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Through Life Monitoring of Composites

GENERAL INTRODUCTION

Composites are a well known family of materials, of increasing commercial importance. Of particular note is the ever increasing use of fibre reinforced polymers (e.g. carbon fibre epoxy) in aerospace and civil engineering. Composites are tremendously competitive in terms of their weight and versatility of fabrication, but they are not without their disadvantages. Polymers are susceptible to a variety of effects which can significantly reduce their strength (and consequently that of the composite); these can range from absorbing other chemicals, to gradually breaking down through exposure to UV radiation or heat.

This poster details some initial work towards a system to detect these seemingly invisible changes which could occur during long service, hopefully offering improvements in safety for critical structures such as aircraft and bridges.

ABSTRACT

The objective of this project is to assess thoroughly the feasibility and effectiveness of a built-in system for monitoring the health of polymer composites over a prolonged service life. This might be achieved by the incorporation of high refractive index, chalcogenide, glass fibres to make use of evanescent wave spectroscopy in the near infrared region. The technique has been successfully demonstrated in other monitoring applications on a small scale. This poster outlines the theory involved and some preliminary work.

THEORY

Water Absorption

A major factor affecting the long term strength of polymer matrix composites is water absorption, especially in epoxy resins. The primary effects on matrix polymers are those which might be expected of plasticization, directly resulting in reduced strength and moduli, significantly lower glass transition temperature (see Fig. 1), and slight swelling.

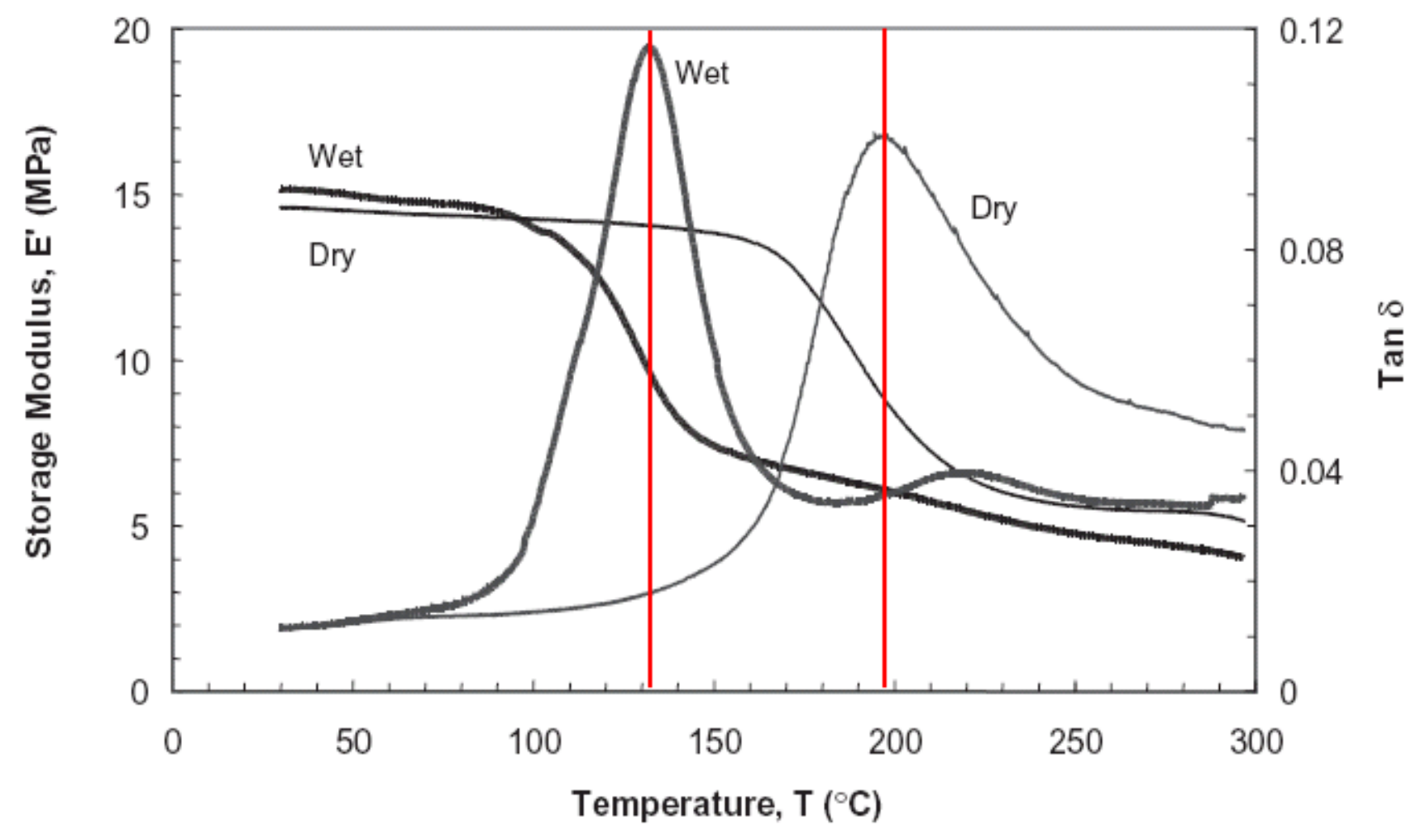

Fig.1: DMTA plot for an epoxy matrix composite; comparison of dry and water saturated materials [1]

Water absorption is by no means the only cause for loss of properties during service, but it will form the basis of the initial phase of investigation, since its effects are well documented and can be induced easily, quickly and repeatably.

Evanescent Wave Spectroscopy

This is the term now generally given to collecting spectroscopic data (usually in the infrared), *via* an optical fibre. The description could apply equally to a family of techniques, used in various forms since the early days of spectroscopy; indeed Sir Isaac Newton observed the presence of an evanescent field and described some of its effects in a publication in 1717.[2]

These methods are based upon the fact that when light undergoes Total Internal Reflection, part of the electric field penetrates beyond the reflecting interface. This is termed the evanescent field or evanescent wave. Fig.2 shows field strength within the two media, the evanescent wave decaying exponentially with distance beyond the surface.

Fig. 2: 2D model of electric field strength for a beam being internally reflected [3]

If the material of lower index absorbs light at certain wavelengths, then the entire beam will be attenuated accordingly. If the beam from a spectrometer is passed through a suitable, unstructured optical fibre immersed in a solution of interest, it is repeatedly internally reflected, interacting with the solution as it does so. Thus a spectrum may be collected whose features are directly related to the thin layer of material immediately adjacent to the

INITIAL WORK

At present the fibres available for experimental work are gallium arsenic selenide (GAS) and tellurium arsenic selenide (TAS) compositions with low glass transition temperatures between 110°C and 160°C. For this reason preliminary investigations have been using the Araldite 5052 system, a room temperature cured, aerospace grade, epoxy resin.

Spectral Response

Experiments were conducted to verify saturation point and optical attenuation in this resin. Fig. 3 shows transmission spectra in the near infrared region, with increasing water content in a thin sample.

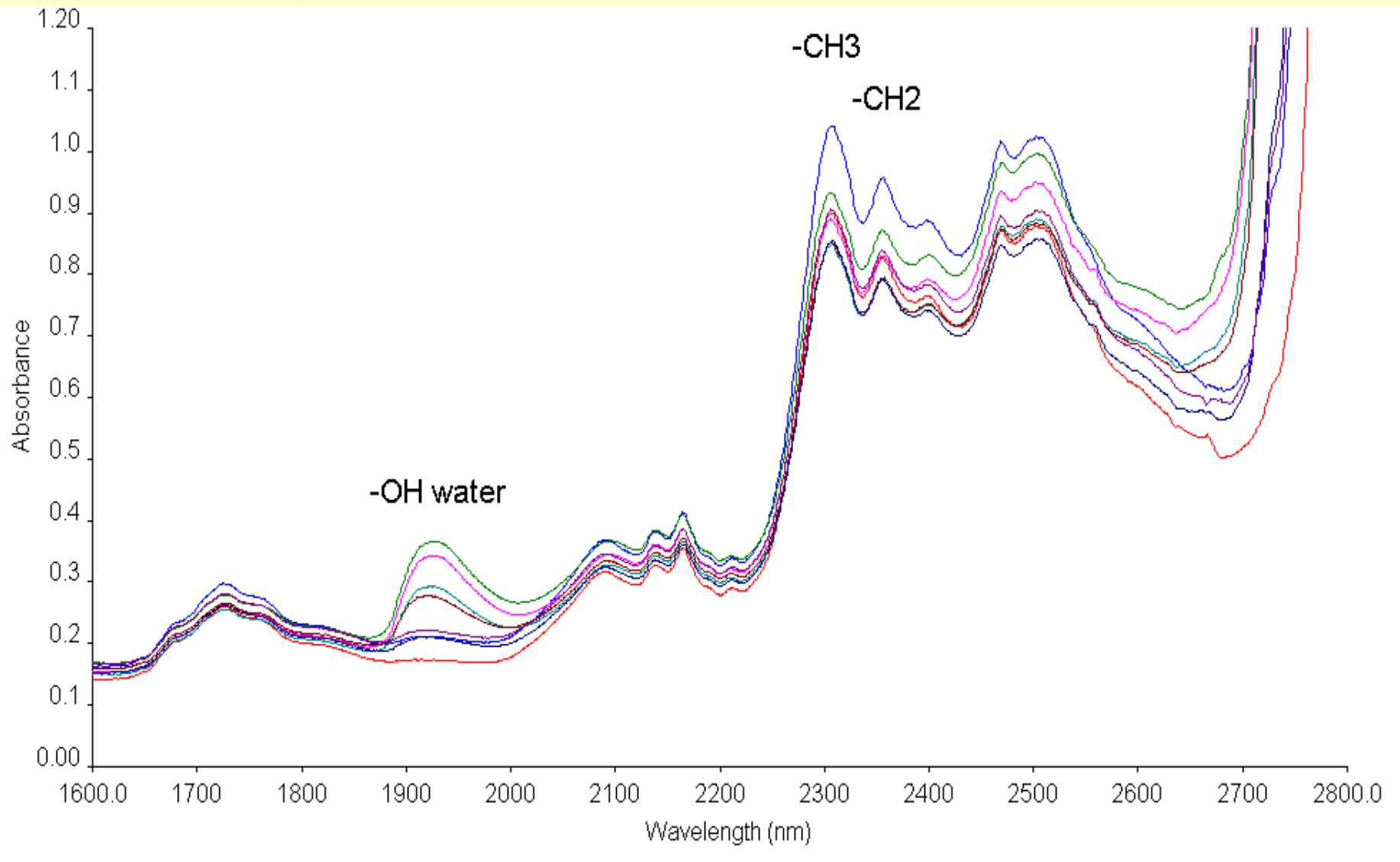

Fig.3: Near-IR Absorption spectra for 5052 resin

The –OH peak position is gradually shifting to the right with increasing water content. Water can hydrogen bond to the polymer chains, so the shift suggests a change in the mean strength of interaction of absorbed water.

The strength of the –OH absorption band relative to that for –CH_3 is plotted against the overall water uptake for the sample, in Fig. 4, showing a roughly linear relationship. This is based on area under the curve due to the breadth of the –OH peak.

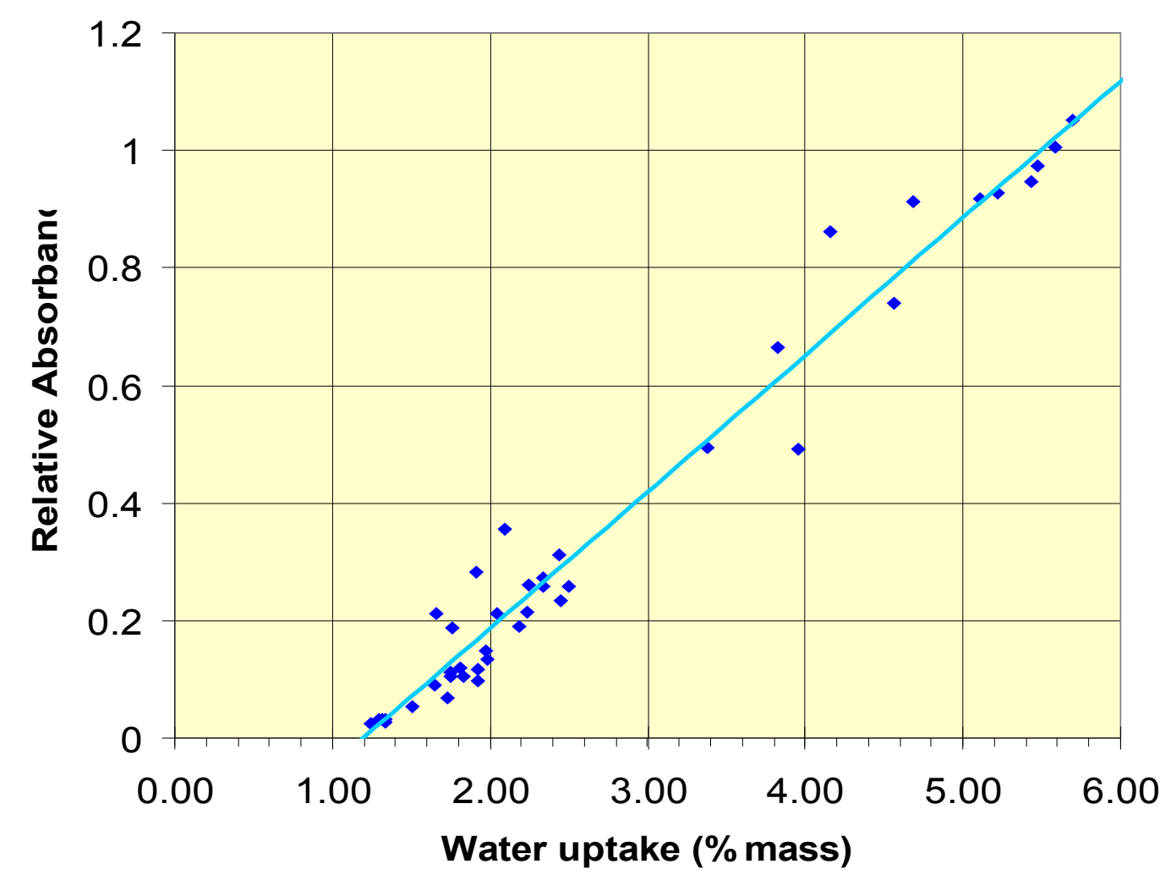

Fig.4: Absorbance @1900nm against water content

Embedded Fibres

First attempts at using the fibres were made in sections of resin little thicker than the ~180µm diameter. Unfortunately this proved less than successful, but has highlighted the question of system durability. After immersion in water, the transmission rapidly dropped away to below noise level, across the entire spectrum. Fibre breakage is not thought to be the cause, rather that the swelling arising from water absorption caused a stress distribution such that the resin delaminated from the fibre, as indicated by the appearance of a silvery sheath over the black fibres. This slight separation may be sufficiently small to induce frustrated total reflectance at infrared wavelengths, causing progressive loss of signal as the delamination propagated along the entire length.

The sample design was revised, and short lengths of fibre were embedded in 5mm thick blocks of epoxy resin. So far, this appears to have prevented such high strain concentrations.

Preliminary tests indicate that water absorption leads to a broad attenuation centred near 1900nm wavelength, of increasing intensity, as seen in Fig.5.

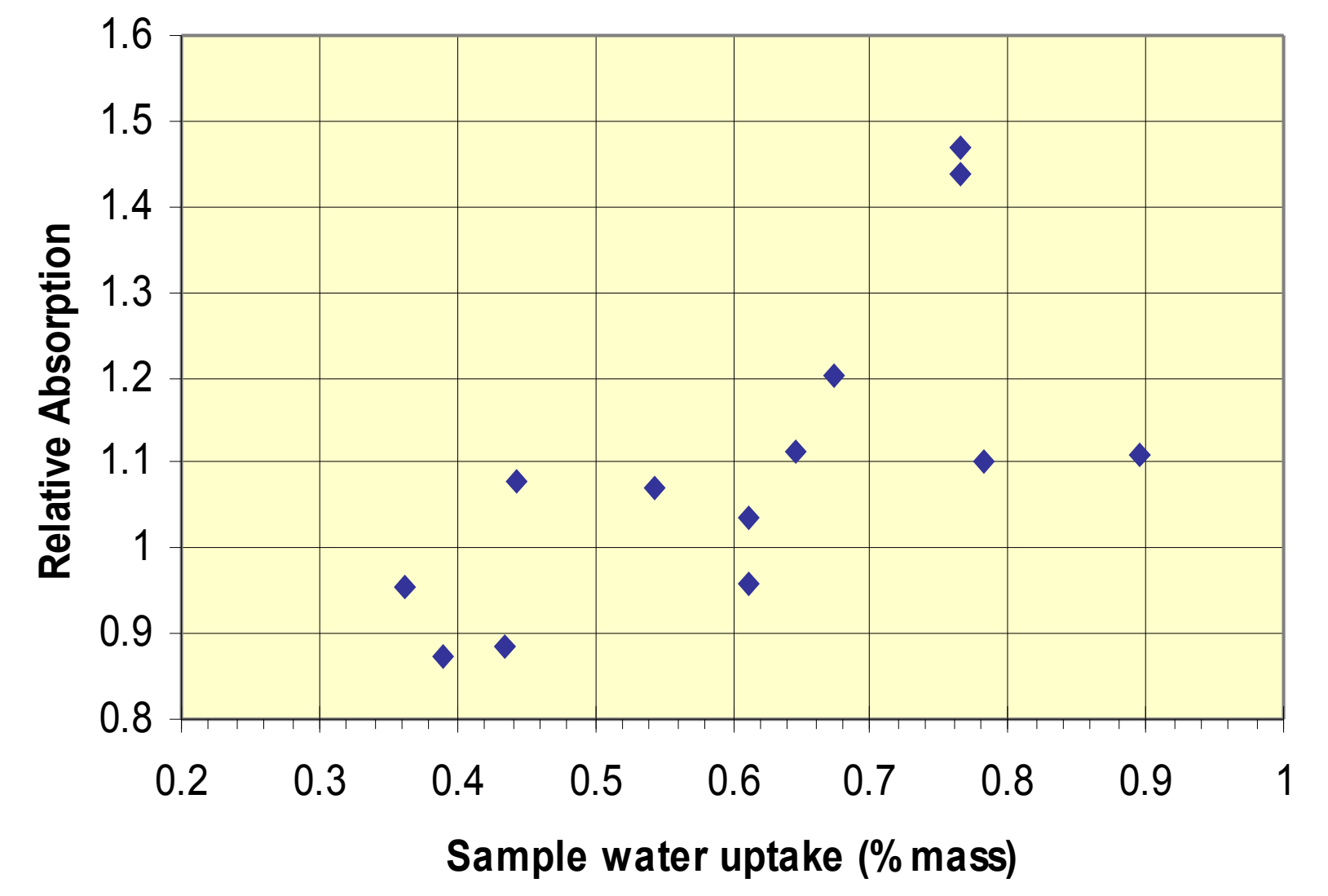

Fig.5: Relative absorption data collected using chalcogenide fibres

CONCLUSION

It has been demonstrated that near infrared evanescent wave spectroscopy can be used to detect increasing water content in a cured epoxy resin system. Furthermore that this can be readily achieved by laying unstructured chalcogenide optical fibres into the moulding.

Further work will examine other polymers and degradative effects. It is also intended that the project shall encompass some tests on the durability of embedded fibres, as well as the effects of practically useful lengths of fibre.

References

[1] JL Abot, et al, "Hygroscopic behaviour of woven fabric carbon-epoxy composites", *J. Reinforced Plastics & Composites* (2005), 24, 195-207.

[2] I Newton, "*Opticks*", 2nd (English) Edition, (1717), book III, part 1.

[3] http://users.ece.gatech.edu/~sungwon/f11.htm author: Sungwon Kim, Georgia Institute of Technology, Atlanta, USA.

GLOSSARY

ATR (*abbreviation:* Attenuated Total Reflectance): Technically this is the phenomenon whereby internal reflection is rendered incomplete due to the rarer medium partially absorbing certain wavelengths. In infrared spectroscopy, a sampling technique (the most widely used form of evanescent wave spectroscopy, *see opposite*), in which the specimen is placed in contact with a prism.

Chalcogenide (glass): a glass formed by one or more chalcogens (S, Se, Te,) with other metals from the transition block or Group III, IV, or V of the periodic table, for example As_2Se_3. They typically exhibit high transparency in the infrared. Small additions of alkali or non-metals modify physical properties, and rare earths can produce useful non-linear optical properties.

DMTA (*abbreviation:* Dynamic Mechanical Thermal Analysis): technique primarily used to examine the viscoelastic properties of a polymer; an oscillating load is applied to a small sample and the resulting displacement measured as the temperature is ramped up or down. Modulus and damping factor (tanδ) can then be calculated. The load can be applied in any desired uniaxial manner, although cantilever or shear are widely favoured; measurements are often taken at more than one frequency.

Frustrated Total Reflectance: internal reflection can also be rendered incomplete if a second optically dense medium is brought so close to the reflecting surface that it is less than the effective penetration depth of the evanescent field. Unlike ATR there is no overall loss or attenuation, the separation of the dense media determining the proportions of the energy reflected or transmitted. A common use for this effect is forming a beam splitter.

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