USE OF MICRO-TENSILE TESTS RESULTS FOR IMPROVEMENT OF FEM SIMULATION OF STEEL WELD

KONOPÍK Pavel[1], DŽUGAN Jan[1], URBÁNEK Miroslav[1], RUND Martin[1], PROCHÁZKA Radek[1]

[1]COMTES FHT a.s., Dobřany, Czech Republic, EU, pavel.konopik@comtesfht.cz

Abstract

The crucial role in the case of any FEM simulation play input data. There is significantly increasing demand on material data measurement for FEM simulation and on their accuracy. The paper deals with the simulation of heterogeneous weld bending determination with the use of local mechanical properties measurements using micro tensile samples. Newly developed Micro-Tensile test technique (M-TT) is employed here. M-TT specimen dimensions are: thickness of 0.5 mm, width of 1.5 mm and parallel length of 3 mm. ARAMIS system using Digital Image Correlation method (DIC) enables precise strain measurement in the course of M-TT.

In the current paper, comparison of heterogeneous weld simulation using "standard material data" such as base metal and weld metal with local material properties determined with the use of M-TT measured from the first base metal, across heat affected zone, weld to the other heat affected zone and second base metal. The simulation is compared to experimental bending of heterogeneous weld. In order to be able to perform a detailed comparison of the results obtained by the experiment and simulation, next to standard load displacement measurement in the course of tests, also local strain measurements were carried out using digital image correlation systems. A final comparison confirmed significantly better agreement of the simulation using local data measurements in both investigated fields, load-displacement record and the local strain distribution in the course of bending.

Keywords: Tensile test, Micro-Tensile Test, FEM simulation, digital image correlation (DIC), steel weld

1. INTRODUCTION

Development of FEM codes together with increasing computer performance allows more and more detailed analyses nowadays. Next to the use of appropriate codes for considered cases, accurate material behavior description becomes crucial in order to simulate real component, structure behavior or technological process [1]. Most of technical parts are hardly to be considered as continuum with uniform properties over whole body component in all directions. Moreover, there are often present many welds in real structures and the FEM simulations should take into account also local material properties that have to be determined with appropriate methods. The inputs for FEM simulations of mechanical loadings calculations are stress-strain curves at appropriate loading rates and temperatures.

There is available hardness measurement for a long time for local properties measurement [2]. However, the resulting values of standard hardness methods do not provide sufficient information. Thus instrumented methods of hardness are being developed [3], but even this method does not provide all required information and thus alternative methods for local properties measurements are being developed such as Small Punch Test (SPT) [4] or presented Micro-Tensile Test (M-TT). SPT is widely used, but its application is traditionally bound with necessity of known correlation parameters valid for a specific material only and thus it is impossible to use it on a blind material [5]. Recently, there are assumptions to used trained neural networks for SPT evaluation [6], but again neural networks can be trained for some material group, but they are not generally valid. Thus, attempt was made to establish method using similar material volume for the experimental sample as in the case of SPT while avoiding of correlations or some inverse FEM simulations in order to obtain searched stress strain curves. Standard method for stress strain curves determination is tensile test and thus M-TT method was developed [7-9], that is free of any correlation or recalculation and standard evaluation formulas can be applied. M-TT performance is shown here in comparison to standard tensile test results and subsequently it is applied to evaluation of mechanical properties change across heterogeneous weld and stress-strain curves are obtained for different strain rates. Application of M-TT results to FEM simulation is demonstrated on three point bending of welded beam. FEM simulation is performed with the use of base metals and weld metal material properties as well as with local properties measured by M-TT. Results of both simulations are compared and significantly better agreement with real experiment of FEM simulation using local properties is shown.

2. EXPERIMENTAL MATERIAL

The investigated material was experimental heterogeneous weld consisting of two chromium-molybdenum heat-resistant steels and weld metal. This type of weld is widely used in the oil and gas industries and in fossil fuel and nuclear power plants. Weld macro is depicted in **Figure 1**. The investigation is performed across all weld zones: Basic material 1 (BM-1), Heat effected zone 1 (HAZ 1), Weld metal (WM), Heat effected zone 2 (HAZ 2) and Basic material 2 (BM-2).

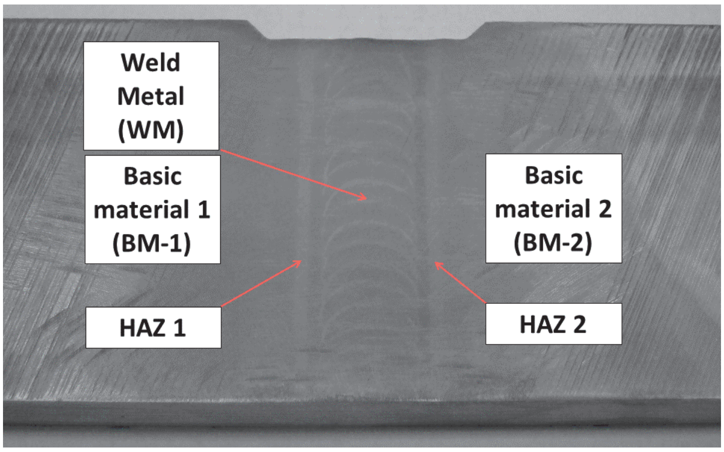

Figure 1 Macro of the investigated heterogeneous weld

3. HARDNESS AND MICRO-TENSILE TESTS

A standard Vickers hardness testing method was used to measure the hardness distribution in perpendicular direction to the weld line. The measurement was performed with the use of automatic hardness tester Durascan at room temperature. The applied load was 9.81N. There was a 1 mm distance between each sampling location.

At the same locations where hardness tests were performed, samples for M-TT were extracted. The M-TT method was firstly verified by comparison with standard tensile tests for the BM1 and BM2, where it was possible to machine standard size samples. The strain measurement for M-TT was carried out with the use of digital image correlation (DIC) system ARAMIS. The principle of the DIC method has been known since 1970s [9]. The system tracks the grey value patterns in images recorded during the test. Images are compared to each other to detect the displacement of a selected point [10]. As a single point is too difficult to find, an area of several points, in ARAMIS called facets, is tracked instead. Each facet has a unique distribution of grey levels (i.e. light and dark pixels of varied light intensity). Based on assumption that grey level of each facet does not change during the test, individual facets are located in reference images and all following images. Strains and other quantities can be calculated from changed position of tracked facet displacements Example of the specimen geometry for M-TT tests is shown in the **Figure 2a** and the testing set up with ARAMIS system is shown in the **Figure 2b**. An example of the strain measurement in the course of the tests is depicted in **Figure 3**.

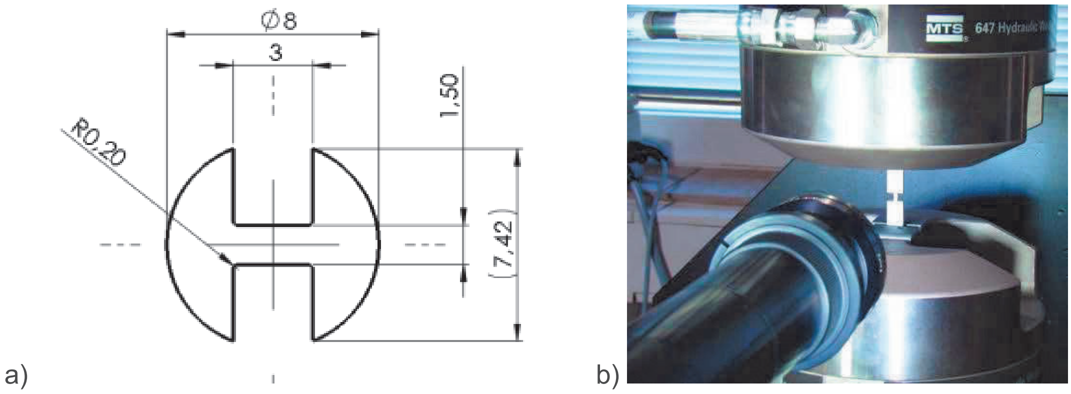

Figure 2 a) M-TT specimen geometry, b) Testing set up for M-TT tests with ARAMIS system

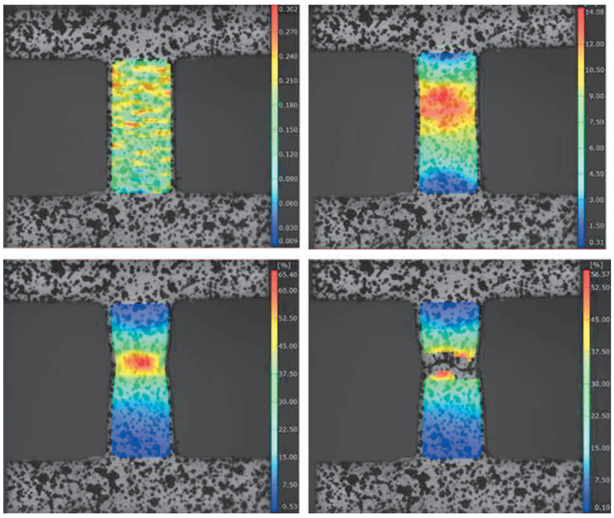

Figure 3 Example of strain measurement at different stages of tensile test for M-TT

Stress-strain curves obtained from the M-TT were compared with those ones obtained from the standard tensile tests. Records from both tensile test modifications are almost identical up to the tensile strength, as can be seen in **Figure 4**. The evaluated material properties are summarized in **Table 1**. The difference between standard tensile tests and M-TT is within 5%.

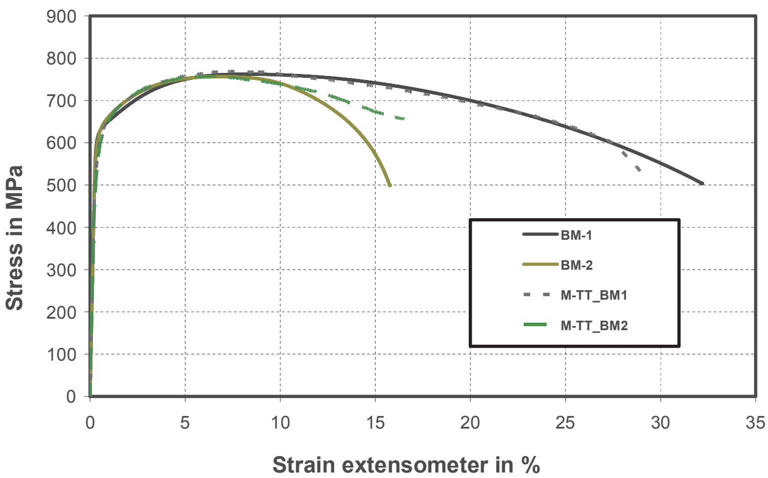

Figure 4 Comparison of standard tensile test records with M-TT records

Table 1 Summarized properties od evaluated material

Specimen	Tensile test	Tensile tests results				
		$R_{p0,2}$	R_m	A_g	A	Z
		[MPa]	[MPa]	[%]	[%]	[%]
BM-1	Standard	622.1	762.3	8.0	20.7	63.9
	M-TT	592.3	762.9	7.0	21.7	62.8
BM-2	Standard	623.1	756.5	6.4	19.2	64.3
	M-TT	594.7	758.6	5.6	18.3	66.3

Subsequently, the M-TTs for mechanical properties change assessment across the weld were performed perpendicularly to the weld line at room temperature under quasi-static loading conditions. Resulting mechanical properties variation across the investigated weld is shown in **Figure 5**.

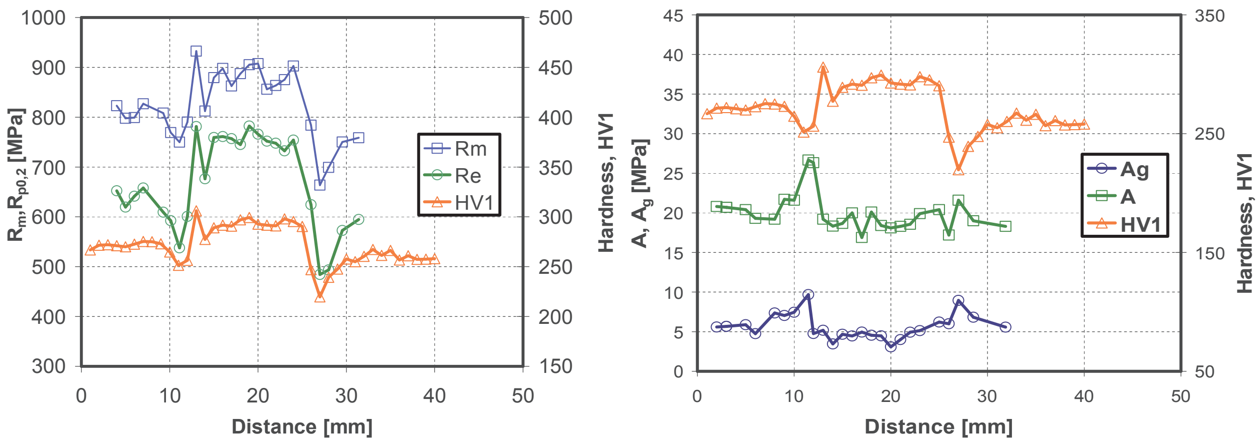

Figure 5 Mechanical properties assessment across the heterogeneous weld

4. FEM SIMULATION OF WELD BENDING

Demonstration of the advantage of local properties measurement for accurate simulation is done with the use of comparison of the experiment and FEM simulation of the experiment. Experiment is carried out on rectangular bar made of the same weld joint as investigated in the previous parts. The bar is of width 20 mm and height of 10 mm with length of 200 mm with weld in the middle part.

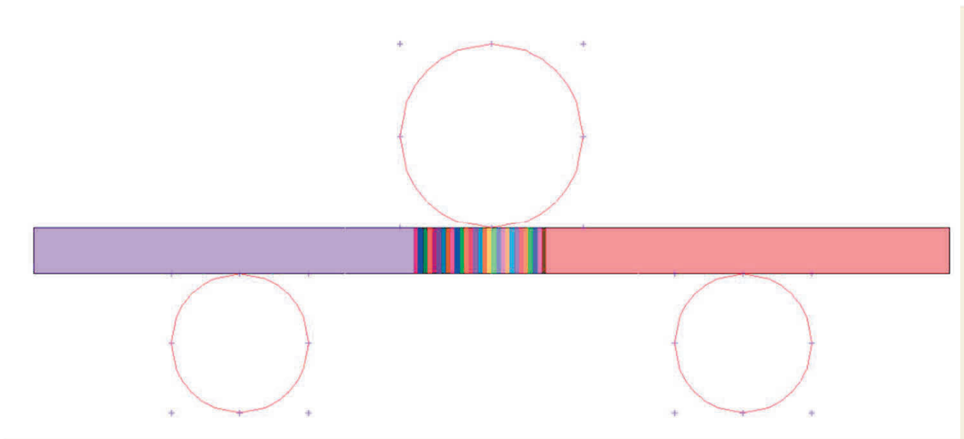

Figure 6 FEM model with local properties simulation

FEM simulation of the heterogeneous weld joint bending was carried out using two sets of material data: global material properties and local material properties. In the case of global material properties consideration, mechanical properties of the base metal 1 and 2 and weld metal were used. In the case of local properties utilization, region of heat affected zones and weld metal were divided into region of width of 1 mm and for each of this segment local mechanical properties obtained from M-TT tests were assigned. Model for this calculation is shown in **Figure 7**. The results of simulation for both approaches are compared with the experimental results, **Figures 8, 9**. Comparison of the three point bend sample response to load for both simulated case and experimental measurements are compared in **Figure 10**. Excellent agreement is found between simulation with local properties consideration and experimental measurements.

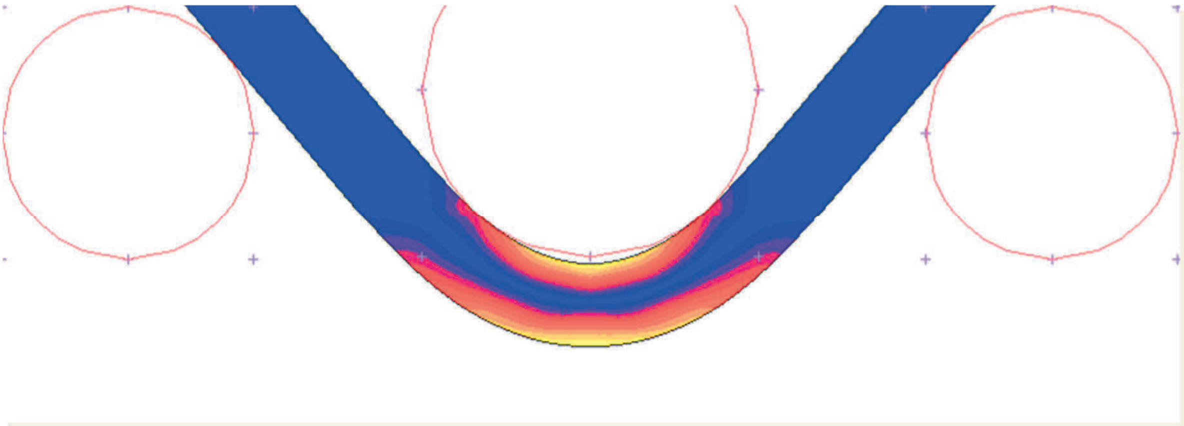

Figure 7 Strains calculation based on global material properties

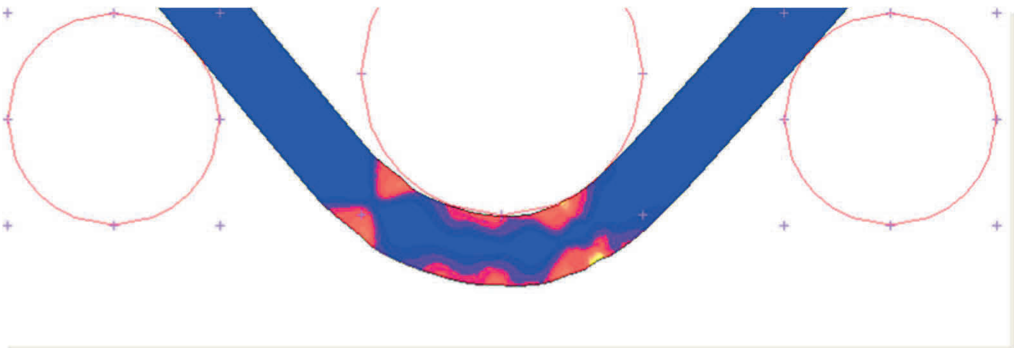

Figure 8 Strains calculation based on local material properties obtained with the M-TT

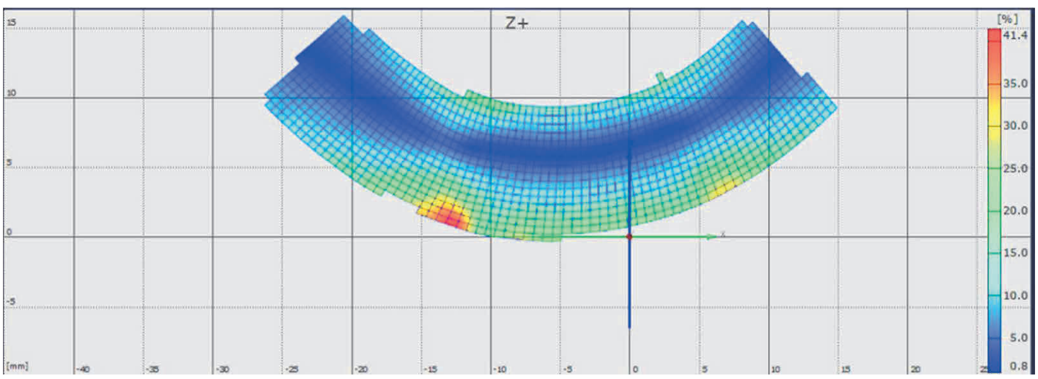

Figure 9 Experimentally measured strains

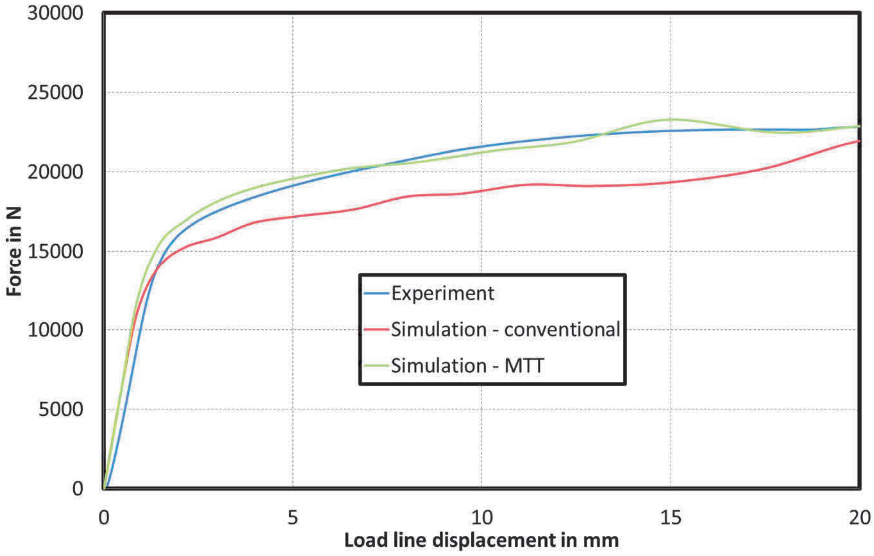

Figure 10 Comparison of records obtained during experimental measurement and simulation using local data from the M-TT and simulation using global material properties

5. CONCLUSION

The paper is dealing with the FEM simulation of heterogeneous weld bending with the use of local mechanical properties measurements by micro tensile tests method (M-TT). Local properties of weld were measured in more than 40 regions across base metals, heat affected zones and weld metal. Strain rate sensitivity of the materials investigated was also evaluated with the use of M-TT for several regions. These data were subsequently used as an input data for FEM simulation of three point bed test of veld joint.

Two simulations were performed. The first one, using “standard” approach based on global material properties for each of the base metals, and weld. The second simulation was using local properties measured by M-TT across whole weld joint. The results of both simulations were subsequently compared with the results obtained from the experimental tests. Simulation using local material properties exhibited significantly better agreement with the experimental results than in the case of the use of global material properties. Thus local properties are essential for an accurate FEM simulation results for any kind of heterogeneous materials investigation.

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REFERENCES

[1] ZEMKO, M., HODEK, J., KRAUS, L., DLOUHY, J. FEM modelling of continuous extrusion of high-strength metals using commercial conform machine. *Advanced Science Letters*, 2013, vol. 19, no. 3, pp. 701-704.

[2] ISO 6507-1:2005. Metallic materials - Vickers hardness test - Part 1: Test method

[3] HAGGAG, F.M. *In Situ Measurement of Mechanical Properties Using Novel Automated Ball Indentation System, Small specimen Test Technique Applied to Nuclear Reactor Pressure Vessel Thermal Annealing and Plant Life Extension*. 1st ed. Philadelphia: ASTM STP 1204, 1993, pp. 27-39.

[4] Small punch test method for metallic materials, Part B: A code of practice for small punch testing for tensile and fracture behaviour, CWA 15627.

[5] DZUGAN, J., KONOPIK, P., RUND, M., et al. Determination of local tensile and fatigue properties with the use of sub-sized specimens. In *ASME Pressure Vessels and Piping Conference 2015*, vol. 1A, 2015. WOS:000380290800066

[6] ABENDROTH, M; KUNA, M. Determination of deformation and failure properties of ductile materials by means of the small punch test and neural networks. *Computational Materials Science*, 2003, vol. 28, pp. 633-644.

[7] BRYNK, T., MOLAK, R.M., PAKIELA, Z., KURZYDLOWSKI, K.J. Mini-samples technique in tensile and fracture toughness tests of nano-structured materials. *Materials Challenges and Testing for Supply of Energy and Resources*, 2012, pp 221-234.

[8] KONOPIK, P., DZUGAN, J., RUND, M. Dynamic Tensile and Micro-Tensile Testing Using DIC Method, In *Metal 2014: 23rd International Conference on Metallurgy and materials.* Ostrava: TANGER, 2014, pp. 235-240.

[9] KEATING, T.J., WOLF, P.R., SCARPACE, F.L. An Improved Method of Digital Image Correlation. *Photogrammetric Engineering and Remote Sensing*, 1975, vol. 41, no. 8, pp. 993-1002.

[10] SUTTON, M.A., ORTEU, J.-J., SCHREIER, H. W. *Image Correlation for Shape, Motion and Deformation Measurements. 1st ed.* New York: Springer Science+Bussines Media, 2009. 296 p.