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Determination of Fracture Sites on Glass Fibre Epoxy Composites Using Thermochromic Liquid Crystals*

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Abstract This paper reports on the use of thermochromic liquid crystals for the detection of surface cracks on a glass fibre reinforced epoxy composite material which was subjected to cyclic loading. The results obtained were very successful with the liquid crystals giving a clear indication of the temperature distribution around the fracture site.

Key words thermochromic liquid crystal, fatigue, temperature distribution, crack

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Introduction

Thermochromic liquid crystals have been used in the field of Nondestructive testing for a large number of applications. Simcox[1] discusses the use of liquid crystals in the testing of metal to metal adhesive bonds, identification of delaminations in fiberglass panels, inspection of honeycombed laminate panels and monitoring of the temperature distribution in electronic components. Dixon[2] gives a review of general liquid crystal applications and discusses in more detail the use of liquid crystals in determining the presence of surface and sub-surface cracks in welds and of detecting voids in honeycombed laminate panels. Broutman *et al.* [3] reports the use of liquid crystals to determine fracture sites in glass fibre reinforced Nylon subjected to cyclic loading. Broutman *et al.* [3] used liquid crystals in the raw state and not the micro-encapsulated variety used in the present research.

Theory

Liquid crystals have been used increasingly in engineering research since the 1960's and they are now an accepted research technique in such areas as heat transfer/fluid flow problems and Nondestructive testing. Liquid crystals can be categorized into three groups by virtue of differing molecular struc-

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tures. Smectic liquid crystals have layers of highly ordered molecules in which the long axis of the cigar shaped molecules lie perpendicular to the plane of the layers. Nematic liquid crystals have the long axes of the molecules parallel to each other in a common direction but they are not separated into layers. Cholesteric liquid crystals have a natural twisted structure and are extremely optically active, typically being able to rotate polarized light by thousands of degrees per mm liquid crystal thickness. The molecular ordering of liquid crystals can be altered by such influences as electro-magnetic fields, pressure, surface shear stress and temperature[4].

The research fields of Nondestructive testing and heat transfer generally use temperature influenced liquid crystals, which are the cholesteric liquid crystals, also known as thermochromic liquid crystals (TLC's). These liquid crystals have a reversible colour change when subjected to temperature changes. Specific colour start temperatures and colour temperature bandwidths are achieved during the manufacturing stage when different liquid crystals are combined to produce a compound with the required colour change characteristics. Liquid crystals are an organic compound and have a greasy appearance. When applied in this form to a test sample they are highly susceptible to degradation by UV exposure and chemical contamination.

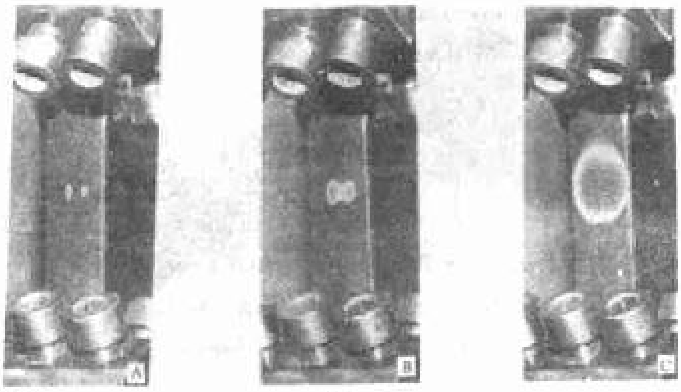
The method of micro-encapsulation[5] has significantly reduced these problems and allows the liquid crystal to be applied in an increased number of methods. The test samples used in the present research were sprayed with micro-encapsulated TLC's using an artists spraygun. This allows a uniform layer of TLC's to be applied to irregular shaped test samples. The micro-encapsulation also improves the viewing of the colour change as the problem of correct viewing angle, necessary for the raw TLC, is removed. As a sample is heated the liquid crystal changes from colourless to red, yellow, green, blue, violet and then to colourless again, the colour sequence is reversed when the sample is allowed to cool. The TCL's are usually viewed against a black background ensuring that light is not reflected back through the liquid crystal coating which would result in a weak intensity colour change. Care should be taken when applying the liquid crystal, too thin a coat will result in a poor colour change whilst too thick a coat produces a milky colour change and can increase the response time of the liquid crystal[6].

Experimental method

The experimental apparatus used for the current research was a Hongshan cyclic loading machine which is capable of subjecting samples to a variety of loading conditions. The samples used in the tension-tension loading were glass-fibre reinforced epoxy resin of 200mm length and 25mm width. Two thicknesses were used, sample A was 3mm thick and sample B was 1.5mm thick. Each sample had a slit approximately half way along the 200mm dimension of the strip. The slit was 10mm long and was placed in the middle of the 25mm dimension. The sample B is a damaged one. The X-ray detecting shows that there are two cracks which can not be seen on the surface. During operation of the loading machine the slit was perpendicular to the direction of the loading forces. The samples used for the three point bending test were two rectangular steel bars 150mm long, 30mm high and 15mm wide. Each bar had a crack present which ran from the edge of the bar to the middle of the bar and was 15mm long.

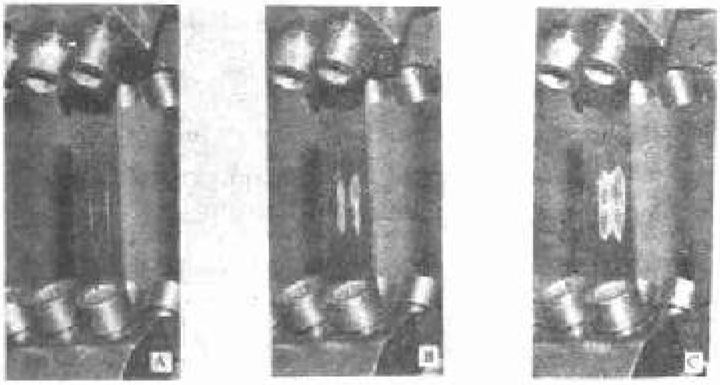
Before testing could take place all samples had to be coated with liquid crystals. Firstly the side of the sample to be coated with liquid crystals was thoroughly cleaned with acetone, this was to ensure that any dirt, grease, fingerprints etc., which could damage the liquid crystal were removed from the surface. The sample surfaces were then sprayed with Hallcrest BB-G1 black paint to provide a good contrast background. The samples were sprayed with Hallcrest BM/R35C1W/C17-10 liquid crystal which gives a red start temperature of 35℃ and a bandwidth to the blue start temperature of 1℃.

All tests were carried out at an ambient room temperature of 25℃, however it became apparent that this temperature was too low to carry out experiments with the samples and the surface temperature of the sample was raised to the liquid crystal colour start temperature using a halogen lamp.



A B C

Fig. 1 Photographs of sample A isotherms



A: 19 Seconds B: 81 Seconds C: 164 Seconds

Fig. 2 Photographs of sample B isotherms

Results

The results obtained from the glass-fibre epoxy composites were good and clearly demonstrate that thermochromic liquid crystals can be used to show the thermal distribution around a crack when a test sample is subjected to cyclic loading. Figure 1 shows the resulting temperature patterns on the surface of sample A.

Photographs 1A to 1C show the isotherms at increasing time periods throughout the tests. The temperature isotherms from the slit root and there develope are shown.

Figure 2 shows isotherms from the fatigue test of smaple B. Photographs 2A to 2C show the liquid crystal isotherm which appeared 19, 81 and 164 seconds respectivily after initiation of the cyclic loading. Two inner cracks can be seen clearly. These cracks go through two roots of slit and are perpendicular to it. These cracks have appeared because the heat is produced by friction between two sides of each crack.

The experiments to determine the temperature distribution around the root of a crack in a steel bar were not as successful. Because of the good conductivity of metal, the temperature tends to average quickly. But as an NDT method thermochromic liquid crystals are still quite good. If there is a crack, in the steel bar and the one end of the steel bar is heated, one can see the color jump over the crack from red to green sharply.

Conclusions

The current research has shown that thermochromic liquid crystals provide excellent qualitative results when determining the temperature distribution around a surface fracture in a glass fibre epoxy composite. The liquid crytal shows that the temperature rise starts at the roots of the crack and the isotherm expands with time due to hysteresis heating. Detecting a crack in a steel bar is also successful. The technique can easily be made quantitative by using a suitable liquid crystal calibration technique before and after a vibration test.

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用热致液晶检测纤维增强复合材料的裂纹扩展

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摘要　报告了用热致液晶对玻璃纤维增强环氧树脂材料表面裂纹疲劳过程进行的检测，成功地给出了裂纹周围的温度场分布.

关键词　液晶，疲劳，温度场分布，裂纹

中图法分类号　TB302.1