Inline measurement of residual stresses in large format objects

According to Gregor Saur and Henning Katte, StrainScanner is the first fully automatic measuring system that allows a precise and fast measurement of residual stresses and their orientation in real-time. Accurate and reproducible measurement make applications possible that previously could not be realised directly in the production process. The equipment's scaleability allows flexible use in a wide range of applications.

The StrainScanner, the latest development from ilis of Erlangen, Germany is an imaging inline polarimeter system for the automatic and continuous measurement of residual stresses directly in the production process. Tempered flat glass, optical raw glass and display glass are analysed directly in the process with the highest accuracy and reproducibility. In addition to the advantage of objective documentation of all measurement results, 100% inspection and automatic evaluation enable optimisation and improved control of the production process. In thermally toughened flat glass, a novel calculation method also allows the objective determination of visually disturbing so-called anisotropies.

The measuring instruments of the StrainScope series, already successfully introduced by ilis, enable the objective measurement of the stress distribution in real-time and thus fulfil the fundamental requirement for 100% inspection of production. However, due to the limited image field size, measurement is limited to rather small objects, for example bottles. Large objects such as flat glass or raw glass blocks could not be measured directly in the production process so far. The latest StrainScanner makes the measurement accuracy known by the StrainScope now also available for continuous production processes and large formats by capturing the moving objects segmentally by several cameras and assembling the individual shots to an overall image.

Basics of photoelasticity

Polarised light changes its properties while passing through a birefringent medium. While many of the crystalline materials are birefringent, amorphous materials such as glass only show this behaviour when mechanical stresses are present. This effect is called stress birefringence. In general, optical retardation is used as a measure of stress birefringence.

The determination of stress birefringence takes place in a polariscope setup: The measuring object is placed between two crossed polarising filters and illuminated with a monochromatic light source. The background appears dark, as the second polarising filter (called the analyser) is oriented perpendicularly to the transmission direction of the first filter, thereby blocking the transmitted light. Stresses in the measuring object lead to an alteration of the polarisation angle by the effect of birefringence and therefore to a brightening of strained areas, which is proportional to the underlying stresses (figure 1, left). The quantification of the optical retardation is then carried out by a simple intensity analysis.

However, the intensity is also dependent on factors other than stresses, in particular the brightness of the light source and the transmittance of the measuring object, which on the other hand is influenced by the thickness, colouration and coatings. Therefore, the intensity evaluation has to be calibrated elaborately for each product.▸

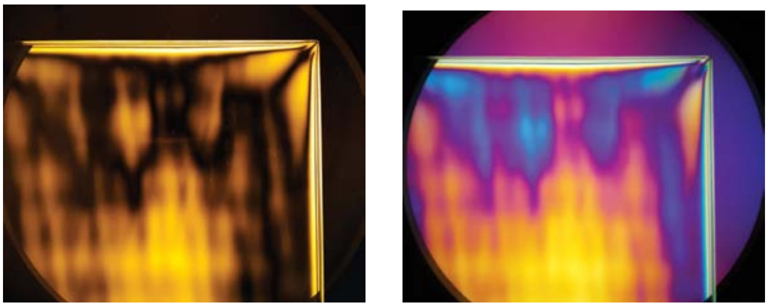


Figure 1: By using crossed polarising filters, brightening in areas with residual stresses are visible in the polariscope picture of a tempered glass pane (left image). When using white lighting (right image), interference effects result in a coloured picture.

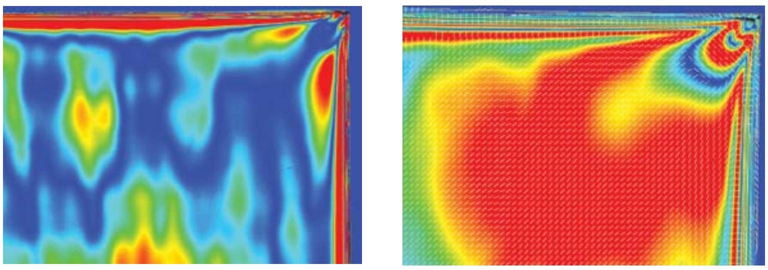


Figure 2: With linear polarised illumination (left image), only stresses in two specific orientations are determined correctly. Under circular polarised illumination (right image), stresses in all orientations are measured correctly with the amount and direction.

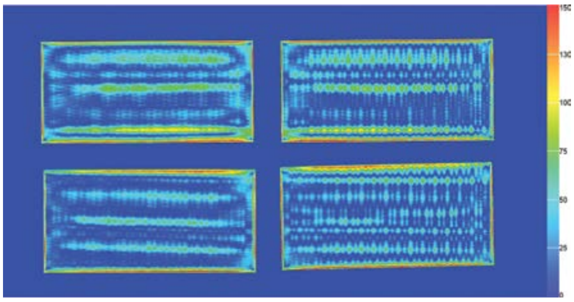


Figure 3: Stress distribution is measured in real-time and displayed as a false colour image.

Figure 4: Typical anisotropy phenomena in architectural glazing. The glass pane in the middle of the image has been produced in an isotropy-optimised toughening process and shows no disturbing optical effects (photo courtesy of arcon).

Figure 5: In co-operation with arcon, the first inline StrainScanner was installed in Feuchtwangen for the objective and continuous measurement of the quality of toughened safety glass (photo coutesy of arcon).

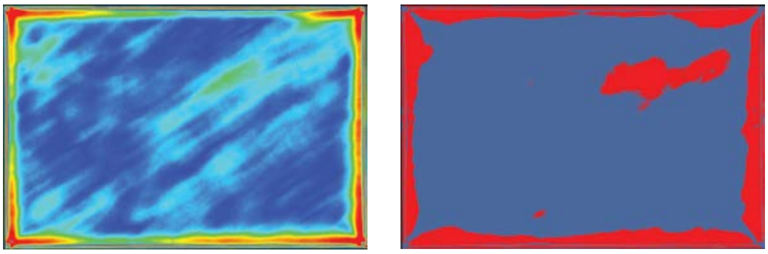


Figure 6: Based on the measured vectorial stress data of a glass pane (left image), the anisotropy simulation visualises unwanted anisotropic effects under the most unfavourable lighting conditions.

By using a white light source, a colour image can be generated with an additional optical element (first order red) between the measuring object and the analyser. The different interference colours correspond to different levels of stress (figure 2, right). Determination of the optical retardation is then done with the help of colour tables. Coatings, colourations and the influence of the light source can also falsify the measurement result.

The dependence on the illumination and properties of the measuring object can be avoided by a rotatable analyser. This setup is called a polarimeter. For the measurement itself, the rotation angle of the analyser is determined at which the intensity at the measured point is minimal. The desired optical retardation value is directly proportional to the measured angle and can easily be calculated from it.

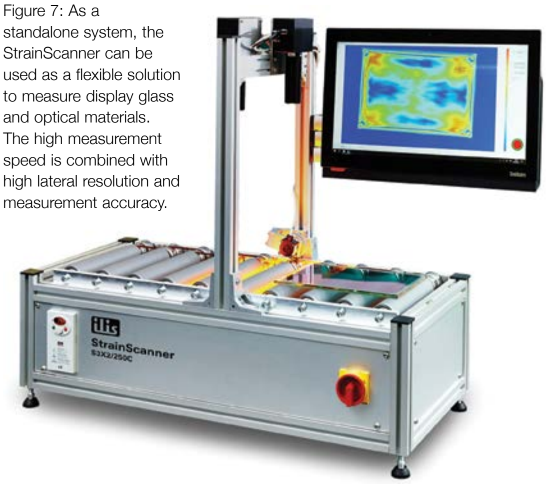
Automatic measurement

The time-consuming and mechanically vulnerable rotation of the analyser can be avoided by using a special polarisation-resolving camera. The StrainCam used in the StrainScanner, which is also utilised in the StrainScope, calculates the optical retardation for each pixel without any moving part and delivers, in addition to the grey value image, a high resolution stress image of the measuring object in real-time.

Normally, a monochromatic linearly polarised light source is used for illumination. In linear polarisation, however, the generated optical retardation is dependent on the orientation of the stresses (mechanical stresses are forces and thus vectors). If the stresses are orientated in 45° to the transmission direction of the polariser, the measured value corresponds to the retardation sought. In the case of orientation parallel to the polariser, the measured value is zero (figure 2, left). In general, however, orientations of the stresses in a measuring object are neither known nor constant over the area. In order to determine the actual stresses using linear polarised illumination, it is necessary to perform several measurements under different polarisation angles and to superimpose the individual results appropriately. However, this approach contradicts the requirement of real-time capability.

For this reason, a circularly polarised light source is used in the StrainScanner. This allows the determination of optical retardation, independent of orientation. In addition to the amount of stress, the StrainCam also provides orientation information (azimuth angle) for each pixel (figure 2, right).

Figure 7: As a standalone system, the StrainScanner can be used as a flexible solution to measure display glass and optical materials. The high measurement speed is combined with high lateral resolution and measurement accuracy.



Continuous measurement

In the StrainScanner, the entire width of the measuring object is captured by several adjacent StrainCams. Lengthwise, the measuring object moves on a roller table underneath the cameras. The individual images of the cameras are then automatically assembled, taking the speed of the transport rollers into consideration.

This results in a continuously updated live image of the measurement objects, the stress distribution of which is visualised in false colour display, similar to what one would expect from thermal imaging cameras (figure 3). The StrainScanner automatically detects individual measuring objects in the live image. If several measuring objects are in the image at the same time, they are segmented and can be analysed and stored separately. In this way, stress optical effects can be correlated with the previous production process.

Anisotropies in flat glass

An important application of the StrainScanner is the objective measurement and evaluation of optical anisotropies in thermally toughened architectural glass. Anisotropies are caused by irregularities in the tempering process and are noticeable as undesirable spots or streaks in partly polarised sunlight (figure 4).

In co-operation with the company arcon, a pilot facility has been realised in Feuchtwangen, Germany, which continuously scans glass panes in the format of up to 3m x 6m, in a resolution of 2.7mm and a speed of 500mm per second (figure 5).

The measurement values are used as input for the calculation of the isotropy value developed by arcon, as well as the so-called anisotropy simulation. The isotropy value is the surface portion of the glass pane, which is free from disturbing anisotropic effects, even under the most unfavourable lighting conditions (figure 6). The anisotropy simulation is an intuitive visualisation of the disturbing effects on the pane. Contrary to other methods, this calculation considers the viewing angle with respect to the glass pane.

Display and optical glasses

The size of the StrainScanner is almost freely scaleable to the application. Whereas in the measurement of anisotropies in architectural glass it is necessary to cover large widths of up to 3300mm, in other applications a small field of view is sufficient for the benefit of a higher lateral resolution. As an alternative to the inline version, which is installed directly in the existing production process, StrainScanner is also available as a standalone system with its own roller table. This makes the equipment an ideal solution for applications in which a fast yet precise measurement is required, for example the testing of optical materials and display glass (figure 7). ●

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