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APPLICATION OF AUSTENITIC STEELS IN ENERGY ABSORBING STRUCTURES

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Abstract

Occupants protection during vehicle crash is one of the major problems considered at vehicle designing stage. The increasing safety as well as comfort requirements results in the total vehicle weight increase. On the other hand, higher mass influence on the fuel economy of vehicle. Thus, it is very important to maintain or even reduce vehicle weight. One of the solutions of this problem is application of a new materials having good strength-to-weight ratio i.e. high strength steels (HSS). They are often used in protective and energy absorbing structures in automotive industry.

One of HSS so-called austenitic steels are characterized by excellent mechanical properties such as: high strength, strong strain, and strain rate hardening. Those mechanical effects are consequence of microstructural evolution during strong deformations i.e. twinning and phase transformation. As a consequence those steels are very good material for the purposes of energy absorbing and protective structures.

This article presents the results of mechanical properties tests of VP159 austenitic steel. On the basis of experimental data, the JC constitutive model has been calibrated. The obtained results were used for the computer simulations of energy absorbing of square profiles made of analysed material. The results were compared with other types of steel.

Keywords: *aluminium alloys, CO_2 emission, electric vehicle, vehicle structure*

1. Introduction

The growing number of vehicles on the road increases the probability of an accident. To reduce the risk of losing life or health of passengers in a car in result of collision more and more sophisticated methods of accident prevention (traction control, ABS, drive assistant, driver fatigue monitoring), and mitigation of accidents (air bags, curtains, seat belts, head restraints, crumple zones or roll cages) are used. Developments in crashworthiness is stimulated on one side by increasingly stringent crash test requirements (ECE, SAE), on the other by customers who pay attention to the purchased vehicle collision safety.

The need to ensure high safety standards is one of the most important reasons for the continuous increase in vehicle weight, which in two decades amounted ca. 50% [1]. The increase in weight implies an increase in fuel consumption, which is very undesirable effect. Therefore, in recent years a very strong development in the field of high-strength steels can be observed, which can help increase strength of the structure, while maintaining or even reducing a component weight. In the automotive industry to build critical body parts, the so-called Advanced High Strength Steels (AHSS) are increasingly used. Among them, you may distinguish Dual Phase (DP), Transformation Induced Plasticity (TRIP), High Strength Low Alloy (HSLA), and Complex Phase (CP) steels. This paper analyzes the energy absorption capacity of rectangular steel sections, made from commercially available AHSS. The analysis was performed using the FEM in an ABAQUS / Explicite environment.

The subject of the study was the following steel sheets:

- VP159, t_0=1.50mm,
- BH300, t_0=1.40 mm,

- HSLA350, t_0=1.60mm,
- 440W, t_0=1.40mm,
- TRIP590, t_0=1.45mm,
- DP600, t_0=2.62mm,
- DP800, t_0=1.19mm.

2. Constitutive modelling

Stress-strain curves of the tested materials determined from previous work [2, 3] are shown in Fig. 1. In contrast, sensitivity of plastic flow stress on deformation rate is shown in Fig. 2 All the tested materials have a strong effect of work hardening and strain rate hardening, which is typical behaviour for AHSS. The yield strength of individual steels ranges from ca. 400 MPa to ca. 900 MPa.

The dependence of plastic flow stress can be described using the ratio form of the constitutive equation, which is a function of strain, strain rate, and temperature [4]:

$$\sigma(\varepsilon,\dot{\varepsilon},T)=\left(A+B\varepsilon^{n}\right)\left(1+C\ln\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)\right)\left(1-\left(\frac{T-T_R}{T_m-T_R}\right)^{m}\right), \tag{1}$$

where:

A – yield stress for reference parameters: temperature T_R and strain rate $\dot{\varepsilon}_0$,
B, n – coefficients of work hardening,
C – coefficient of strain rate hardening,
T_m – melting temperature.

Because of the small number of parameters required to determine in the JC model during calibration process, it is often used to describe the mechanical characteristics of materials, including various types of steels. In the course of determining the parameters of the model, an important simplification is the fact of splitting the equation into three independent terms that describe the relationship between stress and strain, strain rate and temperature. The lack of coupling between the model input quantities simplifies the model and its calibration. This results in the relatively narrow range of application and low accuracy of the model. To improve the compatibility of the simulation carried out with using the JC model with the experimental results the parameters of the equation can be determined for the conditions similar to the given application, for example, for ballistic applications - apply calibration at large values of deformation rate, and for hot plastic forming - calibration for elevated temperature and large deformation.

The coefficients of JC equation obtained on the basis of experimental data from the literature [2, 3] are shown in Tab. 1. Calibration of the model was carried out using non-linear interpolation function in the Origin ver. 8.1.

Tab. 1. Coefficients of the Johnson-Cook constitutive model

Steel	A	B	n	C	m
BH300	260	555	0.49	0.0256	0.5
HSLA350	310	415	0.39	0.0249	0.5
440W	260	601	0.63	0.0242	0.5
HSS590	299	777	0.39	0.0145	0.5
TRIP590	405	880	0.60	0.0124	0.5
DP600	134	946	0.21	0.0206	0.5
DP800	464	1067	0.38	0.0157	0.5

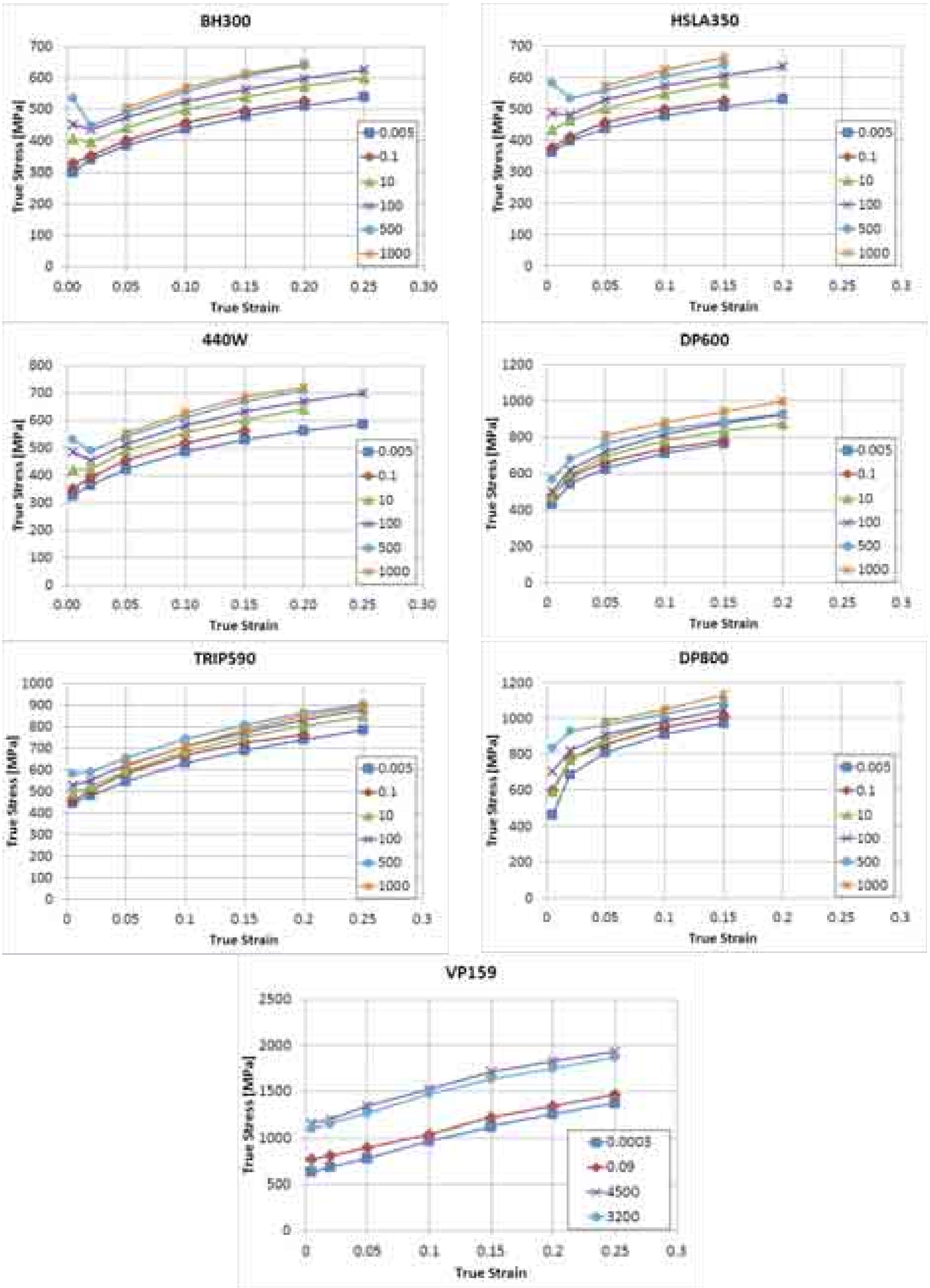

Fig. 1. Stress-strain curves of analyzed AHSS

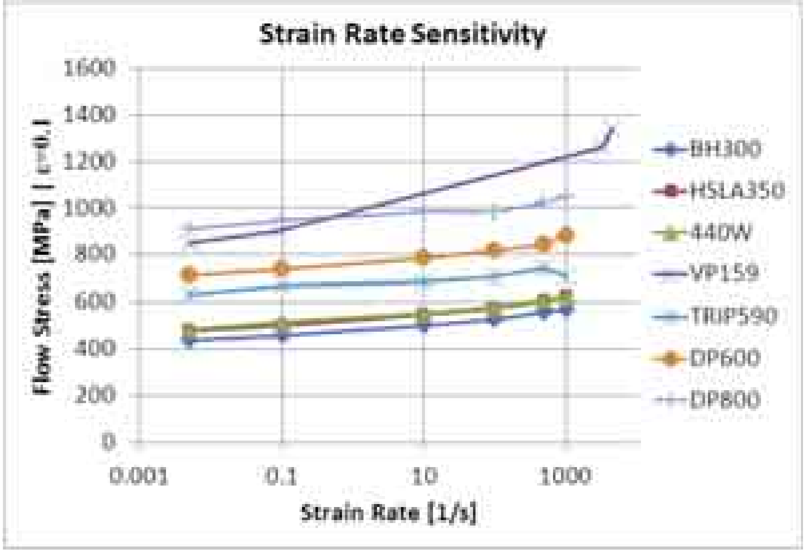

Fig. 2 Strain rate sensitivity of analyzed AHSS

3. Analysis using the finite element method

To assess the ability of energy absorption of the profiles made from tested materials the computing environment ABAQUS / Explicit was employed. The subject of analysis was rectangular profile with a length of 50 cm, and 5cmx10cm cross section with rounded corners. Rounding diameter was 5 mm. The simulation used the elements of "shell" type with three points of integration. The thickness of the material was assumed the same as the thickness of the starting sheet. The analysis was performed for the two deformation speeds: 0.01 m/s (quasi-static) and 25 m/s (dynamic). The second speed is typically found in vehicles during crash tests. The profile view in successive stages of deformation is shown in Fig. 3. One end of the beam was rigidly restrained in all degrees of freedom, while the second was moving along the beam axis with a preset speed until achieving the displacement of 0.4 m.

The graphs of energy absorbed by the profiles made of the tested materials are shown in Fig. 4. By analyzing the curves, it can be concluded that for high-speed deformation the profiles are able to absorb more energy than for low speeds. This behaviour is affected by the strong effect of hardening of all types of tested steels under the influence of the growing rate of deformation. The effect of the strain rate hardening is stronger than the impairment caused by adiabatic heating of the material, therefore, you can observe a tendency to increase in absorbed energy.

The tested energy-intensive items made in the form of rectangular profiles utilize the replacement of the kinetic energy with the energy of plastic deformation. The significant differences among the curves for different materials, shown in Fig. 4, are due to differences in mechanical properties and different sheet thicknesses. To make an objective assessment of the energy absorption by the profile made from a given material the normalization of the results was performed, which consisted in referring the total energy absorbed by the element to the mass of that element. Results in a normalized form are shown in Fig. 5.

4. Summary

1. Increase in the speed of deformation causes an increase in the total capacity of the element to absorb energy, which is due to strain rate hardening of the material.
2. The normalized energy absorption is affected by the mechanical characteristics of material and the thickness of the used sheet.
3. Steel type VP159, which was the subject of the author's own research work [5, 6] is characterized by very good energy absorption properties.

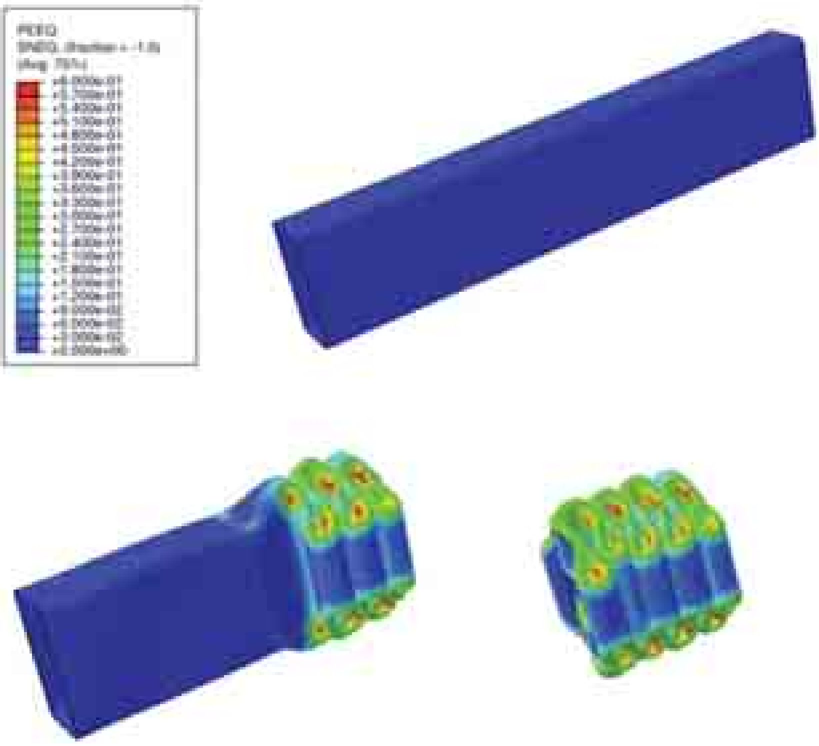

Fig. 3 Subsequent stages of profile deformation (VP159 steel, quasi-static conditions)

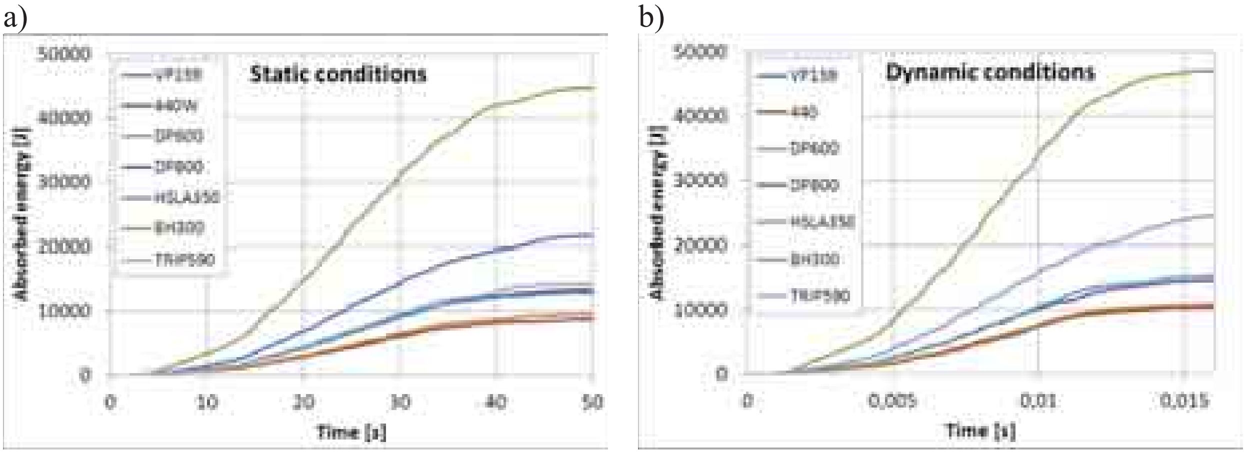

Fig. 4. Energy absorption; (a) velocity 0.01 m/s; (b) velocity 25 m/s

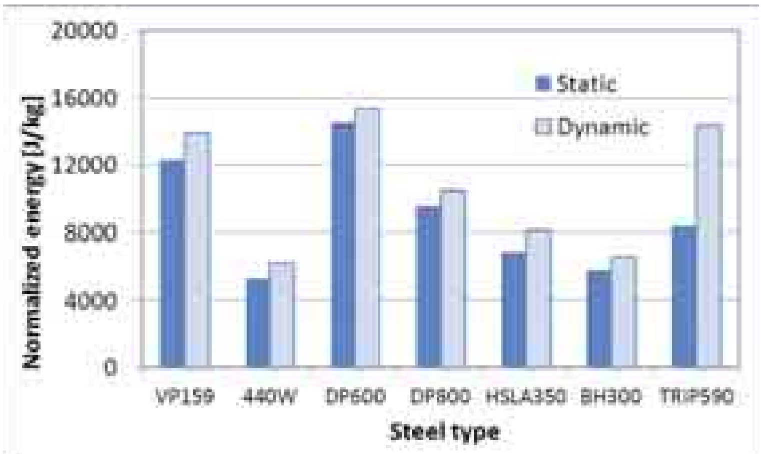

Fig. 5. Normalized total energy absorption

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