DYNAMIC TENSILE AND MICRO-TENSILE TESTING USING DIC METHOD

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Abstract

Dynamic tensile testing of structural materials is becoming more and more important due to the need to obtain relevant data for components design mostly with the use of FEM in many industries such as automotive and power industries. The difference of the material behaviour under dynamic loading and quasi-static loading is that the dynamic strength or yield stress usually increases as the strain-rate increases. There is often a lack of experimental material or local properties of material are required. In many cases standard samples are too big and thus miniature samples based techniques have to be applied. The newly developed Micro-Tensile test technique (M-TT) is employed in this paper. M-TT specimen dimensions are based on Small Punch Test (SPT) sample volume of 8 mm in diameter and 0.5 mm in thickness. The following M-TT samples dimensions are usually used: thickness of 0.5 mm, width of 1.5 mm and parallel length of 3 mm. For precise strain measurement at high strain rate a high speed camera was used and the obtained record was evaluated by the ARAMIS system using the Digital Image Correlation method (DIC).

The dynamic M-TTs were compared with dynamic tensile tests performed on standard samples and the results are presented here.

Keywords: Tensile test, Micro-Tensile Test, high strain rates, digital image correlation (DIC)

1. INTRODUCTION

In order to obtain reliable FEM simulation results the provided input material data have to include not only the behaviour of the investigated material under standard quasi-static testing conditions, but also under service loading conditions. The input data are usually obtained with the use of standard quasi-static tensile tests. However, the new applications need also dynamic material properties that can be achieved thanks to significant improvements of new testing equipment possibilities and evaluation procedures providing deeper insight into behaviour description.

Materials testing at high strain rates is important especially for materials that are used in applications where impact damage is probable, such as in pressure vessels, vehicles etc. At the moment, high strain rate testing is not widely standardized; however, several documents with recommended procedures exist even for sheet tensile testing (one of them is for example [1], but a number of others can be found).

In the current study the tensile specimens used for dynamic testing were standard flat specimens made from a sheet with width of 10 mm and parallel length of 20 mm. In addition, a new testing technique using miniature specimens called Micro-Tensile test (M-TT) was used and its usability was verified. The geometry of the M-TT specimen is based on the SPT geometry and enables for example to measure local mechanical properties of heterogeneous materials or current mechanical properties of experimental material sampling non-invasively from the component in operation.

2. DYNAMIC TENSILE TEST

The tensile tests in this paper were carried out at room temperature at different loading velocities resulting in initial strain rates ranging from 0.0015 s^{-1} to 375 s^{-1}. The servo-hydraulic system MTS BIONIX (see **Fig. 1** left) was used for tests up to 1000 $mm \cdot s^{-1}$ loading velocity and the impact tester IM30T (3 m high Drop Weight Tower - DWT, see **Fig. 1** centre) where tests with impact velocity from 1000 to 7500 $mm \cdot s^{-1}$ were performed.

Due to a short parallel length (2.7 mm) of M-TT specimens, strain rates from 0.0015 s^{-1} to 375 s^{-1} can be reached on the servo-hydraulic system MTS BIONIX.

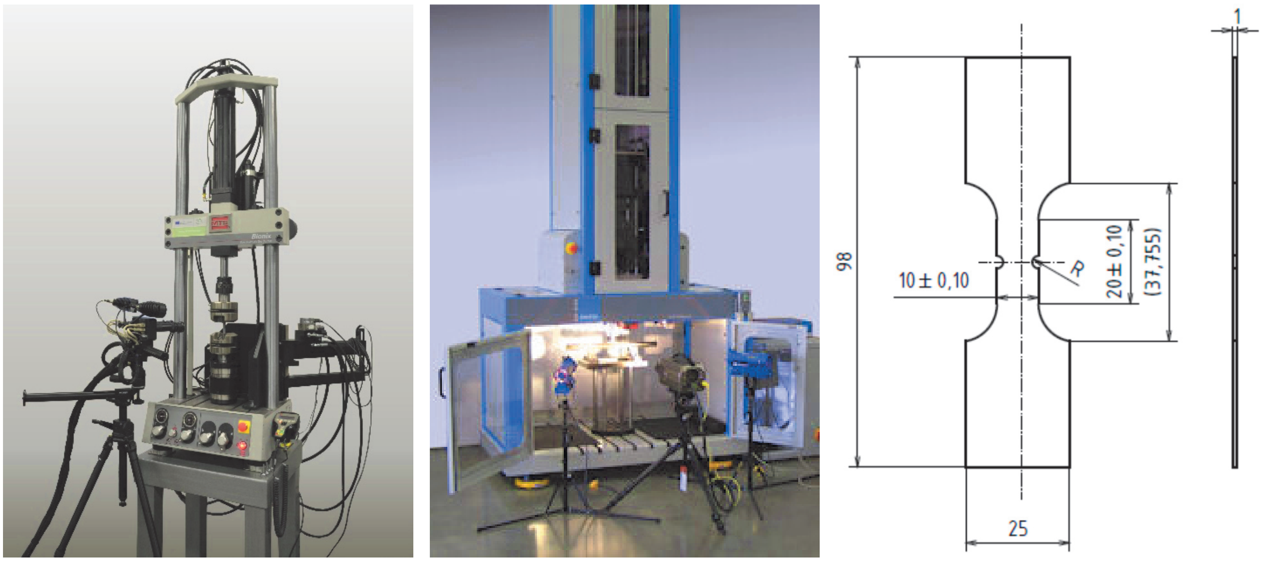

Fig. 1 Left) system MTS BIONIX, centre) impact tester IM30T, right) geometry of sheet specimen

2.1 Experimental material and specimens geometry

Two different non-ferrous metals were used. The first one was the aluminium alloy 6005, which is general purpose extrusion alloy, suitable for structural products where medium strength properties are required. Typical application fields are ladders, train- and truck building, marine constructions, off shore applications, etc.

The second one was zirconium sheet. In the work [2] high strain rate sensitivity was measured for zirconium specimens with notches of radii R = 5 mm, 10 mm and 15 mm (the geometry of specimens is depicted in **Fig. 1** right). In order to obtain the data for standard samples, specimens without notch (R0) were measured in the present work.

Both standard tensile test geometry specimens mentioned above and M-TT geometry specimens were used in the current study. The geometry of M-TT specimens (see **Fig. 2** left) is based on the SPT geometry. The usability of the M-TT geometry for the quasi-static tensile test was proved in previous works [3], [4], [5]. For dynamic properties measurement, the geometry was modified as follows: the width was increased to 2 mm and the thickness to 1 mm, see **Fig. 2** right.

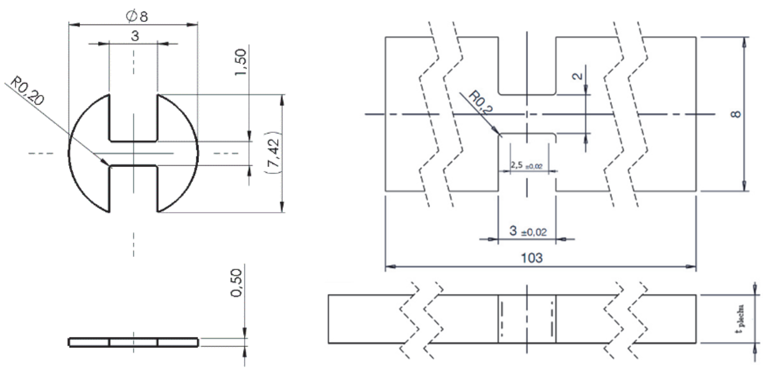

Fig. 2 Left) M-TT specimen geometry, right) modified M-TT specimen geometry for dynamic testing

2.2 Digital Image Correlation (DIC)

Traditionally used mechanical extensometers attached to the sample can successfully measure longitudinal and transversal strains; however, their use at high strain rate testing is almost impossible. Firstly, there is often insufficient amount of data acquired from the extensometer during the dynamic event, and secondly, dynamic tests could be destructive to the extensometer itself. Especially for high strain rate testing, optical methods proved to be more suitable. There are various methods of optical measurement available for strain measurement - for example laser extensometers or video-extensometers. Latest development in the field of deformation measurements are methods that calculate and evaluate deformation on the whole recorded surface of the specimen - full field deformation measurements. One of these methods is the Digital Image Correlation (DIC) method. The principle of the Digital Image Correlation (DIC) method has been known since 1970s ([6], [7] and many others). It is based on the recognition of change in the sequence of images. Stochastic pattern is applied on the surface of the specimen prior testing. The test itself is recorded by one (2D in-plane deflection measurement) or two (3D) cameras. Under the load, the specimen is deformed and so is the applied pattern. Comparing the images, changes in the pattern are registered and displacements and strains are calculated. Systems based on this method enable 3D strains measurements of either testing samples or real components.

2.3 Tensile test performance and results

Tensile tests were performed at room temperature under quasi-static and dynamic loading conditions using standard and M-TT samples. Two non-ferrous metals - aluminium and zirconium sheets - were tested. The strain measurement was performed using the DIC method based ARAMIS system [8]. Because the tests were fast (ones to tens of milliseconds), they were recorded using a high-speed camera. The recorded images were then uploaded to the evaluation software ARAMIS and calibrated (based on the initial width of samples that was measured prior to test using optical microscope). Values of UTS confirmed the rising trend with increasing loading velocity. The colour maps in **Fig. 3** and **Fig. 4** show the distribution of major strain (strain in direction of highest achieved strain) over the sample. Representative records of the tests of both investigated materials for the strain rates 0.0015, 0.66 and 375 s-1 are shown in **Fig. 5**. Records for high strain rates tested in the impact tester IM30T show big oscillations which caused difficulty in evaluation. On the other side, M-TT records obtained from the MTS BIONIX are smooth and therefore the M-TT specimens can be in many cases even more convenient for measurement of dynamic properties (in our case up to 375 s^{-1}) than standard tensile specimens. The evolution of tensile strength depending on strain rates from 0.0015 to 375 s^{-1} is depicted in **Fig. 6** and **Fig. 7**. In addition, the results obtained from zirconium sheet were compared with the results from work [2] and it was found out that the current strain rate sensitivity corresponds to the previous one. The evolution of tensile strength for notched specimens (from the work [2]) and for specimens without notch is depicted in **Fig. 8**.

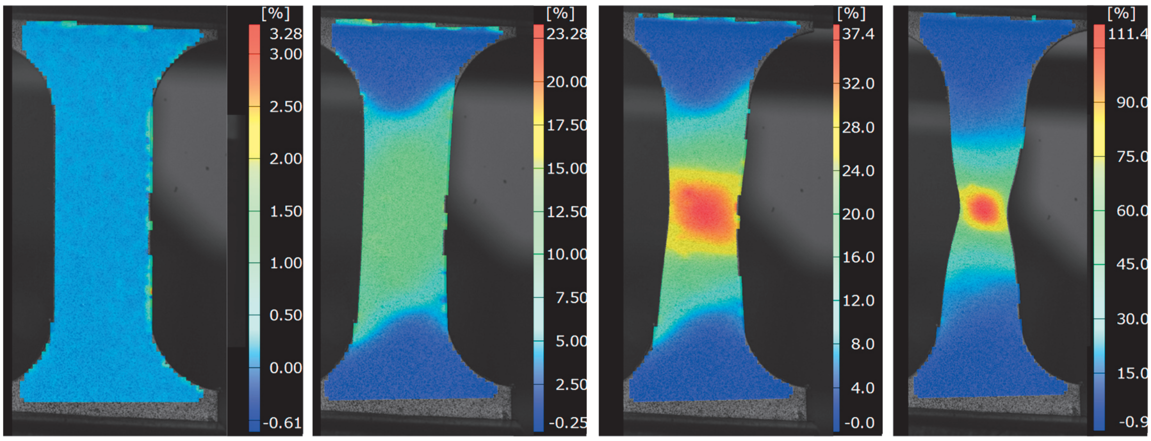

Fig. 3 Colour map of major strain of standard sample without radius

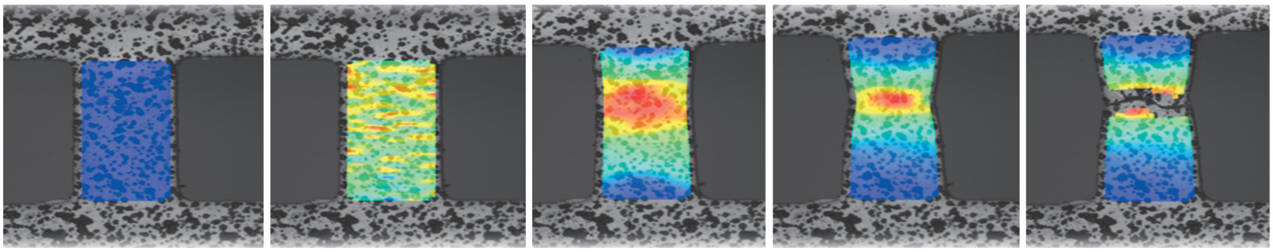

Fig. 4 Colour map of major strain of M-TT sample

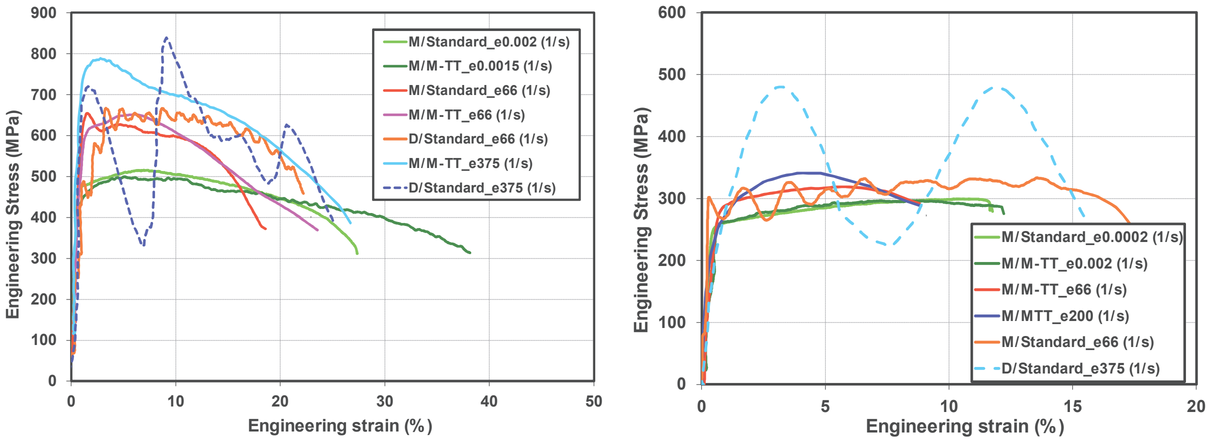

Fig. 5 Representative tensile test records, left) zirconium sheet, right) aluminium sheet

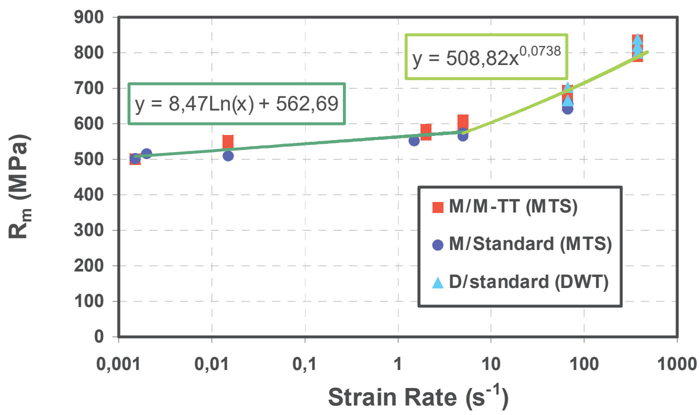

Fig. 6 UTS dependence on various strain rates; zirconium sheet

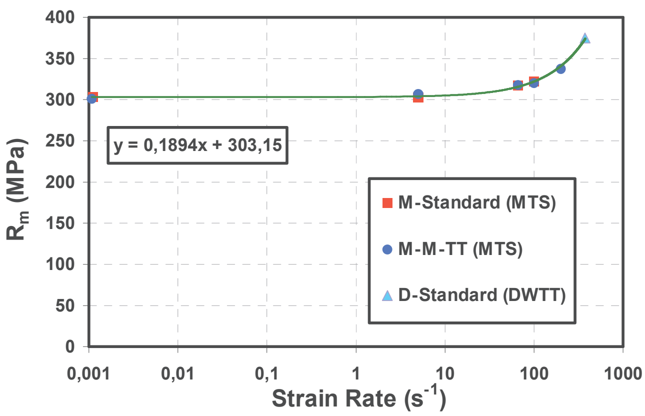

Fig. 7 UTS dependence on various strain rates; aluminium sheet

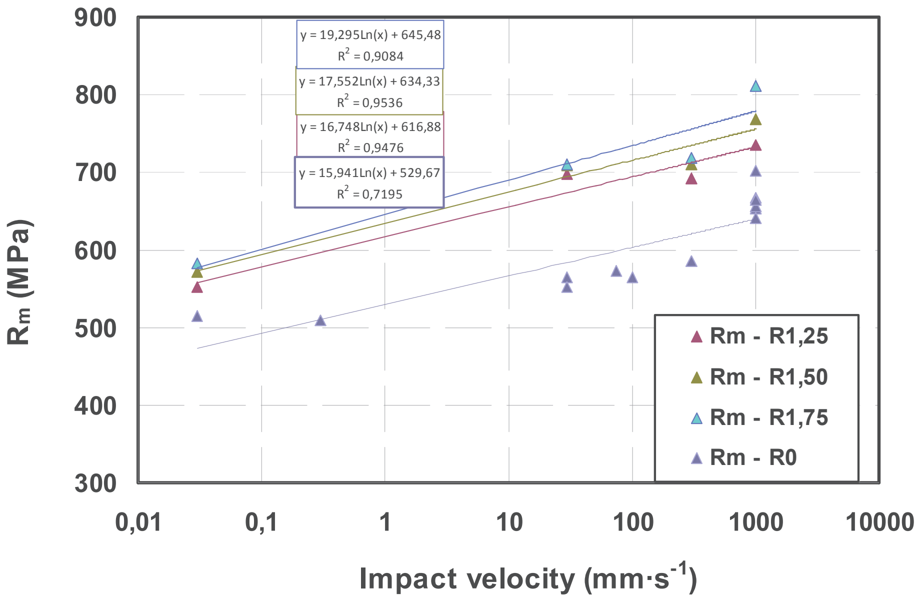

Fig. 8 UTS dependence on loading velocity, zirconium sheet;
Results of R1,25; R1,50 and R1,75 specimens were used from the work [2]

CONCLUSION

Within this work, tensile tests using standard and M-TT specimens were performed. Tests were carried out at room temperature with initial strain rates ranging from 0.0015 s^{-1} to 375 s^{-1}. The investigated material were two non-ferrous metals; aluminium and zirconium sheets. Using the standard tensile samples the strain rate up to 66 s^{-1} could be reached on the servo-hydraulic system MTS BIONIX and for a higher strain rate the impact tester IM30T had to be used. Using the M-TT samples, strain rates from 0.0015 s^{-1} to 375 s^{-1} were reached with the use of the servo-hydraulic system MTS BIONIX only. The experiment proved the usability of the M-TT for dynamic properties measurement. Optical measurement using a high-speed camera is very suitable for the tests of zirconium and aluminum sheets described in this paper. The recorded images were evaluated using the digital image correlation method resulting in a precise measurement of sample elongation. Also, as all visible surface of the sample can be evaluated by the DIC method, the map of local surface strains could be created. The combination of the DIC and high strain rate testing promises the possibility to ensure highly precise input data for computer modeling and material behavior prediction.

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