LIFE ASSESSMENT OF GFRP COMPOSITE AND THERMOSET EPOXY THROUGH CREEP AFTER MARINE ENVIRONMENT EXPOSURE

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Abstract

This paper discusses the creep performance of unidirectional Glass Fibre Reinforced Polymer (GFRP) composite laminates, and their epoxy resin matrix, prior to and after having undergone accelerated ageing in synthetic ocean water. Both pristine and exposed specimens were evaluated via mechanical testing at a range of temperatures to enable application of Time-Temperature-Superposition (TTS). Significant differences in mechanical performance were revealed and are comprehensive.

1. Introduction

Pipelines currently represent the most used means of delivering fluids for energy production. Pipe failures rarely cause fatalities but disrupt production and can cause significant environmental damage. The immediate effects of a failure include unavoidable repair work, involving costs as high as tens of millions of dollars if it occurs in an environmentally-sensitive area. Oil & Gas operators are continually exploring technologies that will help reduce the incidence of pipeline failures. One of the promising technologies is concerned with the use of non-metallic materials, particularly Glass Fibre Reinforced Polymers (GFRPs). Demand for these materials is increasing due to their excellent degradation resistance and good material strength and flexibility in manufacturing [1]. Studying and understanding processes that influence material durability (e.g. fluid contact, mechanical loading, environment) represent critical aspects, when designing for safety as well as manufacturability and operability [2], since long term exposure of GFRPs to various environments will eventually lead to irreversible changes in their properties, and the effective limitation of their operating life.

According to a January 2018 TechnipFMC report [3], there are currently 11,000 km of installed flexible pipes working in this industry, with the offshore domain remaining critical to the future. RnR Market Research [4] reports there are currently 518 active Oil & Gas pipelines in the Asia-Pacific area with a total length of 202,069 km. A further 60,013.93 km are to be added by the end of 2020. Composite flexible pipes account for 1% of existing Oil & Gas pipelines, with immense room to grow considering future addition and replacement needs. It is therefore apparent why, flexible composite pipes, Glass fibre reinforced polymer pipes (GFRP pipes) among them, are more eagerly sought.

2. Methodology

The materials selected for use in the experimental study consist of commercially available epoxy resin (Ampreg 26) and Electrical/Chemical Resistant (E-CR) glass fibres (3B Advantex SE 2020). Over 200

tests were performed using Type L thermoset resin dumbbells, with dimensions as defined in ASTM D1822-99. These were machined out of in-house manufactured plates using a steel two-piece mould with interior dimensions of 250 × 250 mm. A manually operated hydraulic press equipped with heated platens allowed for the application of an elevated post curing cycle, as per the resin manufacturer data sheet, of five hours at 80°C. The resulting resin plates showed minimal to no porosity.
Additionally, Vacuum Assisted Resin Transfer Moulding (VARTM) was used to manufacture thin laminates consisting of two plies of the unidirectional glass fabric with epoxy resin, at an average thickness of approximately 1.8 mm, after curing 24 hours at room temperature. Fibre layers for the composite were stacked following the same direction in order to favour unidirectional specimen machining. Transverse (90°) unidirectional composite specimens, with dimensions as defined in ASTM D3039M-08, were obtained using a water-jet cutter. In preparation for tensile creep testing, both specimen types were sanded and tabbed using 60 grit sand paper and Z70 Cyanoacrylate adhesive.
Accelerated ageing principles were combined with information on matrix glass transition temperature (T_g), and operational limitations for a potential product manufactured from the base materials, leading to a selection of testing conditions between 25 °C and 80 °C in approximately 15 °C increments. A performance baseline was then established, with mechanical tests performed at a cross-head displacement rate of 2 mm/minute, on a machine equipped with a temperature controlled chamber. Initial results underlined material susceptibility to viscoelastic behaviour increased significantly at temperatures over 55°C, therefore in the interest of simplification this was established as the limit for later creep experimentation as well as chemical exposure. Additional specimens were submerged in synthetic ocean water, as per ASTM 1141, at 55 °C for 126 days, redried for two weeks and then tested. Creep experiments were conducted on a bespoke test machine equipped with a temperature controlled chamber at 23 °C, 40 °C and 55 °C using different percentages, usually between 80% and 60%, of the previously determined failure stress of the materials.

3. Results

Matrix relaxation at around 40 °C allows for slightly higher load carrying capacity in the composite when compared to room temperature. This phenomenon, visible in Figure 1, was observed during quasi-static testing of specimens at various stages of exposure, and creates certain difficulties when attempting to manipulate data using Time-Temperature-Superposition (TTS).

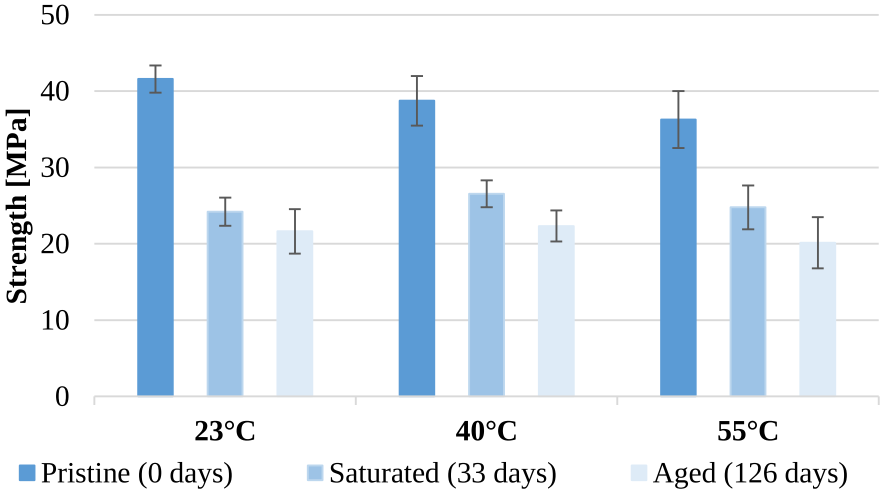

Figure 1. 90° UD composite performance

On average the thermoset resin is 10% weaker, while the 90° UD composite loses approximately 50% of its initial strength. In terms of creep behaviour, it only translates to lower starting values, and underlines the existence of a complex behaviour, visible in Figure 2. Creep performance is significantly lower after exposure for both materials.

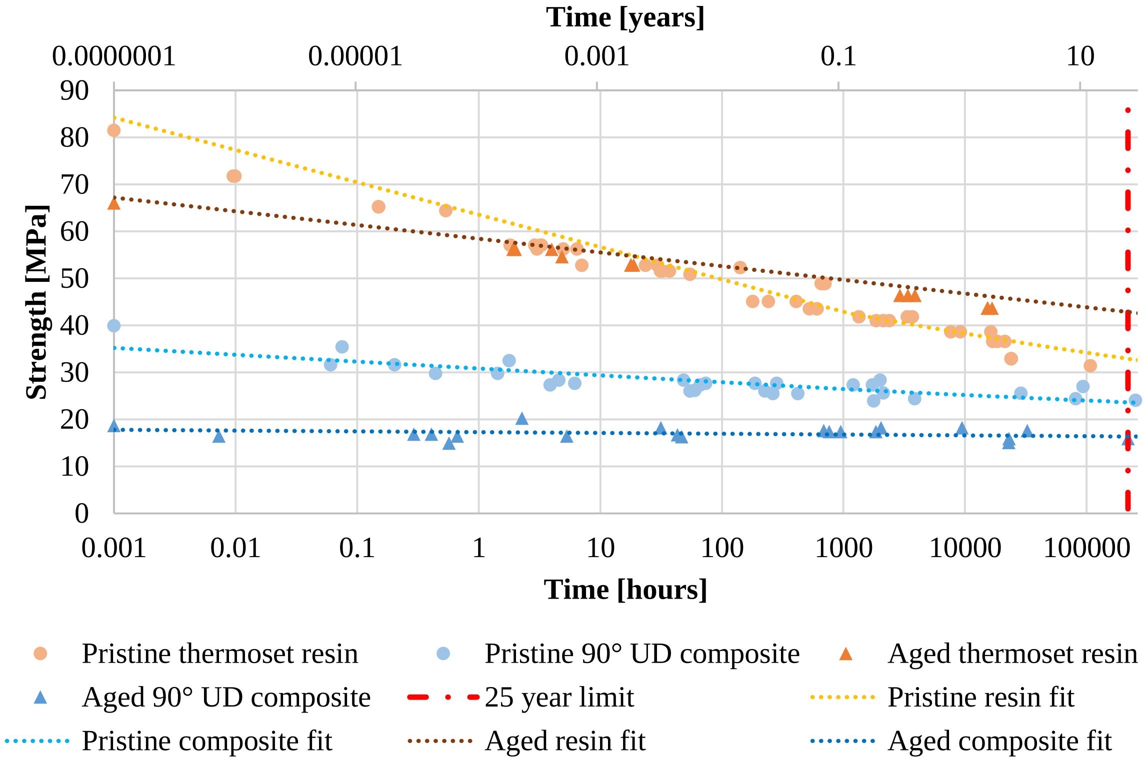

Figure 2. Creep performance comparison based on master curves at room temperature

Data fitting was achieved using a simple computational tool and a geometrical approach relating the initial value of each individual temperature used to construct the master curve to the slope of the chosen reference, in this case room temperature of 23 °C. A quantification of the performance drop of the investigated materials is presented in Table 1 below.

Table 1. Creep performance summary

Material	State	Temperature [°C]	Overall performance drop for 25 years [%]	Average Rate [%/year]
Thermoset resin	Pristine	25	60	2.4
	Aged		37	1.5
90° UD composite	Pristine		41	1.6
	Aged		12	0.5

3. Conclusions

Prediction of long-term life using tensile creep on a GFRP laminate as well as its matrix resin under temperature and synthetic ocean water exposure was performed with the aim of establishing a low resource accelerated testing methodology based on TTS. Quasi-static tensile tests were carried out along with creep tests up to 700 hours at various temperatures and different stages of exposure for the two materials.

The results show a high dependence of overall strength as well as rate of degradation on the exposure conditions, namely medium absorption, time and temperature. Master curves depicting the strength of both composite and matrix material were constructed by using creep data with TTS. These seem to indicate that even though initial strength is significantly affected by chemical exposure, degradation in time (25 years) under stress and temperature, is less severe. Chemical changes that occurred due to the process of water absorption and re-drying, as well as the potential additional curing of the resin during exposure clearly affect the above mentioned rate.

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