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DP 600 STEEL RESEARCH OF DYNAMIC TESTING

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Preliminary Note – Prethodno priopćenje

Dynamic tensile testing of sheet steels is becoming more important due to the need for more optimized vehicle crashworthiness analysis in the automotive industry. For generating data in dynamic conditions, was using different assay techniques. DP (dual phase) steel is suitable for large complicated shape such as fenders, doors, bumpers and roofs. For experiments was used two testing method servo hydraulic and single bar method. Experiments were realized on steel grade DP 600. Steel were performed and evaluated static and dynamic tests. Microstructure and substructure in static and dynamic loading conditions was investigated.

Key words: DP 600 steel, mechanical properties, microstructure, substructure, dislocation

INTRODUCTION

The automotive industry is constantly evolving and thus it is necessary to build research, development and innovation capacity. Testing and product testing is a standard part of the process of innovation. The materials used to manufacture car body are subjected to destructive tests that simulate the behavior of components or whole car at impact. Destructive tests are designed to be optimized material relationship with regard to the required characteristics of the vehicle. An improved understanding of the behaviour of automotive materials at high velocity is driven by the challenges of diverse crash legislation and competition amongst car makers. The strength of a sheet steel product is dependent on the speed at which it is deformed [1, 2]. The mechanical behavior of materials under dynamic or impact loading is different from that under static loading. When a structure deforms in the dynamic state, the inertia effect and the propagation of stress waves are so important that the material properties are influenced by the strain rate [3 - 5]. Tensile testing of metallic sheet materials at high strain rates is important to achieve a reliable analysis of vehicle crashworthiness. During a crash event, the maximum strain rate often reaches 10^3 s^{-1}, at which the strength of the material can be significantly higher than under quasi-static loading conditions. Thus, the reliability of crash simulation depends on the accuracy of the input data specifying the strain – rate sensitivity of the materials. The strain – rate range between 10^{-3} to 10^3 s^{-1} is considered to be the most relevant to vehicle crash events based on experimental and numerical calculations. In order to evaluate the crashworthiness of a vehicle with accuracy, reliable stress-strain characterization of metallic materials at strain rates higher than 10^{-3} s^{-1} is essential [6 - 8].

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MATERIAL AND EXPERIMENTAL METHOD

Experimental material: DP 600 steel with a gauge of 1,5 mm. The steel sheets for automobile exposed body panels are required to excellent press-formability (e.g., deep-draw ability and stretch-formability), high surface quality and homogeneous coated surfaces after press forming. Some grades of DP steels are strengthened by a combination of elements for solid solution, precipitation of carbides and/or nitrides, and grain refinement [9, 10]. The microstructure of DP 600 steel is shown in Figure 1. Another common element added to increase the strength is phosphorous. The higher strength grades of DP steel type are widely used for both structural and closure applications. A characteristic feature of dual phase steel is a structure that consists of 70 to 90 % ferrite and 10 – 30 % martensitic. In this case fraction of martensitic was found 11,62 %. DP steels are used widely in various parts of the body such as braces, brackets and wheels car [9 - 11].

In BCC (ferrite) materials the slip systems are quite different from those in their FCC counterparts. The related dislocation evolutions are also expected to be different. In FCC metals, dislocation interactions dictate the dislocation evolution.

For BCC materials, the dislocation dynamics are generally dominated by the friction force between screw dislocations at low temperatures (about 0,1 - 0,2 Tm, Tm: melting point) while activated by both friction and dislocation interactions at high temperatures. In addition, in BCC materials dislocation depends much on the relative slips of the screw and edge dislocation [4]. Recently [12], in order to describe the intermediate behavior of hcp materials and certain alloy steels, both Peierls stress type interactions (predominant in bcc) and inter-

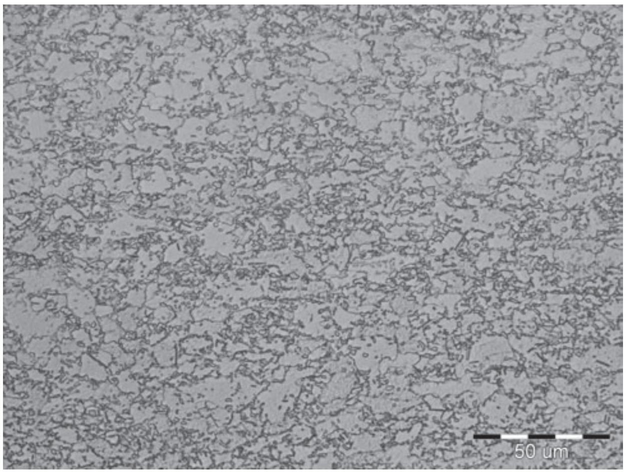

Figure 1 Steel DP 600 microstructure

section of forest dislocations type interactions (predominant in fcc) were introduced into single equations (1), (2), (3), (4) written in the form [13]:

$$\sigma = \sigma_a + Be^{-\beta T} + B_0\sqrt{\varepsilon e^{-\alpha T}} \qquad (1)$$

where

$$\beta = \beta_0 - \beta_1 \ln \varepsilon \qquad (2)$$

$$\alpha = \alpha_0 - \alpha_1 \ln \varepsilon \qquad (3)$$

and

$$\sigma_a = \sigma_G + kl^{-1/2} \qquad (4)$$

In equation σ is the misses equivalent stress, ε is the misses equivalent strain, ε is the strain rate, T is then absolute temperature, l is the average grain diameter, and a, is a constant a thermal stress due to the effect of solutes and σ_G initial dislocation density. The quantities B, β_0, β_1, B_0, α_0 and α_1, are constants related to the thermally activated dislocation interactions while k is the microstructural stress intensity for overcoming the resistance to deformation at grain boundaries [13].

The concept of the rotating flywheel machine showed Figure 2. Basic element, a wheel disc with diameter 600 mm and width 100 mm, is equipped with a self-aligning, forked hammer. The hammer is normally kept in a wheel pocket and blocked in this position by a slid able pin. The wheel is accelerated by electric motor to selected speed, measured with a rotary encoder. When selected speed is achieved, the slid able pin is moved by an electromagnet, unlocking the hammer that rotates to working positions, striking an anvil connected to sample. The hammer's velocity ranges from 5 to 50 m/s giving as a result available, impact energy from 1,4 to 140 kJ. Because the needed work to sample deformation up to fracture is less than 60 J, thus the impact velocity is almost constant during the test [8]. DP steel deformed microstructure was evaluated depending on strain rate. On the samples after static and dynamic tests was observed structure and substructure of materials.

Static tensile tests were realized at three speed load. Tensile tests of samples deformed with strain rate 1,6 10^{-5} m/s, 1,6 10^{-4} m/s and 6,6 10^{-3} m/s. Chemical composition of tested steel is obtained in Table 1. Table 2. shows the results of static tensile tests.

Table 1 **Chemical composition of DP 600 steel / %**

C	0,072
S	0,06
N	0,005
Mn	1,18
P	0,017
Si	0,01
Al	0,057
Nb	0,002
V	0,003
Ti	0,001

Table 2 **Mechanical properties of used materials under static loading rate**

Mechanical properties		Loading rate / m/s		
		$1{,}6.10^{-4}$	$1{,}6.10^{-3}$	$6{,}6.10^{-3}$
DP	F / N	18 242	18 512	18 622
	R_e / MPa	346	363	365
	R_m / MPa	561	573	578
	A_{80} / %	23	21	24

Table 3 **Mechanical properties of used materials under dynamic loading rate**

Mechanical properties		Loading rate / m/s		
		6	12	20
DP	F / N	10 723	12 517	13 581
	R_m / MPa	705	824	894

For dynamic tensile tests rotating flywheel machine RSO was used at three speed load 6 m/s, 12 m/s, 20 m/s Tensile curves of samples deformed with strain rate

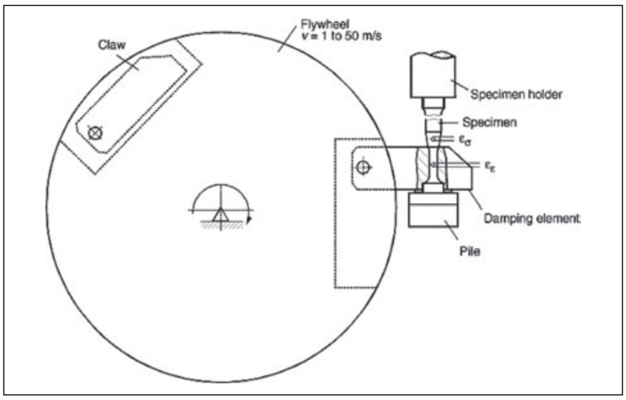

Figure 2 Rotating flywheel machine

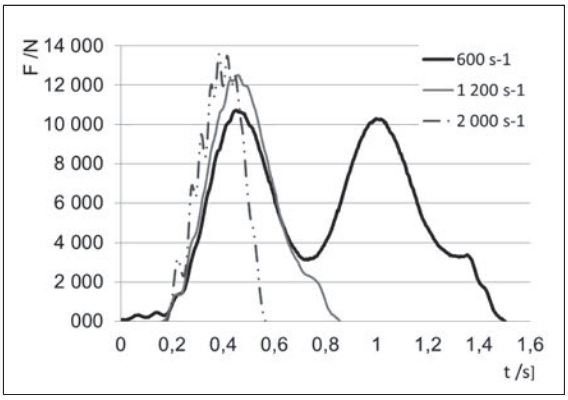

Figure 3 Dynamic tensile curves of DP 600 steels

600, 1 200 and 2 000 s^{-1} shown in Figure 3. Table 3 shows the results of dynamic tests.

RESULTS AND DISCUSSION

Ratio of grain size from distance fracture tip is graphically represented in Figure 4.

After the static and dynamic tensile test, the specimens were thinned to 100 μm by grinding with abrasive paper. Then we used automatic electrolytic thinning of specimens for transmission electron microscopy Tenu Pol -5. A JEOL 2100F transmission electron microscope (TEM) with STEM detector was used to investigate the microstructures of DP 600 steel. Figure 5 shows substructure of DP 600 steel in static conditions and Figure 6 in dynamic conditions.

CONCLUSION

The aim of this study is effect of strain rate on plastic properties of automotive steel. For comparison of static and dynamic properties was used, DP 600 – steel. From the measured values for the DP 600 steel there is an observable increase in yield strength and tensile strength.

- Yield strength of DP 600 steel increased from 346 MPa ($1,6 \cdot 10^{-4}$ m/s) to 365 MPa ($6, 6 \cdot 10^{-3}$ m/s).
- Tensile strength of DP 600 steel increased from 561 MPa ($1,6 \cdot 10^{-4}$ m/s) to 894 MPa (20 m/s).
- The microstructure changes significantly during the deformation process under both quasi-static and dynamic tension.

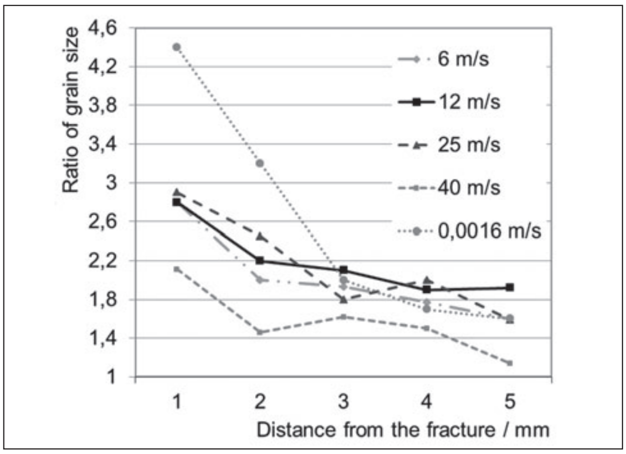

Figure 4 Ratio of grain size from distance fracture

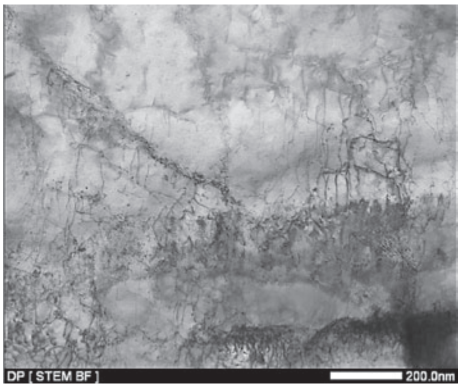

Figure 5 Substructure of DP 600 steel in static conditions

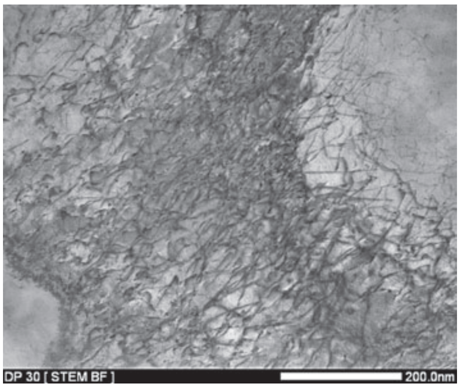

Figure 6 Substructure of DP 600 steel in dynamic conditions

- Ratio of grain size from distance fracture tip in dynamic conditions has flatter course then in static conditions.
- From the investigated substructures of DP 600 steel, was seen influence strain rate on density of dislocations.
- Under dynamic conditions increased dislocation density which influenced on increased yield strength DP 600 steel.
- When the strain rate increases the time necessary for overcoming of local obstacles in the slip plane is shorter.

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Note: The responsible translator for English language is Melania Fedorčáková, Košice, Slovakia