RESEARCH OF TRIP STEEL MECHANICAL PROPERTIES UNDER CONDITIONS OF PLANE SHEAR STRESS

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Abstract

These days is still increasing emphasis put on making the production process of sheet metal stampings, which are used in the automotive, aerospace or power industries, more accurate and fast. These aspects need to be proportionately respected with respect to the economic side of these components production and in light of still increasing environmental requirements. This paper deals with the research of tested ultra-high strength steel mechanical properties under conditions of planar simple shear test (ASTM B831). The research of these properties is applied for ultra-high strength TRIP steel HCT690T EN 10346. In the experimental part was carried out plane shear tests to determine the basic mechanical properties and deformation characteristics of tested material. In the future research, measured data will serve as additional input material characteristics for numerical simulations, which can contribute to increase accuracy of computation for the given forming process.

Keywords: Ultra high strength steel, mechanical properties, planar simple shear test, photogrammetry

1. INTRODUCTION

These days, (ultra) high-strength steels belong among the most interested materials in the automotive industry - not only for their high strength, but also for their relatively favourable processing properties, which depend on the given type of steel. These materials can be applied for the production of various car-body components, reinforcements or e.g. deformation zones. Moreover, tendency to use these materials rests mainly in the ecological aspects – reduction of CO_2 production, thus to reduce the specific weight of cars.

In order to correctly define and stabilize the production process of given components, numerical simulation is nowadays the integral part of preparation phase for the whole process. With the help of numerical simulation, it is possible to simulate the production process of relevant part and thus to obtain both stress and strain analysis of such production process. For the correct running of these numerical simulations, it is necessary to describe and define in detail the individual material properties and characteristics, which are determined by the material testing. To more accurately description of material deformation behaviour during numerical simulation, it is necessary to apply the advanced material computational models. These material models run on the basis of input material characteristics, which must be implemented into the environment of numerical simulations. However, the material basic mechanical properties aren´t enough here, but it´s needed to supplement the data arising from other types of material testing. As one of these additional tests, there is planar shear test, by which can be determined the stress-strain curve of tested material under shear stress. The following chapters describe and evaluate the planar shear test of TRIP steel HCT690T EN 10346.

2. EXPERIMENTAL PART - PLANAR SHEAR TEST

Shear test is a material test, where is applied the shear stress on the tested material. Such material test is performed as a simple shear stress test according to the American standard ASTM B831 (ASTM, 2005). This test is used for simulation of shear stress condition in one shear zone of formed material to determine the mechanical properties of material under shear stress. As a result of this test there is a stress-strain curve of tested material and consequently the resulting mechanical properties of material at shear stress [1-3].

This is a planar shear test, where the sample is clamped in the jaws of testing device and by means of the jaws translational movement is required shear stress state created right in the center of sample – i.e. in the area of so-called bridge due to the sample geometry (see **Figure 1**). The initial dimensions of tested sample were as following: initial measured length in the bridge L_0 = 4.72 mm and thickness t_0 = 1.14 mm [1,2].

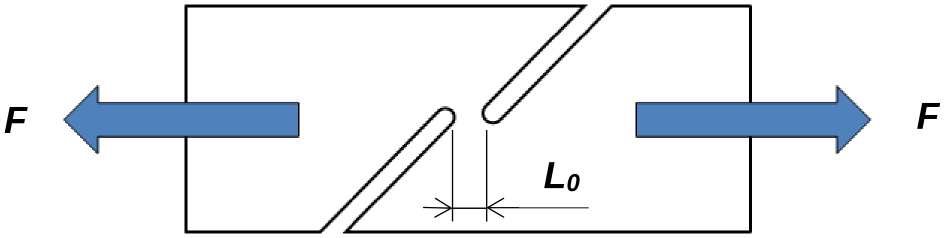


Figure 1 Loading scheme of sample at planar shear test

To perform the shear test, samples of the given initial dimensions and required geometry were prepared by the laser cutting machine (see **Figure 2**). Individual samples were cut out in the directions 0°, 45° and 90° with respect to the rolling direction of the base material - rolled metal sheet. Own shear test was performed at the testing device TIRAtest 2300, where the sample was clamped in its jaws and loaded by the uniaxial tensile stress state. The force was recorded by the strain gauge head integrated in the testing device, the longitudinal displacement and relevant strains were measured by the optical device from Sobriety company.

Figure 2 Laser cutting of sample for the shear test (left) and final geometry of the sample for planar shear test (right)

In order to be able to detect the displacement and deformation of the material by an optical device, it was necessary to provide the samples for shear test with a special pattern, by which software creates a deformation network of so-called facets. The displacement of these individual facets is then identified by the evaluation software at each point during the test performance. Based upon the displacement of these facets, it is then possible to evaluate the deformation of the material in the area of shear stress. The realization of the shear test on the testing device TIRAtest 2300 can be seen in **Figure 3** (left) and scanning of the sample using the optical system MERCURY RT is shown in **Figure 3** (right). In the upper part is shown area for computation (blue colour) and there is also shown initial distance between two points (magenta colour), which was subsequently used as change of length ∆L.

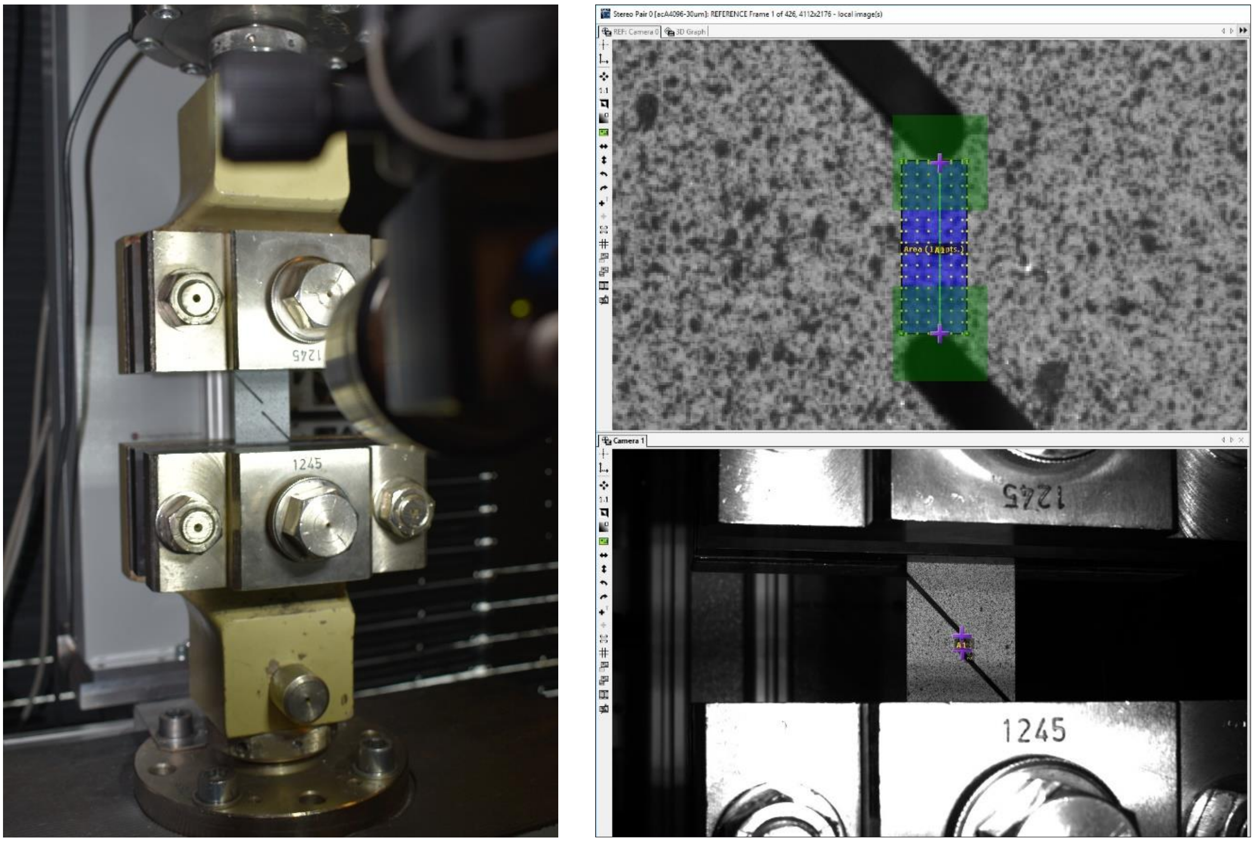


Figure 3 Realization of the planar shear test (left)
and scanning of sample by means of the contact-less optical system MERCURY RT (right)

Using the planar shear test, force vs. displacement of the test sample at the area of planar shear zone was determined. This dependence was further recalculated to the dependence of effective stress σ_i and effective strain φ_i according to the Von Mises yield criterion, which is done by Equation 1.

$$\varphi_i = \sqrt{\frac{2}{3}(\varphi_1^2 + \varphi_2^2 + \varphi_3^2)} \tag{1}$$

where:

φ_i- effective strain (1),

$\varphi_1, \varphi_2, \varphi_3$- relevant major strains (1).

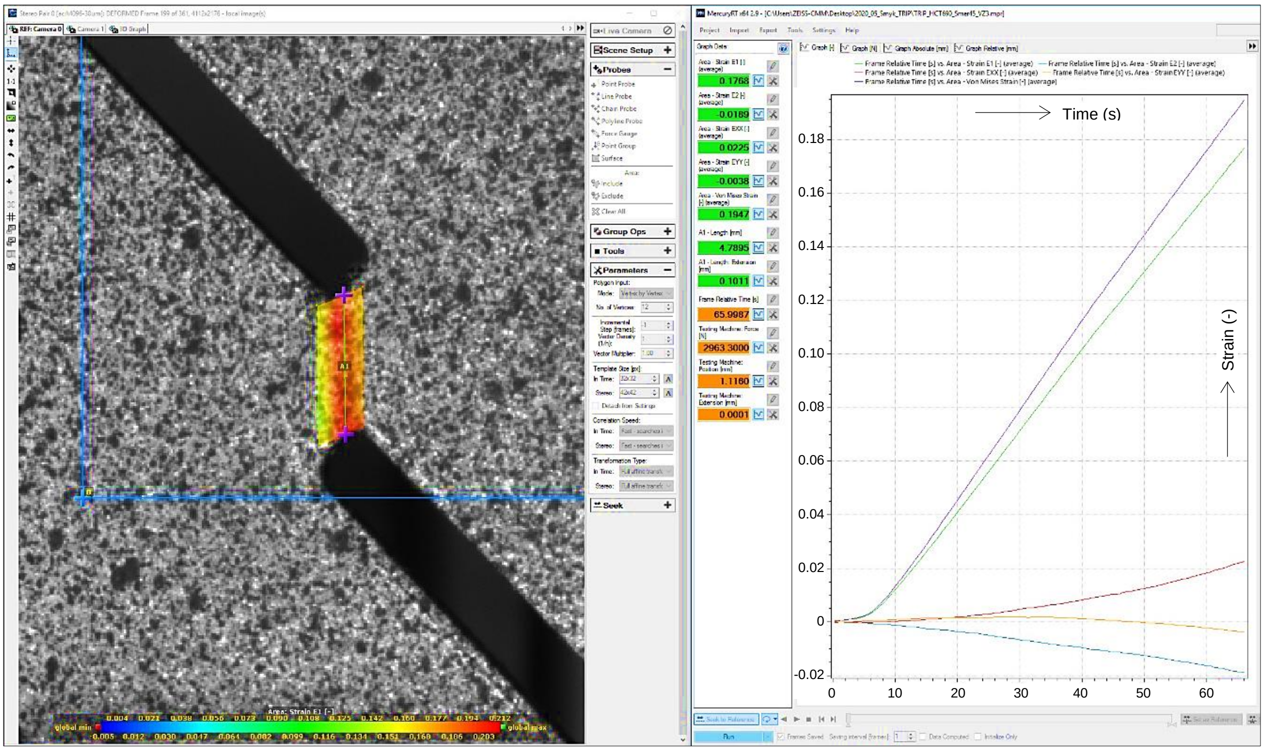
In order to mathematically define this resulting dependence of effective stress and strain values into the environment of numerical simulations, relevant stress-strain curve was subsequently replaced according to the Krupkovsky power law approximation that is expressed by Equation 2 [4].

$$\sigma = \mathrm{K}(\varepsilon_{\mathrm{pl}} + \varepsilon_0)^n \tag{2}$$

where:
σ - true stress (MPa), K - strength coefficient (MPa), n - strain hardening exponent, ε_{pl} - plastic true strain and ε_0 - offset of strain.

3. RESULTS

In this paper was deformation analyzed with the help of photogrammetry - i.e. contact-less deformation measurement by software MERCURY RT. Own deformation was evaluated by the Von Mises yield criterion directly in the same software. The subsequent complete evaluation of stress-strain curves and final dependences was done is software Origin 2020. In **Figure 4** course of the plain shear test in the environment of Mercury RT is illustrated. In the left part scanned area is shown, where deformation occurs. Individual colors represent relevant magnitude of strain acc. to scale. In the right part own course of deformation during the plain shear test in dependence on time is by graph illustrated. The determined values of mechanical properties at planar shear stress are then presented in **Table 1**.



MercuryRT x64 2.9 - [C:\Users\ZEISS-CMM\Desktop\2020_05_Smyk_TRIP\TRIP_HCT690_Smer45_VZ3.mpr]

Frame Relative Time [s] vs. Area - Strain E1 [-] (average)
Frame Relative Time [s] vs. Area - Strain E2 [-] (average)
Frame Relative Time [s] vs. Area - Strain EXX [-] (average)
Frame Relative Time [s] vs. Area - Strain EYY [-] (average)
Frame Relative Time [s] vs. Area - Von Mises Strain [-] (average)

Graph Data
Area - Strain E1 [-] (average): 0.1768
Area - Strain E2 [-] (average): -0.0189
Area - Strain EXX [-] (average): 0.0225
Area - Strain EYY [-] (average): -0.0038
Area - Von Mises Strain [-] (average): 0.1947
A1 - Length [mm]: 4.7895
A1 - Length: Extension [mm]: 0.1011
Frame Relative Time [s]: 65.9987
Testing Machine: Force [N]: 2963.3000
Testing Machine: Position [mm]: 1.1160
Testing Machine: Extension [mm]: 0.0001

Figure 4 Von Mises strain distribution at planar shear test in the environment of software MERCURY RT (major strain E1 - green curve; minor strain E2 - blue curve, strain in the X direction EXX - red curve; strain in the Y direction EYY - brown curve; Von Mises strain – magenta curve)

Table 1 Mechanical properties of TRIP steel HCT690T under shear stress

Rolling direction (°)	$R_{p0,2}$ (MPa)	R_m (MPa)	C (MPa)	n (1)	φ_0 (1)
0	159.72	294.51	392.467	0.1867	0.0028
45	151.22	268.49	362.486	0.1769	0.0013
90	163.02	282.27	355.695	0.1392	0.0008

Determined dependences of effective stress vs. effective strain during the planar shear test at individual directions 0°, 45° and 90° regarding the rolling directions are graphically shown in **Figure 5** (left). In addition to that, in **Figure 5** (right) is given an example of computation Krupkovsky approximation to determine relevant approximation constants ***C***, ***n*** and $\boldsymbol{\varphi_0}$.

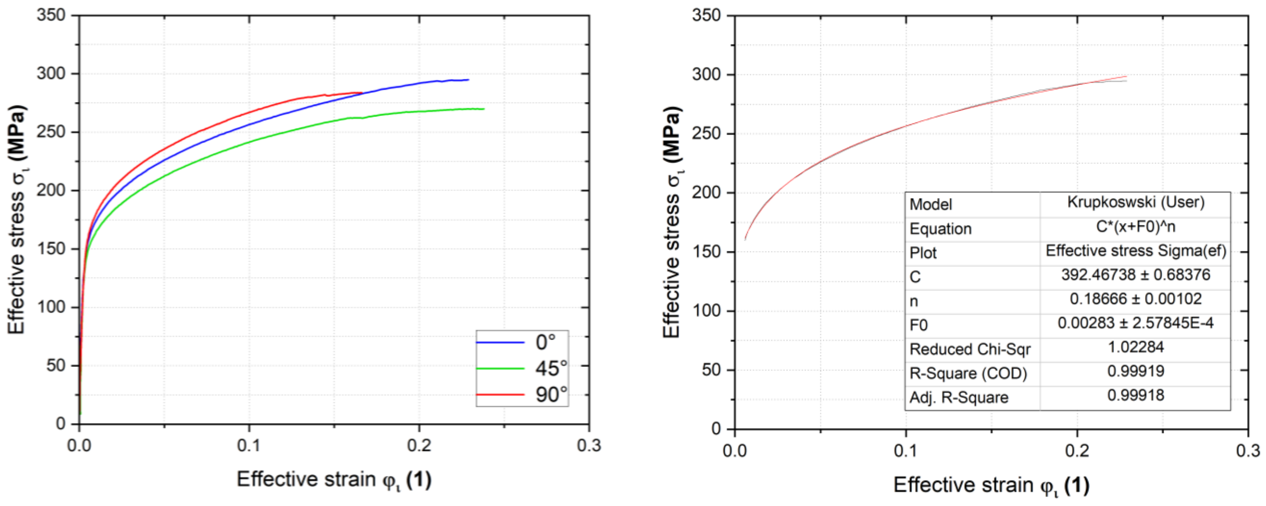


Figure 5 Effective stress σi (MPa) vs. effective strain φi (1) in the relevant directions (left) and example of approximation according to Krupkovsky (right)

4. CONCLUSION

In the previous chapter are summarized measured results and determined mechanical properties of material under planar shear stress. Graphs then show the stress-strain curves in the relevant directions as dependences of effective stress and strain during shear test, as well as an approximation of these dependences according to Krupkovsky.

The implication of this article rests in the utilization of experimental research results, which will further serve as additional input data and material characteristics to define the material computational model in the numerical simulation of sheet metal forming process. These additional data can increase not only the accuracy of the deformation process computation, but subsequently also the material spring-back at bending. Based on these facts, it is also possible to perform the so-called compensation and thus to guarantee the most accurate results of numerical simulations in the production process.

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REFERENCES

[1] YIN, Q., et al. An experimental and numerical investigation of different shear test configurations for sheet metal characterization. *International Journal of Solids and Structures*. 2014, vol. 51, no. 5, pp. 1066-1074.

[2] DENTI, L. Additive Manufactured A357.0 Samples using the laser powder bed fusion technique: Shear and tensile performance. *Metals* 2018, vol. 670, no. 8(9), pp. 1-15.

[3] WEI, L. *Identification of strain rate dependent hardening sensitivity of metallic sheets under in-plane biaxial loading*. Mechanical engineering. INSA de Rennes, 2015. Wuhan University of Technology, 2015.

[4] HOSFORD, W.F., CADDEL, R. *Metal Forming (Mechanics and Metallurgy)*. New York: Cambridge University Press, 2007.