EXPERIMENTAL ANALYSIS OF DYNAMIC PLASTIC BEHAVIOR OF MATERIALS BY THE HOPKINSON BAR TECHNIQUE

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ABSTRACT – In this paper original experimental methodologies of dynamic plastic behavior of various structural materials in a wide range of strain rates up to 10^5 s^{-1}, and at selected temperatures are presented. Identification of constitutive models and their verification are also included.

INTRODUCTION: Fundamentally important is the better understanding of complex behavior of materials under unusual – extreme – loadings, including plastic deformations. By impact loadings we mean rigid hitting and crash, blasts, and similar events which result in extensive, often localized deformations as well as high strain rates and strong wave effects. The Hopkinson bar technique, also known as Kolsky bar technique, is nowadays one of the most widely used experimental techniques for the measurement of the elastic-plastic properties of materials at high loading rates. Several research studies are reported in the literature on the mechanical behavior of many kinds of metallic and brittle solids, composites and soils. To authors' knowledge, the works on the dynamic plastic behavior during various modes of loading are scarce in the literature and still a lot of effort is required to understand an influence of high or very high strain rate during large plastic deformation of tested materials, including temperature effects. The paper focuses the attention on experimental tests, their interpretation, theoretical modeling and numerical aspects, confirmed by finite element method simulations (FEM).

PROCEDURES, RESULTS AND DISCUSSION: The Split-Hopkinson pressure bar (SHPB), named after Bertram Hopkinson [1914], sometimes also called as Kolsky bar [1949], is an apparatus for testing the dynamic stress-strain elastic-plastic response of materials in compression. The Hopkinson bar technique has been extensively developed in the past decades in the world including Poland. Versions for other stress states such as tension, torsion, shear, and axial/shear combination have been developed based on the same principles and similar mechanisms. The differences among these versions are only in loading and in specimens gripping systems. Various Hopkinson bar schemas are discussed here. They are equipped with the infrared (IR) and high-speed cameras and environmental chambers enabling to cover key areas and recent application advances in studies of dynamic plastic behaviour of materials at lowered, room and elevated temperatures. Due the limited volume of this paper only selected schemes and results of experimental studies are presented.

The usual way of material characterization at higher strain rates is the Hopkinson bar method, which enables strain rate sensitivity evaluation of materials in the range up to $5{\cdot}10^3 s^{-1}$. Miniaturized direct impact compression method (DICT) is one of the techniques which enable material testing at rates higher than those typically possible to attain on the Hopkinson bar arrangement. The device for the DICT testing with the upper strain rate limit equal to $10^5 s^{-1}$ was designed and developed at IFTR PAS, Malinowski et al. [2007] – see Fig. 1.

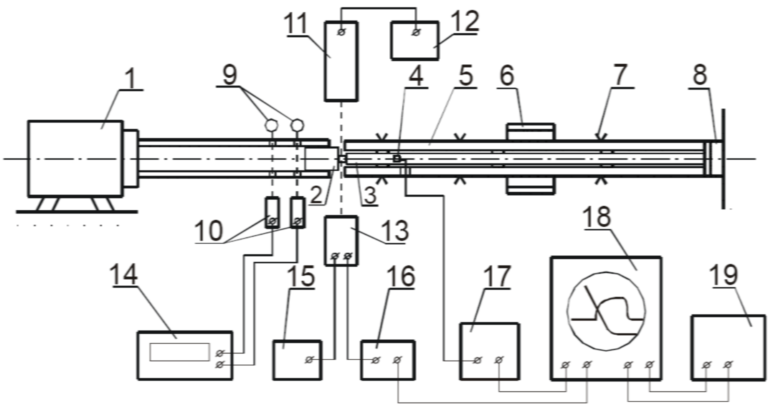

Fig. 1. General scheme of DICT, 1 – air gun; 2 – striker; 3 – transmitter bar; 4 – SR gage; 5 – decelerator tube; 6 – main support; 7 – supports; 8 – dumper; 9 – light sources; 10 – photodiodes; 11 – laser diode; 12 – supply of 11; 13 – photodiode (displacement measurement); 14 – time counter; 15 – supply unit of 13; 16 – DC amplifier; 17 – SR amplifier; 18 – digital oscilloscope; 19 – PC.

The stress-strain curves of two different kinds of aluminum alloys, obtained using the MDICT apparatus are presented in Figs. 2 and 3. The specimens of 1,5 mm diameter and 0,5 mm thickness were fabricated form extruded round bars.

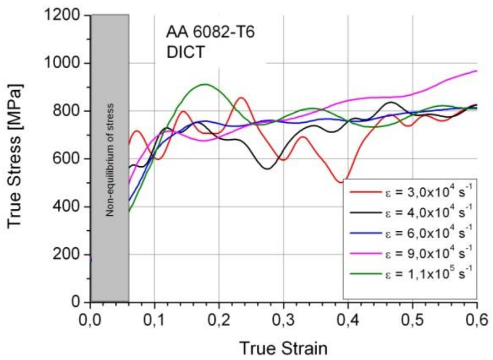

Fig. 2. Plastic stress-strain curves of AA 6082-T6 at very high strain rates.

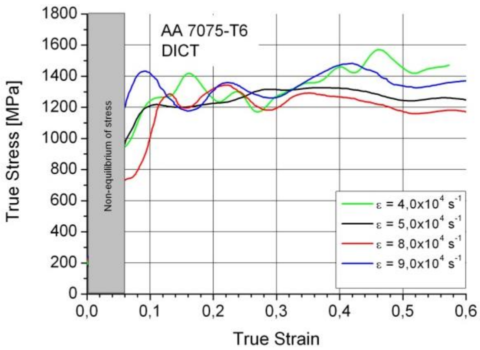

Fig. 3. Plastic stress-strain curves of AA 7075-T6 at very high strain rates.

Original methodologies are also offered for complex data analysis of structural materials, including determination of required mechanical properties of materials in a wide range of strain rates and temperatures, identification of constitutive models, and their verification by means of special natural and numerical experiments. A set of verification tests based on the Hopkinson bar technique includes: modified Taylor tests, DICT tests, and dynamic indentation experiments. Subsequently, constants of constitutive models were determined by numerical simulations using the Autodyn solver as well as the Autodyn and Multi Objective Genetic identification Algorithm (MOGA) to solve an inverse problem of impact deformations, Kruszka et al. [2012].
The models defined by results of one-dimensional static and dynamic experiments well describe behaviors of these materials in conditions of the complex stress state, as well as allow to construct yield surfaces - see Fig. 4.

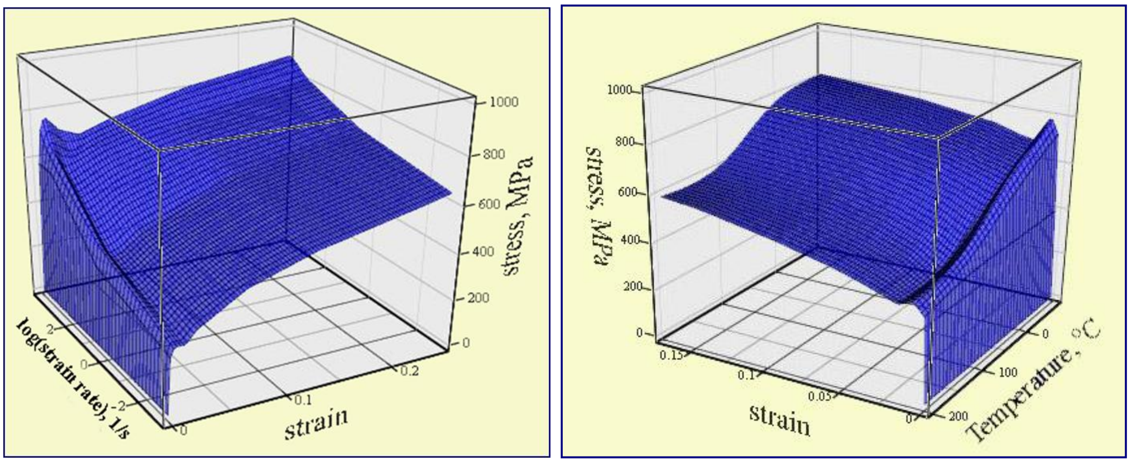

Fig. 4. Yield surfaces in form of stress as a function of strain and logarithm of strain rate (left diagram) or temperature (right diagram) for St0S Polish building steel tested in the "as-received" state.

CONCLUSIONS: Introduction of specimen miniaturization for dynamic tests enables reaching of very high strain rates up to 10^5 s^{-1}. Advantage of the presented set of verification tests manifests itself by more complex analysis of tested materials in comparison to experiments based on the Hopkinson bar technique. Strain rates and ranges of plastic deformations are significantly wider, and therefore, the experimental and numerical verification enable more effective extrapolation of data in order to obtain reasonable constitutive relationships.

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