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MEASUREMENT METHOD FOR DETERMINATION OF MATERIAL PROPERTIES IN CONDITION OF RAPID HEATING AND HIGH DEFORMATION RATES

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Abstract*: This work deals with a proposal of measuring method used to establish material properties measured in conditions of rapid heating and high deformation rates. These conditions are typical for recent technological processes. However, no exact material characteristics have been available for the development of these processes. The knowledge of stress-strain behaviour of material is necessary for development and optimization of technological process, particularly when FEM simulation is applied. The parameters have been in many cases just estimated. To measure them precisely, new technique has been designed which enables us to determine the forces applied to the specimens and specimens deformations during dynamical loading controlling temperature development at the same time.*
Key words: *strength, ductility, strain, measurements*

1. INTRODUCTION

Several recent technological processes are typically performed at high deformation rates and steep temperature gradients. To optimize technological processes with the support of calculations by, for example, finite element methods, it is necessary to know precisely the stress-strain relationship in the whole range of the outer conditions that might occur during the process and that can change dynamically. It is often very difficult to establish these parameters in dynamic loading conditions and standard measurement methods can often not be applied. This is the reason why a new method has been developed to determine deformation resistance, yield point, tensile strength, ductility and contraction of high-strength steels during rapid heating. This method can be utilized for dynamic tests of material at chosen elevated temperatures of a specimen. Heating is done by combined resistance high-frequency method in very short time intervals. It was necessary not only to design and assemble the experimental set-up but also to develop a suitable method for evaluating the measured data.

2. EXPERIMENTAL PROGRAMME

2.1 Optimization of specimen shape

It is more convenient when measuring mechanical properties to use specimens with simple geometry which will be loaded uniaxially and thus, at least at the beginning, by uniaxial stress. The most common shapes of specimens are cylinders or prisms. The active part of the specimen has a shape ensuring homogenous stress distribution. The ends of the specimens are adjusted to be mounted into the testing machine so that the axis of the testing bar is aligned exactly with the axis of the machine jaws. (Drozd, 2001).

Three different specimen shapes were designed by finite element method for given statistical values of R_m. Two of the main factors of the optimization process were homogeneous temperature field distribution in the active part of the specimen and the ability to reach the desired high deformation rate. The specimen with an active length of 15mm and a diameter of 5 mm was chosen as the most suitable one after measuring the temperature field in the axial direction of the specimen. Maximum relative temperature deviation during heating of the specimen was under a set value of 5% along the whole active part of the specimen and in the whole heating temperature interval. The temperature was measured at the surface of the specimen by an attached thermo-couple and the temperature field was simultaneously monitored by thermo-vision camera.

2.2 Proposal of testing methodology

The material was tested according to the conditions of the model process, deformation rate being . From this deformation rate was calculated the necessary rate of actuator motion as, (1),
where Lc is the tested length (CSN EN ISO 6892-1, 2009). This requested rate was tested by the order: jump 50 mm in 0.11s. The displacement-time relationship can be divided into three stages: stage 1– rise time to the desired rate, stage 2 with constant feed rate and stage 3 of actuator braking. This time behaviour was not satisfactory because of the insufficient dynamic of rise time and therefore a new tool was designed which helps to deform the specimen only when the rate reaches the desired value, which means at the beginning of stage 2.

This tool was used to perform tensile tests which provided us with stress-strain diagrams. However, the diagrams did not correspond to the physical behaviour of the material. FMEA (Failure Mode and Effects Analysis) was therefore applied and it was found that a measurement failure had occurred due to an impact on the tool. Position and force detectors started to give unreal values during this impact.

A special strain gauge component was designed to avoid this measurement problem. The component consists of four resistive strain gauges connected into a bridge of two strain gauge couples placed at opposite sides of the tool. This allowed both temperature and prospective parasitic bending compensations. Deformation was monitored during the test by a rapid video extensometer. This recording can be used to evaluate not only the deformation-time relationship but also to establish the contraction of the specimen. The video extensometer offered the possibility of synchronizing the video record with the input analogue signal with a voltage from 0 to 5 V. An adjustable amplifier was therefore designed for the strain gauge. It can be used to measure forces in the range of 0 – 5 V. Video recording was made at a speed of 10 000 fps, data from the force sensor were recorded with a sampling rate of 100kHz. A higher frequency of sensor data was chosen to filter off signal noise caused by induction-resistance heating.

2.3 Evaluation of obtained data

Records from both testing machine and video extensometer were available after the tests. Information about temperature development, actuator shift and force were obtained from testing machine data. The video extensometer provided data from the strain gauge, such as force development and the changes to the specimens' geometry, elongation, contraction and local contraction.

Excel software was used to process and evaluate data. With the help of macros and Visual Basic tools were prepared enabling sensor records to be read and also from the video extensometer which analysed the optical record of deformation. Proof yield stress was calculated from recorded data according to generally known figures used in literature and standards (ČSN EN 10002-5, 1998).

It is necessary to use values from the true stress – true strain diagram to estimate formability of the material on the basis of a tensile test or as input data for FEM analysis and technological calculations.

The low of preservation of volume ($\Delta V = 0$) is valid in the area of uniform plastic deformation (from yield point to ultimate strength), implying:

— — —— (2)

and thus it must be a assumed that true stress is:

(3)

True relative deformation is given by the sum of small deformation steps and thus

— — —— (4)

Once ultimate strength R_m is reached, localised deformation of the specimen occurs, and it is therefore necessary to calculate true stress from the changing cross section of the specimen. This is determined from the optical record made by the video extensometer. The true stress-strain diagram is then an increasing function in contrast to the engineering stress-strain diagram which is a decreasing function. The highest stress in this case corresponds to the true stress in the moment of fraction.

3. APPLICATION OF TESTING METHOD

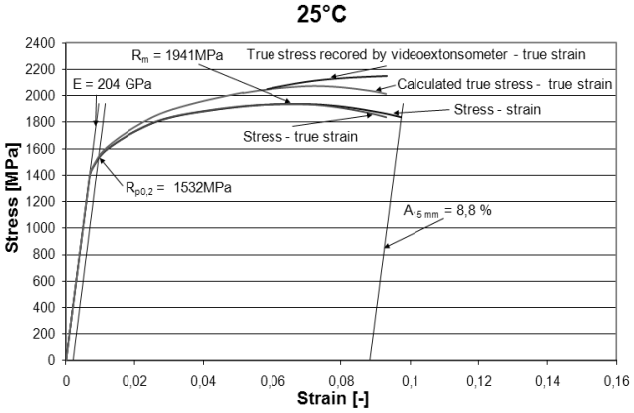

Fig. 1. Stress-strain diagrams after 5 second hold at the temperature of 25°C

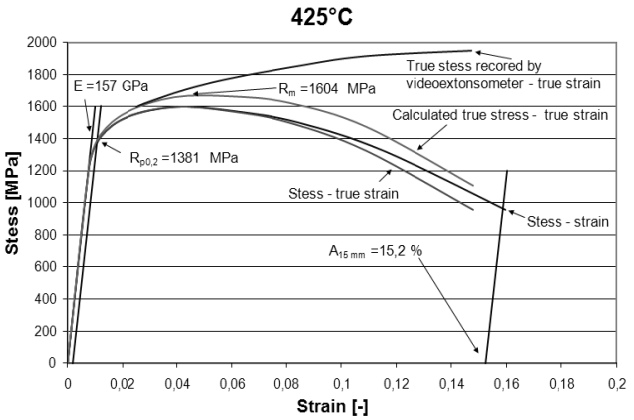

Fig. 2. Stress-strain diagrams after 5 second hold at the temperature of 425°C

Measuring method was tested on 42SiCr steel, which was in structural state with high strength and good ductility obtained by Q-P process (Quenching and Partitioning). Different testing temperatures were chosen with regards to temperature instability of multiphase microstructure and to possible technological impact on this structure. A five second hold was applied in all the cases. The diagrams for temperatures of 25°C a 425°C are shown here for illustration purposes (Fig.1, Fig.2).

4. FURTHER PROPOSED PROCEDURE

- Estimation of measurement uncertainty (Němeček, 2008).
- Testing of developed method for more temperatures and different materials.
- Equitation (1) does not consider any elastic deformation of testing equipment (Wozniak, 2010), elastic deformation however does occur during the experiment, which means that only part of the crossbar shift rate is transferred to tested specimen. To evaluated this phenomenon.
- To evaluate the method

5. CONCLUSION

The connection of dynamic testing equipment with highly dynamic precise heating is the basis for measurement of deformation characteristics of materials in conditions corresponding to real dynamical technological processes. The proposed measuring method enables uniform heating of a specimen from room temperature to several hundred degrees centigrade in the range of several seconds and then its deformation with initial strain rates up to 100 s^{-1}. The deformation force and deformation path can be registered with the help of a strain gauge system connected to a high speed optical extensometer. True stress - true strain can then be evaluated from the obtained values. The advantage of this procedure lies in the fact that it is not limited by the necking of the specimen. The true stress-strain relationship can be obtained practically up to the fracture of testing specimens.

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