STATIC AND DYNAMIC TENSILE CHARACTERISTICS OF DP 600 STEEL SHEETS

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Resume

Dynamic tensile testing of sheet steels is becoming more important. Experimental dynamic tensile technique is depending on the strain rate. Each serves for a specific range of strain rates and provides specific type of information. For experiments was used two testing method servo hydraulic and single bar method. Experiments were realized on steel grade DP 600. DP-type steels are low-carbonsteels with soft ferrite and hard martensite. Steel were performed and evaluated static and dynamic tests. Substructure was investigated in static and dynamic loading conditions.

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1. 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 behavior 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 - 3]. 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 [4, 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, 7].

Dislocation densities are important parameters in theories of mechanical properties of crystalline materials. Regardless of the dislocation evolutions, these well studied materials share the common face center cubic structure (FCC) atomic arrangement. In contrast, seldom can one find similar reports on materials with a body center cubic (BCC) structure. This is incentive to understand BCC materials because 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 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 [8, 9].

An important challenging issue in the automotive industry is the light-weight, safe design and enhancement of crash response of an auto-body structures. Most used automotive steels are IF steel, DP steel, BH steel, TRIP steel and microalloyed steel. Dual-phase steels consist of a microstructure which contains predominately martensite (there can be small amounts of retained austenite, bainite or pearlite) in a ferrite matrix and these steels exhibit characteristic mechanical properties, i.e. continuous yielding, high tensile strength to yield strength ratio and very high initial work hardening rates. The combination of high strength and high ductility has made DP steels very attractive to industry, particularly the automobile sector. Mechanical properties of DP steels depend on a number of parameters including the strength, morphology and volume fraction of the constituent phases [10, 11]. The objectives of this research were to determine the effect of deformation velocity (ranging from 8.33. 10^{-3} s^{-1} to 2000 s^{-1}) on mechanical properties and substructure for sheets made from steel DP 600.

2. Experimental method

Automotive DP 600 steel 1.6 mm in thickness was used for a static and dynamic tensile test. We used the average of three measurements for every loading speed. A static test was realized according to standard EN ISO 6892-1. The dynamic tensile test was realized according the ČSN EN ISO 26203-1 standard used test equipment that can reach speeds greater than 10^{-3} s^{-1} of strain. A flywheel machine was applied for the dynamic tensile tests. A scheme of the rotating flywheel machine and a set of stand is shown in Fig. 1. The 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 slidable pin. The wheel is accelerated by electric motor set to selected speed, measured with a rotary encoder. When selected speed is achieved, the slidable pin is moved by an electromagnet, unlocking the hammer that rotates to working positions, striking an anvil connected to sample. The velocity of the hammer ranges from 5 to 50 m/s, yielding available impact energy from 1.4 to 140 kJ. Because the needed work to the sample deformation up to fracture is less than 60 J, thus the impact velocity is almost constant during the test [12, 13]. Rotating wheel with a measurement system is shown in Fig. 2. Signal from the hammer goes to an amplifier and then to oscilloscope. Data from the oscilloscope are evaluated programs on computer. The result is a graph of the force - time.

3. Results

Chemical composition of investigated DP 600 steel in mass (%) is presented in Tab. 1.

The samples were etched by 2% Nital. Microstructure of DP 600 steel is shown in

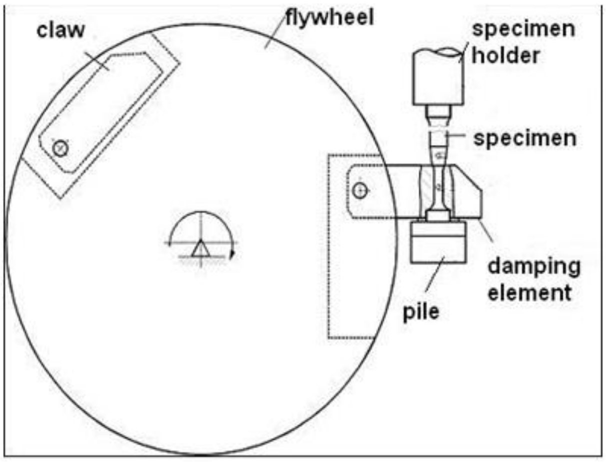

Fig. 1. Rotation wheel RSO.

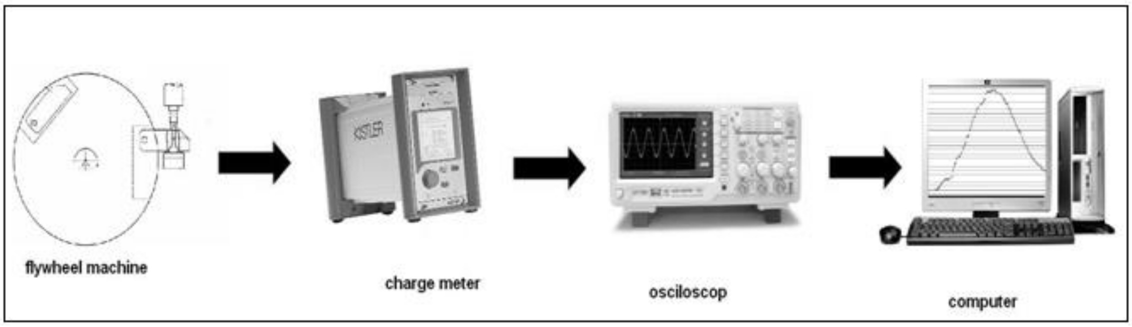

Fig. 2. Rotating wheel with a measurement system.

Table 1

Chemical compositions (in mass. %) of DP 600 steel.

element	**C**	**S**	**N**	**Mn**	**P**	**Si**	**Al**	**Nb**	**V**	**Ti**
mass. (%)	0.0013	0.0105	0.0017	0.082	0.011	0.006	0.055	0.001	0.002	0.04

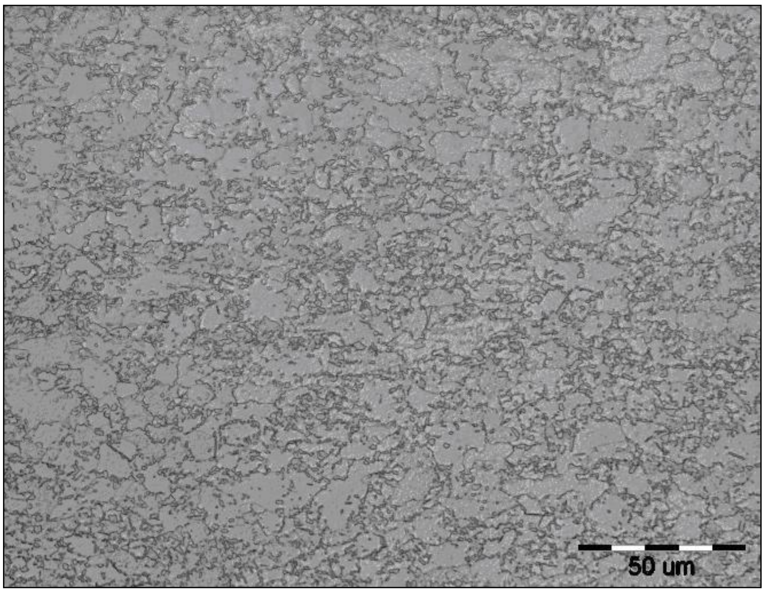

Fig. 3. Microstructure of DP 600 steel.

Fig. 3. Static tensile tests were realized at three strain rates 8.33. 10^{-3} s^{-1}, $8.33.10^{-2}$ s^{-1} and $3.33.10^{1}$ s^{-1}. Tensile curves of samples deformed in static condition are shown in Fig. 4. For the dynamic tensile tests, an RSO rotating flywheel machine was used at three strain rates 600 s^{-1}, 1200 s^{-1} and 2000 s^{-1}. A tensile curve obtained in dynamic condition is shown in Fig. 5. Comparison between static and a dynamic mechanical yield strength of tested steel is in Tab. 2.

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. TenuPol - 5. A JEOL 2100F transmission electron microscope (TEM) with STEM detector was used to investigate the microstructures of DP steel. Substructure of DP 600 steel in static conditions is shown in Fig. 6 and in dynamic conditions Fig. 7. For metals, at low strain rates, the true stress increases linearly with the logarithm of strain rate. At high strain rates exceeding 10^{3} s^{-1} the true stress increases approximately linearly with the strain rate. Dislocation densities are important parameters in theories of mechanical properties of crystalline materials.

When the strain rate increases the time necessary for overcoming of local obstacles in the slip plane is shorter. The dislocation density increased under dynamic conditions and this influenced the increased yield strength of DP 600 steel. Yield strength of DP 600 steel increased from 561 MPa ($8.33.10^{3}$ s^{-1}) to 894 MPa (2000 s^{-1}). Changes of plastic properties were evaluated by elongation. In static conditions elongation increased from 34.5 % ($8.33.10^{-3}$ s^{-1}) to 39.5% ($3.33.10^{-1}$ s^{-1}) and in dynamic conditions from 15.8% (600 s^{-1}) to 20.5% (2000 s^{-1}).

4. Conclusions

The Aim of this study was to compare static and dynamic characteristics of DP 600 steel sheets. Flywheel testing machine can be successfully used for dynamic tensile test with straining velocity 5–50 m/s. Yield strength of DP 600 steel increased from 561 MPa to 579 MPa in static conditions (3.1 %) and 705 MPa to 894 MPa in dynamic conditions (22 %). Total percentage increase for DP 600 steel was 59 %. We conclude that with increasing strain rate in DP 600 steels, there is an increase in strength properties and change plastic properties.

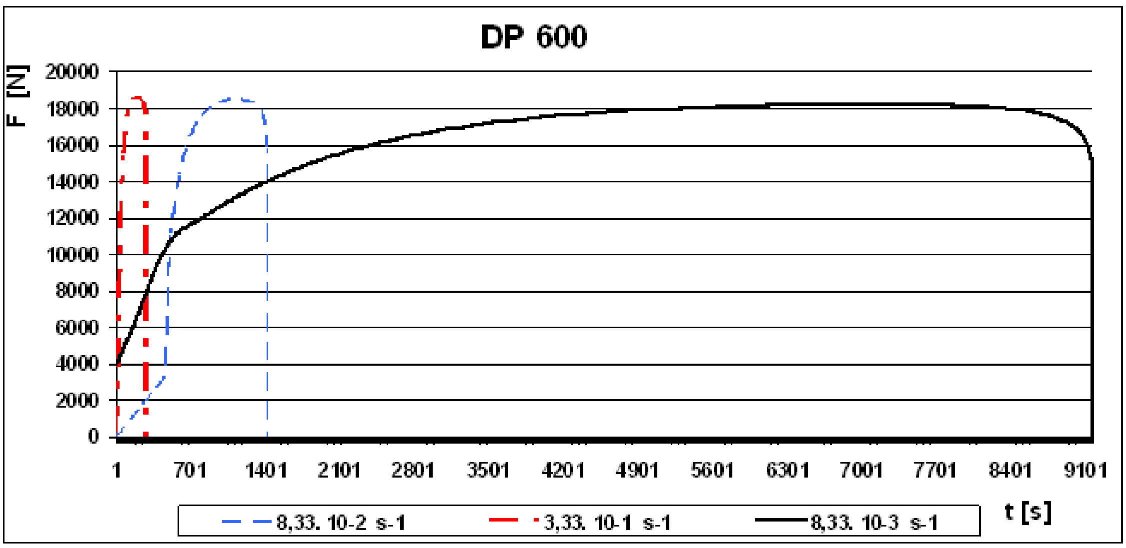

Fig. 4. Static tensile curves of DP 600 steels.
(full colour version available online)

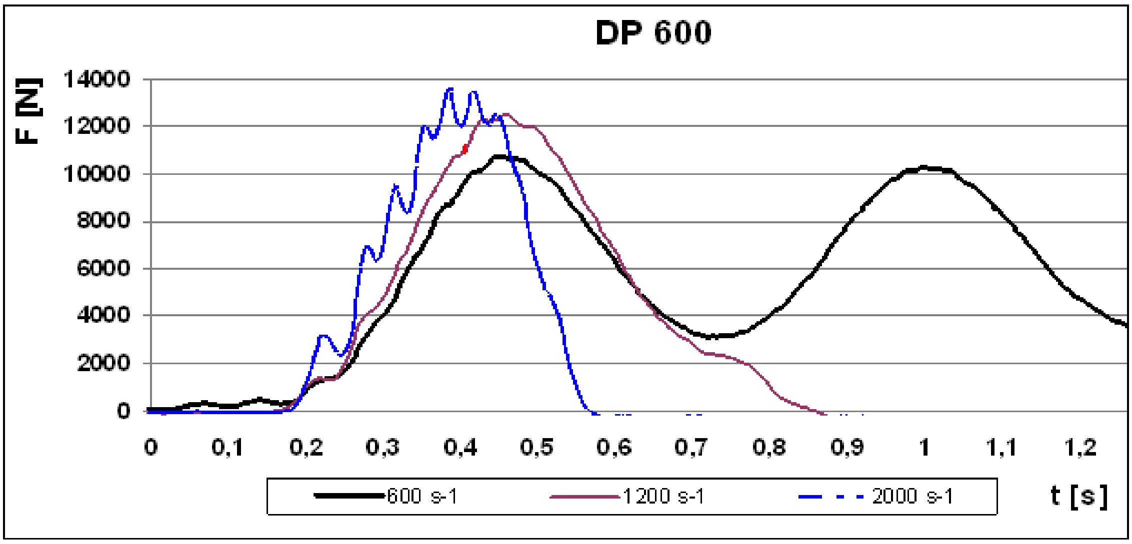

Fig. 5. Dynamic tensile curves of DP 600 steels.
(full colour version available online)

Table 2

Comparison between static and dynamic yield strength of tested steel.

Material	Mech. properties	Strain rate					
		static			dynamic		
DP 600		$8.33.10^{-3}$ s^{-1}	$8.33.10^{-2}$ s^{-1}	$3.33.10^{-1}$ s^{-1}	600 s^{-1}	1200 s^{-1}	2000 s^{-1}
	R_m (MPa)	561	574	579	705	824	894

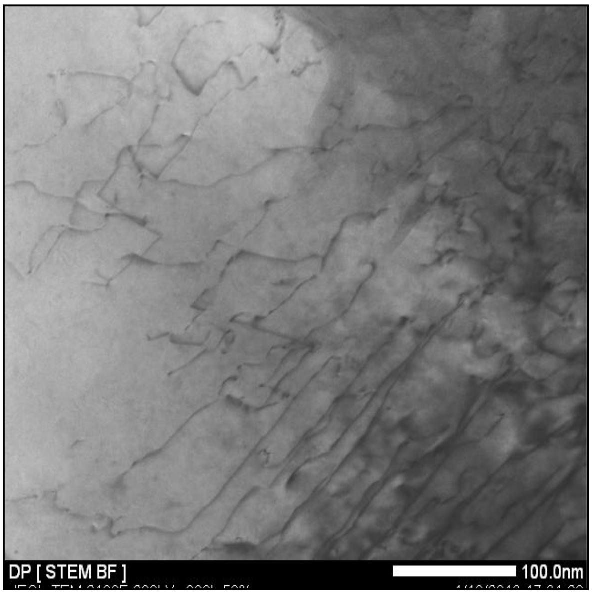

Fig. 6. Substructure of DP 600 steel in static conditions.

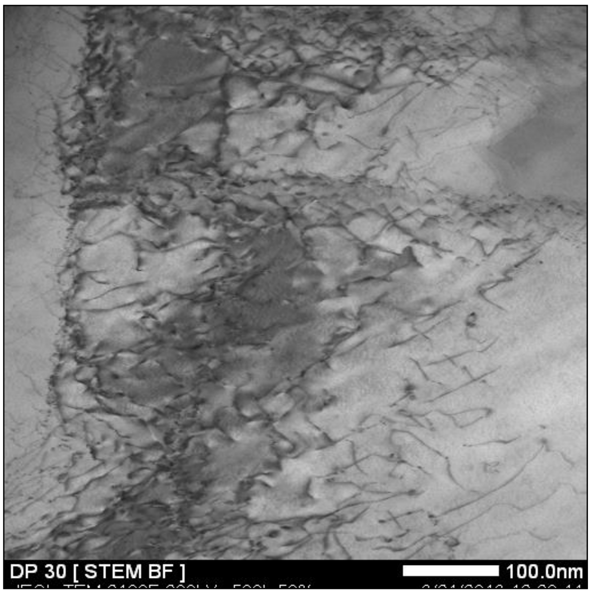

Fig. 7. Substructure of DP 600 steel in dynamic conditions.

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