INFLUENCE OF THE FORMING METHOD/SURFACE STATE OF TEST PIECES ON THE MEASURED MECHANICAL PROPERTIES OF STEEL FOR COLD PROCESSING

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Abstract

The paper presents the influence of the forming way of test pieces on measured values of the mechanical properties of steel for plastic cold processing. During research the two-dimensional samples were analysed after forming by die shearing, milling and electrical discharging, at an angle: 0, 45 and 90 ° with reference to the rolling direction. Examinations concerned analysis of changes of surface microstructure, degree of grains deformation, evaluation of the surface state - roughness, surface development factor. The side sample surface was checked from the viewpoint of macrostructure and topography changes determined by PhaseView optical assembly for 3D surface scanning. In the elaboration the basic mechanical properties were compared, i.e. tensile strength, yield point, elongation. It was stated that the cutting method as well as the orientation of the test sample axis in relation to steel sheet rolling direction (despite annealing) influence measured steel mechanical properties.

Keywords: Steel forming, discrepancy of steel properties, correlation: forming method - steel properties

1. INTRODUCTION

The constant pressure on cars weight reduction causes, that for the production of various components of this type construction more and more modern technologies and high-quality materials are applied [1]. It is obvious that in conditions of the increasing competition, in everyday use cars cannot be applied materials commonly applied in special purpose vehicles (like titanium alloys, or high strength composites) because of very high price. From the above follows an aspiration to getting maximal and repeatable mechanical properties with reference to relatively cheap materials which includes iron carbon alloys. The car body is one of basic construction element that influences vehicle weight. Steel made extrusions (belonging to advanced high-strength steels AHSS) are still most often materials applied for its production. This steel apart from the increased structural strength also demonstrates better formability. Generally steel belonging to AHSS group can be divided into the following types: dual phase (DP), transformation induced plasticity (TRIP), complex phase (CP) and martensitic steels (MART) [2]. During the extrusions designing/production forming process simulation is very important stage. For this purpose a software based on a finite element method (FEM) is usually applied - Dyna Form, Auto Form, etc. [3]. In every software for the proper determination of the process simulation course essential is to insert the appropriate material parameters/constants - real properties of shaped material. The real properties of steel delivered for shaping are sometimes far from data included both at the specification, the material certificate, as well as the software library. It can lead to defected elements production and generates significant financial losses. With reference to the above an experimental verification of initial material intended for the production and determination real material constants is really necessary. A way of test samples shaping can also affect values of measured material properties. There are a lot metal cutting methods commonly used to cut steel: friction sawing, cold sawing, oxygen-acetylene flame cutting, plasma cutting, laser cutting, shearing, water-jet cutting, etc. [4, 5]. Flat samples are most often cut out on milling machines, electro discharge device or with the press and blanking die. All of mentioned methods can exert influence on the change of the structure and the properties of studied materials. Meanwhile EN ISO6892-1:2010 standard [6] demands that the manner of the samples preparation doesn't exert influence on material properties and recommends preparation of test samples made of materials showing the considerable strengthening as a result of the deformation by the milling, grinding, etc. In the case electrical discharge method the surface of steel is subjected to the influence of the very high temperature [7] that can result in essential changes of structure, the hardness, the state of stresses and chemical composition in the heat affected zone (HAZ). Additionally this kind of method can generate micro-cracks supporting spalling and initiation and propagation of macro-cracks. Samples cut out by cold working can next undergo surface hardening that in specific conditions can have a significant influence on measured properties. In this work an influence of the way of cutting of flat tests samples on values of mechanical properties determined with one axial tension test was being analysed.

2. EXPERIMENTAL

2.1. Strength test methodology

Investigation regarded the flat samples of steel grade S420MC with 2.5 mm thickness. S420MC steel belongs to Automotive Structural Steel widely applied for cold forming automotive parts as frames and other components. The measured properties: $YS_{0.2}$ (yield stress), TS (tensile strength), and A (elongation) was next used for proper material parameters evaluation necessary for cold forming process simulation [8, 9]. The chemical composition both according the specification and quality certificate as well as basic mechanical properties are presented in **Table 1**.

Table 1 Chemical composition and mechanical properties of examined steel

Source	**Chemical composition, % wg.**								
	C	Mn	Si	P	S	Al	Nb	V	Ti
Acc. spec.	-0.1	-0.9	-0.2	-0.02	-0.012	0.01-0.08	0.012-0.06	0.012-0.08	-0.1
Acc. cert.	0.037	0.058	0.025	0.013	0.002	0.027	0.014	0.021	0.0008

Source	**Basic mechanical properties**					
	$YS_{0.2}$, MPa	TS, MPa		A_{min}, %		HV10
	Min.	Min.	Max.	L_o=80mm	$L_o=5.65\sqrt{S_0}$	
Acc. spec.	420	480	580	17	22	150-190
Acc. cert.	461.9	522.2		22.2	not given	not given

Mechanical properties were determined by one axial tension test. Three different test sample cutting methods were compared: milling, electro discharge and blanking die. During investigation also the influence of rolling direction on mechanical properties values was evaluated. For this purpose samples were cut at an angle 0 °, 45 ° and 90 ° with reference to the rolling direction. The basic mechanical properties was measured on flat samples with gauge length of test piece L_0 = 80 mm. The sample drawing and real sample view after tension test is presented in **Figure 1**.

2.2. Microscopic observations

The mechanical properties analysis was supported by microscopic observation with application of optical microscopes: metallographic (Axiovert 100A) as well as stereoscopic. Moreover the surface state was analysed with application of ZeeScan optical system that enables roughness and waviness evaluation both in 2D as well as 3D system (isomorphic surface image).

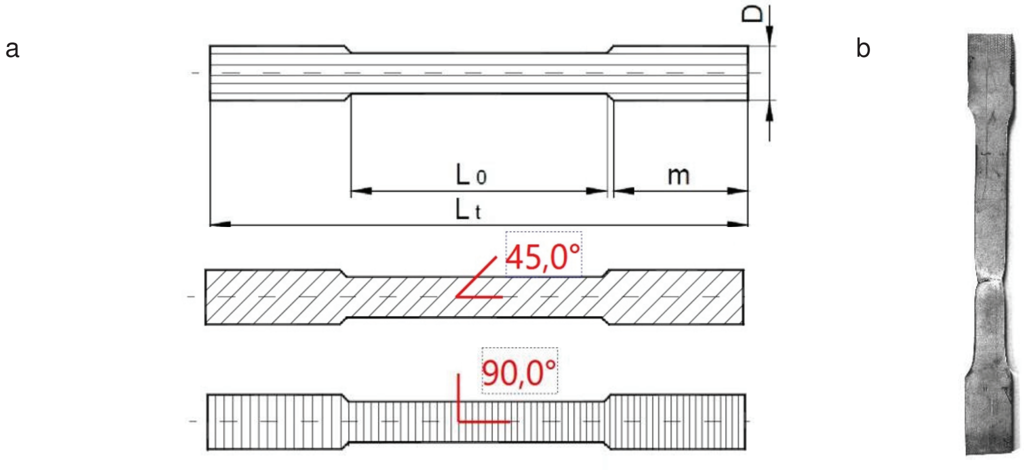

Figure 1 A test sample drawing with marked rolling lines direction - a, real sample view after the strength test

3. ANALYSIS OF RESULTS

3.1. Strength test

For every of measurements series from achieved characterizations the mean values of $YS_{0.2}$ (yield stress), TS (tensile strength), and A (elongation measured by contacting extensometer) were calculated. In **Table 2** the mean values are put together for individual method of samples cutting out. Additionally the trend of yield stress changes is presented in **Figure 2**.

Table 2 The tabulation of mechanical properties measured on investigated samples

Cutting method	Rolling angle, °	$YS_{0.2}$, MPa	TS, MPa	A, %
milling	0	459 ±8.92	522 ±4.97	20.89 ±1.25
	45	470 ±2.29	518 ±2.73	19.71 ±0.28
	90	482 ±2.58	529 ±2.81	17.58 ±0.41
electro discharge	0	458 ±6.05	519 ±6.18	20.76 ±0.99
	45	463 ±3.01	515 ±0.48	20.41 ±0.73
	90	484 ±2.40	533 ±0.57	16.67 ±1.00
blanking die	0	471 ±7.02	524 ±7.72	19.49 ±0.54
	45	488 ±1.47	529 ±0.88	17.42 ±0.81
	90	495 ±6.86	537 ±2.94	15.46 ±1.76

It results from the **Table 2** and **Figure 2**, that changing the rolling angle from 0 to 90 ° both YS and TS increase. The biggest difference was measured in case of YS for electro discharging machining and it amounts to 26 MPa (ab. 6%). Values of elongation are changing in opposite direction to YS and TS, i.e. transferring from 0 to 90 ° angle elongation (A) value decreases about max. 4% both for electro discharge and blanking die cutting methods. Generally mechanical values measured in samples cut by milling and electro discharging methods are similar. The maximal difference value reaches here 7 MPa.

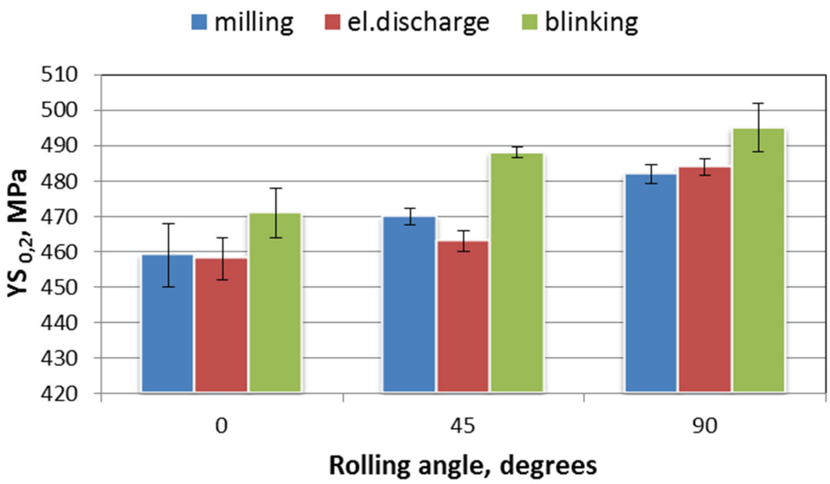

Figure 2 The trend of measured yield stress change with dependence on kind of cutting method and rolling direction angle

3.2. Microstructure analysis

Results of microscopic observation are presented in **Figure 3**. The cross section microstructure shows that in milled test samples (**Figure 3a**) there is practically no grain size differentiation. Equiaxed grains are observed sometimes very close to the outside surface. Directly on the surface traces of cooling medium are observed in the form of 3 - 4 µm thickness layer. Structure after electro-discharging machining reveals relatively thick porous layer 16 - 23 µm - **Figure 3b** situated on the surface being the product of high temperature processes. The emptiness depth reaches here even 8 µm.

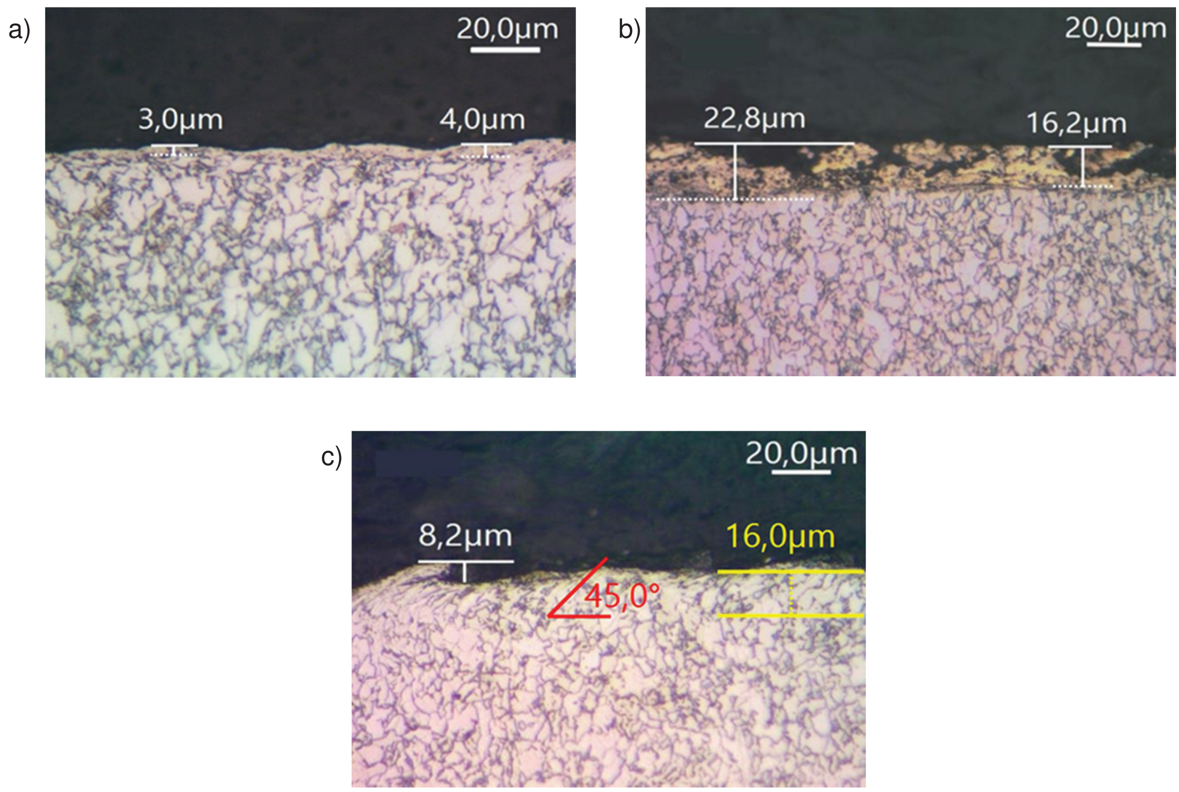

Figure 3 The surface cross section microstructure, etched with 4%HNO_3: a - shaped by milling; b - after electro discharge machining; c - after blanking die

The surface under the created scale layer is relatively smooth and grains are homogenous without any deformations. The last cutting method - blanking die creates very rough surface full of feather edges - **Figure 3c**, that height is about 8 μm. Near the surface the deformed grains oriented at an angle 45 ° to the outside surface are observed at a depth of 16 μm.

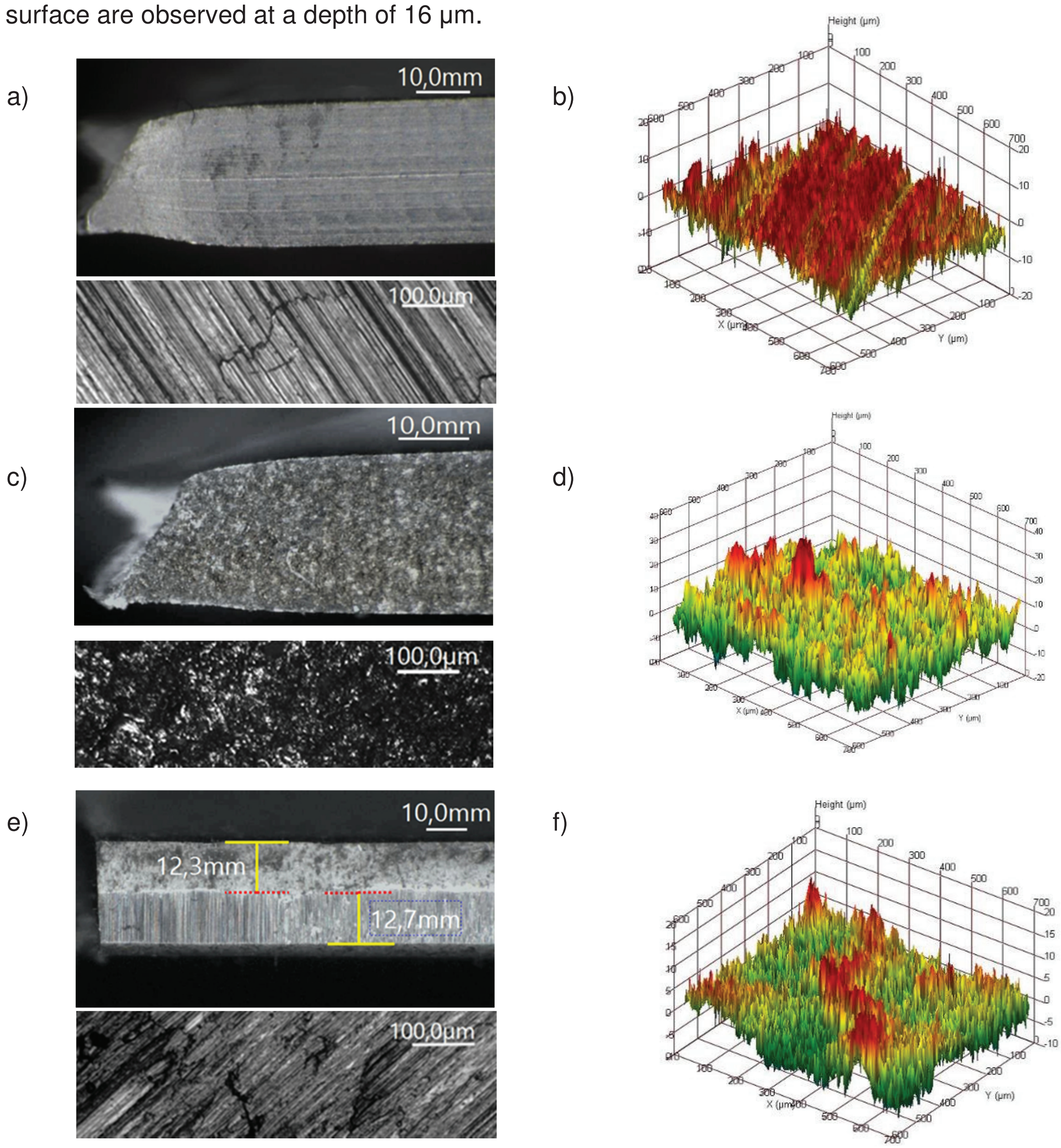

Figure 4 Macro and microstructure of investigated samples together with its topography: a, b - after milling; c, d - after electro discharge machining; e, f - after blanking die

The appearance of test samples side surface in macro and micro scale together with its isometric surface image is presented in **Figure 4**. Generally the surface roughness is very important factor. On one hand it influence on the steel drawability and friction coefficient. On the other the simply correlation is valid: the greater roughness the higher tendency to micro-cracks initiation and propagation. Supplier can deliver the steel sheet in different roughness grades. For cold rolling annealed materials it is usually: 0.4 - 1.0; 0.1 - 0.5; 0.05 - 0.1; 0.2 - 1.5 μm. According the measurement of the front test samples surface its roughness equals to 0.96 μm, i.e. steel belongs to grade smooth dull (R_a = 0.4 - 1 μm). The R_a values measured on the side wall for the individual cutting methods are as follows: milling - 2.72 μm; electro discharge machining - 4.53 μm ; blanking die - 3.44 μm. The measured R_a values very well correspond to surface structure character presented in **Figure 3**, where the most porous surface is achieved after EDM and the most smooth and flat surface is guaranteed by milling. On the side surface observed after milling - **Figure 4a**, the mechanical treatment lines/grooves are visible that near sample break area stay more dense. There is no micro-cracks and other signs of fracture brittleness. Although the side surface after electro discharge machining - **Figure 4e** is very rough and porous its inferior quality is only feigned. The metallic surface under scale layer is relatively smooth without HAZ. By contrast, the surface after blanking die is divided into two parts: first is created by cutting (with thickness up to 13 mm), the second one is broken off (- 12 mm thickness). A lot of surface irregularity and topography differentiation are observed that can support cracks initiation and propagation. So, considering the above it could be stated that the most reliable data can be achieved by milling sample shaping. Results measured with test samples cut by electro discharge machining are almost the same like in the case of milling samples. The maximal difference value reaches only 7 MPa. The highest mechanical properties - highest deviation from the values determined by two previous cutting methods were measured in the test samples shaped by blanking die with rolling angle equal to 90 °. It mainly result from surface layer hardening caused by cold working.

4. CONCLUSION

1. It is evident that the cutting method as well as the orientation of the test sample axis in relation to steel sheet rolling direction (despite annealing) influence measured steel mechanical properties.
2. The highest mechanical properties were measured in the test samples cut by blanking die method with rolling angle equal to 90 °. It mainly result from surface layer hardening caused by cold working. The difference between mechanical properties (TS, YS) measured for samples shaped by milling and blanking die method reaches correspondingly 8 and 12 MPa, i.e. 1.4 and 2.6 %.
3. Although electro discharging machining change the steel surface layer essentially - on the surface the porous and rough scale layer is created, the measured mechanical properties are almost the same like in the case of milling samples. The maximal difference value reaches 7 MPa.
4. It is clear that starting the simulation of cold sheet steel forming the necessary is to verify the mechanical properties of every delivered batch of material. Moreover the attention should be focused both test samples shaping method and rolling orientation, because the totally influence of mentioned factors can result in mechanical properties deviation at the level of 8%.

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