



The use of thermoelasticity and photoelasticity to investigate the mechanical properties of polymeric materials

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ABSTRACT. A study of the damage evolution of a polymer (polycarbonate) during a quasi-static tensile test was performed. The thermographic and photoelastic nondestructive techniques are used to detect and quantify the damage of polymer specimens. The thermographic technique, carried out by a termocamera, allows to detect and quantify the temperature variations, which are related to the stress values and damage of the material. Exploiting the birefringence characteristic of polycarbonate, a photoelastic analysis was carried out to analyze the stress distribution in the necking area of the specimen. A circular polariscope with monochromatic light was utilized in order to detect the isochromatic field. The results obtained by the photoelastic study were compared with the thermographic data and a correlation model is proposed. Besides, finite element analyses were carried out with the aim of comparing the stress distribution observed by the photoelastic and thermographic analyses.

KEYWORDS. Thermoelasticity, Photoelasticity, Polycarbonate.

INTRODUCTION

The basic difference between polymers and other materials resides in the viscoelastic properties of polymers. The mechanical, as well as optical, properties of polymers such as modulus, strength and Poisson's ratio vary with time. While many materials have properties that vary with time due to creep at high temperature, corrosion and other factors, the time dependent behavior of polymers is due to their molecular structure. One demonstration of the time dependent nature of polymers is that they exhibit characteristics of both an elastic solid and that of a viscous fluid. However, for stresses equivalent to the upper yield point, both steel and polycarbonate show evident striations or slip lines (Lüders bands [1]), at an angle of 54.7° to the load axis. The information provided by thermographic and photoelastic analyses are useful to allow the complete characterization of the mechanical properties of the material. Further, giving good information regarding the mechanical behavior during the test, the elastic and plastic phase are well identifiable.

MECHANICAL PROPERTIES, A PHOTOELASTIC AND THERMOGRAPHIC EVALUATION

The mechanical properties of polymers are frequently obtained using a uniaxial tensile test at a constant rate of strain. It is to be noted that many approaches to determining the yield point are used. In agreement with the standard [2], yield point is the first point on the stress-strain curve at which an increase in strain occurs without an increase in stress. The elastic limit is at much higher strains for polymers than for metals. With polymers, permanent deformation does not occur until the deviation from linearity is much greater than 0.2%. Even if the 0.2% offset method to determine yield stress cannot be used in polymers, it was reported in order to suggest some consideration. Also the 1% offset stress was evaluated.

The specimen used is in agreement with the standards [2] and it is reported in Fig. 1.

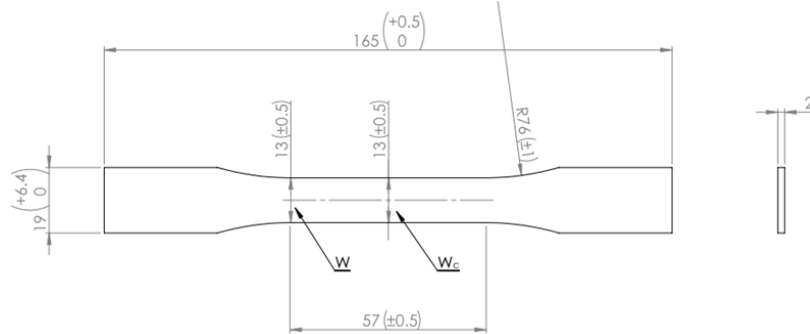


Figure 1: Specimen dimensions.

In order to ensure the necking zone in the gage zone, the width at the center of the specimen W_c shall be $+0.00$ mm, -0.10 mm if compared with respect of the width W of the specimen. With the aim of a thermographic analysis of the specimen under tensile test, it is possible to evaluate the temperature distribution in the tested area. In Fig. 2 the stress-strain behavior of polycarbonate and the temperature trend during the test is shown.

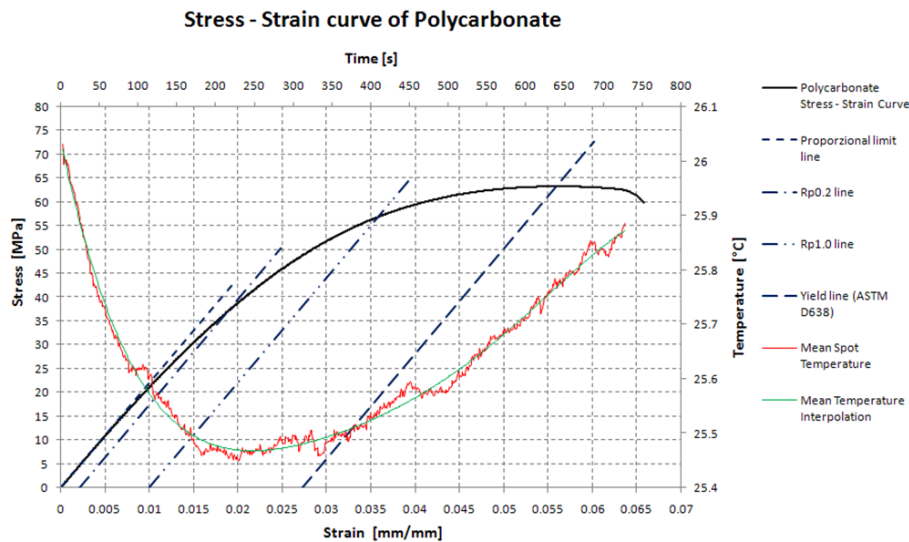


Figure 2: Stress-Strain curve and temperature distribution in polycarbonate specimen during tensile test.

In Tab. 1 a summary of the mechanical properties of polycarbonate is given.

Crosshead Speed [mm/min]	0.5
Young's Modulus [MPa]	2205
$R_{p0.2}$ [MPa]	37
$R_{p1.0}$ [MPa]	57
Peak Stress [MPa]	63

Table 1: Mechanical properties of polycarbonate.

Theoretically a decrease in temperature is associated with elastic behavior of the material, otherwise the increase in temperature denotes the start of plastic phase [3]. From the diagram it is possible to assume that a plasticization occurs before reaching the stress, suggested from standard for the identification of the yield point. A temperature rise is already observable, in fact, from the first 300 seconds, when the stress is about 47 MPa. The area where the average of the specimen temperature during the test was evaluated is shown in Fig. 3.

With the aim of a circular polariscope the fringes formation during the tensile test were observed. This analysis permits an evaluation of the whole field in term of stress distribution. It is also useful, besides, for the localization of shear bands and



point of maximum stress along the specimen. Shear bands develop in polymers due to large scale movement of molecular chains and usually start in a zone of higher stress than the close region or at a point of stress concentration. In Fig. 4 the image sequence, related to the instants of observation during the tensile test, is reported.

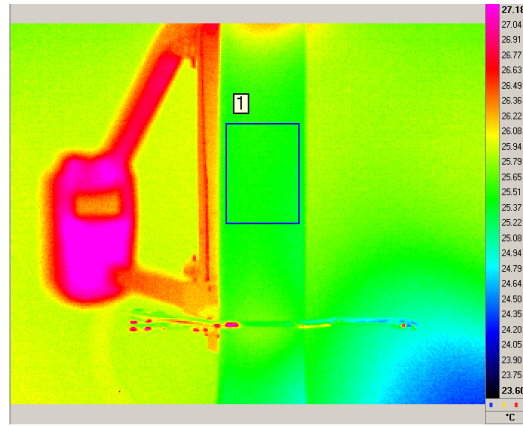


Figure 3: Thermographic analysis of the tensile test.

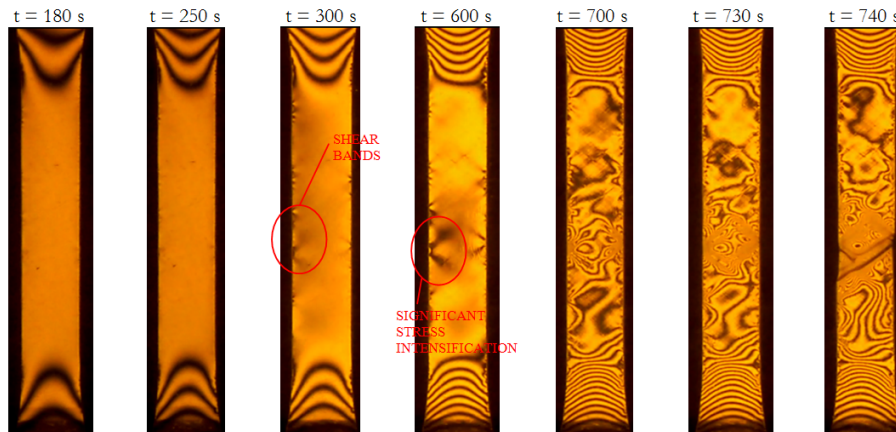


Figure 4: Photoelastic analysis of the specimen during tensile test.

It is possible to observe the incoming of shear bands already from first 300 seconds and therefore assume that stresses of about 47 MPa imply local plasticization. With the increase of crosshead displacements, plastic regions grow in number, time 600 seconds, but only few points become relevant in term of stress concentration.

In particular, as shown in Fig. 4, a significant increase of stress is evident only in one zone. It will be in this zone that the fracture will appear. The photoelastic analysis is coherent with the thermographic evaluation that suggest an increase in temperature at about 300 seconds. The photoelastic analysis is useful to verify the right model for the characterization of the stress-strain curve and the damage criterion in a numerical approximation. The mechanical properties of the material and the tensile test are modeled in Abaqus. In Fig. 5 it is shown a comparison between the photoelastic observation in the ultimate instant of the tensile test and the corresponding situation provided by finite element simulation.

In Fig. 5 the plastic deformations during the tensile test are observed. It is clear that the model approximates well the test both in terms of deformations of the specimen and from the point of view of the damage model.

CONCLUSION

In the present work the mechanical properties of a polymeric material, polycarbonate, were evaluated. Not only a tensile test was performed but also thermographic and photoelastic analyses. The information provided by stress and thermal fields are significant in order to suggest a complete characterization of the material. Thermographic examination helps to correct discern the instant in which the plasticization of some zone begins and with the help of



photoelastic observations these zones can be directly viewed. Photoelasticity is also useful to compare the material modellization in numerical analyses.

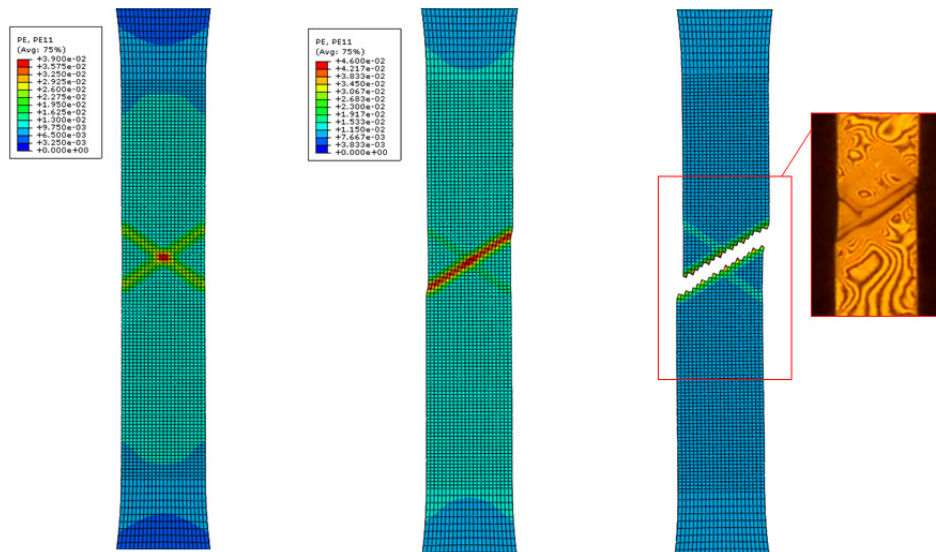


Figure 5: Finite element analysis of the tensile test of polycarbonate.

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