Acta Mechanica Slovaca 15 (3): 46 - 51, 2011

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Article information
Article history: AMS-Volume15-No.3-00117-11
Received 18 March 2011
Accepted 11 May 2011

Tensile Tests of Flat Bars at High Strain Rate

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BIOGRAPHICAL NOTES

Ivo Dohnal, Ing., born 1986. Since 2010 PhD student, Department of Metal Forming and Plastics. 2010 graduated from Faculty of Mechanical Engineering, Brno University of Technology. Research activities: Doctoral thesis deals with high strain rate. Using device is the Split Hopkinson Pressure Bar Test (SHPBT). The aim of doctoral thesis is modification SHPBT to Split Hopkinson Tensile Bar Test.

Miroslav Šlais, Ing., born 1981. Since 2005 PhD student of forming theory and technology, Department of Metal Forming and Plastics. 2005 graduated from Faculty of Mechanical Engineering at Brno University of Technology. Research activities: Mathematical representation of forming processes stress and strain analysis at high strain rates. Modelling of the mechanical properties of materials formed at real strain rates, with outcomes for constitutive equations of mathematical representation of formed materials. Experimental examination of loading, and stress and strain analysis of metal-forming tools.

Milan Forejt, Prof. Ing. CSc., born 1939. Since 1998 professor of forming theory and technology, Department of Metal Forming and Plastics. 1965 graduated from the Aircraft Faculty of Military Academy in Brno. Research activities: Mathematical representation of forming processes stress and strain analysis in the dimensioning of forming tools, employing elastic and elastic-plastic FEM programs and simulation programs for large plastic deformations. Modelling of the mechanical properties of materials formed at real strain rates, with outcomes for constitutive equations of mathematical representation of formed materials. Experimental examination of loading, and stress and strain analysis of metal-forming tools. Member of Scientific Board of Institute of Forensic Engineering of Brno University of Technology. Member of the branch board of Manufacturing Technology. Member of the National board of examiners for the field of engineering technology, Chairman of the board of examiners for final BSc examinations in the field of engineering technology. Supervisor of doctoral students in the fields of Engineering technology and Forensic engineering. CSNMT Czech Society for New Materials and Technologies (member of board). EVU European society for research and analysis of accidents, national chapter V CZ (member). Technical guarantor of symposium B – metal forming, of the International conference on metallurgy and materials – METAL 2006, 2008. Member of the international scientific committee of the conference "Advanced engineering technologies and materials – PRO-TECH-MA 2006, 2008, 2010. Member of the scientific committee of the international conference "Advanced Manufacturing Engineering- NEWTECH-2011.

Radko Samek, Prof., Ing., CSc., born 1930. Brno University of Technology, Fakulty of Mechanical Engineering, Institute of Manifacturing Technologies, from 2002. Profesor, Dep. of Metal Forming and Plastics. 1954, Military Technical Academy Brno, Specialisation - Design of Airplanes. Research activities: Approximation of Flow Stress Curves (Influence of high strain rate and biaxial stress), Technological limits of forming, Theory and technology of thin walled tubes forming. Member of Scientific Board of the University of Defence, Member of Scientic Boaard of FME-UT Brno, Member of GACR, subcomitee.

KEY WORDS

Flat bars, Stress-strain, Strain Rate, Carbon Steel, Split Hopkinson Tensile Bar test-SHTBT

ABSTRACT

Plastic deformation of metallic materials and alloys is a complex process that depends on a number of factors with the effect of strain rate being of particular importance. Dynamical tests are used for determination of mechanical properties. Split Hopkinson Pressure Bar Test is often used for these experiments. The paper deals with possibilities of testing device for flat bars adapted at Hopkinson test. The aim of this work is concentrated on strain rate influence on DC 01 steel too.

1. Introduction

Currently technologic proposals use modern computer simulations that predict behaviour of metal materials depending on dynamical loading and forging conditions. Strain rate is one of the dominant factors, that significantly influences results of mechanical behaviour. The aim of this paper is to describe deformation behaviour of material loaded under dynamic tensile tests. The DC 01 steel was used for these experiments. DC 01 is low carbon steel with good ductility and suitable for deep drawing [1]. Specimens were made from metal sheet of 2 mm thickness by laser cutting. Chemical composition and static mechanical properties are shown in Tab. 1.

Table 1 *Chemical composition and static mechanical properties of steel are marked according to EN 10130: DC 01 (DIN 1.0330; ČSN 11321).*

C [%]	Mn [%]	P [%]	S [%]	Rm [MPa]	Re [MPa]	A [%]
0.05	0.22	0.008	0.01	315	206	41.3

2. Experimental Techniques

The Split Hopkinson Tensile Bar Test (SHTBT) was used for determination of material dynamic mechanical properties. A typical Hopkinson test setup consists of a gas gun, a strike bar (projectile), an input bar and an output bar.

The gas gun accelerates the strike bar and after leaving the snout it impacts centrically on the input bar, where it produces an elastic, compressive pulse (incident pulse).

This pulse propagates through the input bar until it reaches the input bar/specimen interface. There is partially reflected back into the input bar (reflected pulse) and partially transmitted through the specimen into the output bar (transmitted pulse). The stresses of three pulses in the bars are detected by capacitance detectors, which are connected to a digital storage oscilloscope.

Special device was developed by Institute of Manufacturing Technologies in collaboration with Institute of Material Science and Engineering, Faculty of Mechanical Engineering, Brno University of Technology. This device is object of privacy type so it cannot be described. Different versions of this device were developed on basis of literature sources and possibilities of Hopkinson test device [2]. The device is permanently innovating to minimize interaction of loading pulses.

The specimens are situated in device for tensile test between the input and the output bar as shown in Fig. 2.

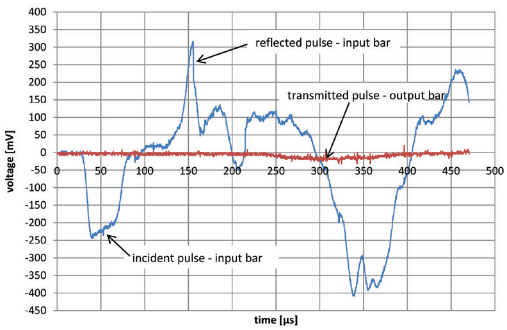

Fig. 2: *Recorded pulses for TAH - 04 specimen made of DC 01steel.*

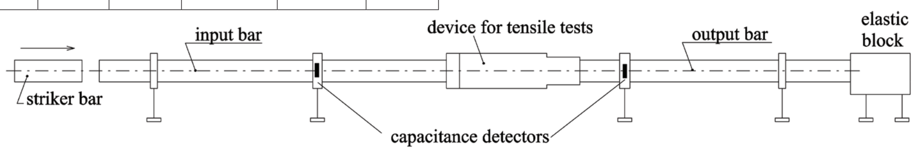

Fig. 1: *SHTBT with device for tensile tests.*

Table 2: *Initial and final dimensions of specimens.*

Specimen	Referential length [mm]	Final length [mm]	Deformation [-]	Loading conditions			Commentary
				Filling	Impact velocity		
				t_p [s]	t_v [µs]	v [m/s]	
TAH - 03	15.00	21.70	0.44	7	900	16.70	Creation of neck
TAH - 04	15.00	21.60	0.44	10	770	19.50	broken

3. Results and Evaluation

SHTBT is based on one-dimensional stress wave theory [3]. Recorded pulses are processed by computer and the values of stress, strain and strain rate in the specimen can be determined by using these equations

$$\sigma(t) = \frac{ES_{bar}}{S_{specimen}} \varepsilon_t(t)$$

$$\varepsilon(t) = \frac{-2C_0}{L_{specimen}} \int_0^t \varepsilon_r(t)\,dt$$

$$\dot{\varepsilon}(t) = \frac{-2C_0}{L_{specimen}} \varepsilon_r(t)$$

where:

S_{bar} - output bars cross sectional area,
E - elastic modulus of output bars,
$S_{specimen}$ - sample's cross sectional area,
$\varepsilon_{t(t)}$ - transmitted strain history,
$\varepsilon_{r(t)}$ - reflected input bar strain history,
$L_{specimen}$ - specimen length prior to impact,
C_0 - infinite wavelength wave velocity in the input pressure bar.[3]

Referential and final dimensions of specimens and loading conditions are shown in Tab. 2. All tests were carried out at room temperature (23 °C). The incident pulses were generated using a 100 mm striker bar. Referential shape of specimen is shown in Fig. 3.

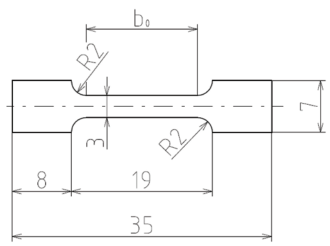

Fig. 3: *Initial dimensions of specimen (thickness of 2 mm) for dynamic tensile test (SHTBT).*

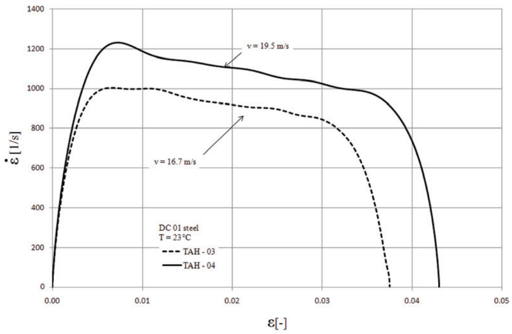

Fig. 4 *Strain rate in dependence on strain.*

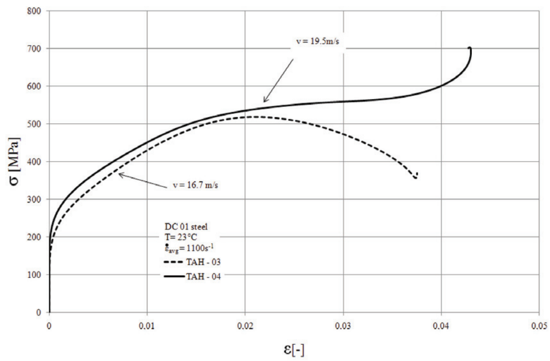

Fig. 5: *Stress in dependence on strain.*

4. Discussion

Median strain rate was approximately of 1000 s^{-1} to 1100 s^{-1} and dynamical yield stress of 220 MPa to 240 MPa as shown in Fig. 5. Static yield stress of DC 01 steel lies between 190 MPa to 200 MPa. Consequently this steel is hardening and neck is created in place of maximal stress.

Initial plastic deformation and increase of hardening were recorded by performed tests i. e. record of material dynamic yield stress and progress of homogenous plastic deformation during action of incident pulse. Further shape of stress – strain dependence cannot be relevantly recorded because the length of incident pulse is limited by possibilities of the test device and there are also interferences of reflected pulses in bars. Finally, relevancy of SHTBT is based on homogenous plastic deformation by one dimensional state of stress.

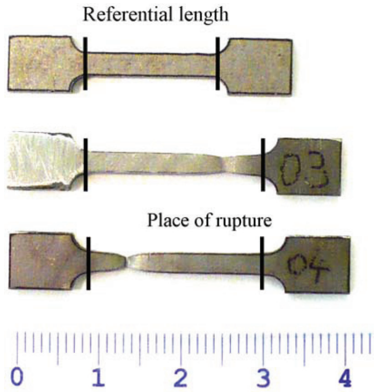

Fig. 6: *Specimens before and after dynamic tensile tests - examples.*

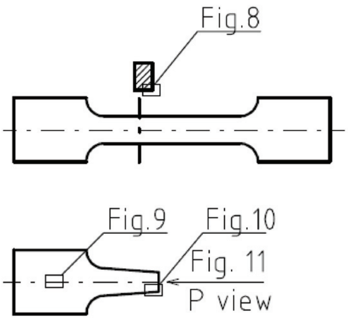

Fig. 7: *Location of specimens.*

Depth of heat-affected zone is caused by laser beam cutting was measured from the border edge of specimen and it was 50 µm, see Fig. 8. Original ferrite-pearlite structure is shown in Fig. 9.

The influenced band by ductile fracture is shown in Fig. 10 and Fig. 11. Original polyhedrosis grains are deformed in direction of shock loading.

5. Conclusions

The goal of this paper was to introduce a new developed device that enables performing of dynamic tensile tests of flat specimens at SHTBT. DC 01 steel thickness of 2 mm was chosen for initial tests. It was found out that strain rate significantly influences mechanical behaviour of this steel, see in Fig. 4 and 5. Depth of heat-affected zone does not influence final dynamic mechanical properties

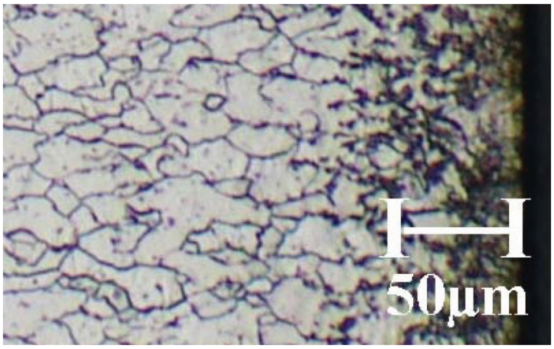

Fig. 8: *Cross section of referential length.*

Fig. 9: *Longitudinal section original structure.*

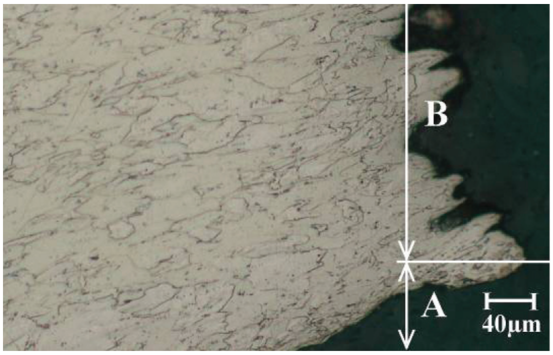

Fig. 10: *Longitudinal section of rupture .*

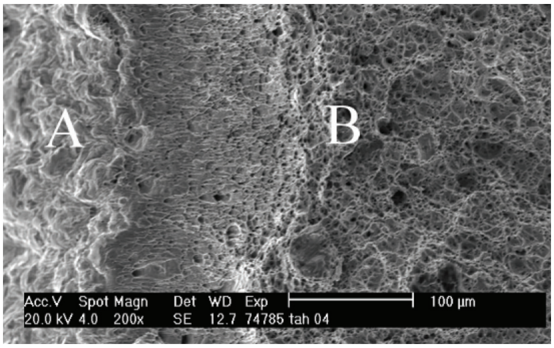

Fig. 11: *View P - Place of rupture A+B (A – deformed grains in direction of loading, B – areas of ductile fracture).*

of tested material. There are no obvious changes in microstructure at room temperature and dynamic tensile loading conditions.

The shape of stress dependence on strain cannot be recorded relevantly up to failure limit. Further research will be focused on improvement of the device for SHTBT, its adjustment and methodology of evaluation. Next goal is unification and prolongation of incident and transmitted pulse. So it will be possible to obtain information about material behaviour not only at onset of plastic deformation process.

6. Acknowledge

This paper was created with support specific research in Brno University of Technology; grant FSI-J-10-47, FSI-S-10-81 and FSI-S-11-26.

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