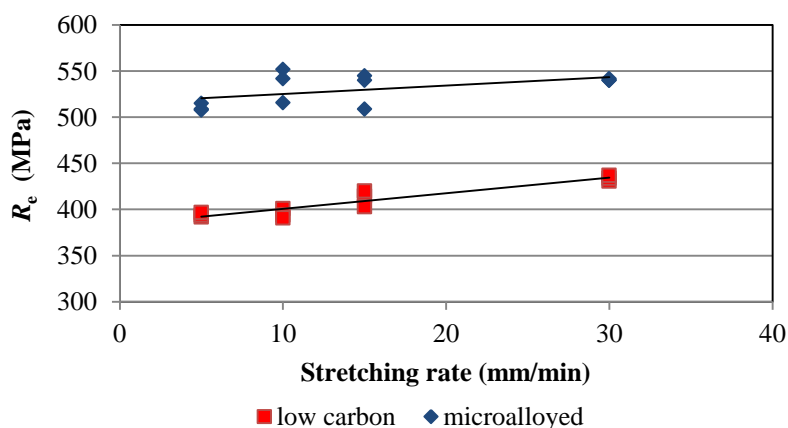


Figure 2. Dependence of the yield stress on stretching rate for low-carbon steel and niobium microalloyed steel

Previous investigations have shown the presence of niobium precipitates in the examined microalloyed steel [7,10]. By comparing the values of the measured yield stress, the higher amounts are observed in the case of microalloyed steel. This was expected as it is precipitation hardened steel. It can be noticed that in both steel with the increase of the stretching rate there is increase in the measured values of the yield stress. In the case of microalloy steel, this increase is somewhat lower. Similar observations are also measured on the values of tensile strength, figure 3.

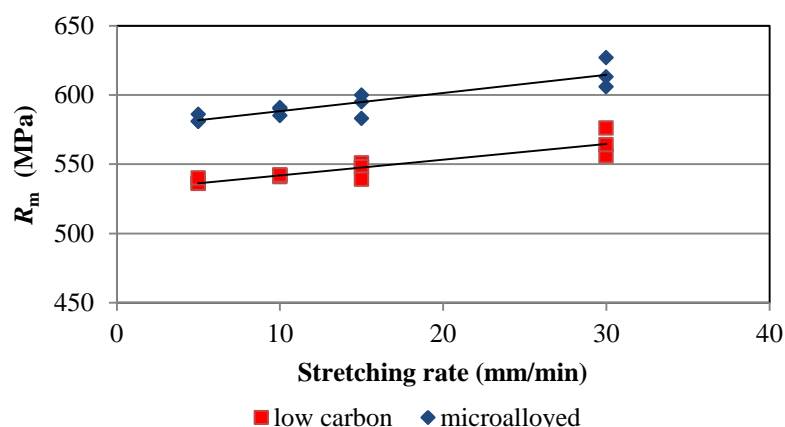


Figure 3. Dependence of the tensile strength on stretching rate for low-carbon steel and niobium microalloyed steel

Higher values of tensile strengths are also measured in the case of microalloyed steel. This was expected due to the presence of niobium precipitates. By increasing the stretching rate, the increase in tensile strength for the both tested steels was measured. It is clearly seen that increase of strength is of the same intensity for both steels. On the other hand, the elongation for both steels shows a drop by increasing the stretching rate, figure 4.

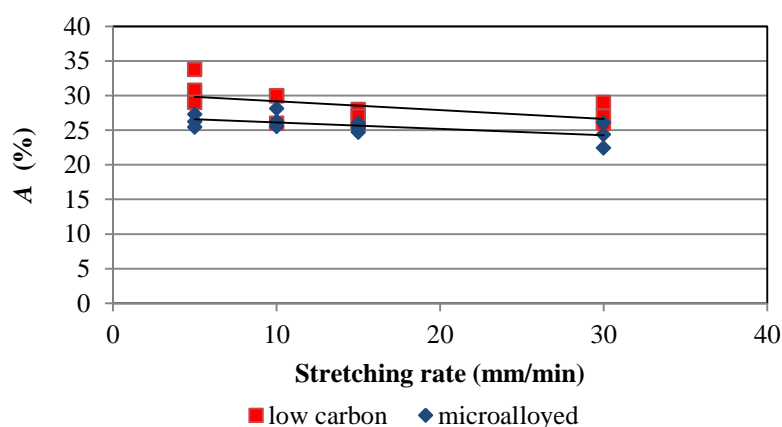


Figure 4. Dependence of the elongation on stretching rate for low-carbon steel and niobium microalloyed steel

From the obtained dependences, it can be concluded that both steel have a similar dependence on the change of stretching rate. Studies on other microalloyed steels have shown the opposite, i.e. that those steels are less sensitive to strain rate [2]. This is explained by the fact that due to the existence of obstacles to the dislocation movement, the steels become less susceptible to changes in strain rate [2]. On the other hand, some inhomogeneity in the material may also affect the drop in deformability as indicated in [5]. Most of the research on hardening due to change of strain rate is expressed by the R_e/R_m ratio [2,5-7]. The resulting dependences of the measure R_e/R_m ratio with the increase in the stretching rate from our research are given in figure 5.

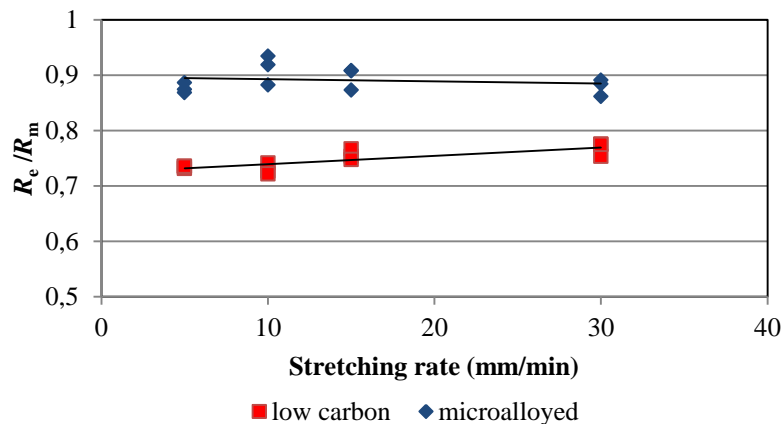


Figure 5. Dependence of the R_e/R_m ratio on stretching rate for low-carbon steel and niobium microalloyed steel

It is noted that the R_e/R_m ratio in the case of ordinary low-carbon steel shows a significant increase with increase of stretching rate. From this it can be concluded that the increase in the strain rate results strong strengthening of this steel. The yield stress increases more significantly and at higher strain rates there is a need for more significantly forces to be applied for the onset of plastic deformation. In the case of microalloyed steel, it can be seen that the R_e/R_m ratio remains constant. According to earlier claims [2,5] it could be concluded that the tested microalloyed steel is insensitive to changes in strain rate. On the other hand, measured changes in the amount of all mechanical properties show strong dependency on the stretching rate.

Previous research on this niobium microalloyed steel has shown that there are no inhomogeneities that could cause a decline in plasticity [7,10]. It can be concluded that in this case the R_e/R_m ratio is not a good indicator of the steels strain rate sensitivity. It is very important to consider other values of mechanical properties as well. The constant R_e/R_m ratio is explained by the fact that with the increase of the stretching rate there was an equal increase in values of yield stress and the tensile strength, and the ratio remained unchanged.

4 Conclusion

Both tested steel shows a clear increase in the values of yield stress and tensile strength with the increase in the stretching rate.

On the other hand measured drop in the elongation is a clear proof of strengthening during cold plastic deformation. In the case of low-carbon steel without the presence of a precipitate, increase in strain rate promotes elastic deformation. This is indicated by decrease of the R_e/R_m ratio. This should be taken into account in the subsequent cold processing of this steel.

In the case of microalloyed steel, where the presence of small precipitates of niobium has been shown by earlier studies, the dependence on the stretching rate is equally expressed. It is shown slightly smaller increase in the amount of yield stress. On the other hand, the tensile strength increases and the elongation decrease with the increase of the stretching rate. In this case the R_e/R_m ratio cannot be taken as a true indicator of strain rate sensitivity, since in the case of microalloyed steel it has a constant amount for all used stretching rates. In case of microalloyed steel other tensile values have an expected trend with the increase in the stretching rate. This is characterized by an equal amount of increase in the yield stress and tensile strength.

When considering strain rate sensitivity we believe that all the values of the mechanical properties must be taken into account.

Acknowledgements

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