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DYNAMIC CHARACTERISTICS OF AUTOMOTIVE STEEL SHEETS

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Preliminary Note – Prethodno priopćenje

The aim of this experimental research was to perform an analysis of deformation characteristics on two different types of steel: IF steel, and micro-alloyed steel were used automotive industry. For that purpose changes of properties of these materials were carried out by static $10^{-3} \cdot s^{-1}$ and dynamic $10^{3} \cdot s^{-1}$ strain rate assess its plastic properties. Vickers micro hardness test was carried out by the static and dynamic loading condition and describes different hardness distribution. The higher strain hardening of materials was obtained too that was confirmed by distribution of dislocations.

Key words: steel (IF, S420), sheets, dynamic tensile test, hardness HV1, dislocation structure

INTRODUCTION

In engineering practice, understanding the behaviour of steel under extreme loading conditions is essential for accurate prediction of material response when subjected to a combination of severe load scenarios such as collision [1, 2]. Strain rate is a significant external factor and its influence on material behaviour in forming process is a function of its internal structure. Influence intensity of the strain rate on strength properties is an internal structure of the material function. Special attention is paid for progressive IF steels and micro-alloyed steels in research [3]. Interstitial free steel (IF) contain only a small amount of carbon (C < 0,005 %). They are known with a very good deep-ductility and on the other hand good deep-ductility a material ability to deform plastically oneself without breaking is determined by Re / Rm ratio [4]. Micro-alloyed steels are characterized by a ferrite-pearlite fine-grained structure with small quantities (max. 0,15 %) of combination of elements of Al, Ti, Nb and V [5]. An increase of strength characteristics can be obtained by grain refinement and precipitation curing. The mechanical properties of the micro - alloyed steels are largely given by a type of microstructure which depends on the chemical composition and the processing technology [6].

MATERIAL AND EXPERIMENTAL METHOD

Two materials, IF Steel and S420 micro-alloyed steel were experimental investigated. Table 1 shows its chemical composition.

Tensile testing at the specified rates of strain is carried out using servo - hydraulic testing machine Zwick 1387. Figure 1 describes the size of the test bars.

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Tensile testing under static conditions was carried out according to EN ISO 6892-1 Standard at three speed loads of traverse.

Table 1 **Chemical composition /mas. %**

	IF	S420
C	0,0013	0,12
S	0,0105	0,002
N	0,0017	-
Mn	0,82	1,44
P	0,011	0,009
Si	0,006	0,05
Al	0,055	0,046
Nb	0,001	0,035
V	0,002	0,2
Ti	0,04	0,016

Recalculation of speed load of traverse at the strain rate was calculated according to following equation (1):

$$\dot{\varepsilon} = \frac{\varepsilon}{t} = \frac{v}{L_0} \qquad (1)$$

where:
$\dot{\varepsilon}$ - relative deformation, t - duration of the deformation, L_0 – working length of the test bar, v - speed of the load

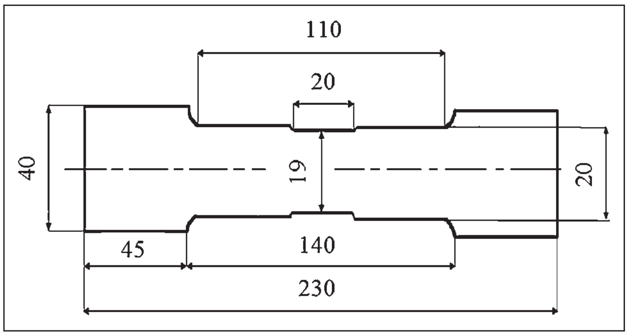

Figure 1 The size of the bars

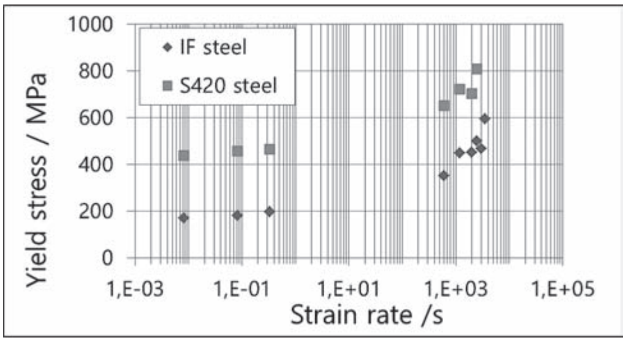

Figure 2 Dependence strain rate of IF and S420 steel sheets stress

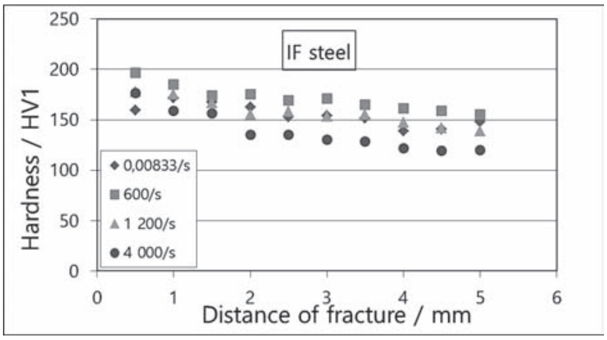

Figure 4 Effect of hardness HV1 on the distance from the quarry at different strain rates IF steel

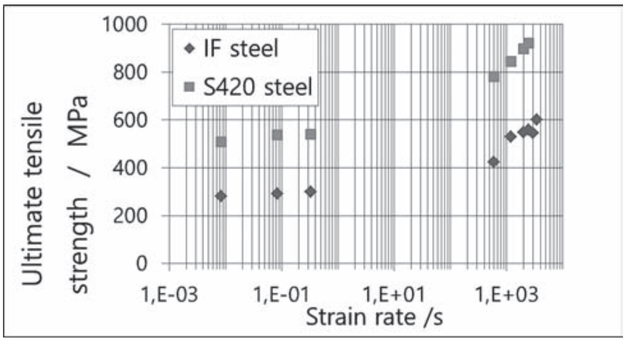

Figure 3 Influence of loading rate on Re / Rm

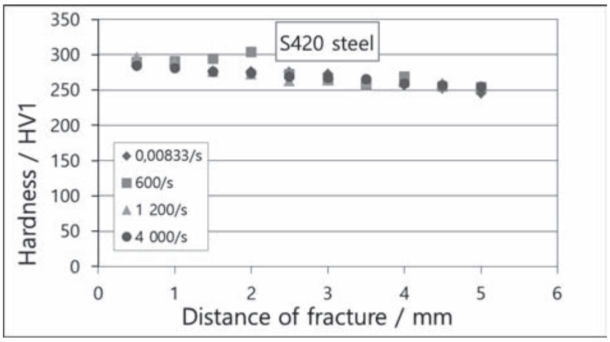

Figure 5 Effect of hardness HV1 on the distance from the quarry at different strain rates S420 steel

Dynamic tests were performed according to ISO 26203-1 and ISO 26203-2 Standard by a rotary hammer RSO. Measured data was evaluated by Program Scope 4.

Figure 2 shows the strain rate dependence of IF steel and S420 steel sheets at various yield stress. Figure 3 shows graphic values dependence ratio Re / Rm for both investigated steels.

HV1 hardness

Microhardness was determined by Vickers indentation (hardness testers LECO 700 AT) under a load of 9,81 N with a dwell time of 10 s. Hardness HV1 was measured from the fracture line every 0,5 mm. Indentations were observed in confocal microscopy (PLU NEOX 3D SENSOFAR) [10]. Figure 4 summarises the values HV1 for IF steel and Figure 5 summarises the values HV1 for S420 steel.

Substructure

Structure evolution of the material was determined by examining of samples obtained under static conditions at strain rate $8{,}3 \cdot 10^{-3} \cdot s^{-1}$ and dynamic conditions at strain rates of $3\,000 \cdot s^{-1}$ and $4\,000 \cdot s^{-1}$. Samples were observed in a JEOL 2100F transmission electron microscope at 300 kV with STEM detector. The dislocation density was then determined using the following formula (2) [7]:

$$\rho = \frac{1}{t}\frac{\sum_{1}^{N} n_i / L_i}{N} \tag{2}$$

where:

n_i - the number of intersections of the i th scanning line with dislocations, L_i - the length of the i th scanning line, t - the thickness of the foil from which the image was obtained, N - the number of scanning lines.

The thickness of the Transmission electron microscopy (TEM) foil was measured from the thickness fringes associated with the extinction distance. Table 2 shows calculated value of density of dislocations tested steels at different strain rates. The total dislocation density was measured from TEM images to be about $6{,}5 \times 10^{13}$ 1 / m^2 [7]. TEM observation revealed that dislocations in the static condition IF steel Figure 6 ($\dot{\varepsilon}$ = $8{,}33{\cdot}10^{-3}{\cdot}s^{-1}$) were mainly present in the form of planar structures. Stacking faults and planar dislocation structures (regular dislocation pile-ups, planar tangled bundles) were often observed in this condition.

Table 2 **Dislocation densities used materials**

Material	Strain rate / s^{-1}	Dislocation density / m^{-2}
IF	$8{,}33 \cdot 10^{-3}$	$2{,}0976 \cdot 10^{11}$
	600	$3{,}9723 \cdot 10^{11}$
	2 000	$8{,}8584 \cdot 10^{11}$
	4 000	$1{,}3011 \cdot 10^{12}$
S420	$8{,}33 \cdot 10^{-3}$	$7{,}8491 \cdot 10^{11}$
	2 000	$1{,}5225 \cdot 10^{12}$
	4 000	$2{,}4813 \cdot 10^{12}$

During the dynamic stage $\dot{\varepsilon} = 4000 \cdot s^{-1}$, dislocations were still mainly present in the form of planar structures as observed by TEM (Figure 7). The dislocation state was different to that in the static condition, except the planar

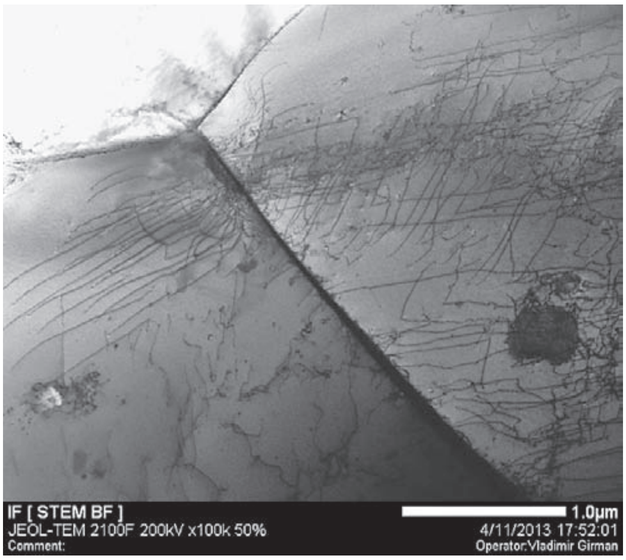

Figure 6 Dislocation structure of IF steel in the static condition ($\dot{\varepsilon}$ = 8,33.10^{-4} · s^{-1})

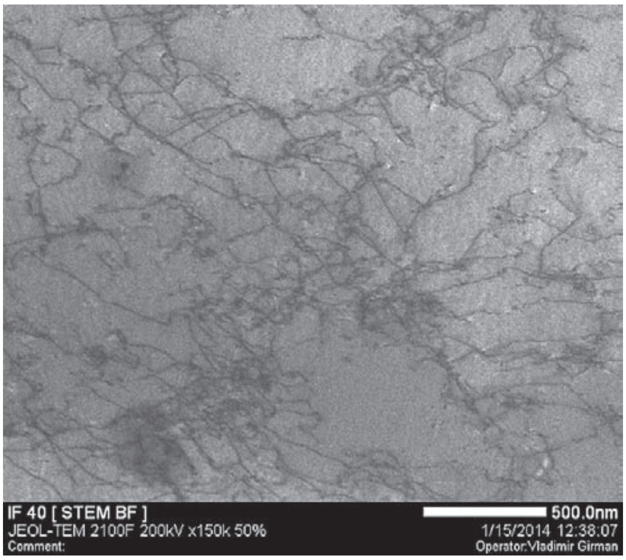

Figure 7 Dislocation structure of IF steel in the dynamic condition ($\dot{\varepsilon}$ = 4 000 · s^{-1})

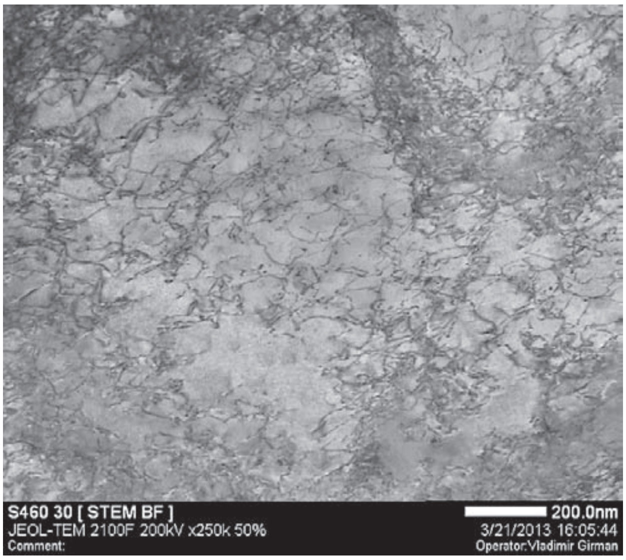

Figure 8 Dislocation structure of S420 steel in the static condition ($\dot{\varepsilon}$ = 8,33.10-4 · s^{-1})

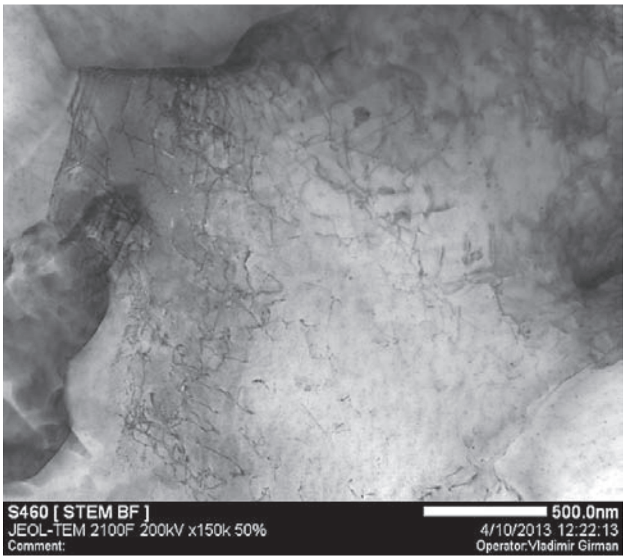

Figure 9 Dislocation structure of S420 steel in the static condition ($\dot{\varepsilon}$ = 3 000 · s^{-1})

structures in this condition were more evenly distributed and stacking faults were less often observed [7].

Figure 8 shows steel S420 under static conditions, dense dislocation arrangements close to a grain boundary, whereas dislocations in the middle of the same grain were much less dense. At the dynamic condition ($\dot{\varepsilon}$ = 3 000 · s^{-1}), the dislocation density was observed to be much higher than that static condition. Dislocations were dense, tangled and distributed homogeneously (Figure 9).

RESULTS AND DISCUSSION

The mechanical behaviour of high strain rate induced damaged two automotive a steel condition has been reported here. Tensile tests at strain rates of 10^{-3} - 10^{3} · s^{-1} were made at room temperature.

Experimental results obtained influence of strain rate on the basic mechanical properties of steels tested in accordance with the general regularities that grow with increasing strength properties (Figure 2) and potentially also to a change in deformation properties. More growth yield strength (Figure 3).

The significant increase of strength properties under dynamic stress rather than under static stress could be explained by an increasing of a lattice against movement of dislocations. We assume: If the deformation is dynamical due to not enough time to pass it through the best-oriented planes and also the slips may pass with higher critical shear stresses in systems of planes. Therefore greater stress is needful for deformation.

The highest ratio Re / Rm = 0,99 was reached for IF Steel at the rate of 3 500 · s^{-1} but the loss of plastic stability and subsequent decrease in elongation became possible in dynamic conditions. The ratio Re/Rm is almost unchanged in the range from 0,85 to 0,87 for the S420 steel (Figure 3) as a consequence of lower steel sensitivity to a change of the rate of deformation.

Hardness process of HV1 followed the distribution of deformation (Figure 4 and Figure 5). HV1 decreased according the increasing of distance from the quarry site. The relative increase of hardness due to hardening plastic deformation is mainly the result of its size. IF steel has significant increase of HV1 and S420 steel has lower values of HV1 according to the value of elongation.

CONCLUSION

This paper reports the dynamic tensile properties of IF and S420 automotive steel sheets. Dynamic tensile characteristics for both steels were investigated at the strain rates from $8{,}33.10^{-3}$ s^{-1} to $4\,000 \cdot s^{-1}$.

Following conclusions can be concluded from the obtained results:

- With the increase of strain rate occurred to increase the strength properties of the test steels.
- If the mechanical properties under quasi-static loading were considered as a base the dynamic yield strength was increased substantially. When the uninterrupted tensile test was performed at a strain rate of $1 \cdot s^{-1}$ the yield strength (Re = 0,2 %) was increased by 16 % for IF steel and for S420 steel by 6 %.When the strain rate was $10 \cdot s^{-1}$ the yield strength was increased by 98 % for IF steel and for S420 49 %. The tensile strength was increased also with increased strain rate.
- Ratio Re / Rm for tested steels were increased according the increase of deformation rate depending on structural steel construction. Re / Rm was increased from ca. 0,6 to 0,86 for IF steel passing dynamic loading ($\dot{\varepsilon} = 8{,}33 \cdot 10^{-3} \cdot s^{-1}$) and it was practically changeless for S420 steel with its value of 0,85. A significant increase of the ratio Re / Rm is a threat to local loss of plastic stability.
- Due to the results of the examination of the evolution process of dislocations it was found that the dynamic response can be associated with the regrouping of dislocations. IF steel compared with S420 steel had fewer barriers to the movement of dislocations. The speed effect, that has impact on the resistance of lattice against motion of dislocations, was more reflected in dynamic load conditions.

Acknowledgement

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Note: The responsible translator for English language is Mgr. Soňa Polakovičova TUKE, Košice, Slovakia