Jerzy BAKUNOWICZ*

THE POLYCARBONATE AS A MODELLING MATERIAL IN PHOTOELASTICITY

POLYKARBONÁT JAKO MODELOVÝ MATERIÁL VE FOTOELASTICIMETRII

Abstract

The paper is focused on the results of the polycarbonate fundamental researches aimed at the material constants identification. Particularly, the optical properties were taken into consideration. The results obtained were illustrated with several examples of polycarbonate practical application in the photoelasticity experiment.

Abstrakt

Příspěvek rozebírá výsledky výzkumu polykarbonátu s ohledem na identifikaci materiálových parametrů. Částečně byly respektovány optické vlastnosti polykarbonátu. Získané výsledky jsou ilustrovány na několika příkladech praktického využití polykarbonátů ve fotoelasticimetrii.

1 INTRODUCTION

A vast group of plastics based on carbon acid polyesters and hydroxide compounds is commonly known as polycarbonates. Taking into consideration their fine properties, the polycarbonates have found application as a constructional medium, displacing the glass and the polymethyl methacrylate effectively, wherever the good transparency is demanded indisputably. Besides ready-made goods, one can find diversity of semi-finished elements of variable geometry. Among them, there are in trade homogeneous, flat plates of thickness from tenths to dozen of millimetres.

The discovery of photoelasticity effect in the polycarbonates was essential from point of view of modelling experiment [1]. The main obstacles in the application of these plastics as modelling materials are difficulties during modelmaking. The process is based on injection moulding method, very expensive, in individual production especially.

The appearance of semi-finished elements range mentioned before made the polycarbonate application easier to a considerable degree, not only limited to flat models, but also extended to spatial structures. But the producer even do not expect such a field of application, though the experimenter is forced to identify the material properties on his own.

This short labour reports the results of the tests of the polycarbonate Makrolon™ produced by Bayer, Germany. They were focused on mechanical and photoelasticity properties identification. Also some general observations about fields of application, modelmaking, and preparation are quoted here.

2 MATERIAL PROPERTIES

The research subject were flat polycarbonate plates from 0.7 to 12 mm thick. The constant thickness is provided during hot-rolling in temperature over the Glass temperature. This is the reason

* Ph.D., Eng. Department of Aircrafts and Aircraft Engines, Faculty of Mechanical Engineering and Aviation, Rzeszów University of Technology, ul. Wincentego Pola 2, 35-959 Rzeszów, tel. (+48) 856 19 23, e-mail bakun@voila.fr

of machining internal stress that cause strain retained when cooling. The optical effect, which is observed in polarized light beam as plain fringe order, is the evident proof. This strain field must not be neglected, because the fringe orders recorded were always high (e.g. for plate 4 mm thick, the order at 3 to 3.5). With, so called, *needle method* help it was found the compressive strain is parallel to the rolling direction. It results in the orthotropy of the optical effect, which one of the principal direction of orthotropy corresponds with rolling direction. Similar undesirable optical effects are caused by mechanical working with improper parameters. Too fast tool movement effects with plastic overheating locally, giving similar strain appearance.

It seems one and only successful method of material annealing is warming up in temperatures between Freezing and Glass temperature (practically 150 centigrade [2]). Some certain regimes should be maintained when warming. Since polycarbonate is hygroscopic body and it accumulates water when stored, the warming process has two stages. First, the model must be dried (24hs, 60 centigrade). Otherwise the water will boil inside the material causing bubbles. Only dried model can be warmed up in the second stage at 150 centigrade. The elements should be flat and pressed to the base, because when warming up the elements tend to stand up. The properly carried process enables to remove the optical effect entirely.

In order to quantitative determination of the optical effect the Stress-optic coefficient K_σ was measured for both principal optical orthotropy directions for material as delivered and for warmed up one also. Three different methods were applied:

- Flat specimen tension [3];
- Half-surface method [4];
- Wheel compression [2].

Every method gave the same result, regardless of the heat treatment (Table 1). High optical sensitivity of the polycarbonate [1] was affirmed in the experiment.

In addition to photoelasticity properties, the course of experiments for mechanical properties determination was led. The main goal arose out of the influence of material thickness and rolling on the properties change. The row of specimens [5] different in thickness and cut along the principal directions was prepared. They allowed finding:

- Young Modulus in exact tension test with strain gages help;
- The stress-strain curve and Tensile Strength in static tension test.

The tests did not show any significant relation between supposed factors and properties measured. Therefore the manufacturing process does not have influence.

Finally, the Poisson Ratio in span-beam bending test was measured by strain gages. The results are collected in Table 1.

The polycarbonate in standard conditions is in forced elasticity glass state. The stress-strain curve has the wide non-linear area (Fig. 1), where birefringence of material is still valid. The optical effect observed has character similar to plastic deformations in metallic materials. It entitles to formulate the qualitative similarity criterion of the stress-strain characteristics.

The mechanical creep did not occur in tests.

Tab. 1 Photoelastic and material properties of Makrolon™ polycarbonate

Stress-optic coefficient	Young Modulus	Poisson Ratio	Tensile Strength
$K_\sigma\left[\frac{N}{mm \cdot fringe}\right]$	$E[MPa]$	ν	$R_m[MPa]$
10	2450	0.42	68

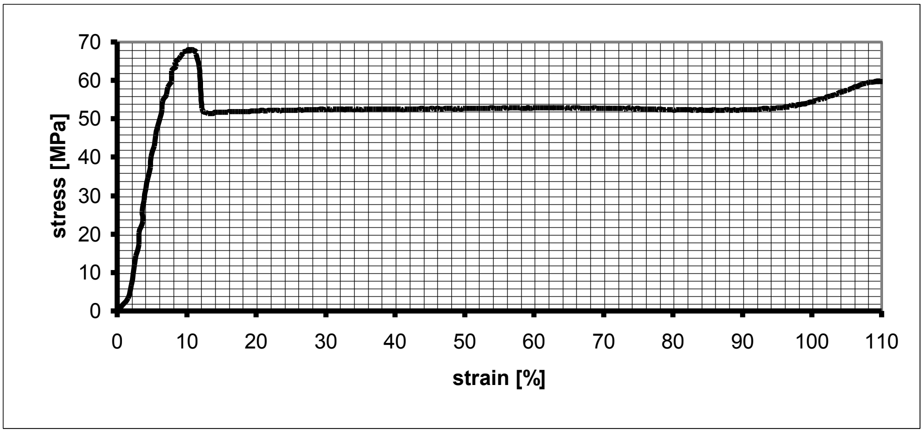

Fig. 1 Stress-strain curve of Makrolon PC

3 APPLICATIONS

The polycarbonates in the form of flat plates mentioned have found a wide application range in model mechanics. It replaced the materials based on the epoxy resins easily, furthermore some kinds of models, difficult or impossible to make before, are within reach. The problem of plates precise casting disappeared.

In the flat models area, like these for fundamental researches, thick plates are used. The geometry is made in milling process.

The excellent constructional features of the polycarbonate create conditions for manufacturing spatial, thinwalled models. Taking into account its high elastic limit and the similarity criterion of characteristics not only the simulation of large postbuckling deformations, but also identification of local zones of destruction, similar to plastic deformation in prototype is possible. (Fig. 2).

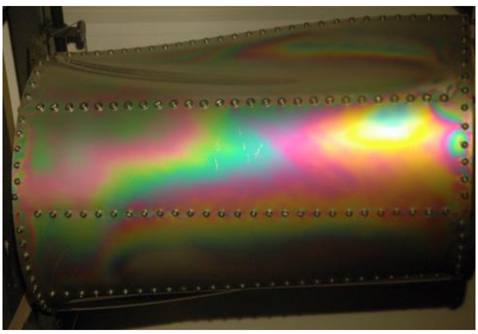

Fig. 2 A large postbuckling deformation of thinwalled structure in constrained torsion [6]

The mentioned similarity criterion was checked for certain basic problems of the elasticity theory and gave proper quantitative results (Fig. 3, on the left).

The next research area is cyclic fatigue loads [e.g. 7]. The raw of various notches and cracks as initiators was examined. At present, the determination of the critical stress intensity factor K_{1C} is on the bench. Exact values of this constant are published rarely [8]. All of these actions are drawing to a formulation of the qualitative similarity criterions for fracture mechanics. The change of plastic mechanical properties during cyclic fatigue should be considered also [9].

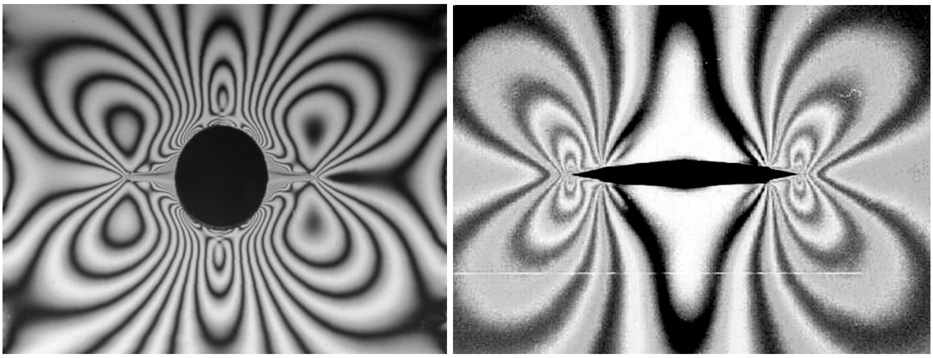

Fig. 3 Optical effect in circular polarized light on thinwalled flat models. On the left: simulation of the plastic deformation around symmetrical notch critical section [GOŁAS, B.; KOPECKI, H. not published]. On the right: crack propagation during cyclic tension [7]

4 CONCLUSIONS

In the context of presented considerations it could be said the described polymer with its photoelasticity, mechanical and constructional features is an excellent modelling material. The spectrum and the range of possible loads are much wider than for other modelling materials. The undesirable optical effect, possible to remove should be remembered.

REFERENCES

[1] CLOUD, G. L. Mechanical-optical properties of polycarbonate resin and some relations with material structure. *Experimental Mechanics*. 1969, IX, Nr. 11, pp. 489-499. ISSN 0014-4851.

[2] WOLNA, M. *Materiały elastooptyczne (in Polish)*. 1st ed. Warszawa - Poznań : PWN, 1993. 230 pp. ISBN 83-01-11270-0.

[3] PINDERA, T. *Reologiczne właściwości materiałów modelowych (in Polish)*. Warszawa : WNT, 1962.

[4] DOROSZKIEWICZ, R. S. *Elastooptyka (in Polish)*. Warszawa – Poznań : PWN, 1975.

[5] ASTM D638-03 *Standard Test Method for Tensile Properties of Plastics*.

[6] KOPECKI, T. Zagadnienia projektowania cienkościennych ustrojów nośnych z uwzględnianiem zaawansowanych stanów defromacji zakrytycznych (in Polish). In *I Kongres Mechaniki Polskiej*. Warszawa : Politechnika Warszawska, 2007, pp. 71. ISBN 978-83-7207-702-8.

[7] ZACHARZEWSKI, J. An experimental investigation of thinwalled plate crack propagation with circular cut-out subjected to cycles axial tension. *Acta Mechanica Slovaca*. 2006, X, Nr. 1, pp. 651-656. ISSN 1335-2393.

[8] LI, C. K.-Y.; XIA, Z.-Y.; SUE, H.-J. Simple shear plastic deformation behaviour of polycarbonate plate II. Mechanical property characterization. *Polymer*. 2000, XXXXI, pp. 6285-6293. ISSN 0032-3861.

[9] LI, X.; HRISTOV, A. H.; YEE, A. F.; GIDLEY, D. W. Influence of cyclic fatigue on the mechanical properties of amorphous polycarbonate. *Polymer*. 1995, XXXVI, Nr. 4, pp. 759-765. ISSN 0032-3861.

Reviewer: prof. MSc. Pavel MACURA, DrSc., VŠB - Technical University of Ostrava