

PURE SHEARING TESTS OF A PRANDTL-TYPE MATERIAL

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Materialele cromoplastice pot fi incluse in categoria materialelor ce prezintă o curbă caracteristică de tip Prandtl. Ele au fost obținute în România, la Institutul de Cercetări Chimice din București. Materialul cromoplastic este un polimer ce prezintă o comportare liniară - perfect plastică la tracțiune și își schimbă culoarea în zonele deformate plastic: el devine alb atunci când curgerea are loc la tracțiune și respectiv negru atunci când curgerea se produce sub acțiunea unor tensiuni de compresiune. În acest articol, se prezintă teste de răsucire pură, realizate pentru epruvete de tip Iosipescu, confecționate din material cromoplastic. Metoda Iosipescu este extrem de răspândită în analiza experimentală pe plan mondial. Înainte de aceste încercări, au fost realizate teste de tracțiune pentru determinarea caracteristicilor mecanice și ale constantelor elastice ale materialului epruvetelor. Aceste date au fost utilizate în analizele numerice cu metoda elementelor finite, pentru evaluarea stării de tensiune în epruveta Iosipescu. Analiza comparativă a rezultatelor obținute numeric și experimental a confirmat atât valoarea forței necesare pentru producerea articulației plastice cât și forma zonei plastice. Astfel, s-a evidențiat posibilitatea utilizării materialelor cromoplastice în studiul structurilor solicitate elasto-plastic.

Chromoplastic materials can be included in the category of materials that have a Prandtl-type characteristic curve. Such materials were obtained in Romania, at the Chemical Research Institute Bucharest and they are compounded polymers that have a linear-perfect plastic behavior in traction. The material changes its color when a plastic hinge appears, becoming white at yielding in traction and black at yielding in compression. The pure shear tests of such material were made using the Iosipescu method, which is widely considered in the experimental analysis. Also, the mechanical characteristics of the material were obtained by tensile tests, being further used as input data in a finite element code that evaluates the stress state of the specimens. The comparative numerical and experimental study has confirmed both the value of the force that produces the plastic hinge and the shape of the plastic zone. Thus, the study emphasizes the possibility of using the chromoplastic materials in the study of elastic-plastic loaded structures.

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1. Introduction

The chromoplastic materials [1,2] were obtained from compounded polymers in Romania at the Chemical Research Institute from Bucharest. This material exhibits the chromoplastic phenomenon: it changes the color when plastic deformations appear. The plastic zone becomes white when yielding appears in traction and black when yielding happens in compression.

In the case of axial loadings, the chromoplastic material has the following features:

- Linear-elastic behavior for strains smaller than the yield strain ($\sigma < \sigma_y$);
- Plastic deformations under constant stress for ($\sigma > \sigma_y$);
- The chromoplastic phenomenon appears at room temperature (20 °C);
- If the material is loaded till the chromoplastic phenomenon appears, then it is heated at temperatures higher than 110 °C, the colors specific to yielding disappear and the model returns to its initial shape and dimensions; the properties prior to the heat treatment disappear also; if heated again beyond 110 °C, the chromoplastic phenomenon is not present anymore.

The hypotheses about the appearance of chromoplasticity are:

- A mechanism of molecular orientation that is present when crystallinity varies;
- A differential solvation of the components from the material under different stresses;
- An effect of differential diffraction.

One can see a sensitivity of the chromoplastic phenomenon for the above mentioned materials, characterized by a clear difference in color between the loaded and non-loaded areas. The SPD-2 and SPD-7 chromoplastic materials exhibit a characteristic curve similar to the Prandtl schematization (Fig. 1, a) while CSPD-30 shows a curve with a small hardening tendency (Fig. 1, b).

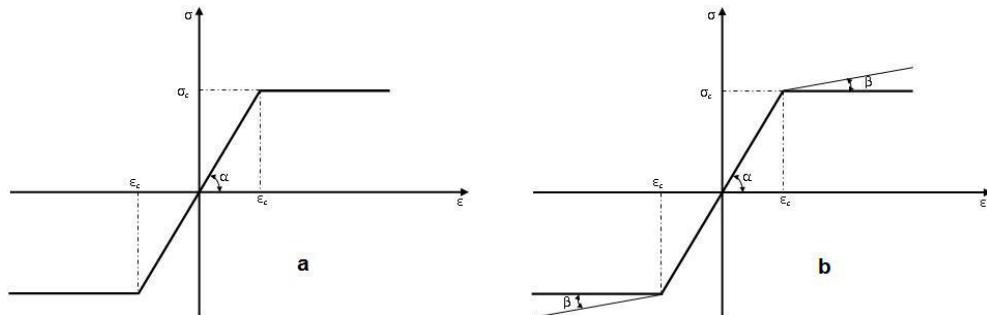


Fig. 1: The Prandtl schematization

The experimental tests performed on such materials can lead, without using sophisticated equipment, to important information about the areas where the first plastic deformations appear, the type of stresses (traction or compression), the values of the load that produced these stresses, and the evolution of the plastic zones while the loads are increased.

One should know the elastic constants and mechanical characteristics of the chromoplastic materials in order to develop models for analytical or numerical studies to obtain the stress distribution. In this way, the numerical and experimental results may be compared to draw conclusions.

For this purpose, experimental tensile tests were performed on Prandtl-type materials to obtain the characteristic curve and to determine Young's modulus E , the yield stress σ_y and ultimate tensile strength σ_0 . The pure shearing tests using the Iosipescu procedure [3,4] were undertaken simultaneously with numerical simulation using the Finite Element method (FEM) to verify the values of the forces at pure shearing failure.

2. Experimental tests

The primary tests were performed for obtaining the elastic constants and mechanical characteristics of the chromoplastic materials. An INSTRON 8801 testing machine was used to test tensile specimens having a diameter of 10 mm. Static tests were considered with a speed of 0.1mm/min, and the characteristic curve from Fig. 2 was recorded.

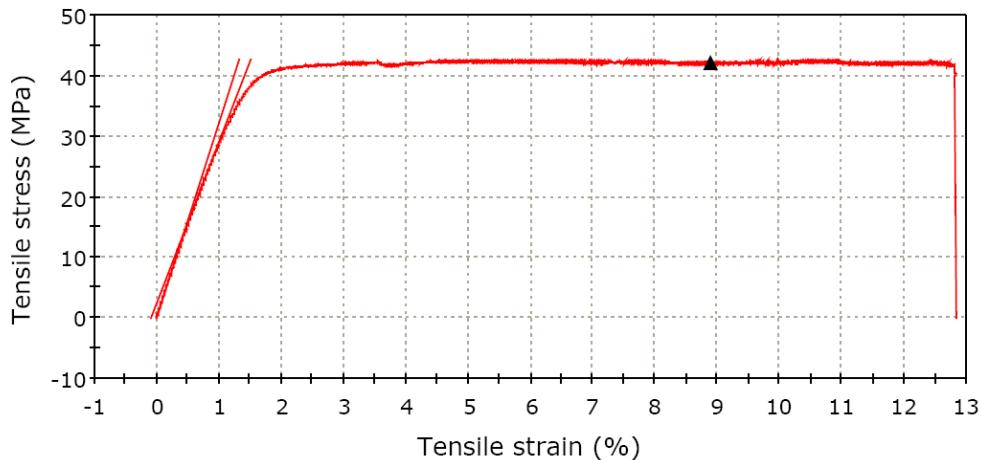


Fig. 2: The characteristic curve of the studied chromoplastic material

Using the curve from Fig. 2, the following data were determined: Young's modulus in traction $E = 32000$ MPa and yield stress $\sigma_y = 42$ MPa.

The Iosipescu specimens used for the pure shear tests were designed taking into account the following features:

- Failure of the specimen should appear in the section where the shearing force produces the pure shearing load;
- The shear stresses distribution in the failure area should be constant;
- The ultimate shear strength should be obtained following the equation $\tau = T/A$ where T = shearing force and A = cross section area.

The pure shear load produced by a shearing force that acts in a certain section of the specimen without having a bending moment may be obtained as shown in Fig. 3.

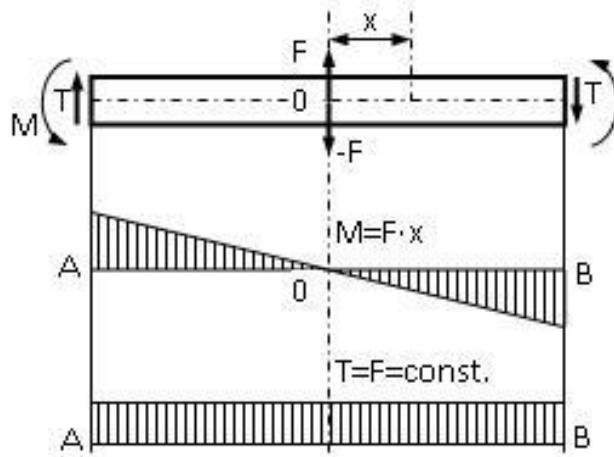


Fig. 3: Load of the specimen for pure shearing

Such a failure may be achieved if the cross section is reduced by manufacturing a rounded V-notch at the end of the weakened section. Using the photoelastic technique, Iosipescu,[3,4] showed that provided the slope of the notch is at 45° with respect to the cross section, the isostatic fringes have the same inclination and thus the maximum shear stress σ_{\max} is constant (Fig. 4 a,b). In order to obtain a uniform distribution of the shear stresses in the failure cross section, the depth of the notch should be a quarter of the specimen height (Fig. 4, a,b).

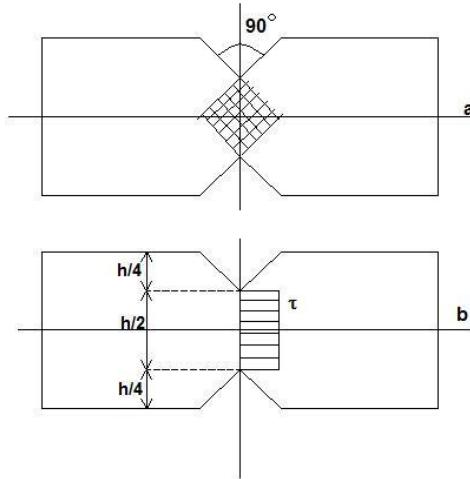


Fig. 4: Shape of the specimen for pure shearing

In Fig. 5 the specimen made of a chromoplastic material, designed to correspond to the requests of a pure shearing test is shown. The loading device is presented in Fig. 6.

The specimen was manufactured from a 10 mm thickness plate made of a chromoplastic material. The thickness of the shearing cross section with zero bending moment was reduced from 10 mm to 2.8 mm, as to have a failure force less than the limit value in compression in the contact area with the grips. For this purpose, the lateral surfaces were mechanically processed near the vertical notches, the thickness decreasing progressively and symmetrically from 10 mm to the minimum value of 2.8 mm in the pure shearing section. Thus, a $2.8 \times 20 \text{ mm}^2$ pure shearing net minimum section was obtained.

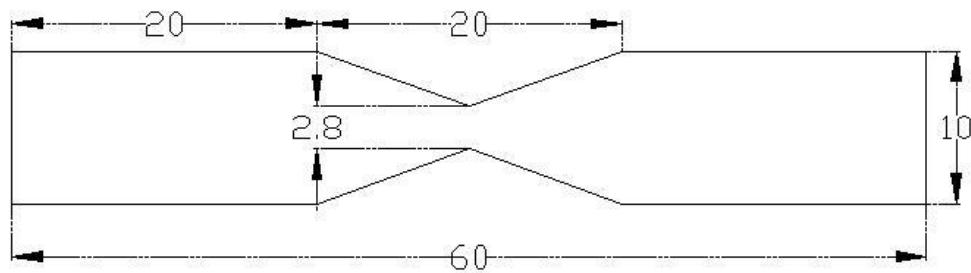


Fig. 5: Geometry of the pure shearing specimen

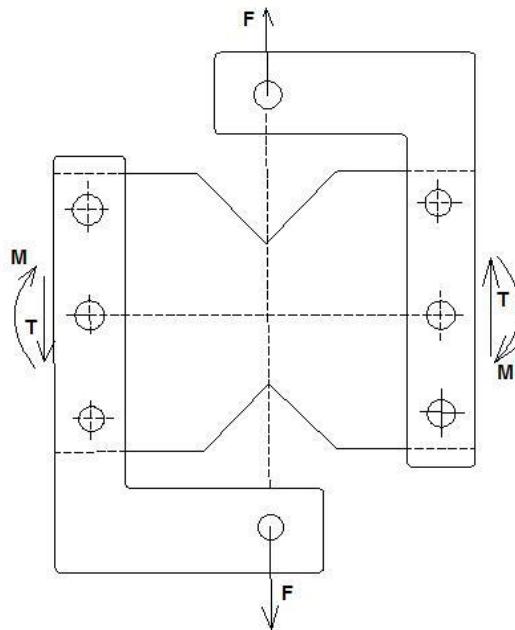


Fig. 6: The loading device

The test was undertaken on the INSTRON 8801 testing machine (Fig. 7) with a test speed of 0.4 mm/min. The obtained displacement-load diagram is presented in Fig. 8.

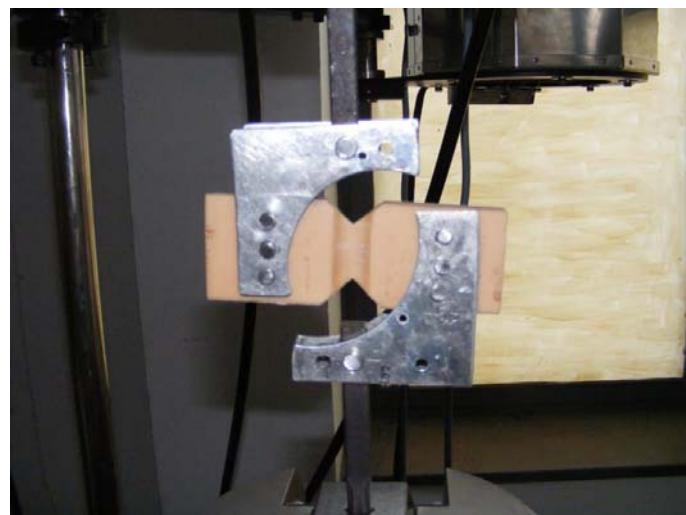


Fig. 7: The testing machine with specimen mounted

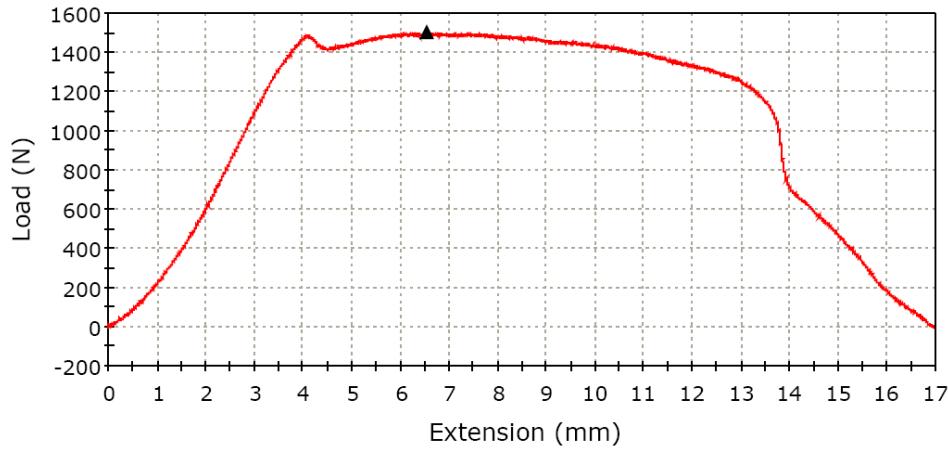


Fig. 8: The force-displacement diagram in the pure shearing test.

One can notice a maximum value of the applied force of 1500 N, meaning a shear stress of 26.8 MPa. At this moment, cracks initiate at the tip of the two notches, in the shearing area (Fig. 9). Afterwards, the force remains constant, while the displacement increases, the cracks propagate visibly (Fig. 10) and, finally, a central internal crack appears and propagates till the final failure of the specimen in the shearing area (Fig. 11).



Fig. 9: Crack initiation at the tip of the notch

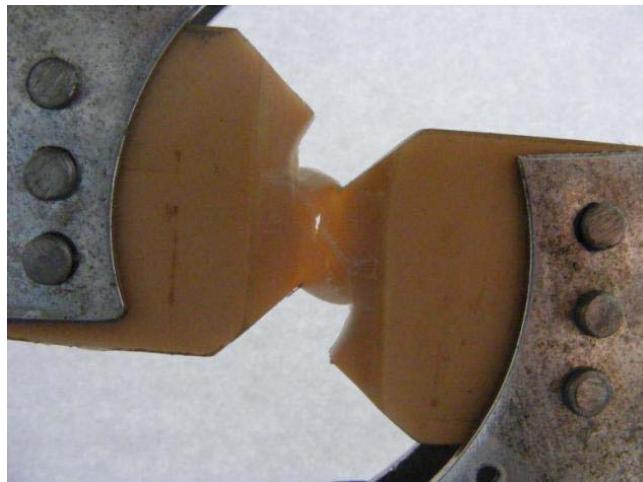


Fig. 10: Initiation of the central crack



Fig. 11: Failure of the specimen.

3. Numerical analyses

The stress distribution in the pure shearing specimen was studied also using the Finite Element method. The numerical three dimensional model has the geometry of the experimentally tested specimen (Fig. 5) and the load is the one resulted from the experimental tests. An eight-noded brick isoparametric element was used for the mesh, resulting a model with 2048 elements and 2673 nodes (Fig. 12).

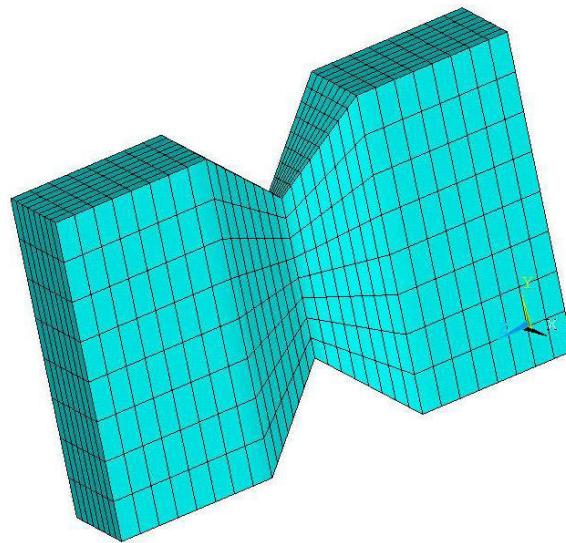


Fig. 12: The finite element model

The distribution of the shear stress is shown in Fig. 13. One can notice that the value of the shear stress in the shearing section is 27.8 MPa and the stress distribution is constant along the cross section.

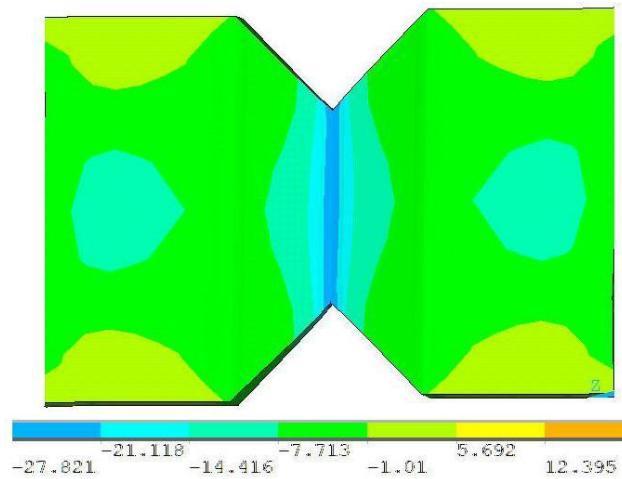


Fig. 13: Distribution of the shear stress in the Oyz plane.

6. Conclusions

The tests performed on specimens manufactured from the chromoplastic material revealed that the requirements established by Iosipescu, [3,4] about the 45° slope of the V-notch manufactured between the sides of the notch and the shearing section, create the condition for pure shearing with a maximum constant value of the shear stress. The specimen obtained using these requirements, was tested in pure shearing. Yielding appeared in this section, with a constant value of 26.8 MPa, till the final failure. A very good agreement was obtained between this value and the one from the Finite Element Analysis (27.8 MPa). The small difference (3.7%) may arise from the fact that the stress raising effect of the notch could not be completely reduced.

From the experimentally obtained values of Young's modulus and Poisson's ratio, one can determine the shear modulus, in the case of linear-perfectly plastic materials. These characteristics are important for the stress and strain analyses performed on models of industrial structures, realized from chromoplastic materials. At the same time, one should take into account the properties of such materials may vary in certain limits, depending on the batch in which the material was obtained. An exact knowledge of the values for the elastic constants and mechanical characteristics is required for a proper numerical analysis.

R E F E R E N C E S

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