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CRUCIFORM SPECIMENS SIZE AND SHAPE INFLUENCE ON STRESS DISTRIBUTION

BY

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Abstract. The paper presents a study on stress distribution from a new cruciform specimen. Was performed a finite element analysis in which have been set cruciform specimen shape and size. Thus was obtained a maximum normal stress state, uniform and homogeneous in the central part of the specimen and maximum shear stresses were recorded at the connection zone of the specimen arms on direction at 45°. Samples were made of two types of material: one with predominantly ductile behavior and one with predominantly brittle behavior. Cruciform specimens from materials with ductile predominantly behavior failed due to shear stresses and those with fragile predominant behavior failed under normal stress effect.

Key words: cruciform specimens; stress state; finite element analysis; material testing.

1. Introduction

To characterize numerical and experimental materials behavior from structure and machine components, which are in a complex states of stress during operating conditions, are required multi-axis and multi-mode experiments (Hannon & Tiernan, 2008). One step forward in this direction is

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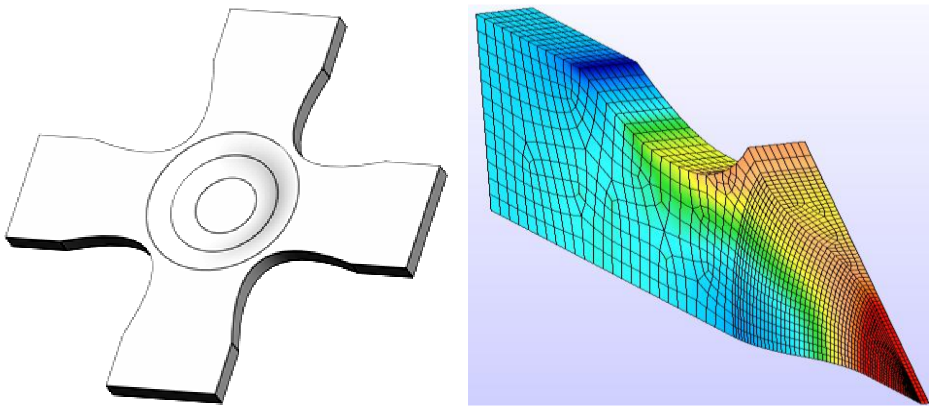
testing cruciform specimens from various materials, like composites (Serna Moreno & López Cela, 2013) under different loading conditions (Makris *et al.*, 2010). Andrianopoulos and Manolopoulos (2014) states that to describe material behavior under multiaxial loadings, strain energy density, is divided in two parts: dilatation (in terms of normal stress/strain) and distortion (in terms of shear stress/strains) and that failure of a material is defined as the loss of material ability to store elastic strain energy, either by slip (plastic flow) or by cleavage (brittle fracture). Main elements that influence the nature of materials behavior (ductile or brittle) are temperature, type of loading (simple or combined, static or dynamic) and strain rate. In Fig. 1*a*, is proposed a new design of a cruciform specimen (Andruşcă *et al*., 2014).



a *b*

Fig. 1 – Cruciform specimen *a*) 3D view *b*) mesh for one eighth of specimen.

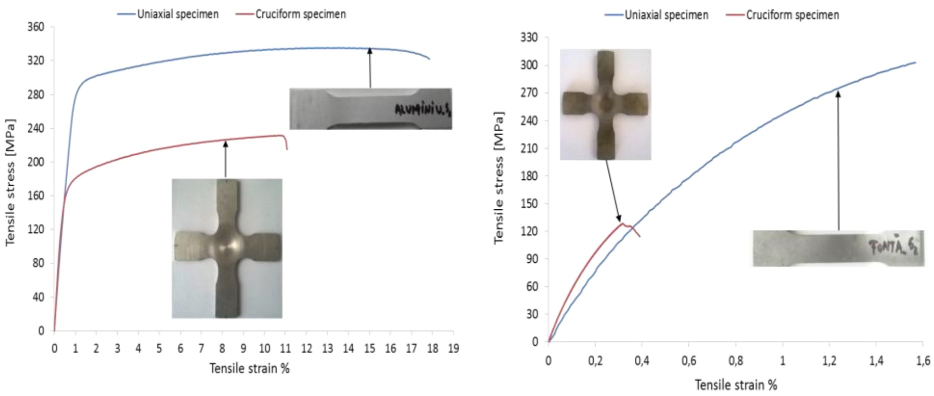
2. Material and Methods

To reduce processing time for calculations and due to the symmetry conditions, in finite element analysis was used only one eighth of cruciform specimen (Fig. 1*b*). Simulations were performed with Algor software, analysis being “Static Stress with Non-Linear Material Models” with elements type “brick”. Cruciform specimens are subjected to a biaxial loading ratio 1:0, meaning that tensile force was applied only in one direction. Materials used in experiments were gray cast iron with lamellar graphite and aluminum alloy.

Equivalent stress in general case can be expressed as using eq. (1):

$$\sigma_{VM} = \frac{1}{\sqrt{2}}\sqrt{\left(\sigma_x - \sigma_y\right)^2 + \left(\sigma_y - \sigma_z\right)^2 + \left(\sigma_z - \sigma_x\right)^2 + 6\left(\tau_{xy}^2 + \tau_{xz}^2 + \tau_{yz}^2\right)} \qquad (1)$$

where σ_x, σ_y, σ_z are normal stresses and τ_x, τ_y, τ_z are shear stresses.



a *b*

Fig. 2 – Conventional stress-strain curve *a*) ductile behavior and *b*) brittle behavior.

Were carried out tensile tests for the two types of materials, with predominantly ductile behavior and with predominantly fragile behavior. Initial were tested standardized specimens at uniaxial tensile, and then cruciform specimens of the same material were tested at tensile in one direction, resulting conventional curves from Fig. 2 *a* and *b*.

3. Results and Discussions

FEA shows a uniform and homogeneous stress state, maximum values of normal stresses concentrated in specimen center and existence of a shear stress gradient in the direction of 45 degrees.

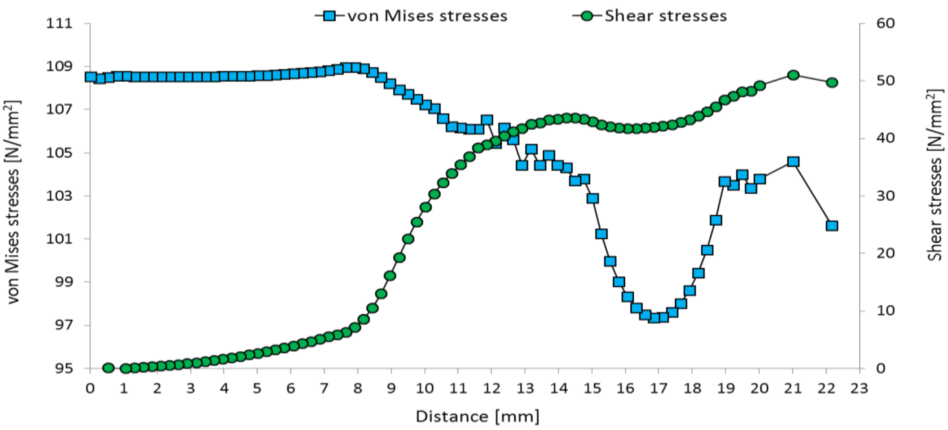


Fig. 3 – Evolution of von Mises stresses and shear stresses stress in cruciform specimen.

Thickness reduction factor, defined like ratio between maximum thickness of specimen and minimum thickness registered in gauge area is ten. Stresses are recorded on the path at 45 degrees what begins from specimen center and ends at the edge corner specimen, composed by the two adjacent arms. The combined effect of cruciform specimen size and shape is the one that generates evolution of von Misses and shear stress distribution in cruciform specimen.

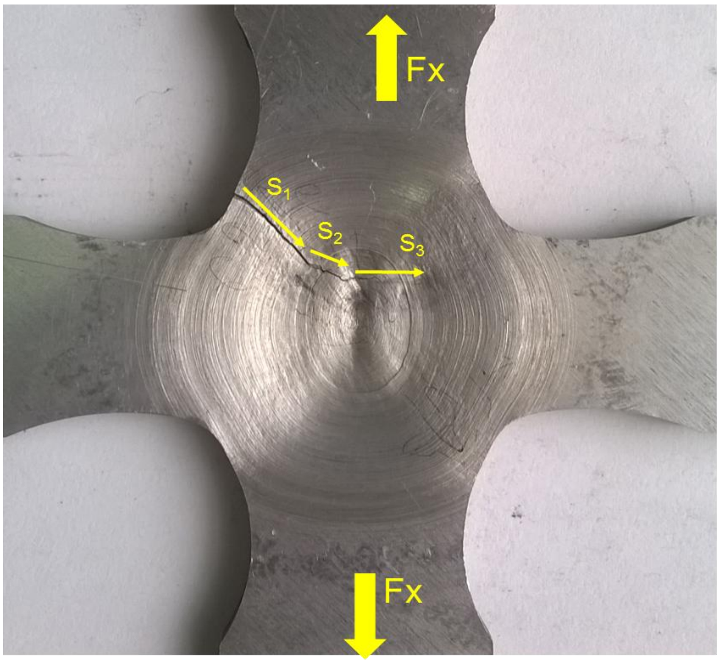


Fig. 4 – Failure of cruciform specimen from material with ductile predominantly behavior.

For materials with ductile preponderantly behavior, failure is initiated by the action of shear stresses and will propagate in a direction at 45 degrees with respect to loading direction. Crack is initiated in corner zone, with a linear progression (S_1) up to thickness transition zone. Here the crack changes its path (S_2) and because of stress concentrators that are in this area. Finally crack stabilizes on a linear segment, near the specimen center where cross section is minimum.

For materials with brittle preponderantly behavior, failure is initiated from the central area as a consequence of normal stresses action (line segment S_1), were cross-section is minimum and is perpendicular to loading direction. Than crack propagates almost symmetric (line segments S_{21} and S_{22}) from specimen center to specimen arms like in Fig. 5.

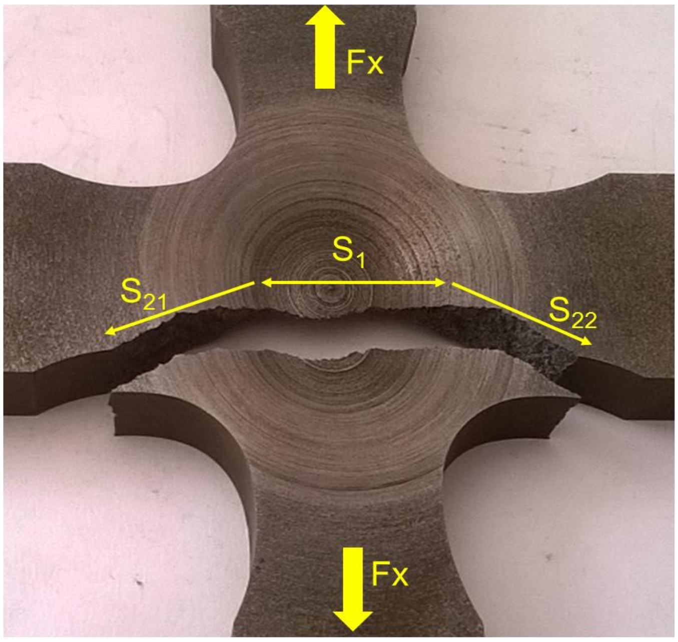


Fig. 5 – Failure of cruciform specimen from material with brittle predominantly behavior.

4. Conclusions

This study investigates the influence of cruciform shape and size on stress distribution. An elasto – plastic finite element analysis was performed to evaluate stress state from cruciform specimens. Normal stresses are maximum in specimen center and shear stresses have maximum values in specimen corner zone on direction at 45°. Under uniaxial tensile test conditions, cruciform specimens made from materials with behavior predominantly ductile failed due to shear stresses and those from materials with fragile predominant behavior failed under normal stress effect. Materials failures in these modes were due to the shape and size of cruciform specimen and influence stress concentrators was insignificant.

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INFLUENŢA FORMEI ŞI MĂRIMII EPRUVETELOR CRUCIFORME ASUPRA DISTRIBUŢIEI TENSIUNILOR

(Rezumat)

În această lucrare se prezintă un studiu asupra influenţei formei şi mărimii epruvetelor cruciforme asupra stării de tensiuni. S-a efectuat o analiză în domeniul elasto-plastic a unei optimi din epruveta cruciformă pentru a evalua distribuţia tensiunilor normale şi tangenţiale. Astfel s-au obţinut valori maxime ale tensiunilor normale în zona centrală a epruvetei, cât şi o distribuţie uniformă şi omogenă a acestora. Tensiunile tangenţiale maxime s-au înregistrat la zona de racordare a braţelor epruvetei, acestea prezentând şi un gradient pe direcţia la 45°. Epruvetele cruciforme au fost realizate din două tipuri de material: aliaj de aluminiu şi fonta cenuşie cu grafit lamelar, unul având comportament predominant ductil iar celălalt predominant fragil. Epruvetele au fost încercate la tracţiune pe o singură direcţie, până la rupere. S-a constatat că în cazul materialului cu comportament predominant ductil, cedarea s-a produs sub influenţa tensiunilor tangenţiale pe direcţia la 45°, cu iniţierea fisurii din zona colţului şi propagarea acesteia spre centrul epruvetei, unde secţiunea este minimă. În cazul materialelor cu comportament predominant fragil, cedarea a avut loc în centrul epruvetei, sub influenţa tensiunilor normale care au avut valori maxime acolo. Iniţierea fisurii a fost în zona calibrată, perpendicular pe direcţia de încărcare, unde secţiunea era minimă, iar propagarea acesteia este aproape simetrică la stânga şi la dreapta (lateral). Cedarea materialelor în aceste moduri s-a datorat formei şi mărimii epruvetei cruciforme realizate, iar influenţa concentratorilor de tensiune a fost nesemnificativă.