STEREOLITHOGRAPHY FOR 3D PHOTOELASTICITY

W Cooke*, R A Tomlinson*, G. Gibbons+ and G C Calvert+,
*Department of Mechanical Engineering University of Sheffield Department, University
Mappin Street, Sheffield, UK, S1 3JD
+University of Warwick, Warwick Manufacturing Group
r.a.tomlinson@sheffield.ac.uk, g.c.calvert@warwick.ac.uk

1. INTRODUCTION

Recently, the use of photoelasticity has become more widespread due to the development of digital methods of fringe analysis [1] that allow a significant reduction in the time taken to achieve a stress map for any given model, particularly when only fractional fringe orders are displayed. However, in order for the full potential of the photoelastic method to be realised, a technique for rapidly producing complex 3-dimensional photoelastic models must be developed. Stereolithography is one so-called 'rapid-prototype' method that works by building a laminar model from a tank of photo-curing resin. A perforated metal plate is submerged in the liquid resin to a depth of typically around 0.1mm. A laser then traces the shape of the first layer of the component onto the plate, curing a thin layer of the resin. The plate is lowered by 0.1mm, and a further layer of resin cured by the laser. By this method, complex structures may be 'laid-up' in a matter of hours.

Previous studies concerned with the use of stereolithography for the production of photoelastic models [2] have noted that unacceptable levels of residual birefringence and stress have remained in the photoelastic model even after conventional annealing methods. Thus the use of such methods has been limited. If the stereolithographic method were developed for photoelasticity, one possible area of interest would be the design and analysis of orthopedic implants.

This paper outlines a series of studies looking at the requirements of photoelastic materials for three-dimensional stress analysis.

2. DETERMINATION OF MATERIAL PROPERTIES OF A NEW RESIN

The first aim of this study was to determine the suitability of a new stereolithographic material, DSM Somos 9120 epoxy photopolymer, for production of complex 3-dimensional photoelastic models. A series of tensile specimens were manufactured from the resin using a SLA5000 machine (manufactured by 3D Systems Inc, USA) with differing lay-up orientations with respect to the longitudinal axis. The glass transition temperature of the material was measured to be 85ºC, using a DMA Instruments Viscoanalyser VA2000 where the specimen was subjected to an alternating load at 10 Hz, with strain rate of $3x10^{-4}$ strain/s. The first batch of specimens was stress frozen just above the glass transition temperature at 90ºC and a graph of (N/t) vs. σ_1 is shown in Figure 1. The inverse gradient of these data will give the stress-optic coefficient of the material in the monochromatic sodium light used. It may be seen that the stress-optic coefficient for Somos 9120 found from the preliminary study (black symbols) was 1.12 kPa.m/fr. However, as the line of best fit does not pass through the origin, the results suggest residual stress of 0.06 MPa, or a residual birefringence of 52.8 fr/m, exists within the material. There is little variation optically for the different lay-up angles.

An assessment of the mechanical properties of these first specimens showed some unusual anisotropy and it was postulated that the specimens were exhibiting creep at the stress freezing temperature. It was thus decided to re-assess the glass transition temperature of the material in the hope that a lower stress freezing temperature could be used. From knowledge of viscoelastic materials it was considered that the glass transition temperature would be found to reduce at lower frequencies [3], and thus it was reassessed at 1, 2.646 and 7 Hz and determined to fall to 80ºC. Thus the experiment was repeated for a stress freezing temperature of 85ºC with a different range of loads. It may be seen from Figure 1 (open symbols) that this reduction in stress freezing temperature had little effect on the optical characteristics of the material, with the stress-optic coefficient observed to be 1.02 kPa.m/fr. A small decrease in the residual stress or birefringence was observed (down to 0.032 MPa or 31.6 fr/m). However, it was seen that at lower stress freezing temperatures the material became mechanically isotropic and values of Poisson's ratio, though still large, were of the order of those expected.

3. RESULTS

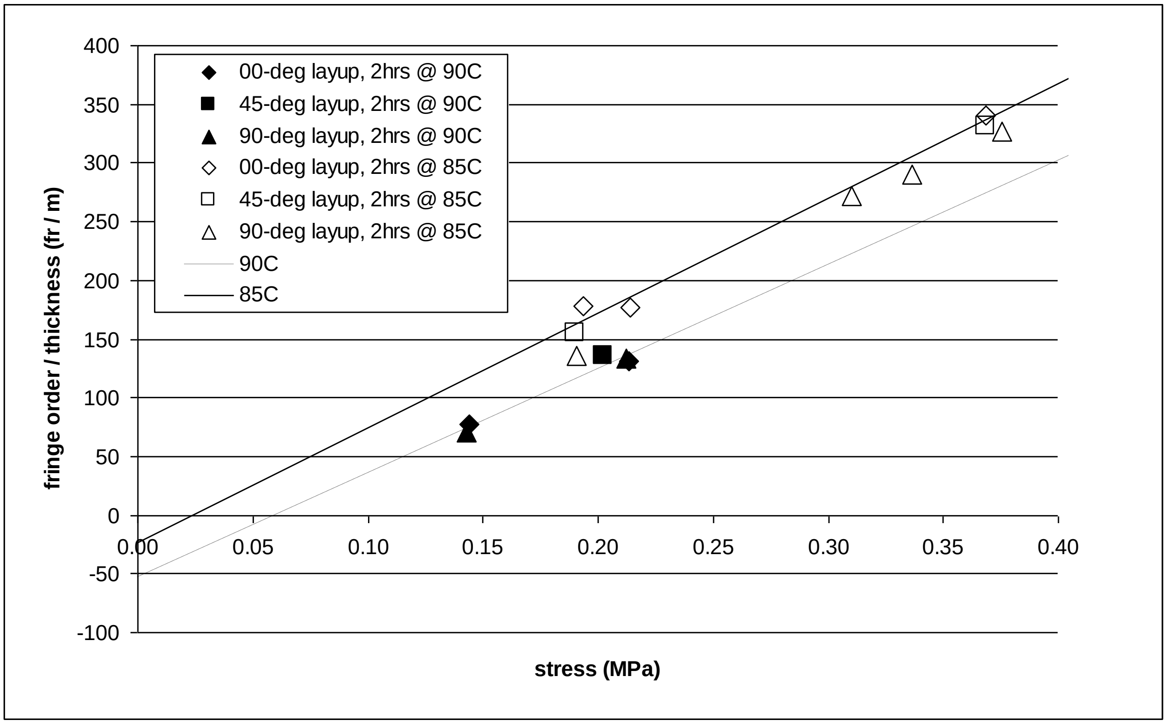

Figure 1 Optical properties for different lay-ups and stress freezing cycles

4. FUTURE DIRECTION

The material was optically consistent over a range of stress freezing loads and model lay-ups, suggesting that it is a suitable material for use in photoelasticity. Further, the levels of residual birefringence noted are small, and may well be associated with experimental or analytical error. There is a large increase in residual birefringence with the use of higher temperature stress freezing cycles so careful determination of the stress freezing cycle is needed.

Somos 9120 was used to manufacture a pair of femurs in a study of hip implants, however these showed an edge effect also observed by Curtis et al [2]. It is thus believed that the edge effect is produced both by moisture absorption and a second mechanism associated with production. Storing the models in dry environments eliminates the moisture effects and it has been suggested that the second, more permanent mechanism may be due to the ultra-violet curing process used after the initial stereolithography process. The curing is completed to remove the ‘tacky’ surface finish of the model, and it is possible that this only affects the outer layer of the material, altering its optical properties. Furthermore, the exposure settings of the SLA machine were such as to create a border around each layer of the femur prior to layer infill, which again, is likely to have introduced an edge effect.

Further experiments are being carried out currently to address this issue including closely controlling the laser energy exposure during building , building models without a skin or rind, and new methods of curing. It is foreseen that these will lead to more suitable processes to generate stereolithography models for photoelasticity.

5. REFERENCES

1. Patterson, E A, (2002) Digital photoelasticity: principals, practice and potential. *Strain*, 38, 27-39.
2. Curtis, J D, Hanna, S D, Patterson, E A and Taroni, M (2003) On the use of stereolithography for the manufacture of photoelastic models. *Experimental Mechanics*, 43, P148-162, 2003.
3. Ferry, J D – Viscoelastic Properties of Polymers. Wiley, Chichester, 3rd edition, 1980.