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A comparison of a tensile test with a planar simple shear test in sheet metals

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Abstract: *The tensile test is commonly considered as the standard test in sheet metals, although the mechanism of plastic deformation during tension is very complicated. The planar simple shear test is more suitable to determining mechanical properties of these materials. In the article, the characteristics obtained in the tensile test are compared with the same obtained in the simple shear test. The investigations were performed on ETP-cooper, CuZn37 brass and low-carbon steel sheets.*

Key words: *plasticity criteria, simple shear test, tensile test*

1. INTRODUCTION

There are two plasticity criteria that have practical application: maximum shear stress criterion (Tresca criterion) and shear strain energy (octahedral-shear stress) criterion (Huber-Mises-Hencky criterion, generally known as von Mises criterion) [1,2]. These criteria are widely used for isotropic and pressure insensitive metallic materials, with the same yield stress both in tension and in compression.

The Tresca criterion is defined as follows:

$$\max\left(\left|\sigma_1-\sigma_2\right|,\left|\sigma_2-\sigma_3\right|,\left|\sigma_3-\sigma_1\right|\right)=2\tau_o\,, \tag{1}$$

where:

σ_1, σ_2, σ_3 – principal stresses,

τ_o – limit value of shear stress equal yield stress under pure shear.

The von Mises criterion is defined:

$$J_2-\tau_o{}^2=0\,, \tag{2}$$

where:

J_2 – is the second deviatoric stress: $J_2=\frac{1}{2}s_{ij}s_{ij}$.

Commonly the value of τ_o is determined by uniaxial tension test and it is equal:

$$\text{- for Tresca: } \tau_o=\frac{\sigma_o}{2}\,, \tag{3}$$

$$\text{- for Mises: } \tau_o=\frac{\sigma_o}{\sqrt{3}}\,, \tag{4}$$

where:

σ_o – yield stress under uniaxial tension.

The value of shear stress τ_o can be evaluated in different tests. The uniaxial tensile test is preferred because of its simplicity and also that for this experiment the conditions of testing are defined by standards. The measurement of stress and strain is easy, because the principal directions of stress and strain are the same as the test directions. But in the tensile test the range of uniform deformation is low because of necking phenomenon. Mechanism of plastic deformation in tensile test is very complicated since constraints of testing machine holders have to keep the axisymmetry of the specimen.

Yield shear stress τ_0 can be determined directly in simple shear test. Using the device shown in Fig. 1a, the simple shear test can be realized without rotation of shear direction. The test device is successful in measurement of mechanical properties of sheet metals [3]. It makes possible obtaining shear characteristics directly in experiment.

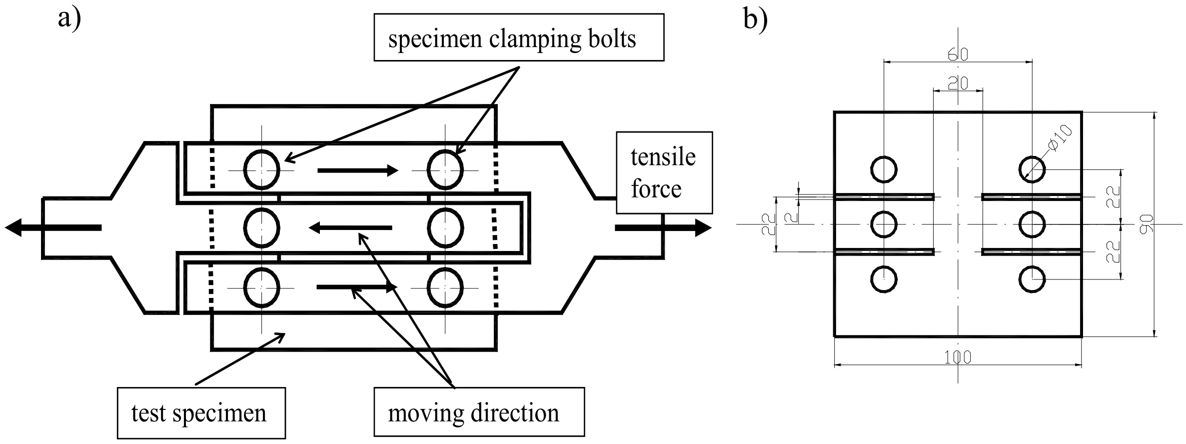

Fig.1. Structure of simple shear device and specimen set (a) and simple shear specimen geometry (b)

In most cases, actual sheet materials are not isotropic materials. Anisotropy means that in a piece of material, a number of material properties can alter in value, depending on the direction in which this property is determined. Anisotropic material behaviour plays an important role in performing material tests. The results of the tests strongly depend on the orientation of the test specimen in the sheet. The mechanical directionality of sheet materials makes it very difficult to produce the pure shear strain by the control of stress state. It may lead to some problems when measure the stress and strain in the deformation of pure shear.

2. EXPERIMENTAL PROCEDURE

The experiments were performed on two kinds of testing machines. The uniaxial tensile test was performed on mechanical testing machine. Two extensometers were used for determining r-value of sheet. The shearing test was performed on hydraulic testing machine. Control and data acquisition were performed by a computer and specially designed programs.

Three different materials were included in the study: ETP-cooper, CuZn37 brass and low-carbon steel sheets. From these materials two kinds of specimens were machined: tensile test specimens and shearing test specimens. Specimens for the tensile test had standard geometry. Specimens for the shearing test are shown in Fig.1b. Specimens were prepared for three different directions of the sheet: parallel - 0^{o}, perpendicular - 90^{o} and skew - 45^{o} to the rolling direction. The basic mechanical properties of used materials are given in Table 1. In the table, A - is total percentage elongation, $R_{0.2}$ - is the yield strength, R_m - is the ultimate tensile strength, r - is the anisotropy coefficient. For each specimen the tensile stress – effective linear strain curves were prepared. These curves were compared with that obtained in simple shear test.

The shear test was performed using the device shown in Fig.1. The relative displacement of one part of shearing device to another was measured by inductive extensometer (it isn't shown in Fig.1). The shear stress τ was determined by dividing the tensile load per sectional area in which simple shear occurs. The shear strain was determined as arc tangent of the ratio: extensometer indication per width of the specimen slot. Shear stress – effective shear strain curves were prepared for each tested specimen.

Table 1. Mechanical properties of test materials

material	thickness [mm]	direction	A [%]	$R_{0.2}$ [MPa]	R_m [MPa]	r
low-carbon steel	1.0	0^o	30	202	325	1.87
		45^o	28	198	325	1.56
		90^o	28	213	326	2.63
ETP-cooper	1.0	0^o	20	241	287	0.69
		45^o	19	239	265	1.14
		90^o	20	249	273	0.99
CuZn37 brass	1.0	0^o	40	267	408	0.9
		45^o	39	243	380	0.79
		90^o	38	251	389	0.76

3. RESULTS AND DISCUSSION

The comparison between results of tensile and shear tests could be done when the deformation index would be the same both in tensile and shear tests. So, the effective shear strain γ was divided by $\sqrt{3}$ to obtain the effective linear strain $\varepsilon = \frac{\gamma}{\sqrt{3}}$ for each tested case. As a result, an example diagram for low-carbon steel is shown in Fig. 2. Tensile stresses and shear stresses were compared for the same direction of the sheet, though as it was shown in [3], the directions for the same or similar degrees of deformation are different by 45^o from each other between tensile test and shear test; the parallel - 0^o and perpendicular - 90^o in tensile test correspond to skew - 45^o (left and right skew direction adequately) in shear test and vice versa. During experiments the skew direction (45^o) was kept the same (right or left) for one kind of sheet material. Such procedure was made for all tested materials.

Basing on such curves as shown in Fig.2, the ratios of shear stress to tensile stress were calculated. The results obtained for tested materials are shown in Fig. 3, 4, 5. It is important to emphasize that only for low-carbon steel the curve of perpendicular 90^o direction shows important difference between 0^o and 45^o directions. In the case of cooper and brass, this difference was observed for 45^o direction.

The τ/σ ratio for low-carbon steel sheet is very stable in considered range of deformation. The values of τ/σ ratio, for 0^o direction, are near 0.5; this result is close to Tresca criterion (Eqn 3), but results for 45^o and 90^o directions are closer to von Mises criterion (Egn 4).

For ETP-copper sheets, in 0^o, 45^o and 90^o directions, the values of τ/σ ratio are considerably over 0.65. It is surprisingly high when comparing with the values of $1/\sqrt{3}$ or 0.5 expected from Mises and Tresca criterion respectively. The results obtained for CuZn37 brass sheets are varying; for low deformation are considerably over the value $1/\sqrt{3}$, for greater deformation are beneath von Mises criterion, with the exception of 45^o - direction. For these two materials differences between curves corresponding to 0^o and 90^o are small.

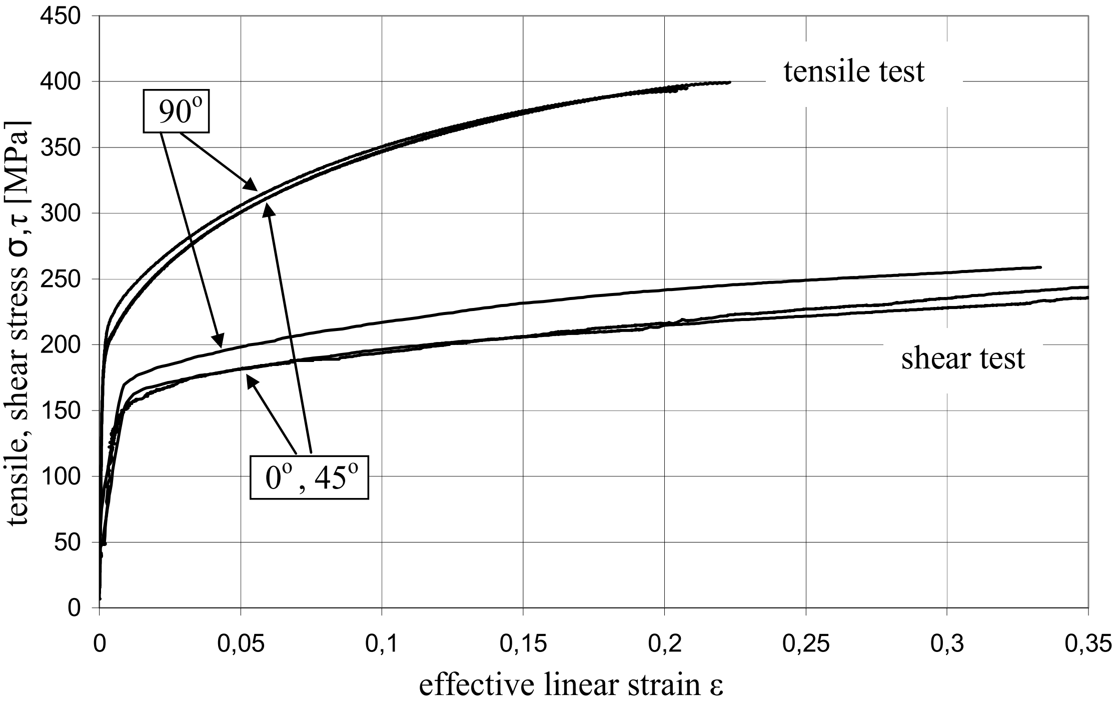

Fig.2. Comparison of tensile test and simple shear test for low-carbon steel sheet (specimen parallel to the rolling direction 0°)

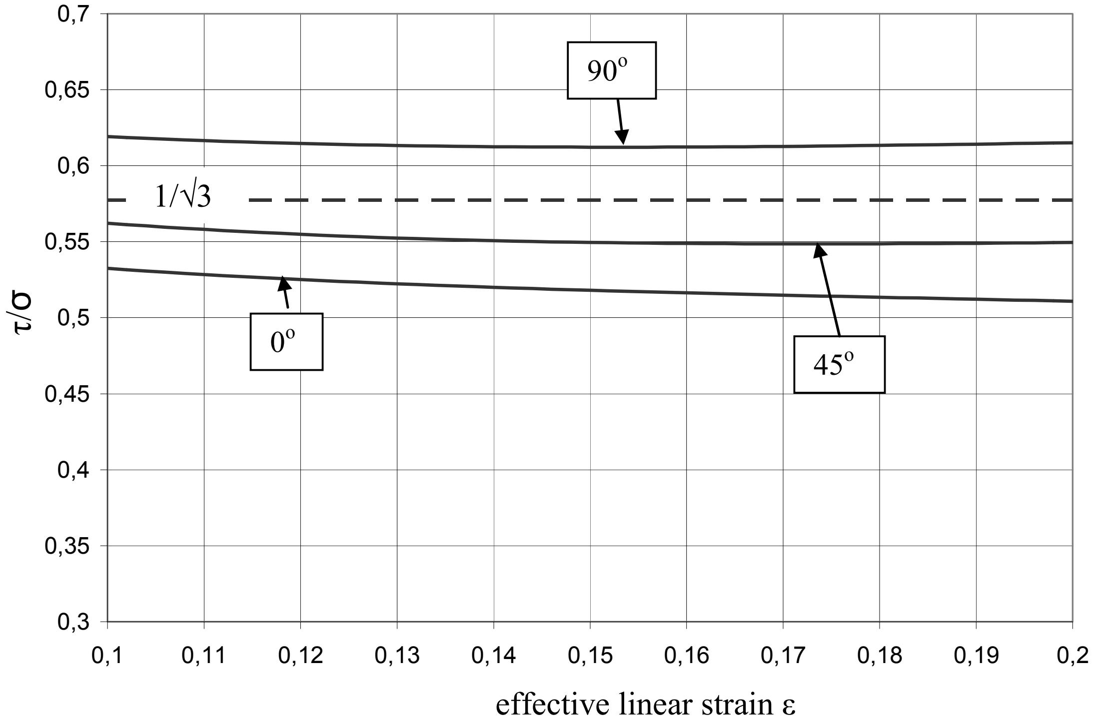

Fig.3.Shear stress and tensile stress ratio for low-carbon steel sheet at 0°, 45°, 90° to the direction of rolling

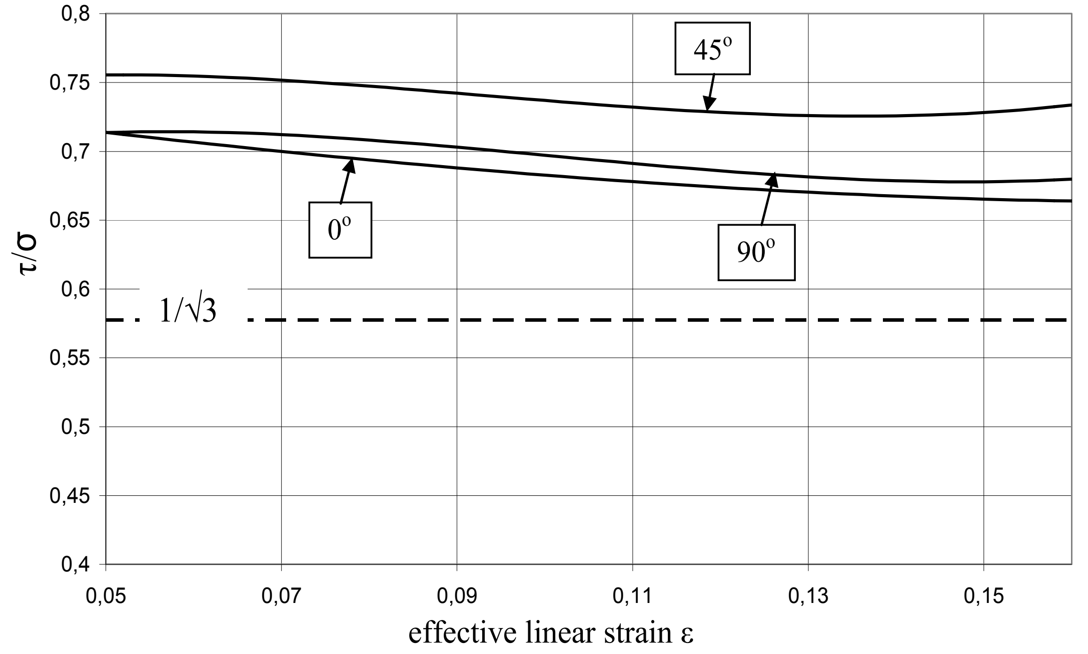

Fig.4.Shear stress and tensile stress ratio for ETP-copper sheet at 0°, 45°, 90° to the direction of rolling

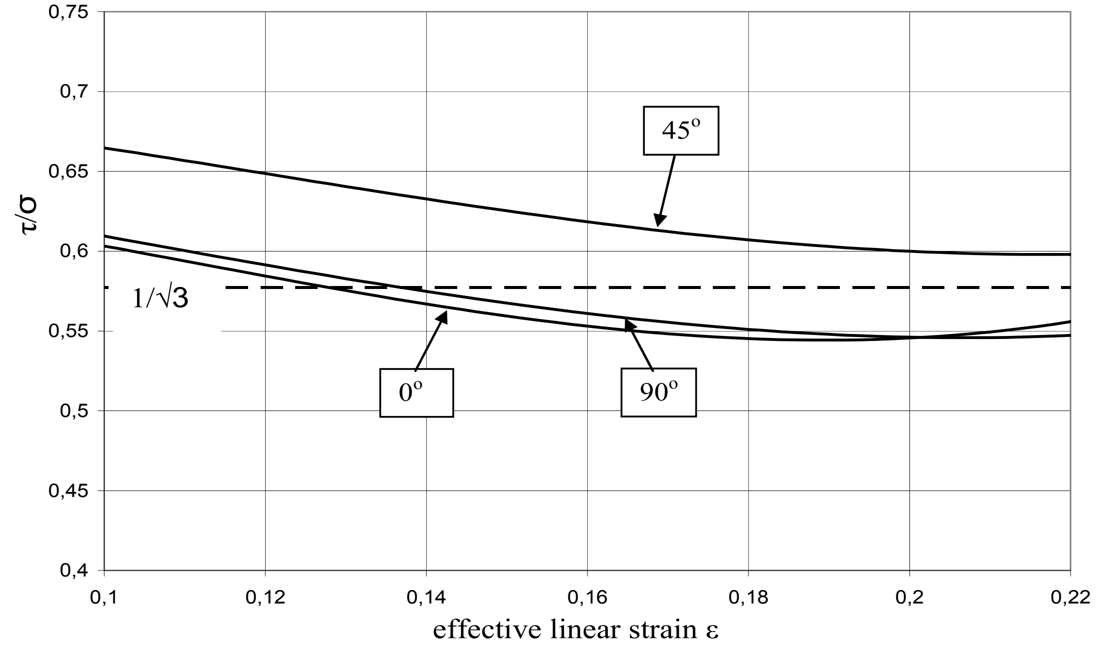

Fig.5.Shear stress and tensile stress ratio for CuZn37 brass sheet at 0°, 45°, 90° to the direction of rolling

The average values of test parameters (in ranges of deformation shown in Fig. 3, 4, 5) are shown in table 2. High anisotropy material, i. e. low-carbon steel (ř = 1.9), have a good agreement with Tresca and Mises criteria. A large difference between plasticity criteria and tested material was obtained for ETP-copper, i. e. almost isotropic material, with mean anisotropy coefficient ř = 0.99. For material, which properties are, in all specimen direction, close to normal anisotropy, i. e. CuZn37 brass (ř = 0.81), the consistency with plasticity criteria is mean.

Table2. Average values of shear stress, tensile stress, ratio of shear to tensile stresses and mean anisotropy coefficient

material	direction	ratio τ/σ	percentage discrepancy with Tresca [%]	percentage discrepancy with Mises [%]	ř-mean anisotropy
low-carbon steel	0°	0.54	8	-6	1.9
	45°	0.57	14	-1	
	90°	0.63	26	9	
ETP-cooper	0°	0.68	36	18	0.99
	45°	0.74	48	28	
	90°	0,70	40	21	
CuZn37 brass	0°	0.59	18	2	0.81
	45°	0.65	30	13	
	90°	0.60	20	3.9	

Main differences between uniaxial tension and simple shear are in the freedom of deformation. A large freedom of deformation takes place in the tensile test; the material can be deformed in width and thickness freely, depending only on its own anisotropic nature. During the simple shear test the limitation of deformation freedom must be ensured; it mainly concerns the rotation of shear direction. In anisotropy material the limitation of deformation freedom must extort shear stresses in the established plane and direction.

Determination of shear stress value τ_o can be also performed in complex stress state by using different form specimens. During experiments specimens can be stretched, twisted and bulged. In most cases these investigations concern plane stress. As it is shown in [4] none of the above mentioned yield criteria agree firmly with different actual materials. The range of τ/σ ratio is wide; its value can vary from 0.3 to 0.7. Among thirty tested materials, five agreed with Tresca yield criterion and nine agreed with von Mises criterion. These results were obtained by different researchers on specimens in form of tubes, solid rods, bars and flat cruciform

4. CONCLUSIONS

The comparison of the simple shear test with the tensile test lets estimate consistency of metal properties with Tresca and Mises criteria. Materials with large anisotropy can show good consistency with plasticity criteria, and materials with low anisotropy can show discrepancy with plasticity criteria. These results need further investigations.

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