CHARACTERIZATION OF STEEL SHEET PROPERTIES USING MICRO-TENSILE TEST AND DIC METHOD

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Abstract

Many parts for automobiles and home electric appliances are made of steel sheets. In sheet metal forming processes, the knowledge of technological values, such as yield or tensile strength and r-value, enables a more precise control of processes and results in many benefits such as an improvement in yield efficiency in machining processes and a decrease in loss of material. The current paper shows the possibility of the determination of all considered properties with the use of the Micro-Tensile Test (M-TT) technique. Previously developed and verified testing procedure of M-TTs for bulk materials is applied here for DC01 steel sheet characterization. To assess the applicability of M-TT for sheet characterization, standard and M-TT tests were performed in 3 orientations: 0°, 45° and 90°. Moreover, for thickness influence evaluation, micro-specimens were machined with several different thicknesses.

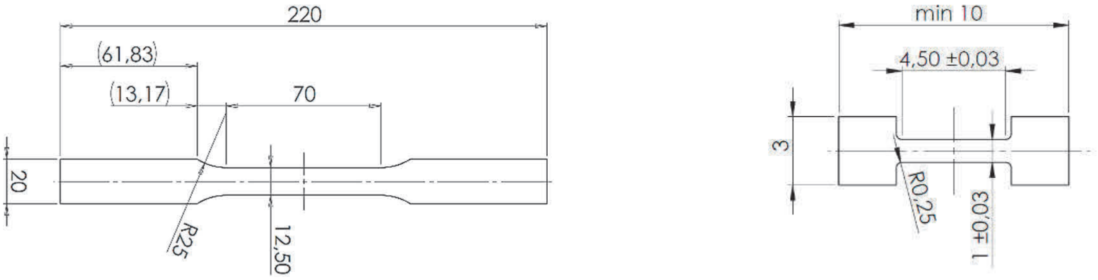
Keywords: Micro-Tensile Test, Digital Image Correlation (DIC), anisotropy, r-value

1. INTRODUCTION

Sheet-metal forming processes are technologically among the most important metalworking processes. Products made by sheet-forming processes include a very large variety of geometrical shapes and sizes, from simple bend to double curvatures even with deep recesses and very complex shapes [1]. Typical examples are automobile bodies, aircraft panels, appliance bodies, kitchen utensils and beverage cans. Sheet-metal forming processes are widely used in the manufacturing industry. To achieve a successful deep drawing process, a study of the stress-strain and anisotropy behavior of the sheet metal to be used is inevitable. The basic and necessary test for sheet material characterization is the quasi-static tensile test with the determination of the plastic strain ratio known as r-value. This test is very well established for the standard specimen size and standards cover both testing procedures [2] and evaluation [3]. However, in many cases, it is not possible to produce standard sized tensile specimens (evaluation of anisotropy of thin-walled tubes) or knowledge of local properties is required (FEM models verification). Such an FEM model can be verified e.g. by the evaluation of local ductility of sheet in the processed component and the results can be confronted with the FEM model prediction for the same location. A number of techniques have been developed to obtain mechanical properties from sub-sized specimens [4-7]. These include specimens that are either miniaturized versions of their full-scale counterparts or specifically designed disc specimens of small dimensions. One of the most used methods is the Small Punch Test (SPT). The SPT is widely used, but its application is traditionally bound with the necessity to know correlation parameters which, furthermore, are not valid generally but for a specific material only [8]. Therefore, previously developed testing procedure of the Micro-Tensile Test (M-TT) is suggested here for anisotropy evaluation. The advantages of the M-TT are very low requirements on the experimental material volume and the possibility of local properties determination, even from real components (with subsequent life time evaluation of the components). The performance of micro-tensile tests (M-TT) for bulk materials characterization has been successfully shown in [9-13] and the corresponding elongation calculation for shorter gauge length than is required according to [2] was suggested in [14]. In this paper, the M-TT application for tensile technological value and r-value determination of sheets is investigated. During the sampling from components with very complex shapes, the M-TT specimen can be expected to obtain lower thickness than is initially used in sheet. Therefore, the M-TT was machined to achieve different thicknesses for indicating thickness effects on tensile results including r-value.

2. EXPERIMENT - TENSILE TEST

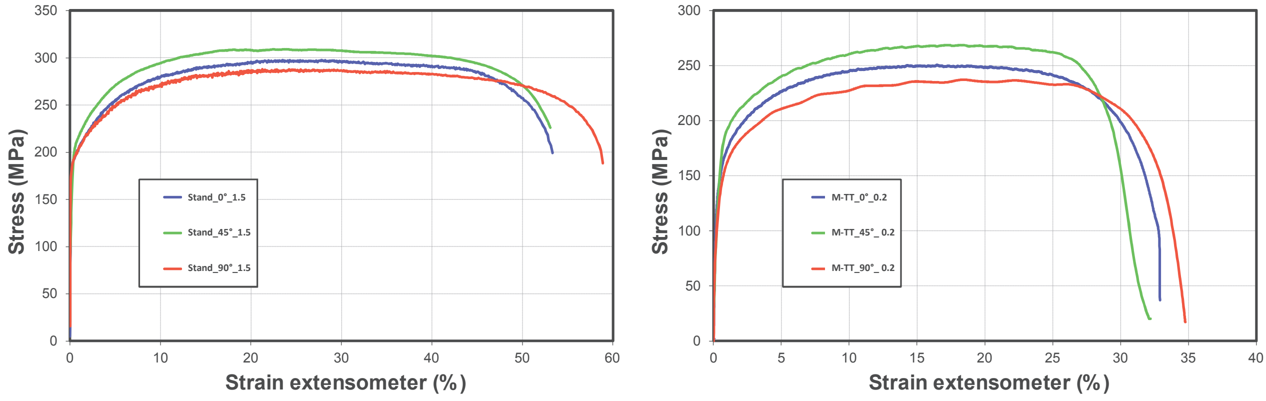
Tensile tests were performed on flat samples made of DC01steel sheet according to standards [2,3]. The original sheet thickness was 1.5 mm. Standard size specimens with a thickness of 1.5 mm and the geometry according to **Figure 1a** were milled as a stock of 10 specimens. M-TT specimens, with the geometry according to **Figure 1b** and thicknesses of 0.2 mm and 0.5 mm, were machined from the middle part of the sheet by spark eroding of the specimen silhouette and grinding to the final thickness. M-TTs specimens with a thickness 1.5 mm were not grinded at all.



(**a**) (**b**)

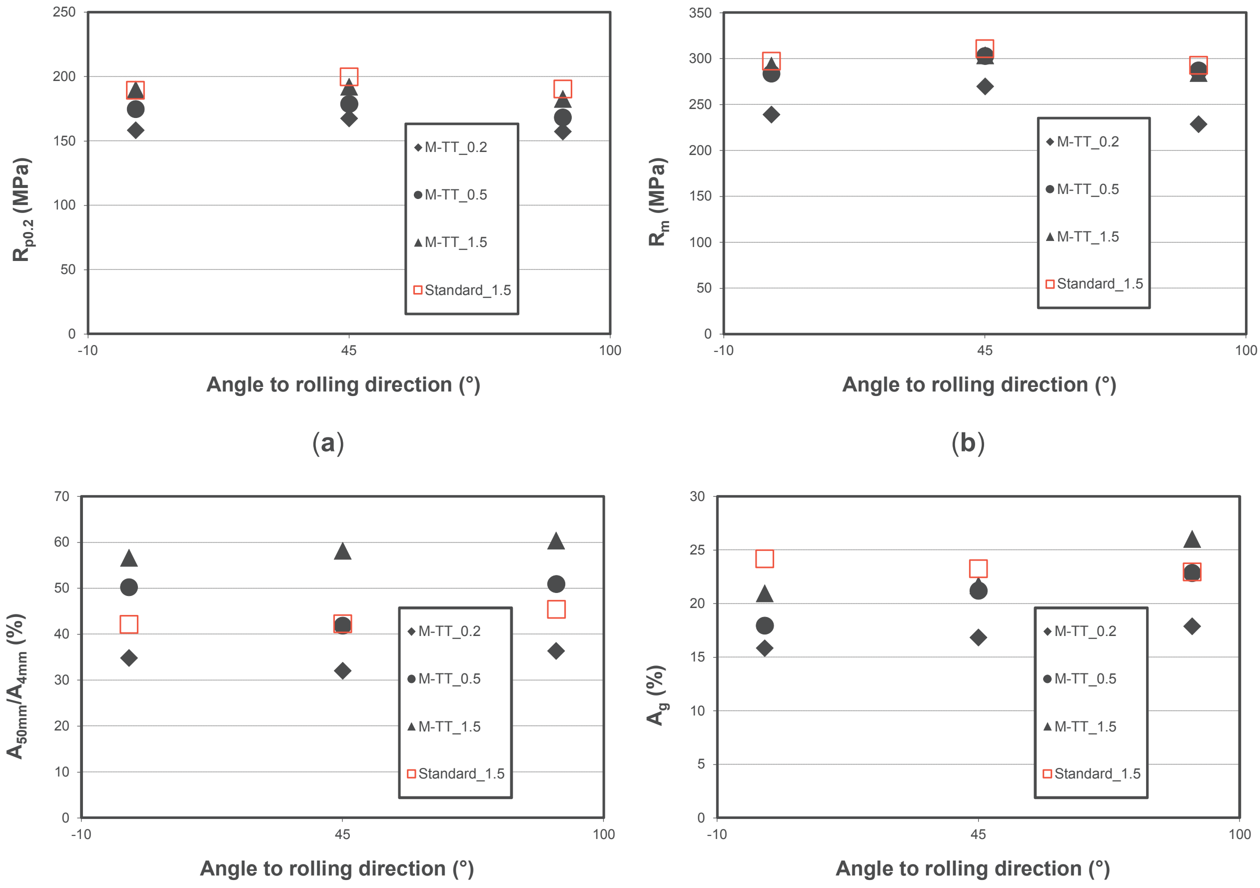
Figure 1 Tensile test specimen geometry: (a) Standard geometry; (b) M-TT geometry

Standard specimen orientations were considered for both specimen geometries: longitudinal direction 0°, diagonal direction 45° and transverse direction 90°, related to the rolling direction. Testing was carried out with the use of the MTS servo-hydraulic testing system with the capacity of 25 kN for standard sized specimens. M-TT specimens were tested on a small size testing system with a linear drive with the load capacity of 5 kN. All tests were executed at room temperature and the strain measurement was achieved with the use of a Mercury RT Digital Image Correlation system (DIC). Three specimens per condition were tested for all considered cases. Quasi-static tensile tests were carried out for both specimen geometries and all sampling directions for comparison of the results obtained from standard size and M-TT specimens. On the basis of these tests, r-value was subsequently evaluated. Specimen designation consists of specimen geometry (Standard or M-TT), specimen orientation and the specimen thickness in mm. Representative tensile curves obtained for standard specimens and M-TT with thickness of 0.2 mm are shown in **Figure 2**. Evaluated tensile properties are graphically depicted in **Figure 3**.



(**a**) (**b**)

Figure 2 Tensile test record: (a) Standard geometry; (b) M-TT geometry, thickness 0.2 mm



(a) (b)

(c) (d)

Figure 3 Tensile test results: (a) $R_{p0.2}$ - proof strength; (b) R_m - tensile strength; (c) A_{50mm}/A_{4mm} - percentage elongation after fracture of Standard/M-TT specimen; (d) A_g - percentage plastic extension at maximum force

3. PLASTIC STRAIN RATIO

Plastic strain ratio known as r-value is one of the key parameters in the metal sheet forming [15-19]. R-value is defined as ratio of true plastic thickness strain to true plastic width strain according to Eq. (1).

$$r = \frac{\varepsilon_b}{\varepsilon_a} \tag{1}$$

The measurement for the plastic strain ratio de-termination was done with the use of continuous strain measurement by DIC system ARAMIS and automatic method describe in [3] can be used.

The plastic strain ratio was determined from the measured data with the use of equation 2:

$$r = \frac{-m_r}{1+m_r} \tag{2}$$

Where m_r is determined from the linear regression fit between the lower limit (2 %plastic strain) and the upper limit (5 % plastic strain) through the origin (see **Figure 4**; X- True plastic length strain; Y- True plastic width strain; 1 - lower limit; 2 - upper limit; 3 - origin; 4 - linear regression between the lower limit and upper limit through the origin). Longitudinal (ε_l) and transverse (ε_b) true plastic strains are calculated according to equations (3) and (4).

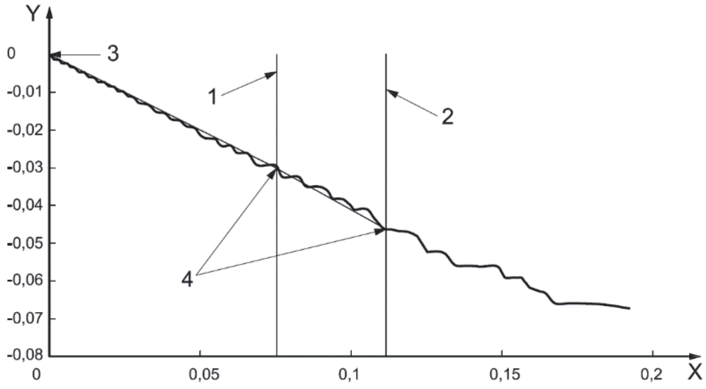


Figure 3 Relationship between true plastic width strain and true plastic length strain [3]

$$\varepsilon_l = ln\left[\frac{L_e - \Delta L}{L_e} - \frac{F}{S_0 . m_E}\right] \tag{3}$$

$$\varepsilon_b = ln\left[\frac{b_0 - \Delta b + \frac{b_0 . \upsilon . F}{S_0 . m_E}}{b_0}\right] \tag{4}$$

where:

L_e	Extensometer gauge length (mm)
b_0	Original gauge width (mm)
ΔL	Instantaneous elongation/ extension of the measurement base (mm)
Δb	Instantaneous width elongation (mm)
F	Force (N)
S_0	Original cross-section area (mm^2)
υ	Poisson constant (-)
m_E	Young modulus (MPa)

Table 1 Tensile test results including r-values

Specimen	$R_{p0.2}$ (MPa)	R_m (MPa)	A_g %	A_{50mm} / A_{4mm} %	Z %	r_{2-5} ---
M-TT_0°_0.2	158.4	238.8	15.8	34.8	58.4	2.03
M-TT_0°_0.5	174.6	283.7	17.9	50.2	78.2	2.06
M-TT_0°_1.5	189.7	292.	20.9	56.6	81.6	2.04
Stand_0°_1.5	189.3	297.2	24.2	42.1	65.7	2.15
M-TT_45°_0.2	167.5	269.7	16.8	32.0	51.8	1.20
M-TT_45°_0.5	178.6	302.8	212	41.9	72.6	1.21
M-TT_45°_1.5	192.	303.5	21.7	58.2	85.6	1.20
Stand_45°_1.5	199.8	310.8	23.2	42.3	41.8	1.19
M-TT_90°_0.2	157.1	228.	17.9	36.4	54.8	2.20
M-TT_90°_0.5	168.2	287.0	22.8	50.9	81.5	2.24
M-TT_90°_1.5	182.5	284.1	26.0	60.4	85.9	2.36
Stand_90°_1.5	190.2	292.7	23.0	45.4	66.7	2.50

4. RESULTS AND DISCUSSION

Standard technological tensile properties were determined according to [2] and r-values for the plastic strain range of 2 - 5 % were evaluated according to [3]. **Table 1** summarizes the average values from all performed tests.

Overall, the agreement ranged from acceptable results to excellent results. The biggest differences were seen in the stress-strain curves obtained from M-TT specimens with 0.2 mm in thickness, where the most significant deviation was measured in respect of $R_{p0.2}$ and R_m. This can have several causes. Firstly, machining and handling with a specimen 0.2 mm thick is challenging and surface finish could possibly have a big influence. Furthermore, the specimens were taken from the middle part of the sheet where the material can be softer than material near to the surface. On the other hand, excellent results were obtained for plastic strain ration for all tested M-TT thicknesses and all directions. Trends obtained here for this parameter are in agreement with those published in [16-20].

5. RESULTS AND DISCUSION

The paper presented here successfully shows the possibility of metal sheet characterization for forming processes with the use of miniaturized tensile specimens. Generally, very good agreement was found for all considered parameters and conditions between the results attained with the use of standard and M-TT specimens. Slight discrepancies between results from M-TT and standard size specimens can be assigned to sampling location of the M-TT specimens in the middle of the sheet thickness, where small material behavior deviation from near surface properties can be expected. Further investigations are planned to assess the influence of the M-TT specimen localization within the sheet thickness.

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