Estonian Journal of Engineering, 2013, **19**, 4, 292–297 doi: 10.3176/eng.2013.4.04

A new method for tempering stress measurement in glass panels[1]

Hillar Aben[a,b], Johan Anton[a,b], Mart Paemurru[b] and Marella Õis[a,b]

[a] Institute of Cybernetics, Tallinn University of Technology, Akadeemia tee 21, 12618 Tallinn, Estonia
[b] Glasstress Ltd, Akadeemia tee 21, 12618 Tallinn, Estonia

Received 14 October 2013

Abstract. It is shown that in tempered glass panels the edge stress and the thickness stress are closely related. Therefore the traditional edge stress measurement gives information also about the thickness stress and the surface stress. Thus for complete analysis of stresses near the edge of a glass panel only the edge stress measurement is needed.

Key words: glass, photoelasticity, tempering stress, edge stress.

1. INTRODUCTION

To check the resistance of tempered glass panels, stress at the surface is to be measured [1]. For that different devices can be used. These devices are comparatively expensive and not all glass factories can afford them. At the same time, by controlling stresses in tempered glass panels, especially in automotive glazing, edge stress measurement is often used [2–5]. Edge stress can be measured with simple polariscopes and several companies manufacture edge stress meters, either manual or automated ones.

Figure 1 (left) shows a photoelastic fringe pattern in a light-field circular polariscope near the edge of a tempered glass panel of 6 mm thickness. The dark stripe on the left is the image of the chamfered edge of the panel. Figure 1 (right) shows the edge stress distribution. In checking automotive glass panels the most important is the area A, where the average stress through the thickness of the

---

[1] This paper was first published in *GPD Glass Performance Days Finland 2013 – Conference Proceedings 13–15 June, Tampere, Finland* (Glass Performance Days, 2013, pp. 216–217). Published with permission of the copyright holder.

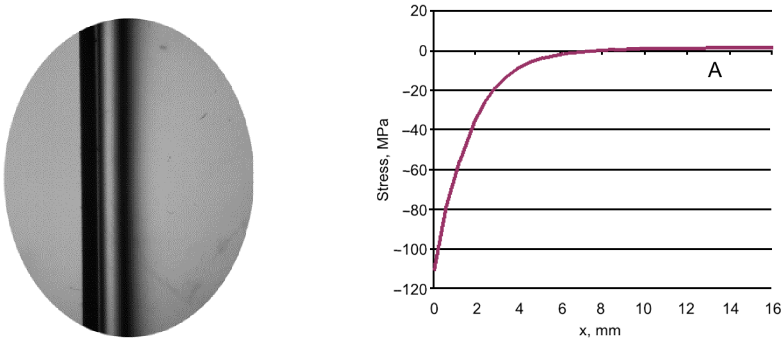

Fig. 1. Photoelastic fringe pattern in a light-field circular polariscope near the edge of a 6 mm thick glass panel (left) and membrane stress distribution (right).

panel is tensile. According to Gulati [6], in this area a delayed crack growth may take place. However, since the thickness stresses are not known, traditional edge stress measurement gives no information about the real surface stresses in the area A and no information is obtained about the thickness of the compressive layer near the surfaces of the panel.

Let us mention that since at the edge of the panel the stress component, perpendicular to the edge, is zero, the stresses at the edge can be correctly determined from the photoelastic image using extrapolation. Inside the panel the stress component, perpendicular to the edge, is different from zero and the photoelastic image does not allow determining separately the stress component parallel to the edge. Both stress components can be determined using e.g. the oblique incidence method [7]. We applied the oblique incidence method for the panel shown in Fig. 1. It was established that up to the distance of 15 mm from the edge the influence of the stress component, perpendicular to the edge, was negligible.

It is evident that the edge stress σ_e and the thickness stress σ_t must be in correlation, and knowing one of them it should be possible to obtain certain information about the other. The aim of this paper is to establish the correlation between the edge stress and the thickness stress in 6 mm tempered glass panels. It is shown that a simple linear relationship exists between the edge and thickness stresses. Therefore measurement of the edge stress gives also the value of the surface stress and real stress distribution in the zone of the average tensile stress. Thus the edge stress measurement is made much more informative than until now.

2. EXPERIMENTS

We ordered from a glass tempering factory 12 glass panels of 100 mm × 300 mm × 6 mm with different degree of tempering, with surface stress σ_s from zero (annealed glass) up to 120 MPa. We measured in all the specimens the edge stress σ_e with the polariscope AP-07 (Glasstress Ltd.), shown in Fig. 2. Since the edges of the specimens were chamfered, extrapolation of stresses near the edge was carried out with a polynomial of 4th degree. Figure 1 (right) shows typical results of an edge stress measurement (in panel No. 8).

The surface stress σ_s in all the specimens was measured with the scattered light polariscope SCALP (Glasstress Ltd.; Fig. 3, left). Figure 3 (right) shows the distribution of the thickness stresses near the surface of panel No. 8. Figure 4 shows the relationship between the edge stress and the surface stress. Considering the inhomogeneity of the residual stress in tempered glass panels [8], the surface stress values in Fig. 4 are the average of 5 measurements. The correlation equation is the following ($R^2 = 0.9405$):

$$\sigma_s = 1.0493\sigma_e + 1.7663, \text{ MPa}. \tag{1}$$

Thus, somewhat unexpectedly, the surface stress in the investigated tempered glass panels was practically equal to the edge stress. That opens up the possibility of determining the whole residual stress distribution near the edge of the panel on the basis of edge stress measurement.

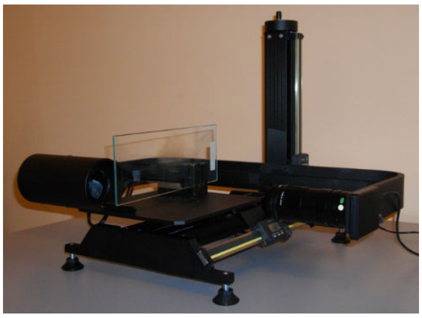

Fig. 2. Edge stress measurement with the automatic transmission polariscope.

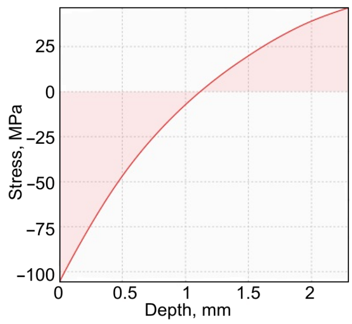

Fig. 3. Surface stress measurement with the scattered light polariscope (left) and thickness stress distribution near the surface (right).

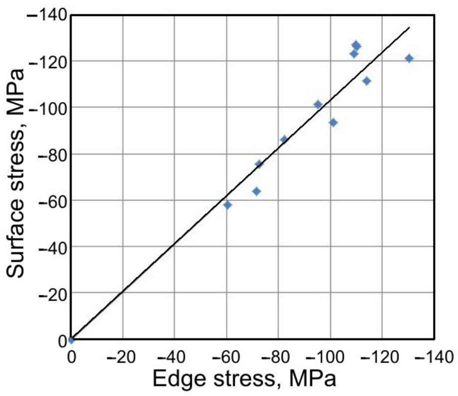

Fig. 4. Relationship between the edge stress and the surface stress in case of 6 mm thick glass panels.

Let us underline that our experiments were carried out with specimens of 6 mm thickness. Some experiments we made with glass panels of 4 and 8 mm thickness showed that an almost linear relationship existed between the edge and surface stresses also in these cases. However, detailed investigation, similar to that described above, is needed for glass of different thickness. Besides, to a certain extent the relationship between the edge stress and the thickness stress may depend on the type of the tempering oven.

3. COMPLETE STRESS ANALYSIS NEAR THE EDGE

Thus standard edge stress measurement gives us the value of the edge stress σ_{e}, the average membrane stress σ_{m} through the thickness in the area A and the surface stress σ_{s}. The distribution of the thickness stress can be approximated as a second-order parabola

$$\sigma_{\mathrm{t}} = \sigma_{\mathrm{t}_0}\left[1 - 3\left(\frac{2z}{t}\right)^2\right]. \tag{2}$$

Here σ_{t_0} is the stress in the midsurface of the panel, t is the thickness of the glass panel and z is the coordinate perpendicular to the midsurface. Figure 5 shows the distribution of the thickness stresses σ_{t}, of the membrane stresses σ_{m} in the area A in panel No. 8 and of the summary thickness stress σ_{sum} in the area A, calculated as

$$\sigma_{\mathrm{sum}} = \sigma_{\mathrm{t}} + \sigma_{\mathrm{m}}. \tag{3}$$

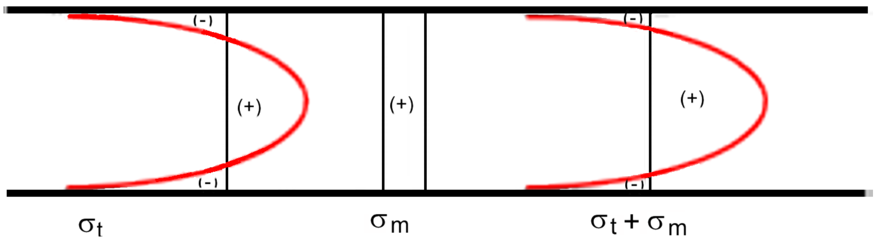

Fig. 5. Distribution of the parabolic thickness stress σ_t, average membrane stress σ_m through the thickness in the area A and the summary stress σ_{sum} through the thickness in the area A.

Figure 5 shows the real thickness stress distribution in the area A, where the average membrane stresses are tensile. It permits one to determine the real surface stress $\sigma_{s,real}$ in this area:

$$\sigma_{s,real} = \sigma_s + \sigma_m. \tag{4}$$

Since $\sigma_s < 0$, according to Eq. (4) the positive membrane stress diminishes the surface compression. Equation (4) gives the real value of the surface stress in the area A. Besides, it gives also the thickness of the compression zone.

4. CONCLUSIONS

It was shown that the traditional edge stress measurement gives information also about the thickness stresses in tempered glass panels. The relationship between the edge stresses and the thickness stresses was experimentally established for glass panels of 6 mm thickness. In the particular case considered in this paper the surface stress was practically equal to the stress at the edge of the panel. Thus complete analysis of stresses near the edge of the panel can be carried out including determination of the real thickness stress distribution in the zone of average tensile membrane stresses and of the thickness of the compression zone near the panel surfaces. This makes the traditional edge stress measurement much more informative than considered until now.

REFERENCES

1. Aben, H., Anton, J. and Errapart, A. Modern photoelasticity for residual stress measurement in glass. *Strain*, 2008, **44**, 40–48.
2. Redner, A. S. Stress measuring methods for quality control and process optimization in glass. In *Proc. Conference "Modelling of Glass Forming and Tempering"*. Valenciennes, 2002, 269–275.
3. Redner, A. S. Automated measurement of edge stress in automotive glass. In *Proc. Conference "Glass Processing Days"*. Tampere, 2003, 1–2.

4. Ajovalasit, A., Petrucci, G. and Scafidi, M. Measurement of edge residual stresses in glass by the phase-shifting method. *Opt. Lasers Eng.*, 2011, **49**, 652–657.
5. Ajovalasit, A., Petrucci, G. and Scafidi, M. Photoelastic analysis of edge residual stresses in glass by automated "test fringes" methods. *Exp. Mech.*, 2012, **52**, 1057–1066.
6. Gulati, S. T., Hagy, H. E. and Bayne, J. F. Delayed cracking in automotive windshields. *Mater. Sci. Forum*, 1966, 210–213, 415–424.
7. Aben, H. and Guillemet, C. *Photoelasticity of Glass*. Springer, Berlin, 1993.
8. Anton, J., Errapart, A., Paemurru, M., Lochegnies, D., Hödemann, S. and Aben, H. On the inhomogeneity of residual stresses in tempered glass panels. In *Proc. Conference "Glass Performance Days 2011"*. Tampere, 2011, 119–121.

Uus meetod klaaspaneelide karastuspingete mõõtmiseks

Hillar Aben, Johan Anton, Mart Paemurru ja Marella Õis

On näidatud, et klaaspaneelide serva- ja pinnapinged on korrelatsioonis. Seega annab traditsiooniline servapingete mõõtmine infot ka pinnapingete kohta. Klaaspaneelide jääkpingete täielikuks määramiseks serva läheduses piisab ainult servapingete mõõtmisest.