Objective measurement of residual stresses

Mechanical stresses can impair the fracture strength and processing ability of glass products. Testing for residual stresses is therefore an important constituent of quality control. Henning Katte* explains a new way of measuring glass stresses in real time.

Fig 1. StrainMatic M2/250 polarimeter system for automatic and objective measurement of residual stresses in container glass.

For decades, manually operated polariscopes and polarimeters have been the standard method for testing the level of residual stress in glass, according to the standard test methods for polariscopic examination of glass containers (ASTM C148).

Polariscopes visualise stress by creating false colours that can be visually compared to reference standards (strain discs or retardation scales) in order to determine the magnitude of stress, but this method is qualitative rather than quantitative and does not work for coloured glasses. Polarimeters, on the other hand, allow a quantitative measurement by determining the stress-induced polarisation change with a rotatable analyser.

However, the measuring results obtained with manually operated polarimeters are strongly dependent on the operator and therefore subjective. In addition, coloured glass is difficult to measure since the intensity of the light source is often not sufficient for a reliable measurement. The results of statistical gauge repeatability and reproducibility (R&R) tests show that the reproducibility achieved with this method is not acceptable.

Automatic measurement

The automatic StrainMatic polarimeter system (***fig 1***) has been developed to eliminate the influence of the operator on the measurement results, to obtain reliable measured values. Measurement and evaluation are fully automatic here; the operator has only to select the suitable programme (in which parameters such as article height and diameter are defined) and begin the measurement. ***Fig 2*** shows the measuring result on a bottle sidewall in false colour display (blue represents low values, green/yellow for medium and red for high values). The area with the highest residual stress is detected automatically and compared with predefined limiting values.

In the case of container glasses, usually only the base is measured, since experience has shown that residual stresses are most critical there due to the contact with the conveyor belt. To enable non-destructive measurement, the camera automatically moves close to the neck finish. ***Fig 3*** shows typical measurements for the base of a food jar. The measured values are displayed in the unit of apparent or real temper number (according to ASTM C148).

The reproducibility of the measurement is in the range of 1/10 temper number, which allows accurate differentiation of the results depending on the position in the annealing lehr and the IS machine. The StrainMatic has been in use for several years and besides quality control, the main purpose of the instrument is the optimisation of the glass annealing process. It has been indicated by several projects that energy consumption can be reduced significantly by consistent optimisation of the annealing lehr settings on the basis of accurate stress measurements.

Real-time measurement

However, a typical measuring time of 20 seconds limits throughput, so that the test consists of random sampling downstream from production. To accelerate the measurement and enable higher testing frequency, a new product line has been developed. The StrainScope (***fig 4***) is capable of measuring and visualising stresses in glass in real time and can be used wherever conventional polariscopes and polarimeters are still used today. The StrainScope can deliver objective and reproducible values, thus reducing the influence of different operators on the measuring result.

At the heart of the instrument is the StrainCam; an intelligent camera that delivers a stress value for every pixel in addition to the grey-scale image. The StrainCam is also available on its own for direct integration on production and testing lines. With a frequency of 600 measurements per minute, the complete production process can be tested, and therefore defects can be avoided.

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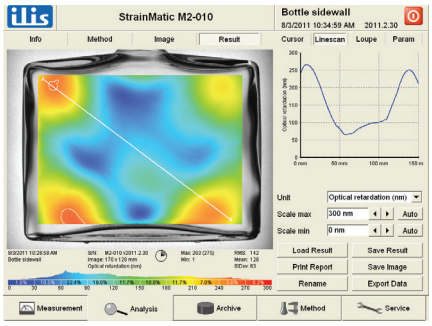
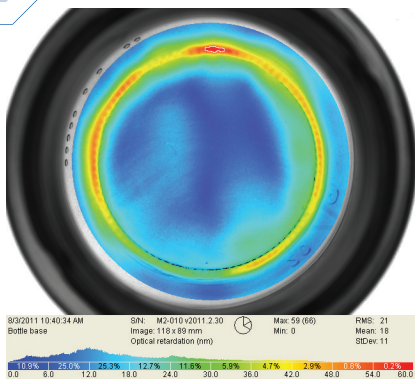
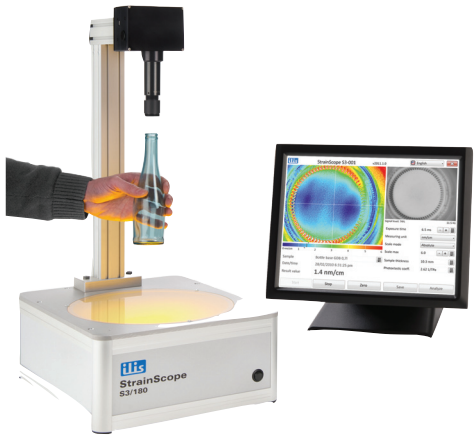
Published in Glass International September 2011



▲ Fig 2. Operator interface of the StrainMatic with measuring result.



▲ Fig 3. Residual stress distribution in the base of a container glass.



▲ Fig 4. StrainScope S3/180 polarimeter system for automatic measurement of residual stresses in real time.

Fig 5 shows a screenshot of the StrainScope operator interface. The large coloured image shows the stress distribution of the sample (in this case the base region of a beverage bottle) within the field of view of the camera. In addition, a grey-scale image is displayed in the upper right corner for orientation. Since the handling is manual, even narrow-neck bottles can be inspected in a non-destructive way by tilting the sample accordingly. The reported result value refers to the crosshairs in the image centre. By pressing the stop button, which can also be activated by a foot switch to keep hands free, the current image is frozen and can be saved to disk for documentation purposes. In addition, the result value can be automatically transferred to a QA system via RS-232/422/485.

Repeatability test

In order to determine the reliability of the three measuring methods (manual with a standard polariscope, automatic with StrainMatic, semi-automatic with StrainScope) a gauge R&R study was conducted. For this purpose, eight food jars with different stress levels were measured with each instrument. Each sample was measured three times by three different operators, resulting in a total of 72 measurements per instrument.

A measure for the suitability of a testing method is the total gauge R&R percentage value, which is calculated from the measurement results. A high value expresses a large operator influence. In effect, gauge R&R values below 30% are considered acceptable, values below 20% are good and values below 10% are excellent. The results showed that the StrainMatic ranked best with a total gauge R&R value of 6%, followed by the StrainScope with 18% and the standard polarimeter with 35%. ***Fig 6*** summarises the measuring results for all test samples.

Summary and prospects

While the fully automated measurement with the StrainMatic showed the best results with respect to reproducibility and wide analysis capabilities, Ilis recommends the StrainScope as more flexible and faster to operate. In addition, the sample handling is similar to a standard polarimeter, meaning new operators may only need minimal training.

Ultimately, it is the application that defines which approach is better suited. In environments where a limited number of operators use the instrument and process optimisation is the main purpose, the StrainMatic may be the best option. When the main focus is regular quality assurance close to production and flexibility is more important than reproducibility, the StrainScope could be more suitable.

With a measuring frequency of up to 20 Hertz (Hz), the StrainCam is intended to be used in inline inspection machines, replacing existin crossed-polariser stress inspection units so that 100% of the production can be checked for residual stress, and threshold values can be defined independently from product characteristics, such as glass colour and other parameters. ■

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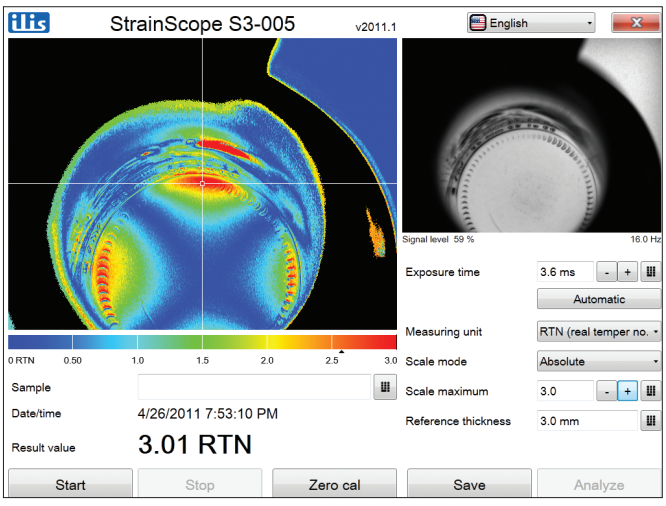
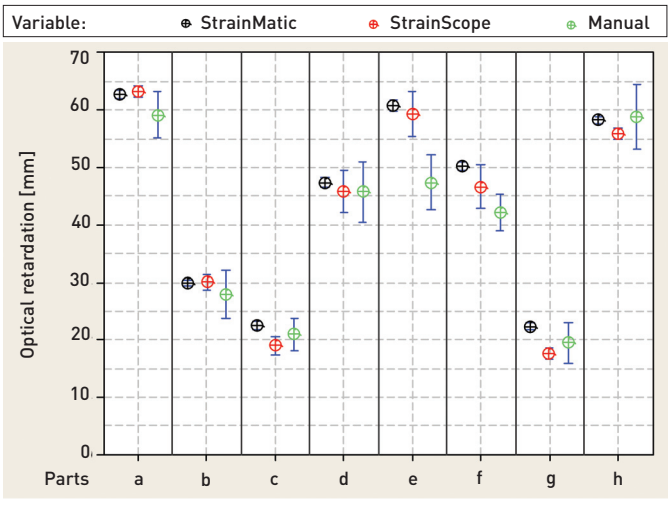


▲ Fig 5. StrainScope operator interface showing the residual stress distribution in the base of a beverage bottle.



▲ Fig 6. Interval plot of the Gauge R&R test results. The blue lines show the variances of the measurement (the longer the lines, the higher the variance).