UTILIZATION OF THE HIGH-SPEED CAMERAS FOR MONITORING DEFORMATION BEHAVIOUR AT THE BENDING IMPACT TEST

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Abstract

Deformation characteristics of the materials used in the engineering industry are mostly determined at the common stress-temperature conditions (mostly loading rate 10 mm·min^{-1} and temperature 20 °C). However in the operating life are materials loaded under conditions which are quite different from these standard conditions. Among such important operating conditions are e.g. operating temperature, state of stress and so on. Last but not least there is also the information about the tested material deformation behavior at the higher strain rates. This paper deals just with the influence of increased strain rate on the deformation distribution and magnitude. That is why there was chosen the bending impact test at the drop tower Instron CEAST 9350. As a tested material was used non-alloyed steel of the common quality acc. to ČSN 41 1373. The first aim of this paper was design of the testing jig. The second aim was subsequently effort to apply high-speed (HS) cameras PHOTRON SA3. For the own deformation computation and its distribution on the sample surface was used software ARAMIS 2M. At this point there was also effort to (by the optical measurement) determine the strain rate corresponding to the used impact velocity of the drop tower tool. So as a result there was not only the own testing jig for bending impact tests but also evolution and graphical illustration of the deformation distribution with the information about the strain rate magnitude. Subsequently from the measured results arise certain important recommendations for the future direction of such research.

Keywords: HS Cameras, photogrammetry, ARAMIS 2M, instron CEAST 9350 drop tower, impact test

1. INTRODUCTION

The measurement of the material deformation behavior under the high strain rates *s* (s^{-1}) provides the very important knowledge e.g. for crash tests or these data can be used as input data for the different numerical simulations [1]. On the other hand, this type of testing is truly very sensitive about its proper preparation. Nowadays there are two main approaches about such type of material testing. The first one arises right from the sample geometry [2]. In this case is used tendency that the higher loading rate v_L (mm·s^{-1}) and the smaller measured length *L* (mm), the higher strain rate *s* (s^{-1}) - see equation (2). Thus for this design are mainly used samples with quite small measured length. The second basic approach uses the contact-less deformation measurement - thus some photogrammetric system. This type of test was used also in the experimental part of this paper. The utilization of cameras for the contact-less optical measurement at high strain rates means very precious preparation - mainly in light of the proper combination of the shutter time and required fps (frames per second) adjustment. That is why such approach is truly very time consuming during the pre-processing phase. Nevertheless, it mostly offers just quite a lot of different quantities to be evaluated at the post-processing phase of the measurement. E.g. in this case (the bending impact test) there was computed not only strain distribution (major, minor, von Mises and so on) and strain rate distribution, but it was also possible to carry out data mapping with the results from the numerical simulations or just compare CAD data in light of the sample dimensions. However (because of this paper scope), these results are not mentioned here. Moreover it can be added e.g. its relevant force from the force sensor for every used frame. On the following pages is described the utilization of such contact-less measurement for the impact test to determine the strain rate corresponding to the adjusted impact velocity for the moment right before the fracture. As a main aim there was to produce the testing jig and to verify applicability of this approach.

2. METHODOLOGICAL BASES AND EXPERIMENTAL PART

The whole experimental procedure consisted of the two major parts. As a first important step there was the adjustment of the HS cameras. Measurement of the true strain ε_T (1) and strain rate s (s^{-1}) distribution on the sample surface arose from the contact-less optical deformation measurement. Thus the most important preparation step was calibration of the HS cameras via the calibration plate and preparation of the testing samples (see **Figure 1**). Finally on the testing sample was applied a stochastic pattern (also see **Figure 1**).

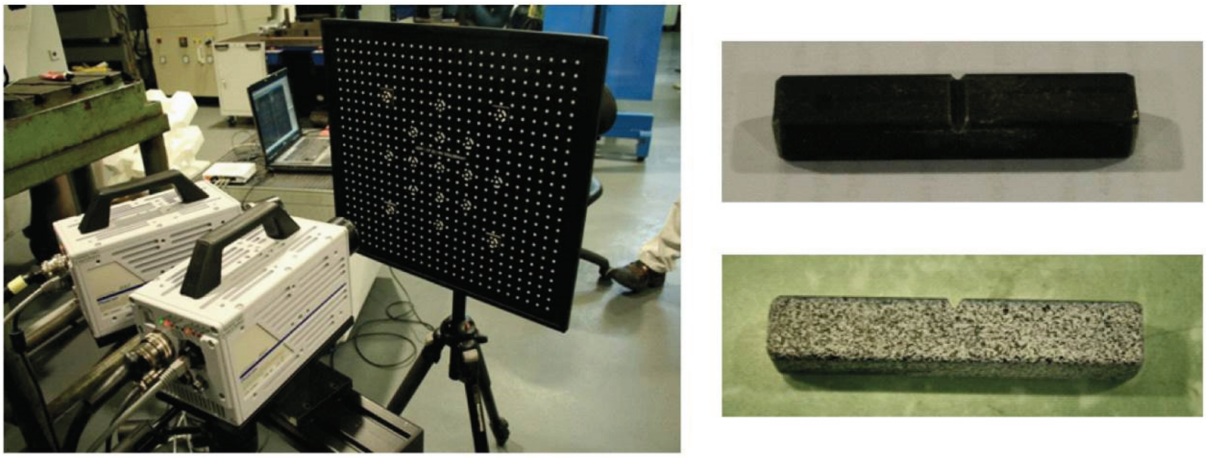

Figure 1 Calibration of the HS cameras (left) and example of the testing sample (right)

After the calibration procedure, HS cameras were prepared for the optical measurement in light of the proper measuring distance, shutter and also exposition time adjustment. After that it was necessary to place the HS cameras into the drop tower Instron CEAST 9350 to record the whole impact test. Their positioning is shown in **Figure 2**. As a starting signal for HS cameras there was used photocell that also served as a staring signal for the force sensor situated above the impactor. Probably the biggest problem was with the positioning of the lighting device (2000 W) because of its thermal influence on the HS cameras.

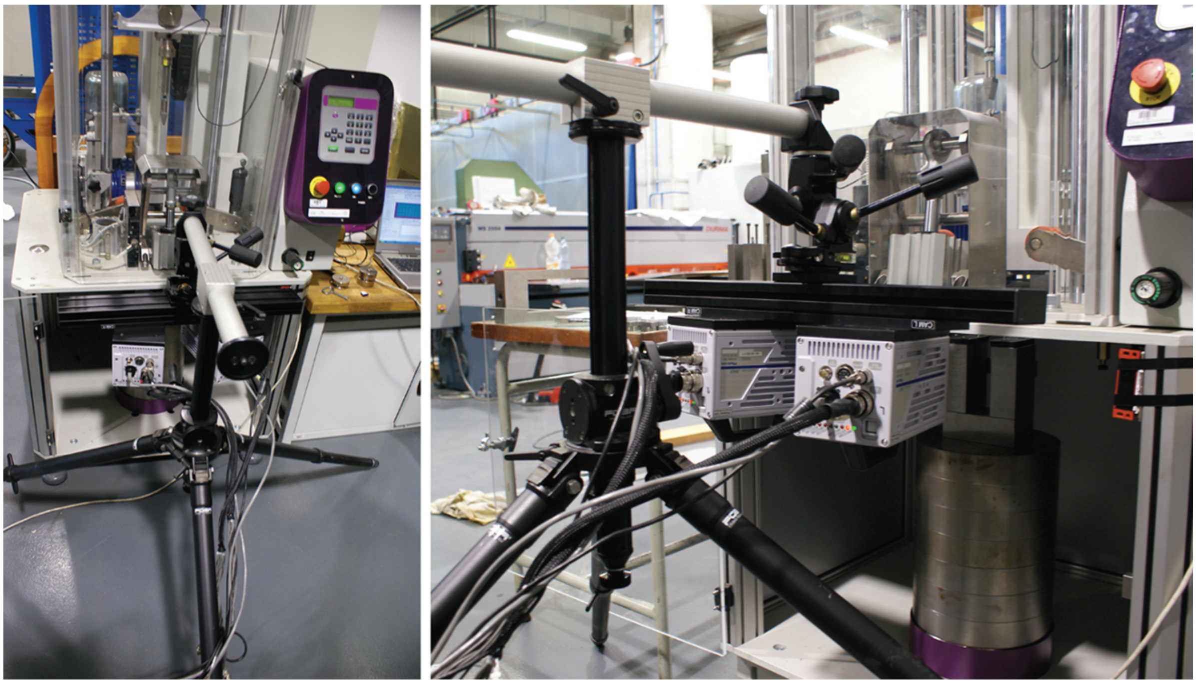

Figure 2 High-speed cameras positioning in the drop tower Instron CEAST 9350

2.1. Design of the testing jig

The impactor has to fulfill requirements arising from the standard ČSN EN ISO 148-2. These requirements are mainly about its dimensions - e.g. width and angle of edge. First proposal of the impactor is then shown in **Figure 3** (left). This impactor was firstly designed as to be one piece. However (after the consultations) its designed was changed into that one which is shown in **Figure 3** (right). This final design of the impactor consists of two pieces which are screwed into each other. There are nuts to set its required position in the drop tower.

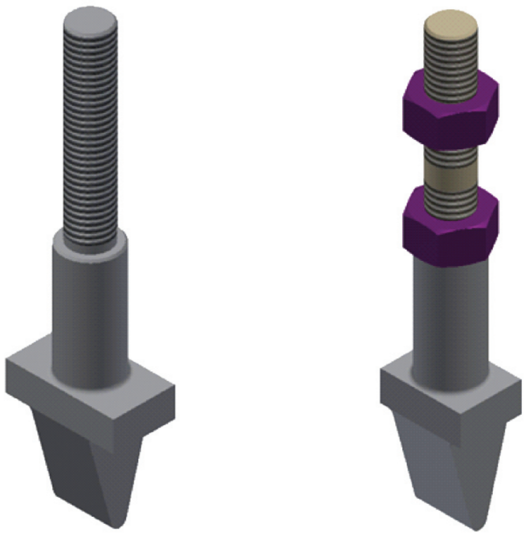

Figure 3 First proposal (left) and final design (right) of the impactor

The design of the own testing jig is shown in **Figure 4**. As a basic there is used mounting plate that is fixed on the lower frame. There is also used a cross-brace to improve stiffness of the whole testing jig. The testing sample is positioned right on the fixed stops. Because there is strong presumption about rapid wearing of the upper inserts, these are designed to be exchangeable and that is why there are also used screws. To improve the stability of the whole testing jig is this jig mounted on the basic disc. Based on the first results it seems that there should be necessary to again improve stiffness of this jig by using another cross-brace.

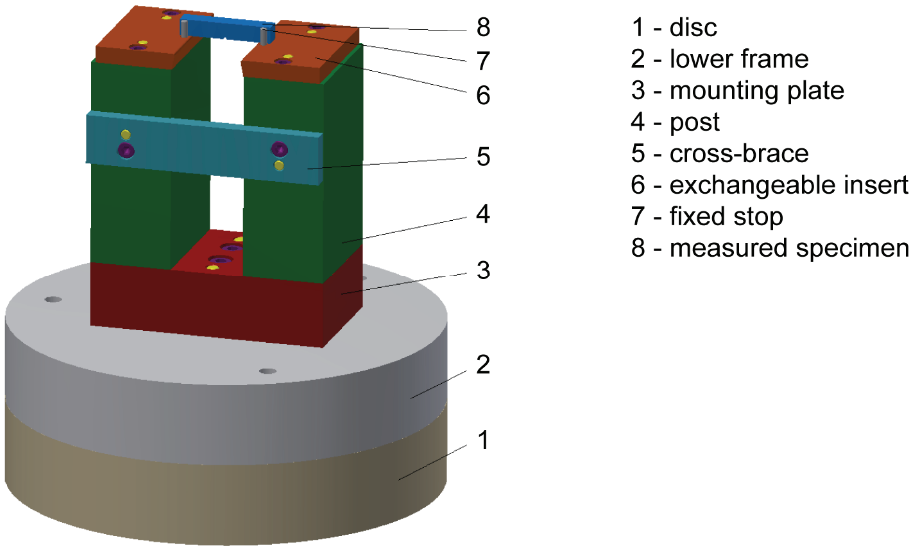

Figure 4 Design of the testing jig

2.2. Results of the true strain ε_T (1) measurement

When HS cameras were calibrated and positioned into the drop tower and after the final adjustment (impact velocity was set to 8.5 m·s^{-1} and data scanning frequency was 15000 Hz - so fps: frames per second) the test was prepared. Subsequently all scanned images were computed in light of the true strain via software ARAMIS 2M. In the **Figure 5** is shown the true strain ε_T (1) distribution in the stage 0 (left and in the middle) and stage 8 - right before the fracture (right). The time step between stages was Δt = 0.0000667 s (15 000 Hz).

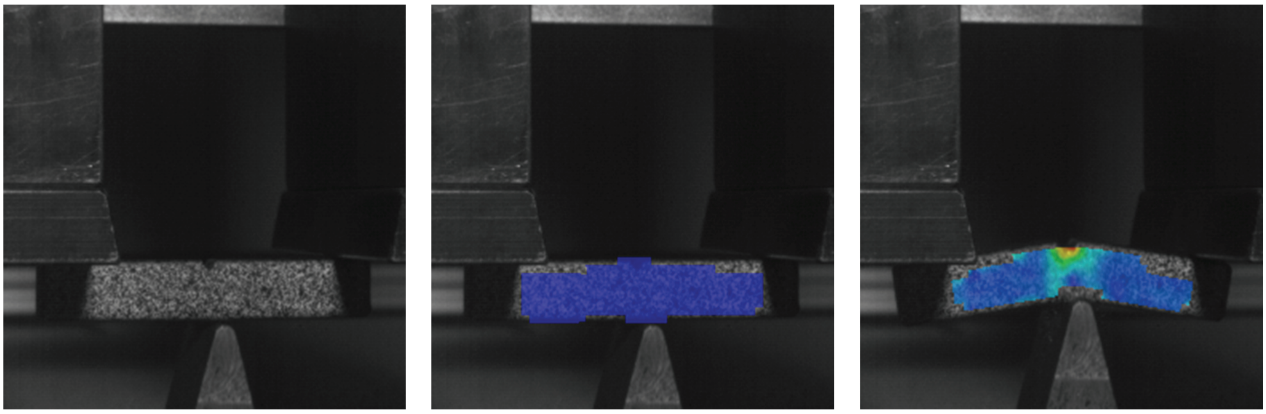

Figure 5 True strain ε_T (1) distribution in stage 0 (left and middle, t_0 = 0 s) and stage 8 (t_8 = 0.000533 s)

In the **Figure 6** is shown detail of the true strain ε_T (1) distribution in the stage right before the fracture which was scanned at time t = 0.000533 s from the stage 0 (taken as 0 s). In this case is shown its distribution on the sample surface in detail to point out differences. It was the first testing sample where maximal ε_T = 0.274. Preparation of measurement and its evaluation is very time consuming. Totally there were tested 3 samples.

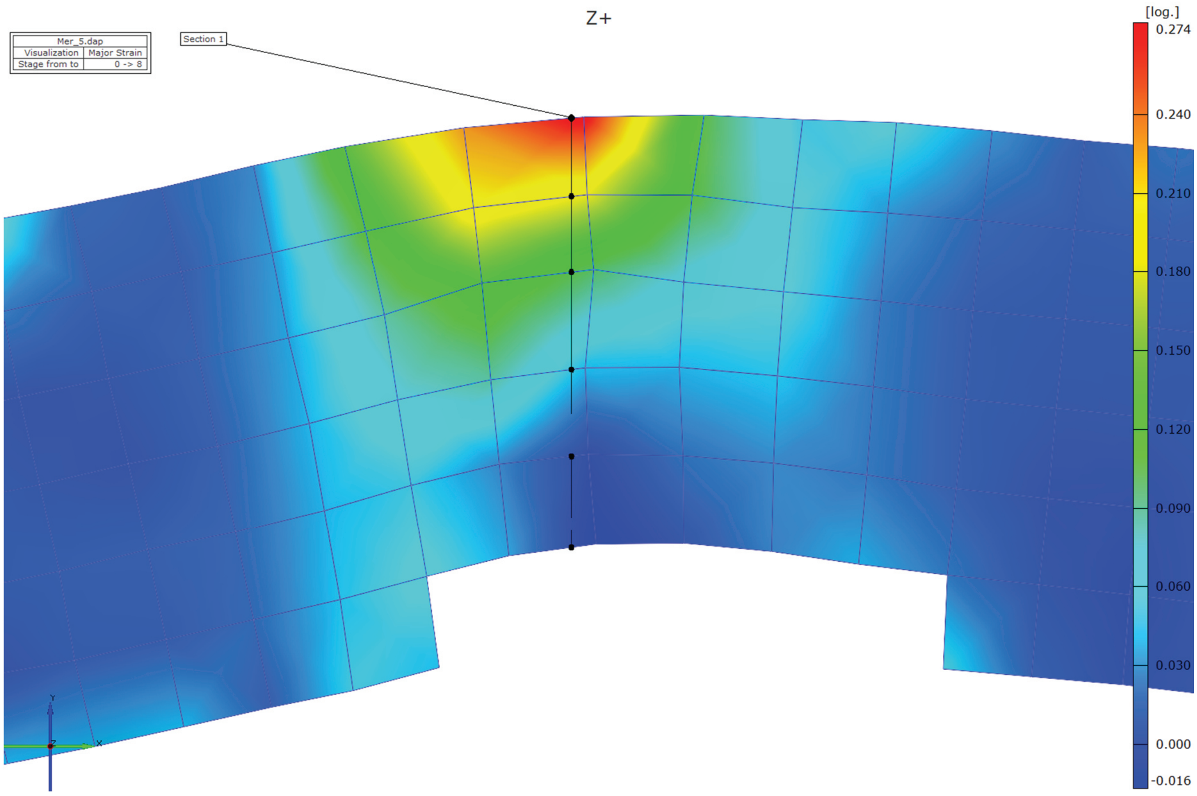

Figure 6 Detail of the true strain ε_T (1) distribution in the stage right before the fracture - t_8 = 0.000533 s

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

The strain rate *s* (s^{-1}) can be mathematically expressed by the equation (2) as a ratio of the true strain and time. With using the equation (1) for computation the true strain can be equation (2) modified in such manner as it is shown below the paragraph. Knowledge of the strain rate magnitude is very important especially e.g. at the crash tests (thus at high impact velocities). In this experiment was its magnitude computed right from the true strain ε_T (1) distribution. Time step between the stages was Δt = 0.0000667 s.

$$d\varepsilon_T = \frac{dL}{L} \tag{1}$$

$$s = \frac{d\varepsilon_T}{dt} = \frac{\frac{dL}{L}}{dt} = \frac{dL}{dt} \cdot \frac{1}{L} = v_L \cdot \frac{1}{L} = \frac{v_L}{L} \quad \left(s^{-1}\right) \tag{2}$$

where:	L	- actual length	(mm),
	t	- time	(s),
	v_L	- loading rate	(mm·s^{-1}),
	ε	- true strain	(1),
	s	- strain rate	(s^{-1}).

Equation (2) is commonly used in the conventional (intend as non-optical) testing of materials under the high strain rates [3]. As a crucial factor there is magnitude of measured length (the lower length, the higher strain rate). On the contrary, at the optical contact-less deformation measurement it´s possible to know the strain rate s on the whole sample surface that is thus not so limited. This distribution is shown in detail in **Figure 7**.

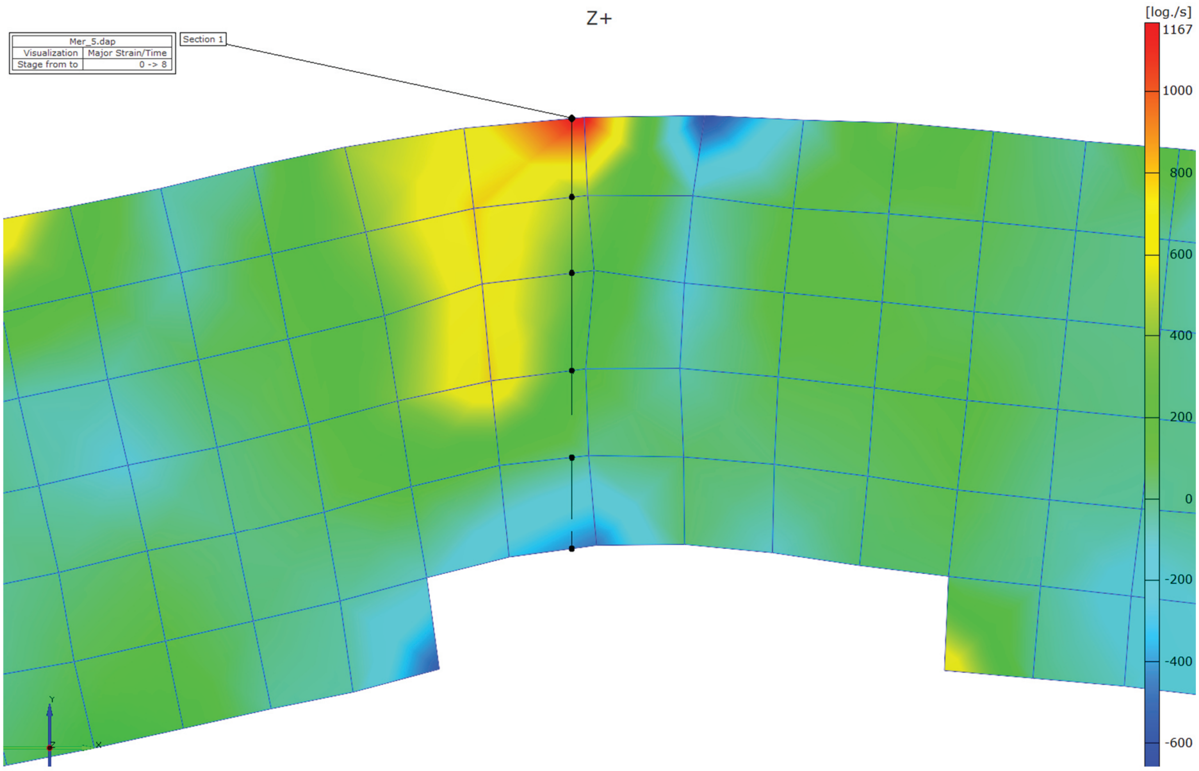

Figure 7 Detail of the strain rate s (s^{-1}) distribution in the stage right before the fracture - t_8 = 0.000533 s

3. CONCLUSION

There were two main aims of this paper. The first aim was to design the proper and functional testing jig for measurement the impact test in the drop tower. Such part was described in the chapter 2.1. Based on the results summarized in this paper is important to add one more cross-brace to improve the stiffness of the testing jig. The second aim was to apply deformation contact-less optical measurement for this test. That is why there were used the HS cameras and system ARAMIS. The results of the first sample are summarized in the chapters 2.2 (true strain ε_T distribution) and 2.3 (strain rate s distribution) and are shown in **Figure 8**. Totally there were measured 3 samples. The magnitude of the maximal true strain ε_T were 0.274, 0.253 and 0.263 and for strain rate s: 1167 s^{-1}, 1032 s^{-1} and 1121 s^{-1}. These values are interesting but the main effort was to verify applicability of such measurement. That was proved, even it is very time consuming and sensitive (mainly in light of used time step) measurement. Nevertheless it offers important knowledge about deformation behavior under high strain rates. As a next step there is presumption to used system PONTOS to scan just points in light of their kinematics values (displacement, velocity and acceleration).

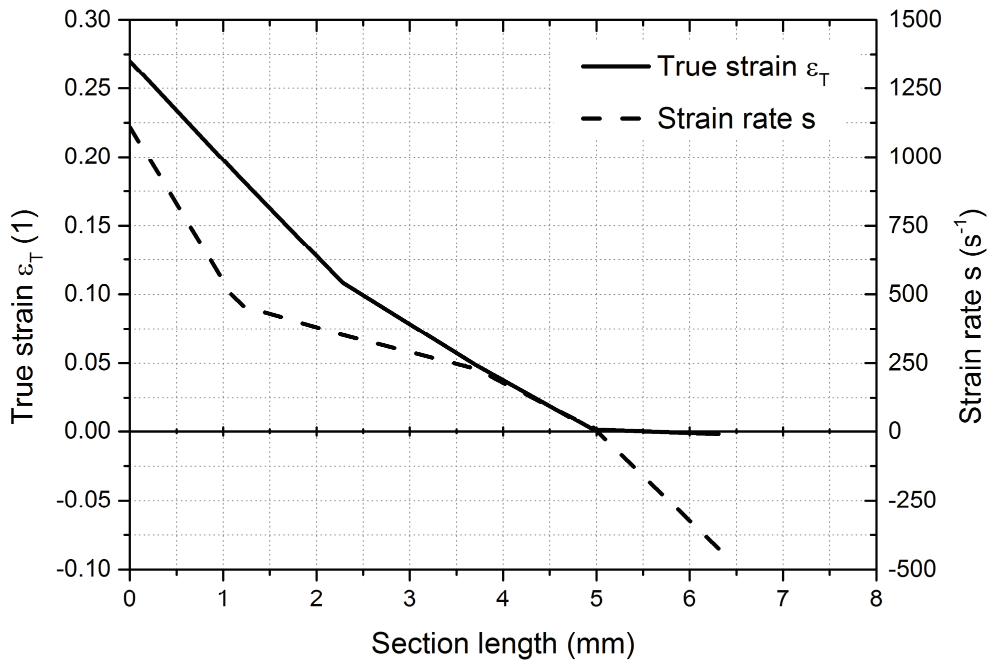

Figure 8 True strain ε_T (1) and strain rate s (s^{-1}) distribution along the section 0 (used in the previous figures) in the stage right before the fracture - t_8 = 0.000533 s

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