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SHRINKING OF POLYMERS IN TECHNICAL PROBLEMS CONSISTING OF TWO DIFFERENT PARTS DETERMINED BY 3D PHOTOELASTICITY USING GAMMA IRRADIATION

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INTRODUCTION

To solve spatial technical problems by three dimensional photoelasticity it is necessary to fix the optical effect in the model. In order to avoid the well known disadvantages of the classical freezing method ionising irradiation is used for that purpose [1, 2]. With this method it is not necessary to enlarge the scaling-factor for the displacement which is in some cases very important especially when shrinking is used to develop the fringe pattern. In addition fixation with ionising irradiation can be carried out without elevated temperatures. The most important advantage compared with the freezing method is given by the fact that Poisson's ratio of the polymers is in this way practically the same as in the simple two dimensional photoelasticity. This is very important because using the classical freezing method temperature treatment above the glass temperature is needed and in this temperature range Poisson's ration of the polymer is practically the same as in plasticized zones so that by using the classical freezing method it is not possible to distinguish between the elastic and the plasticized zones of the model. The mentioned features were already shown in case of two dimensional contact problem [3]. New materials introduced by Beer at all [2] opened additional possibilities in modelling more complex problems. However dealing with models consisting of two (or even more) different parts we have to keep in mind that shrinking in such models causes residual stresses and for that reason an accompanying rheological process is going on.

METHODS

Fixation procedure

The classical photoelastic calibration procedure [4] was used in order to study the fixing phenomenon. Fixed were the fringe pattern in a circular loaded disc by gamma irradiation. Fig.1 shows the procedure in which three different phases are distinguished. Because the fringe distribution in the loaded model is also influenced by creep, a creep phase before the actual fixing phase was applied in order to distinguish between the influence of creep and fixation on the final observed fringe pattern. Shown is the ratio k between the observed fringe values *"n"* as a function of the process to the applied one in the middle of the disc. The creep phase was as long as necessary to calculate the influence of creep also during the fixation phase.

$$k = \frac{n_{\xi=0,\eta=o}(t)}{n_{\xi=0,\eta=o}(0)} \qquad (1)$$

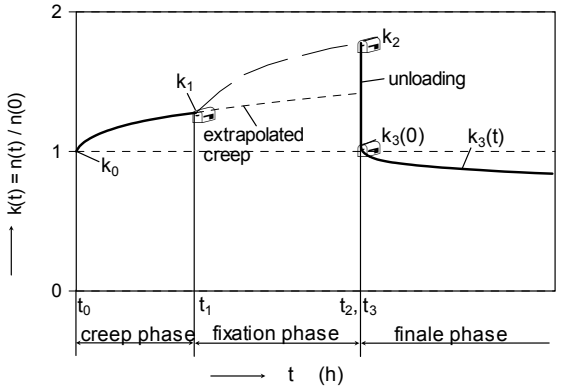

fig. 1 Fixation procedure

Fig 1 shows that during the fixation phase the observed fringe pattern *"n"* are more or less strongly increasing however with an decreasing slope due to the decreasing ability of crosslinking with an increasing dose of irradiation. After unloading the fringe pattern are fixed nearly at the same magnitude as the applied one. That means that it is necessary to start up with a material with remaining ability of polymerisation.

However keeping in mind that the fixation of photoelastic fringe pattern by gamma irradiation is always accompanied by shrinking some limitations

are caused by this fact. But shrinking of homogenous material in a homogenous irradiation field does not cause any anisotropic effect. That means the fringe pattern fixed by gamma irradiation are not influenced by this homogenous shrinking. Except in cases were the models consists of two or more parts with different shrinking abilities in which residual stresses are caused and fixed in this way. Therefore that under the mentioned circumstances shrinking can also be used to solve technical problems connected with shrinking by photoelasticity without additional consideration forced by the accompanying rheological processes due to the arising and increasing residual stresses caused by accompanying shrinking.

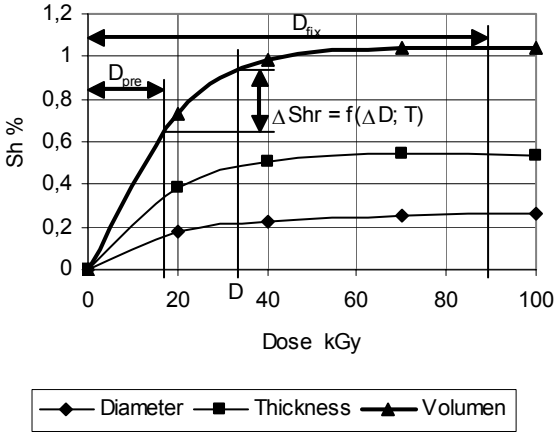

fig. 2

Fig. 2 shows the shrinking of the diameter of the disc used in the calibration procedure, perpendicular to the loading axes as a function of the applied doses *D* for the material under consideration. As certain degree of pre-polymerisation is necessary [1, 2] to machine the model used in the calibration procedure (s. fig. 1). During the fixation phase an additional shrinking occurs as a function of difference $\Delta D=D_{fix}-D_{pre}$. With this value the shrinking of the model is finished if $D_{fix}>D_{sat}$ where saturation is reached. An accompanying measurement of the diameter of the disc perpendicular to the loading axes can be described using the basic equation for photoelasticity [4] as follows

$$\frac{(S_\sigma n)_{loading}}{(S_\sigma n)_{unloading}} \approx \frac{D}{D_0} \qquad (2)$$

S_σ....determined photoelastic coefficient
n (0,0).... fringe value in the middle if the disk

This is a prove for the fact that shrinking during the fixation phase did not influence the photoelastic pattern.
If we use two parts of the same material but with different pre-polymerisation equation (3) is a measure of difference of shrinking.

$$\Delta Shr = f(D_{pre}^{(2)} - D_{pre}^{(1)}) = f(\Delta D_{pre}^{(1,2)}) \qquad (3)$$

However of the different parts of such a model, the shrinking is accompanied by increasing state of residual stresses.

APPLICATION

Experiments were carried out with double Beams consisting of thermally (up to saturation) polymerized Araldit B glued to beams made from material D [2], pre-polymerized by gamma irradiation with 2, 3, 5 and 10 kGy. Fig. 3 shows the darkfield and lightfield isochromatic pattern for the model in which material was pre-polymerized with 2 kGy.

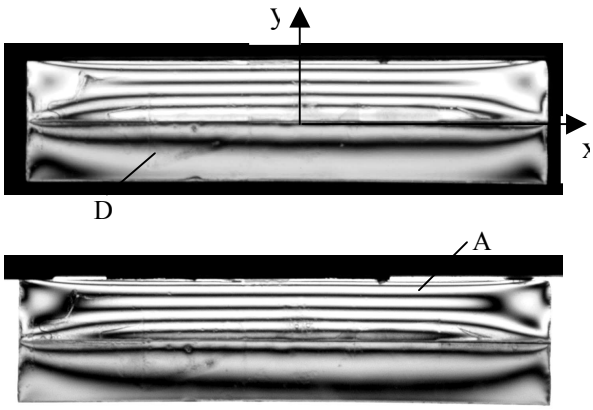

fig. 3

Except of the St. Venant regions of the end of the beam the isochromate pattern shows in both parts practically a superposition of pure bending with axial stretching. A visual inspection of the pictures show nearly no difference. For that reason only for the experiments carried out with Material D pre-polymerised with 2 and 10 kGy the fringe distributions in the middle of the beam, x=0, as a function of the ordinate y are shown in Fig. 4.

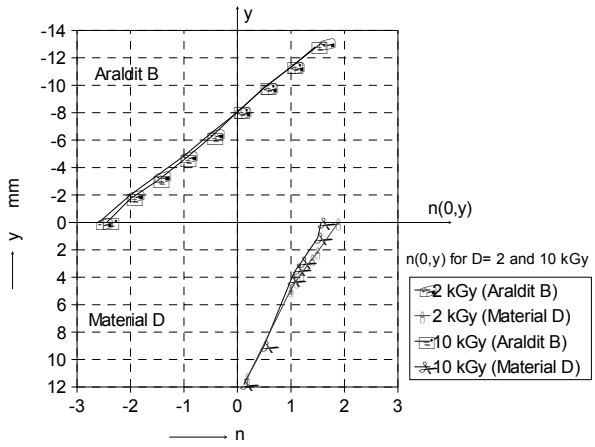

fig. 4

The fringe pattern for these experiments demonstrates that only in the contact region a small difference in fringe distribution occurs in the in the vicinity of the contact area. A close inspection of the fringe values in $y=0^+$ (Araldit) and in $y=0^-$ (Material D), see Fig. 7, is shown in Fig. 5 and Fig. 6.

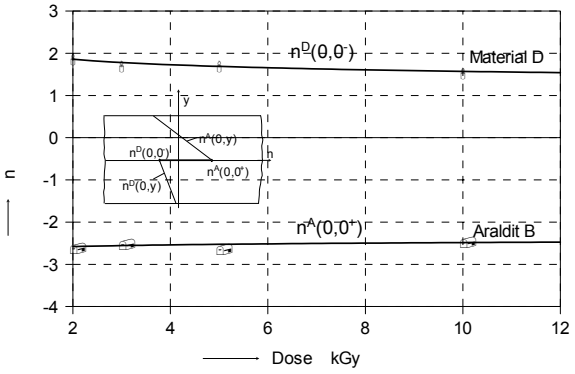

fig. 5

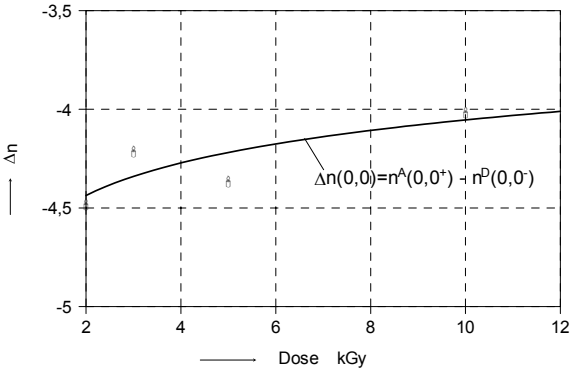

fig. 6

Fig. 5 shows the fringe values $n^A(0,0)$ and $n^D(0,0)$ as a function of applied dose for pre-polymerisation of Material D. This result correspond to the fact that the isochromatic pictures are not easy to distinguish by a pure visual inspection. However it demonstrates for the materials used the shrinking effect and the accompanying rheological effect balance one and other. Fig. 6 taken from Fig. 5 demonstrates this fact too.

STRESSES NORMAL TO THE CONTACT AREA

To determine the stresses σ_2 in the contact area (x, y=0) an additional analysis of the photoelastic informations (isoclinics) would be needed. The following analysis is concerned on the physical mechanism of this process and restricted to the symmetry axes (x=0,y) which is of course an isoclinic (φ=0) equ. 4.

$$\left(\sigma_1-\sigma_2\right)_{x=0,y}=\frac{S_\sigma}{t}n(0,y) \qquad (4)$$
$$=\sigma_1(0,y)-\sigma_2(0,y)$$

where $n(0,y)$ is the experimental information.

We use the equilibriums conditions

$$\int_{-h_2}^{h_1}\sigma_1(0,y)dy=0\,,\quad \int_{-h_2}^{h_1}\sigma_1(0,y)ydy=0 \qquad (5.1,\ 2)$$

for the analysis of the photoelastic information.

Approximative determination of $\sigma_{1,2}(0,y)$

$$\sigma_1(0,y)=\frac{S_\sigma}{t}n(0,y)+\sigma_2(0,y) \qquad (5.3)$$

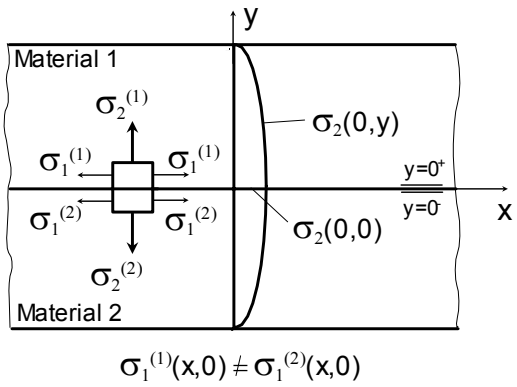

fig. 7

Keeping in mind that at the area $(x,y=0)$ where both partners are glued together we have the following condition for σ_2

$$\sigma_2^{(1)}(x,0)=\sigma_2^{(2)}(x,0) \qquad (6.1)$$

$$\sigma_2^{(1)}(x,h_1)=0\,;\quad \sigma_2^{(1)}(x,h_2)=0 \qquad (6.2,3)$$

Because $h_1\approx h_2=h_m$ and the conditions eqs. (6.1-6.3) we use a quadratic approximation for $\sigma_2(0,y)$

$$\sigma_2(0,y)=\sigma_2(0,0)\left(1-\frac{y^2}{h_m^2}\right). \qquad (7)$$

With this approximation (7) the equilibrium conditions (2), (2.1) takes the form

$$\frac{S_{\sigma 2}}{t}\left[\int_{-h_2}^{0}n(0,y)dy+\kappa\int_{0}^{h_1}n(0,y)dy\right] \qquad (8.1)$$
$$=-\frac{4}{3}\sigma_2(0,0)h_m$$

$$\frac{S_{\sigma 2}}{t}\left[\int_{-h_2}^{0} n(0,y)ydy + \kappa\int_{0}^{h_1} n(0,y)ydy\right] = 0 \qquad (8.2)$$

where $\kappa = S_{\sigma 1} / S_{\sigma 2}$.

From (8.2)we made calculate

$$\kappa = -\int_{-h_2}^{0} n(0,y)ydy \Big/ \int_{0}^{h_1} n(0,y)ydy \qquad (9.1)$$

With eq. (9.1) follows $\kappa \approx 0{,}3$. This value corresponds to the real ratio of the stress-optical coefficients of the materials used in these experiments. Using this result the values $\sigma_2(0,0)$ (see fig. 7) can be calculated using the equilibrium condition (8.1). For the models in which material D was pre-polymerized with 2 and 10 kGy eq. 8.1 yields

$$\sigma_2^{2kGy}(0,0) = -0{,}264 \text{ N/mm}^2$$

$$\sigma_2^{10kGy}(0,0) = -0{,}248 \text{ N/mm}^2$$

With the other models the values for $\sigma_2(0,0)$ are practically the same as for the model in which material D was pre-polymerized with 10 kGy. This corresponds to the results shown in fig. 5 and 6.

NUMERICAL MODELLING

Shrinking was modelled by atemperature difference between the two parts of compounded beams. In a pre-calculation the temperature difference was applied step by step up to an assumed final difference. The rheological behaviour was modelled by a three-parameter solid [5]. The calculations were done using the FEM program MSC.Marc 2001. The relaxation time τ were choosen by experience.

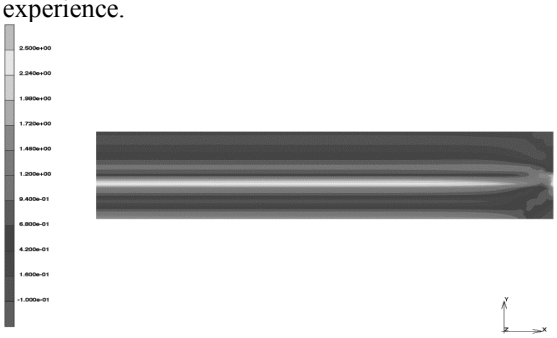

fig. 8

Fig. 8 shows the calculated fringe pattern. Keeping in mind that colour-sequence in photoelastic pictures is quite different to that in the presentation of the numerical result the comparison with the experimental determined fringe pattern was finally quite good. Fig. 9 shows the shear stresses $\sigma_{xy}(x,0)$ in the St-Venant region at the end of the beam. The calculated value of the jump $\Delta\sigma_1(x,0)$ of $\sigma_1(x,0)$ across the contact area (x,0) is 3.54 N/mm^2 whereas the experimentally determined value of $\Delta\sigma_1(x,0)$ (calculated from the result show in fig. 6) is 3,7 N/mm^2. This value is about 16% greater than the numerical one (based at the experimental result) which means that the assumed relaxation= time for the numerical simulation should be corrected.

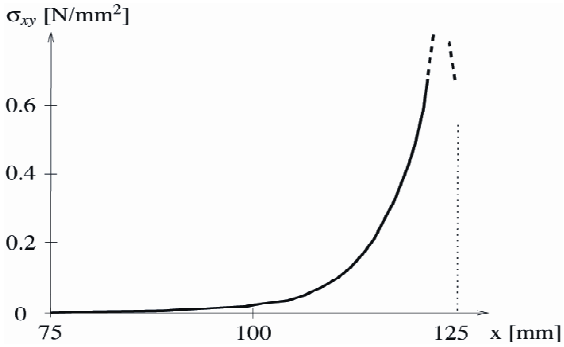

fig. 9

CONCLUSION

Shrinking due to gamma irradiation of polymer is unavoidable. However in case of problems where the model consist of different parts with different shrinking abilities this process is accompanying by arising of residual stresses causing rheological reaction that means a relaxation effect to lower and finally balancing the shrinking effect.

The results of the photoelastic investigation can be used to determine the necessary parameter for a numerical calculation. In this way it is possible to distinguish between the shrinking and the rheological effect.

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