INFLUENCE OF THE DYNAMIC LOADING ON THE MECHANICAL PROPERTIES OF THE ULTRA-HIGH STRENGTH MATERIAL

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Abstract

The paper deals with analysis of the ultra-high strength steel at material tests under the high strain rates. In the experimental part was tested steel alloyed by manganese and boron with the predominant martensitic structure. This steel is used in the automotive industry for the car-body design where it is necessary to have parts which ensure the safety of passengers. To fulfill these required function is for these parts very important to know their deformation behavior under the dynamic loading (crash conditions) because it can vary in comparison with the low and uniform strain rates. Experiment was carried out in the drop tower Instron CEAST 9350 where it is possible to set the magnitude of the impact velocity. Moreover, high-speed cameras PHOTRON SA3 were also used to record the whole test. These cameras monitored the points displacement on the surface of testing sample which was loaded under the conditions of the uni-axial tensile stress state. For the own computation of the kinematics quantities there was used software PONTOS where the main goal was to determine the evolution of the given strain rate s (s^{-1}). Moreover there was recorded the impact energy during the test by means of the force sensor under the different impact velocities.

Keywords: HS Cameras, photogrammetry, drop tower instron CEAST 9350, strength material, strain rate

1. INTRODUCTION

Quite often it is very important to carry out the material test under the higher impact velocities so there is possible to define material deformation behavior at e.g. crash test [1]. Material behavior under the dynamical loading differs a lot in comparison with the low and uniform impact (or loading) velocities. This paper deals with measurement strain rate s (s^{-1}) under the high impact velocity (3 $m \cdot s^{-1}$) for high-strength steel (22MnB5) and that is why tested material was loaded by the high impact velocity (thus dynamical loading) in the drop tower Instron CEAST 9350 controlled by program CEAST VIEW. Clamping of tested sample was carried out by means of the testing jig which makes possible to load sample under the uni-axial stress state. As there was already mentioned before, impact test was done at impact velocity 3 $m \cdot s^{-1}$ and with material 22MnB5 that is manganese-boron steel. This tested material belongs into group of the ultra-high strength steels with ferritic-perlite structure in basic state; ultimate strength R_m = 450 ÷ 550 MPa and ductility A_{80mm} = min 20 %.

Boron steels belong into the steels which are suitable for hardening and tempering. They offer quite good properties for the hot forming and high strength after the thermal treatment - hardening, which takes place directly in the forming tool. Such material property is mainly given by their alloying with the small amount of boron and manganese to improve hardenability. Micro-structure of boron steels after the thermal treatment consists mainly from the martensite and residual austenite. Tested sample from this material were after the thermal treatment and revealed martensite structure [2]. Its material properties were: R_m = 1500 MPa and A_{80mm} = 5 %. Own experiment consisted of two parts. During the first phase there was verified the impact velocity of whole testing system (moveable crossbar connected with testing jig). The second phase was about measurement strain rate s (s^{-1}) during the dynamical tensile test [3]. For both phases of measurement was used the contact-less optical system PONTOS from the company GOM. Because of the high impact velocity was needed to use high-speed (HS) cameras PHOTRON SA3. Data scanning frequency in this case was 5000 fps (frames per second). Within the given calibration volume is system PONTOS subsequently able to compute position, velocity and acceleration in applied points.

2. METHODOLOGICAL BASES AND EXPERIMENTAL PART

Experimental part was made in the drop tower Instron CAEST 9350 (see **Figure 1** - left). This device is designed for impact testing of materials. The major advantage rests in possibility to adjust impact velocity and energy which is defined by weight of the moveable crossbar and its impact height. For the high impact velocities there are preloaded springs which enable to have the impact velocity up to 25 m·s^{-1}.

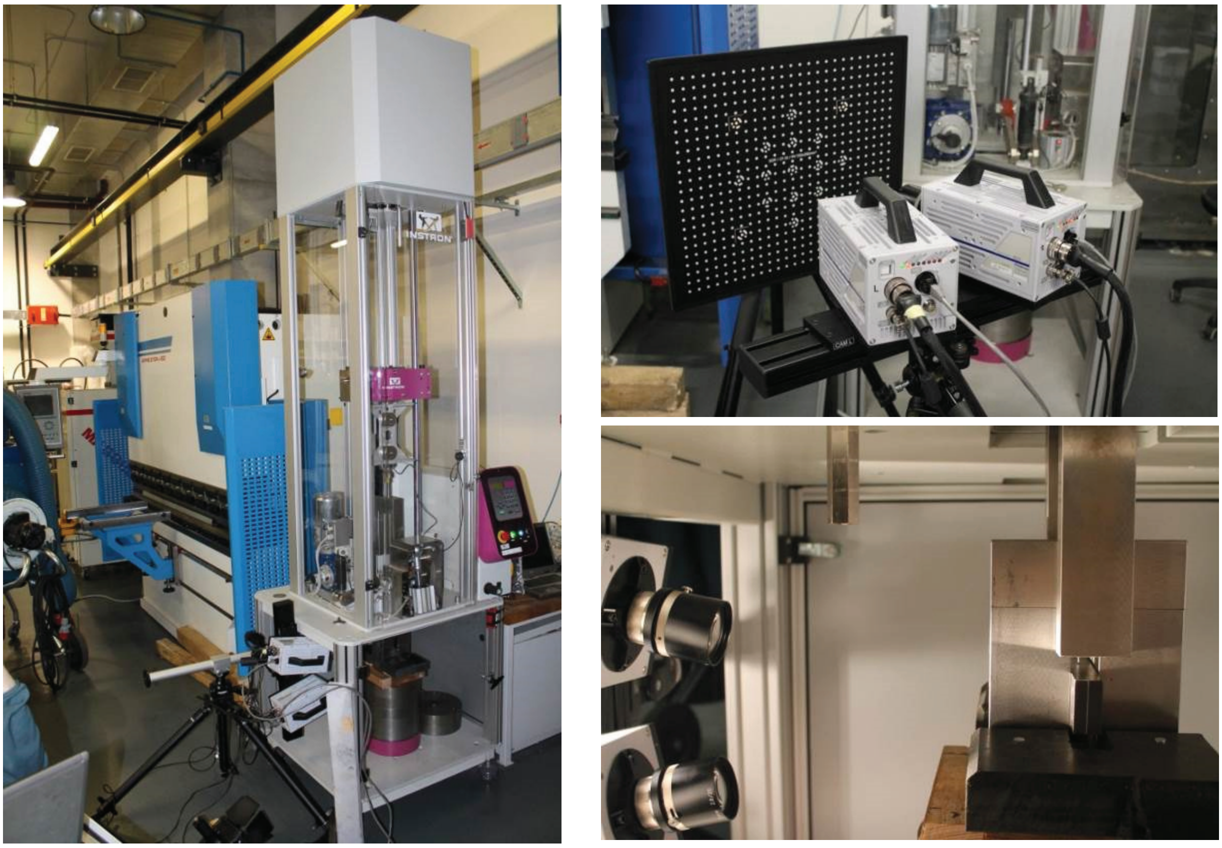

Figure 1 Drop tower Instron CEAST 9350 (left) and HS cameras calibration and positioning (right)

In this experiment was impact velocity set as 3 m·s^{-1}. To verify such magnitude and also to compute the final strain rate *s* (s^{-1}), there were used HS cameras and optical system PONTOS. That is why the first part of measurement was about calibration and adjustment of proper lighting and distance from the testing sample of these HS cameras (see **Figure 1** - right). Very difficult was mainly finding the proper position of the lighting device. Moreover, the testing tool and jig was designed as semi-open which caused the other problems about position of the HS cameras. Testing sample from the material 22MnB5 (see **Figure 2**) with the width 5 mm had a geometry similar to the common samples for static tensile test. Hole and curved part of sample were used to have the proper clamping of this testing sample in testing jig.

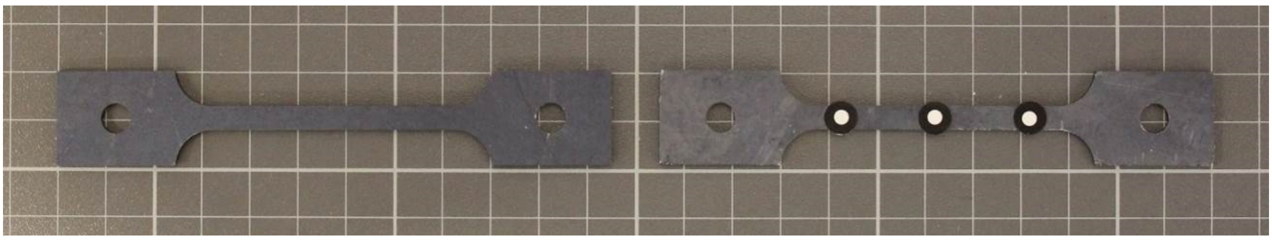

Figure 2 Testing samples (with and without circular points for system PONTOS)

2.1. Verification of the impact velocity v (m·s^{-1})

First part of the experiment was focused on the verification impact velocity v (m·s^{-1}) of the crossbar which was taken as a whole assembly from particular parts that influence the impact velocity and energy. The drop tower Instron CEAST 9350 enables to define the crossbar impact velocity from its weight and impact height. Nevertheless, the jig was jointed with the crossbar. Thus weight of the whole system (now crossbar plus jig) was changed and that is why there was necessary, before measurement the strain rate s (s^{-1}), to verify the actual value of the impact velocity. Such verification was made by optical system PONTOS and HS cameras. Fixed part of the jig was placed inside the tower and on both part of jig (fixed and moveable ones) were bonded circular points (white on black). After calibration of HS cameras there were acquired images and from the given data scanning frequency (3000 fps - thus Δt = 0.000333 s) was computed not only the mutual displacement of these points but also their mutual velocity (thus impact velocity - see **Figure 3**).

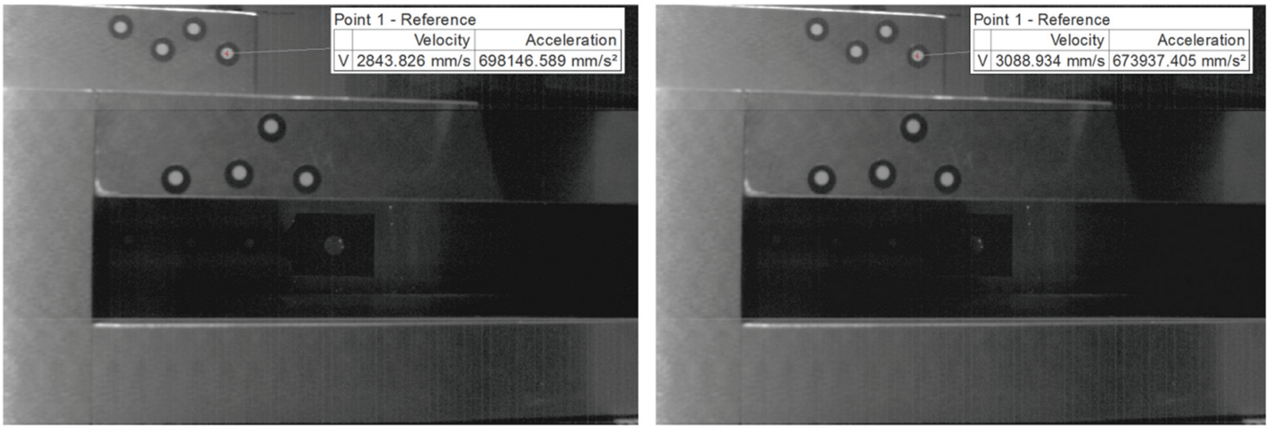

Figure 3 Acquired images for verification impact velocity (system PONTOS) - point 1 was a reference point

After adjusting input data for the crossbar total weight and required impact velocity (3 m·s^{-1}) in the software CEAST VIEW, test was started (images from this test are shown in **Figure 3**). As was already mentioned before, system PONTOS computed displacement, velocity and acceleration of every point. In **Figure 4** is shown the measured velocity of point 1 vs. its displacement along X-axis (mm) and time t (s). It is obvious that final impact velocity was as required (so 3 m·s^{-1}).

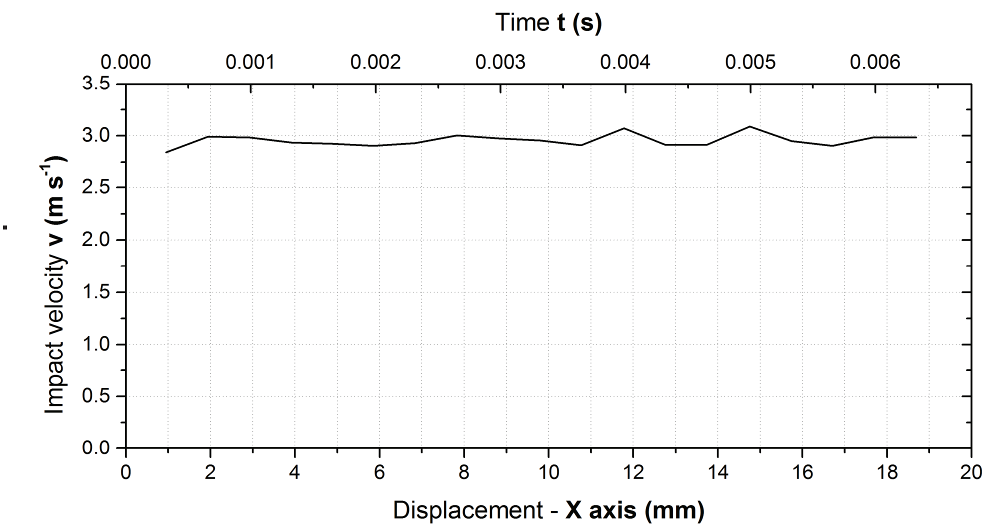

Figure 4 Impact velocity v (m·s^{-1}) vs. displacement along X-axis (mm) and time t (s) - system PONTOS

2.2. Results of the strain rate s (s^{-1}) measurement

As an experiment major part there was measurement of the strain rate *s* (s^{-1}) on the surface on the testing sample which was loaded by uni-axial tensile stress state from the impactor (moveable part of jig). On tested sample were bonded there circular points which were subsequently computed by system PONTOS (**Figure 5**). Impact velocity was adjusted as 3 m·s^{-1} (the verified value). HS cameras acquired images with the data scanning frequency of 5000 fps (thus in this case Δt = 0.0002 s). Time of 0 s was taken from the drop tower.

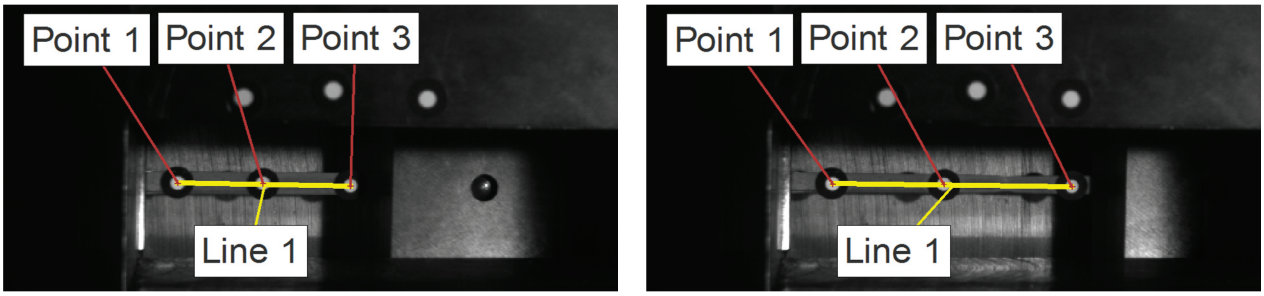

Figure 5 Testing sample at the beginning of test (left) and in the moment right before the fracture (right)

Because the system PONTOS measures the position of every point, there is also possible to measure strain (both engineering and true strain) between these points as point-point distance and its change during test. And from the known value of strain φ_1 (1) and Δt is no more difficult to gain value of strain rate *s* (s^{-1}) by its differentiation. In **Figure 6** is shown this curve of strain rate *s* (s^{-1}) vs. time *t* (s) for line 1. This line was taken as point-point distance between point 1 and point 3. First part of the curve is illustrated in grey color because when the impactor hit the testing sample, there is also motion of the whole clamping system and that is why there isn´t sample deformation (so these values are in grey and aren´t taken as final results). Nevertheless, after time *t* = 0.002 s is upper grip already fixed in the jig and the whole test is now the dynamic tensile test. At the beginning there is rapid increase of strain rate up to maximal values of 50 s^{-1} in time 0.0279. After that value there is decreasing of strain rate which results from the necking and final fracture of sample. Such fracture occurred between points 2 and 3 and that is why it was interesting to compute strain and strain rate (again as point-point distance) also for these points (see conclusion). The whole test lasted 0.0109 s.

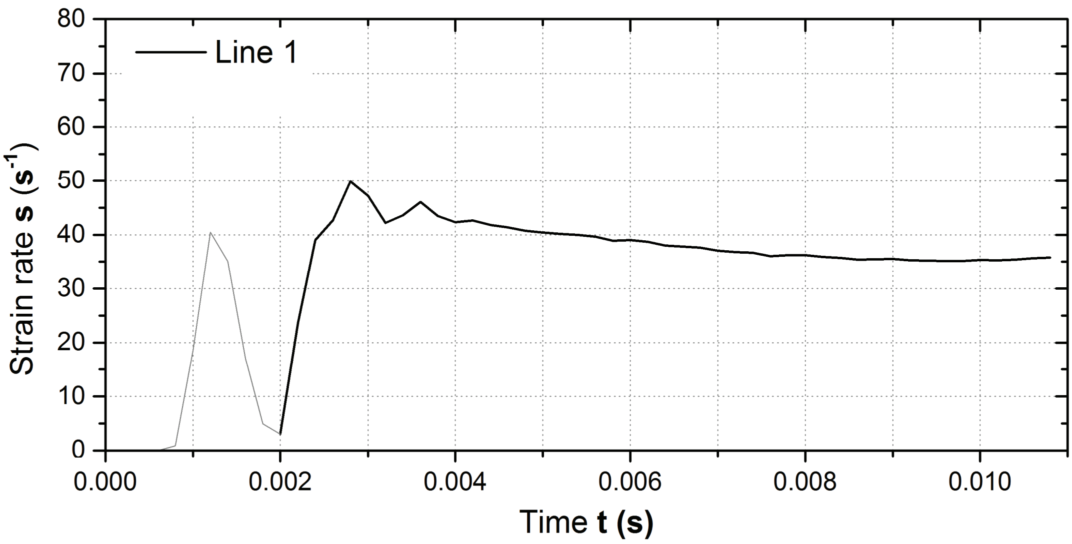

Figure 6 Course of the strain rate *s* (s^{-1}) for line 1 (between points 1 and 3)

3. CONCLUSION

Aim of the experiment was to determine strain rate s (s^{-1}) for ultra-high strength material 22MnB5 by means of the drop tower Instron CEAST 9350. For complex overview there was measured strain rate between all points - line 1 between points 1 and 3, line 2: points 2 and 3 and line 3: points 2 and 3 (see **Figure 7**). The beginning of all curves (in grey color) are the same because there was displacement of the whole testing system (this part was neglected). First deformation of sample occurred in time $t = 0.002$ s and after that was observed the similar character of all three curves. About time $t = 0.005$ s is obvious the difference among curves. The highest increase of strain rate is between points 2 and 3 (line 3) because necking and fracture occurred between these points. There is high non-homogenous deformation in the necking area which caused the steep increase of strain rate. In the moment right before the fracture (t = 0.0109 s) was computed the highest values of strain rate (73.4 s^{-1}). On the other hand, line 2 (between points 1 and 2) decreased with the time because deformation in this region wasn´t so high. Line 1 connects points 1 and 3 and that is why it creates the average curve from the two previous curves (line 2 and 3).

There were two major purposes of this paper. The first one was to verify HS cameras and PONTOS system application possibilities for measurement strain rate *s* (s^{-1}) under the high impact velocities. The second one was focused on the material deformation behavior (here ultra-high strength steel 22MnB5). This paper offers the first results for testing such combination of the ultra-high strength steel, impact test and HS cameras.

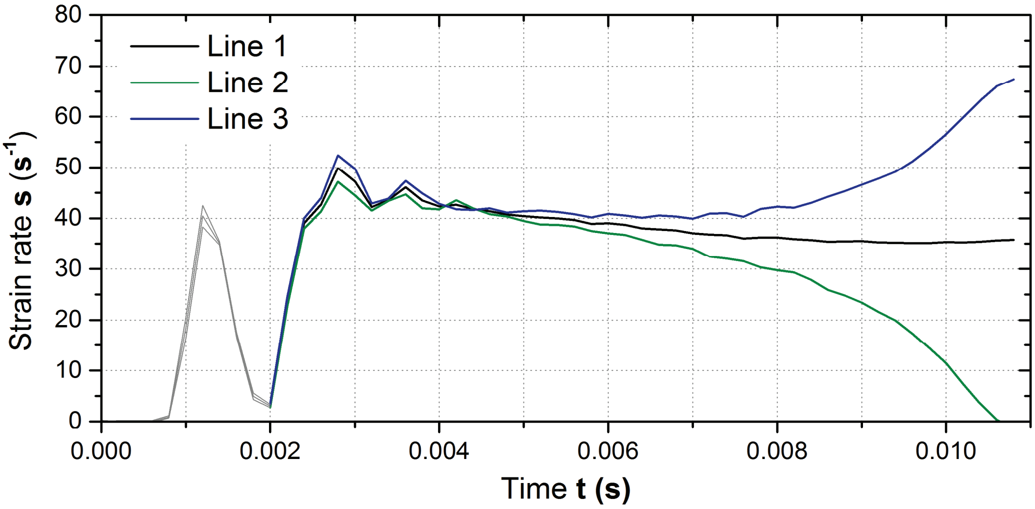

Figure 7 Strain rate *s* (s^{-1}) vs. time *t* (s) for lines 1, 2 and 3

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