THE MICROSTRUCTURE AND MECHANICAL CHARACTERISTICS OF ORTHOTROPIC MATERIALS

VIOREL UNGUREANU
University of Bacău

Abstract: Usually, in order to determine the mechanical characteristic of metallic material is used the tensile test. But, for orthotropic sheet metal testing the tensile test is not representative and is proposed the utilization of planar sharing, planar stretching and compression tests. Those testing methods are easy to implement on conventional testing machines and the obtained results may be used in the sheet metal forming analysis and in the understanding of mechanical behavior of orthotropic materials.

Key words: tensile test, planar sharing, planar stretching, compression test, stress-strain relationship.

1. INTRODUCTION

Also at a microscopic level all the metallic material are anisotropic, at the macroscopic level they may show an isotropic behavior. That is, tensile test performed on specimens cut in different direction from given material shows identical or nearly identical stress-strain relationship. As a result of manufacturing process of sheet metal by rolling, the microscopic level anisotropy become evident also at macroscopic level, thou that, stress-strain curve obtained by tensile tests performed on specimen cut by different direction are different [1]. Those materials having different stress-strain relationships in different direction but that are identical in the same direction are named orthotropic. A real specimen of orthotropic sheet material has a high number of crystallographic grains with preferential orientation.

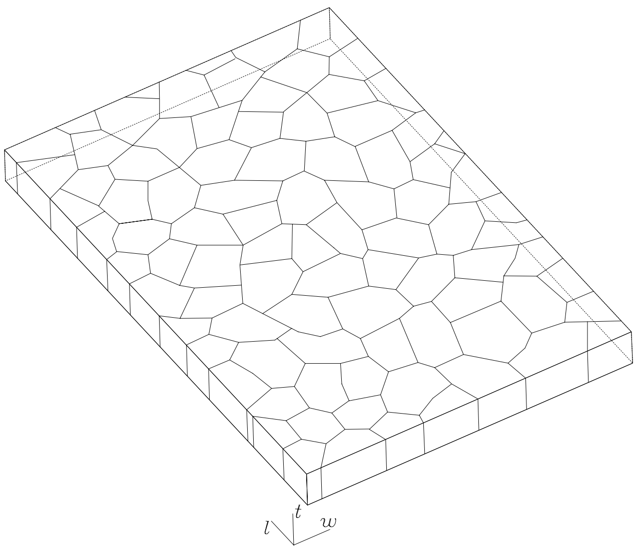

Fig. 1. The plate of analysed orthotropic sheet metal.

Also in the thickness direction we may encounter a number of flattened grains. In order to analyze the mechanical behavior of orthotropic sheet material submitted to a different kind of stress systems, we suppose that exists only one layer of grain with different shapes and preferential orientation reported to the longitudinal (rolling direction) ***l***, widths ***w***. and thickness direction ***t*** (figure 1). If a rectangular plate from figure 1 will be submitted to a different stress state, the plastic flow will arise first in the grain favorable oriented, but the resulting overall mechanical behavior will depend also from unfavorable oriented crystalline grain. Changing from one stress state to the other, the mechanical behavior will depend from number and orientation of different sliding systems. Because of rolling process, the characteristics of component crystalline grain may be different in respect with the rolling, width and thickness directions. Using adequate testing methods may be pointed out some specific behavior of different category of crystalline grains.

2. THE PLANAR SHEARING, PLANAR STRETCHING AND EQUIBIAXIAL TENSION

If a rectangular orthotropic plate from figure 1 is submitted to a tensile stress σ in ***l*** direction and to a compression stress –σ in ***w*** direction, it is in the planar share stress state. In this case, the plastic flow will take place first in the plane and slide directions making angle of 45^{o} with ***l*** and ***w*** direction. This situation is presented in figure 2, where the sliding plane and direction of favorable oriented grain are represented hatched at 45^{o} in respect with ***l*** and ***w*** directions.

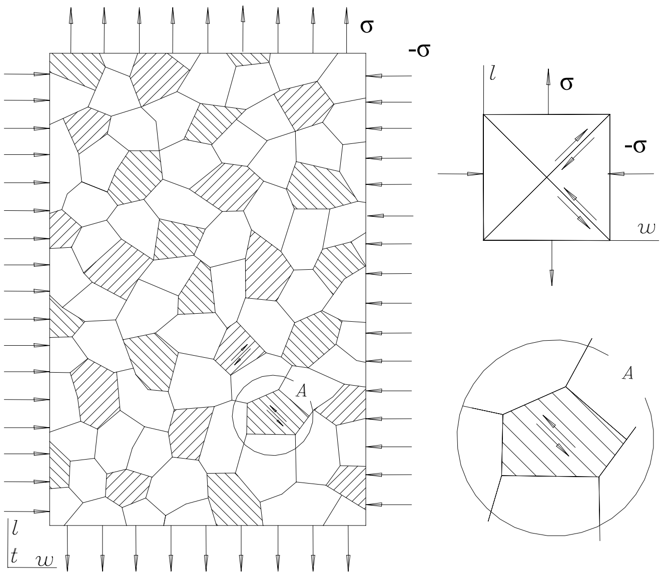

Fig.2. The orthotropic plate submitted to planar share stress.

Another kind of stress state that may be applied to the orthotropic plate is planar stretching, when, for instance, the plate is elongated in ***l*** direction without change of width in ***w*** direction. In this case, the orthotropic plate from figure 1 is submitted to a tensile stress **σ** in ***l*** direction and no stress or negligible stress in ***w*** direction. In this case, the plastic flow will take place first in the plane and slide directions making angle of 45^{o} with ***l*** and ***t*** direction. This situation is presented in figure 3, where the sliding plane and direction of favorable oriented grain are represented hatched at 0^{o} in respect with ***w*** direction. The last situation taking under consideration is equibiaxial tension when the orthotropic plate is submitted to a tensile stress σ in ***l*** and ***w*** direction. In this case, the plastic flow will take place first in all the plane and slide directions making angle of 45^{o} with ***t*** direction. This situation is

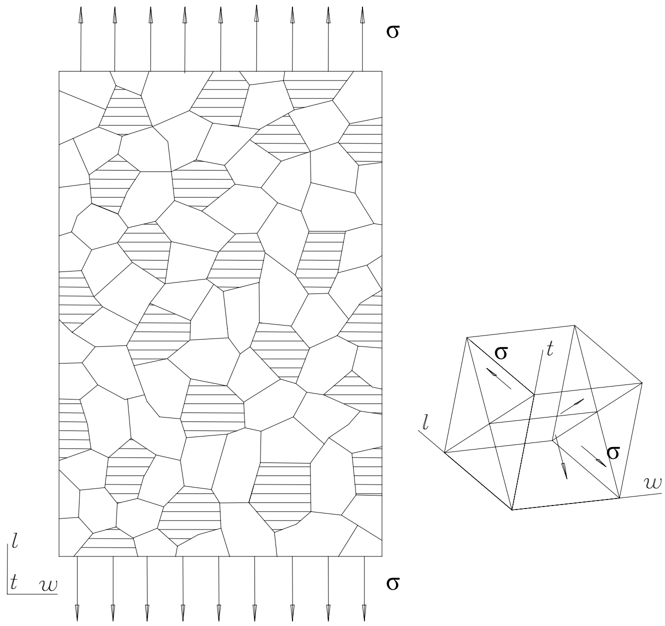

Fig. 3. The orthotropic plate submitted to planar stretching.

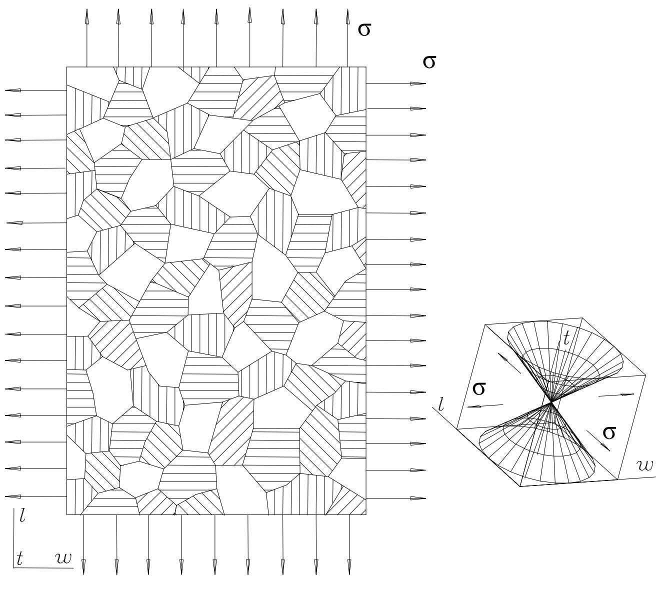

Fig.4. The orthotropic plate submitted to equibiaxial tension.

presented in figure 4, where the sliding plane and direction of favorable oriented grain are represented random angle hatched.

Between the three basic stress and strain situation presented in figure 2, 3 and 4, there are important differences because the properties and number of grain involved are different. Thus, the crystalline grain favorable oriented in planar share test and their properties are different from those favorable oriented in planar stretching. In the same time, the equibiaxial tension includes all the possible crystalline grain that may have a favorable orientation in planar stretching in any direction. The differences between the analyzed stress and strain states for orthotropic materials may be put in evidence by true stress - true (logarithmic) strain curve and the shape of forming limit diagram experimentally obtained for such materials. The planar sharing test [2] and planar stretching are ease to implement on universal tensile testing machine, but the equibiaxial tension needs special devices of Marciniak or hydraulic type. For this reason, we propose the replacement of the equibiaxial tension by compression test of round specimen cut from orthotropic sheet metal [3]. The effect of hydrostatic pressure, acting in this case, consists in the extension of stress-strain curve in the area of large strain. The compression test may be performed also on universal tensile testing machine and is ease to implement.

3. THE FLD'S AND STRESS-STRAIN CURVE FOR ORTHOTROPIC MATERIALS

The most evidently, the orthotropic behavior of materials may be observed by analyze of experimentally determined forming limit diagrams (FLD's) and the stress-strain curve obtained by planar sharing test, tensile test, planar stretching and compression test. Because the experimental obtained FLD's for real material shows more or less accentuated orthotropic behavior, in figure 5 are presented the general characteristics of such materials. The point A corresponds to a pure planar share strain, the point D corresponds to a planar stretching and point F corresponds to a equibiaxial tension. In the AB area is dominant the planar sharing strain, in CD area is dominant planar stretching and in the EF area is dominant biaxial stretching. The passage from one area to the other takes place by transition discontinuities BC and DE. Because in each area the dominant strain are accompanied by the contribution of other strain systems, the amount of plastic deformation are higher than in the characteristic points A, D and F. For example, in the area EF of biaxial tension except the point F the amount of plastic strain is higher because of contribution of planar sharing, while in the point F there is only the contribution of equibiaxial tension. The transition from point D to point E take place by a suddenly arise of plastic strain because the change of grain number and sliding system from planar stretching (figure 3) to biaxial stretching (figure 4). In the same manner, in point C, for example, the amount of plastic strain is higher than in point D because of the contribution of planar stretching and planar sharing.

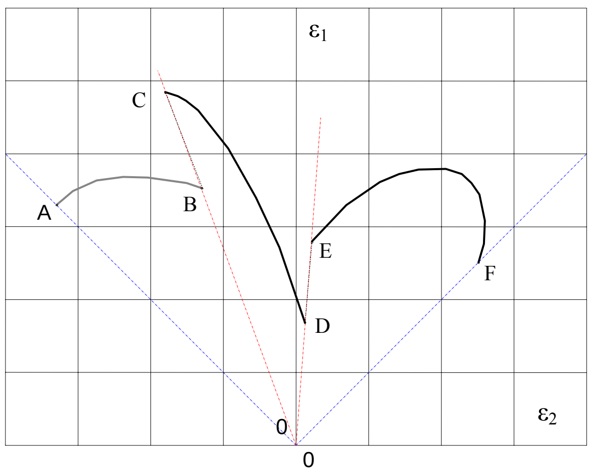

Fig. 5. The general characteristics of FLD for orthotropic materials.

The transition discontinuity BC corresponds to the passage from planar sharing to the planar stretching. The transition discontinuities are more accentuated for orthotropic materials, but they exist even for materials considered to be isotropic. Nearly the points B or C is situated the tensile test. Because in the conventional tensile test are activated sliding systems which belong to planar sharing (figure 2) and planar stretching (figure 3), in this work this test is not considered fundamental for orthotropic materials. In the tensile test are activated the sliding systems that are a combination of those from planar sharing and planar stretching. More over, the tensile test may be situated near point B which belong to a sharing domain, or near point C which belong to the planar stretching domain. In other words, the tensile test does not belong to the same domain for all orthotropic materials, and the anisotropy coefficients determined usually by tensile test are no significance in the biaxial tension area or in other domain than that in which it was determined.

The shape and dimension of specimen used in the FLD's determination, planar sharing and planar stretching was optimized by the FEM in order to obtain uniform stress distribution and to avoid stress concentration in some critical points and premature fracture.

The orthotropic materials are characterized also by stress-strain relationship. If the material has a isotropic behavior, practically is not important which testing method is used. In figure 6 are represented stress-strain relationship obtained for 5182 aluminum alloy by tensile test, planar sharing, planar stretching, and compression test. Because the obtained curve practically overlaps each other, the material may be considered isotropic and is enough to perform only tensile test in order to appreciate the mechanical behavior of such material.

If the material has orthotropic behavior the shape of stress-strain curve obtained for above mentioned testing are very different. Even the tensile test curve depends from specimen orientation in respect with rolling direction. In figure 7 is presented the stress-strain curve for "TIMET" titanium alloy that characterize orthotropic behavior of this material.

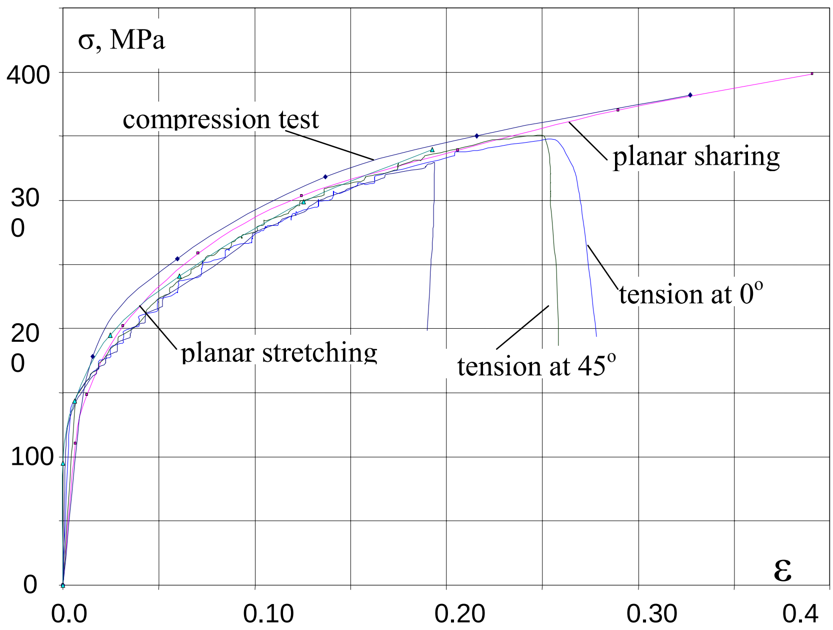

Fig. 6. The mechanical testing for 5182 aluminium alloy.

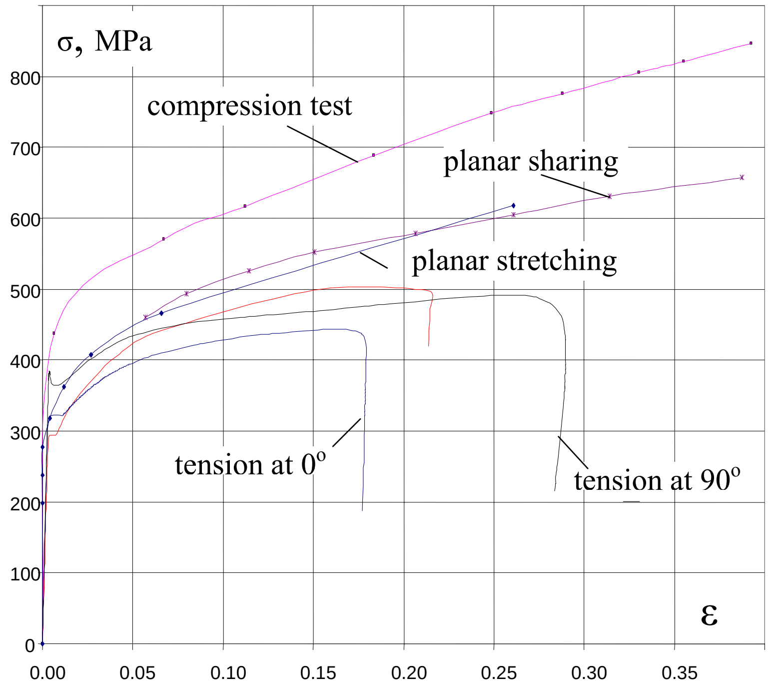

Fig. 7. The mechanical testing for “TIMET” titanium alloy.

4. CONCLUSIONS

For the determination of mechanical characteristics of orthotropic material, the utilization of planar sharing, planar stretching, and compression tests is proposed. Some experimental results show the importance of such testing methods development.

ACKNOWLEDGEMENTS: Some result was originated in the frame of an RTD programme “Copernicus” with E. U.

REFERENCES:

[1] Datsko,J.; W.J. Michell, W. J.. Changes in Mechanical Properties in Metal-Forming Processes. *Journal of Materials Engineering and Performance.* Volume 2(2) April 1993 265-170

[2] Ungureanu,V., Judele, A.. The Enhanced Specimen and Testing Device for Planar Share Strain Test of Sheet Metal *MOCM-9.* Romanian Technical Academy, 2005.

[3] Ungureanu,V.. The Novel Technique for Uniaxial Compression Test of Sheet Metal Specimens and Some Experimental Results. *MOCM-6*. Romanian Academy, Branch Office of Iassy. 2000. pp. 253-257.