Experimental characterization of B500A and RB500W building steels in compression and in tension

Leopold Kruszka[1], *Jacek* Janiszewski[2]

[1]Department of Construction for Transport Infrastructure and Military Engineering, Faculty of Civil Engineering and Geodesy, Military University of Technology, ul. Gen. Witold Urbanowicz 2, Warsaw PL 00-908, Poland
[2]Institute of Armament Technology, Faculty of Mechatronics and Aviation, Military University of Technology, ul. Gen. Witold Urbanowicz 2, Warsaw PL 00-908, Poland

Abstract. The paper covers static and dynamic testing of structural building steels grades B500A and RB500W in tension and compression under wide range of strain rates. The spilt Hopkinson bar technique apparatus is used to investigate the dynamic behaviours both in compression and tension. A detailed knowledge of mechanical properties of those steels at different strain rates at two modes of large deformation is crucial, because the steels are the most commonly used in building structures as well as in protective structures due to their good strength characteristics.

1 Introduction

Although numerical simulations in impact engineering have moved to a leading role in the design of protective built structures due to the pressure to reduce the time and first of all cost of building designing of such structures, still experimental material research in a wide range of strain rates and temperatures are necessary for both constitutive modelling as well as for validation numerical calculations. Constitutive models of such materials describe the stress and internal variables as function of the strain, strain rate and temperature. In large-scale simulations of e.g. protective built structures in fire conditions, the framework of continuum thermo-mechanics is typically adopted to formulate the constitutive models, while thermo-mechanical testing at various deformation modes, including compression, tension, torsion, is used to identify the model parameters. The models have to describe plastic anisotropy, non-linear isotropic and kinematic hardening, strain-rate and temperature dependence, damage evolution and failure. Thus a basic understanding of the physical phenomenon controlling the material response is necessary in large-scale analysis as well as an understanding of how simplifications can be made to still retain sufficient accuracy reliability.

With reference to building structural materials, including new steel alloys introduced in modern construction technologies, there is still a lack of experimental data from dynamic testing within wide range of strain rates including two deformation modes, for example compression and tension. This is important first of all for both objectivity and reliability of the obtained experimental results for the needs of empirical and semi-empirical constitutive modelling. This work presents the preliminary results of the experimental analyses for selected two steels B500A and RB500W [1] tested both statically and above all dynamically using Hopkinson bar technique at compression and tension with the same measuring bars and a high-speed camera. It should be emphasized here that there is no literature data concerning the dynamic strength curves of the discussed steels subjected to both types of above load.

* Corresponding author: leopold.kruszka@wat.edu.pl

2 Materials, specimens and experimental techniques

The object of the experimental investigations were B500A and RB500W structural building steels. The specimens for the mechanical characterization were machined on a lathe by turning from reinforced bars as-received.

Fig. 1. General views of sections of rebar steels tested, as well as tensile specimens before and after tests. a) B500A, b) RB500W.

A cylindrical shape with the initial diameter $D_0 = 4$ mm and the initial lengths $L_0 = 4$ mm were adopted for compression tests (slenderness ratio - $L_0/D_0 = 1$). The geometry of specimens for dynamic testing in tension was 2.7 mm in diameter and 8 mm of gauge length – see Fig. 1a and 1b.

In both cases the same geometry and dimensions were used for quasi-static and high strain rates tests. The same experimental techniques were used to study mechanical properties in tension and compression of both structural steels, i.e. the universal MTS Criterion Model 45 strength machine during static testing, and Hopkinson bar technique during dynamic testing as the conventional split Hopkinson pressure bar (SHBP) for compression testing (Fig. 2a) and as the system suggested by Nicholas [2] in tension testing (Fig. 2b).

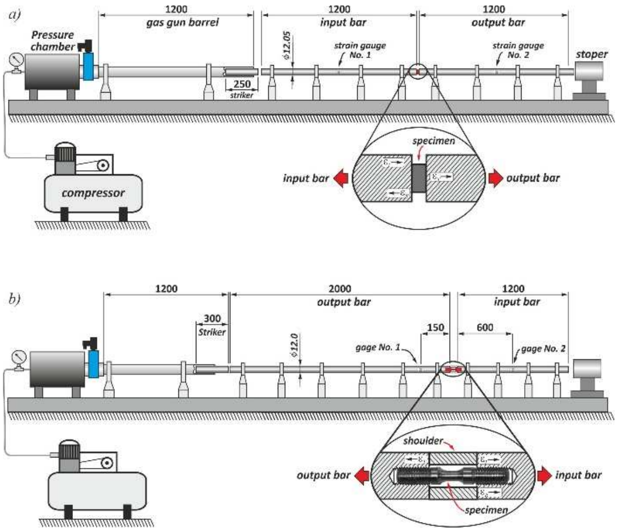

Fig. 2. Hopkinson bar technique apparatus is used to investigate the dynamic behaviours of tested steels in compression (a) and tension (b).

A compression SHPB stand consisted mainly of a launching system (air pressure gun), a striker, an input bar, a output bar (bar system), a velocity measuring device and a computer-controlled high-frequency data acquisition system. The input bar and the output bar were 1218 mm long each, while the striker length was 250 mm. Both the bars and the striker had a diameter of 12.05 mm and were made of commercial maraging steel grade 350, which was heat treated to guarantee a high strength property of bars (nominal quasi-static yield strength $R_{0.2} = 2320$ MPa, Young modulus E = 190.6 GPa, sound speed C_0 = 4866 m/s). Each bar was supported by four linear bearing stands, which were mounted on an optical bench allowing precise alignment of the bars system. More details on the applied compression SHPB stand can found in [3].

Due to modification of above-mentioned bars system it was adapted to configuration in tension. In this case, the input bar and the output bar were 1200 and 2000 mm long, respectively, while the striker length was 300 mm. These bars and the striker bar had a common diameter of 12.0 mm and were made of 42CrMo4 steel (nominal quasi-static yield strength $R_{0.2}$ = 1110 MPa, sound speed C_o = 5140 m/s).

In the tension SHPB technique proposed in [3], the generation and initial transmission of the pulse is identical with the classical SHPB in compression. The compression pulse travels down the output bar until it reaches the specimen, which is screwed into the two bars and placed into a shoulder. The shoulder is made of the same material as the pressure bars, has the same outer diameter of 12.05 mm, and has an inner diameter 6 mm. For such configuration the compression pulse travels through the cross section of shoulder and specimen caused only elastic compression stress in them. Next, the compression pulse continues to propagate until it reaches the free end of input bar, where it reflects and moves back to the specimen as a tensile pulse. Then, it is partially reflected and partially transmitted through the specimen, which is deformed plastically. The shoulder does not participate in tensile pulse transmission since it is not connected in any manner with the bars. This way, the tensile pulse with the transmitted and reflected pulse give useful information possible for determination of constitutive behaviour of the tested steels in tension with strain rate of order 10^3 s^{-1}.

In order to record a plastic deformation process, onset and evaluation of necking in tensile specimens with the use of high-speed camera, the shoulder with observation window was applied.

3 Experimental results

The selected high-speed camera images showing the tension process of specimens made of B500A and RB500W steels were collected in Figs. 3 and 4, respectively.

The static and dynamic tensile processes of both steels were similar, which indicates that the materials tested have similar strength in wide range of strain rates. The shape and size of the neck also prove that the tested steels presented good ductility under dynamic tensile conditions. Detailed analysis using high-speed camera, however, revealed small differences in the necking process of the steel tested. It was found that the diameter of the neck in the B500A steel specimen is slightly smaller than in the specimen made of RW500W steel. In addition, a slightly earlier occurrence of the neck in the B500A steel specimens was noticed than in the RB500W steel. These observations may therefore prove that B500A steel has a slightly higher tendency to the localization of deformations.

It should be noted here that the specimens under dynamic load conditions did not fracture in the first load cycle. The pictures in Fig. 3 and 4 marked with the symbol 150 μs show the state of deformation of the specimens after passing the load wave. The both specimens were broken only when the stress wave after reflections from the free surfaces of the ends of the output rod again reached the specimen and initiated the second tensile cycle.

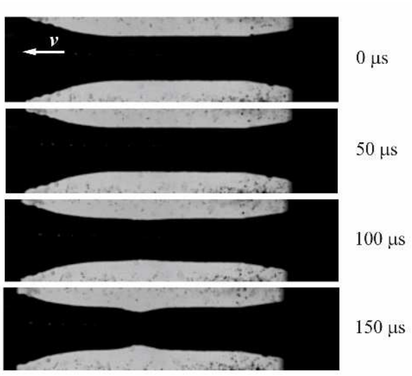

Fig. 3. Selected high-speed camera images showing the specimen tension made of B500A steel.

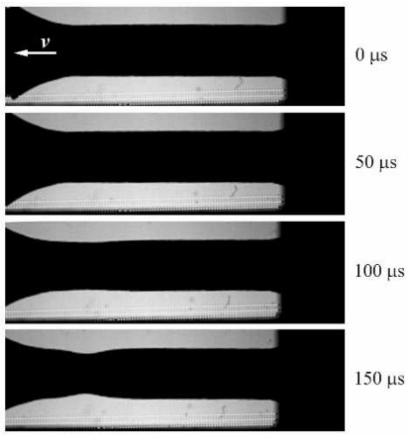

Fig. 4. Selected high-speed camera images showing the specimen tension made of RB500W steel.

The stress-strain curves developed on the basis of the SHPB tests (Figs. 5 and 6) also provide important information on the differences in the mechanical properties of the steels tested. Both under static and dynamic tension or compression conditions, the plastic stress of B500A steel is about 10% higher than that of RB500W steel. In turn, RB500W steel is characterized by a higher plastic hardening compared to B500A steel. It should be noted, however, that this hardening of the tested steels does not depend on the deformation rate, i.e. slopes of quasi-static and dynamic curves are almost the same.

Both tested steels demonstrate similar sensitivity to strain rate, e.g. the increase in yield stress at the deformation rate of 1400 s^{-1} in relation to the quasi-static stress was about 30%. In addition, no significant differences in the sensitivity to the strain rate of the tested steels were found depending on the mode of deformation, i.e. tension or compression.

4 Summary and conclusions

Two building steels under static and dynamic tension and compression loadings are investigated in the paper. The experiments are conducted at quasi-static, dynamic compressive and tensile strain rates. The present investigations revealed that both steels are strain rate sensitive both under tension and compression.

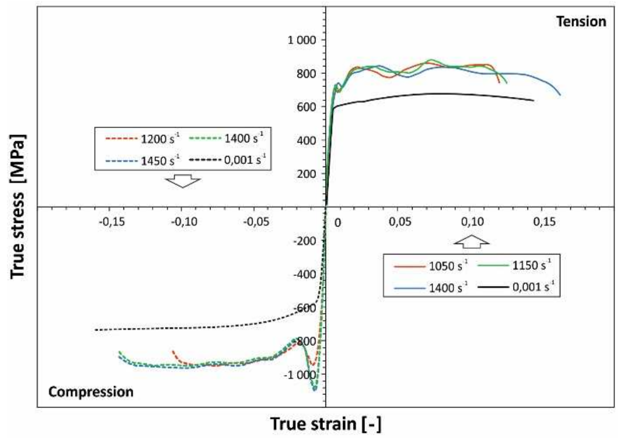

Fig. 5. Stress-strain curves in tension and in compression for B500A steel.

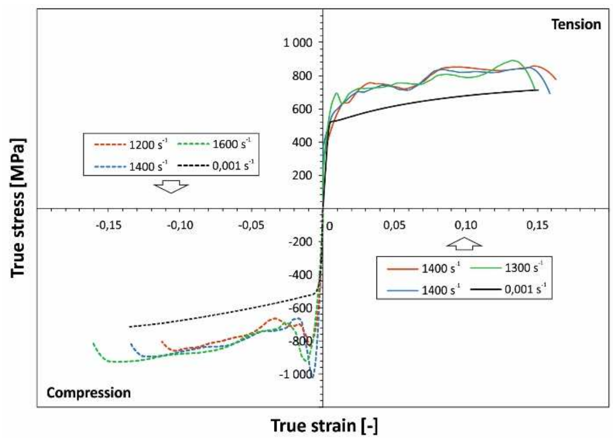

Fig. 6. Stress-strain curves in tension and in compression for RB500W steel.

The authors wish to thank MSc. Civ. Eng. Katarzyna Dycha for her assistance in experiments.

References

1. PN-EN 1992-1-1:2008, *Eurocode 2 - Designing concrete structures - Part 1-1: General rules and rules for buildings*
2. T. Nicholas, Exp. Mech. **21,** 177 (1981)
3. P. Baranowski, J. Janiszewski, J. Malachowski, Arch. Mech. **66**, 1 (2014)