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Flexural behavior of epoxy-carbon composite with diffusion effect

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ABSTRACT

In this paper, the flexural behavior was investigated at different temperatures and different cross-head speeds with and without diffusion effect. The studied material is carbon fiber reinforced derakane epoxy composite. The testing temperature was set at 30, 50, 80 and 100°C to investigate the temperature effect on flexural strength. At each temperature, the testing was conducted at four different cross head speeds (0.05, 0.2, 2 and 20mm/min). The diffusion effect was studied on flexural strength with specimens soaked in sea water at 50°C to saturate. A master curve of flexural strength was formed based on time-temperature superposition principle (TTSP) with shift factor obtained by DMA test. Based on the master curve, the flexural strength was predicted with a 35% drop after using 30 years in an ideal condition without considering pressure, stress, diffusion and so on.

Keywords: epoxy-carbon composite, Environmental effect, Water diffusion, Hygrothermal behaviour

1. INTRODUCTION

The introduction of composite materials in offshore application emerged decades ago. Polymer composites offer substantial weight reduction, superior corrosion resistance, long fatigue life, outstanding vibrational damping and energy absorption, and unlimited potential of innovative material and structure tailoring to meet desired performance requirements. Therefore, polymer composites are increasingly being used in a wide range of applications where long-term service in harsh environments is required, where there are diffusion, pressure, high temperature, stress and so on. Diffusion is one of the most important factors when applied in deep-water offshore structures for petroleum exploration and production where water molecules dissolve into the polymer surface and diffuse through the bulk. Diffusion can affect the material properties significantly, such as changing the glass transition temperature, lowering the tensile strength, flexural strength and so on.

Effective structural use of composite materials requires an accurate knowledge of their behaviour and their response to marine environments. Therefore, performing life prediction is necessary in the design and production of structures because ageing is an important issue under sustained load and service environment.

Master curve of strength against time is usually used in life prediction, especially for the life span of more than a few decades of years, which is nearly impossible to measure by actual experiments. The master curve is normally constructed by the shifting of a set of curves horizontally based on the time-temperature superposition principle (TTSP). The principle establishes that a set of curves of any mechanical property measured as a function of time or frequency and temperature can be matched smoothly, leading to a master curve [1]. The accelerated testing methodology (ATM) based on TTSP has been applied widely for the life prediction of composite materials [2, 3]

In this paper, the flexural behaviour of composite materials was investigated at different temperatures and different cross head speeds. Using the shift factor obtained based on Dynamic Mechanical Analysis (DMA) test, the master curve of flexural strength was constructed for life prediction. The effect of diffusion on the flexural strength was investigated.

2. MATERIALS AND SPECIMEN FABRICATION

The resin is Derakane vinyl ester 470 (Dow Chemical Company), catalyst 90 (ratio 100:1 in weight for resin and hardener). The curing schedule followed a 24 hours at room temperature and 2 hours at 155°C. The resin is reinforced with continuous Toray carbon fibres T300 (Toray Industries Inc.) with 7 μ m in diameter. The epoxy-carbon composite was fabricated into a 1m $\times$ 1m laminated plate with an orthogonal lay-up [0, 90] of 9 plies and 2 $\times$ 2 twill woven type. The laminates consisted of 65% fibre in weight percentage (checked by TGA test) and thickness of 2.55mm. The laminates were then cut into specific dimension for each type of test.

3. EXPERIMENTS AND RESULT ANALYSIS

Dynamic Mechanical Analysis (DMA) tests were carried out by a Dynamic Mechanical Analyzer Q800 with two modes, i.e. temperature ramp and temperature step. The DMA tests were performed in a single-cantilever clamp with specimen dimensions 40 $\times$ 15 $\times$ 2.55mm at an oscillation amplitude of 15 μ m (within the linear viscoelastic region). In temperature ramp mode, the glass transition temperature was determined at a frequency of 1Hz and temperature ramping from 30°C to 150°C at a heating rate of 3°C/min. In temperature step mode, the frequency sweeps from 0.01 to 10Hz with temperature increasing from 30°C to 150°C in a 5°C step at the heating rate of 3°C/min between the steps.

The three-point bending flexural strength was measured by Instron 5569 with environmental chamber at four different cross head speeds, i.e. 0.05, 0.2, 2, 20 mm/min, and four different temperatures, i.e. 30, 50, 80 and 100 °C. The specimens were prepared with a dimension of 160mm in length, 15mm in width and 2.55mm in thickness. The flexural tests were conducted according to ASTM D7264 with a span 120mm. Some specimens were diffused in sea water at room temperature until saturation and tested for comparison of flexural strength before and after diffusion.

Figure 1 and 2 show the flexural strength measured at different cross head speeds versus failure time and temperature, respectively. The results show the flexural strength decreases with the decreasing of cross-head speed, and the increasing of temperature.

Figure 3 shows the water diffusion of specimens in sea water at two different temperatures. The diffusion reaches saturation point after 6 months, with diffusion percentage of 0.58%. The flexural strength of the diffused specimens was measured at different temperatures to compare with those without diffusion, and showing around 20% decrease in flexural strength, as shown in Figure 4.

Figure 1: Flexure stress versus time of epoxy-carbon composite at 30°C with different cross head speeds

Figure 2: Flexure strength versus temperature of epoxy-carbon composite at different speeds

Figure 3: Water absorption of epoxy-carbon composite in sea water at different temperatures

Figure 4: Comparison of non-diffused epoxy-carbon composite with diffused specimens at cross head speed 2 mm/min

Figure 5 shows DMA test results at different frequency and at different temperatures from 30°C to 150°C. The master curve was formed with the shift factor calculated by a Matlab programme, shown in Figure 6. The shift factor has a transition at the glass transition temperature and by the gradient of shift factor against temperature, the activation energy of the material can be determined. Applying the obtained shift factors on flexural strength at different temperatures, the master curve of flexural strength was built as Figure 7. From the figure, we can see that in an ideal condition without the consideration of pressure, corrosion, and so on, the flexural strength decreases by around 1/3 after using 30 years. Therefore, in real application, the decrease in flexural strength should be even more.

Figure 5: Master curve by predicted model based on DMA data at different temperatures and at different frequencies

Figure 6: Shift factor below and above T_g

Figure 7: Master curve of flexure strength at 30°C

4. CONCLUSION

The flexural behaviour of epoxy-carbon composite was investigated at different temperatures and different cross-head speeds with effect of diffusion. The master curve was built based on DMA data and applied to flexural strength. Thus the master curve of flexural strength was formed and predicted that the flexural strength decreased around 1/3 after using 30 years in an ideal condition without pressure, corrosion and so on. The diffusion was investigated to lower the flexural strength by around 20%, thus the diffusion effect should be considered in the design and in the studied of life prediction.

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