DURABILITY OF SUSTAINABLE COMPOSITES IN SHIP DESIGN FOR ENHANCED ENVIRONMENTAL PERFORMANCE: A MULTISCALE APPROACH

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1. INTRODUCTION

The marine industry is one of the largest consumers of composite materials. According to Composite Insights, the demand for composite materials in global marine-composites industry is set to grow 5.8% per year between 2013 and 2018 [1]. Given the rising prices of fossil fuels and the increasing global environmental awareness, there is now pressure on the reduction of the use of crude-oil-based composites. The harsh marine environment represents a unique challenge for the use of sustainable bio-alternatives. Thus there is an interest in the long term structural performance of sustainable alternative fibres and resins for such materials. To certify safe performance of sustainable composite structures it is necessary for the users to know the material properties, processability, and their capacity to sustain loads and retain stability during the whole life cycle. In recent years bio-derived fibres have received much attention and as a result a substantial amount of research has been conducted in order to better understand and quantify their properties [2]–[5]. In the public domain, however, there is still little information to aid the designer about sustainable resins (especially epoxies) and hence composite materials utilising them are not typically considered as a technically viable option. Failure mechanisms during the design life of the material can be identified but the root cause behind its degradation remains unclear. Malmstein at al. [6] reported that after 20 + weeks of hygrothermal ageing the glass/linseed oil specimens lost 72% of their dry strength and that this might be caused by the UV-curing and chemical reactions between water and linseed oil resin and/or fibre–matrix interface. They also revealed that the properties of glass/conventional epoxy kept degrading while the moisture content remained constant indicating chemical degradation of the composite. Reportedly, glass/linseed degraded rapidly during the first 2 weeks of immersion but after 4 weeks until the end of the testing period suffered no further degradation.
Only when knowing both the physical and chemical properties of the resin system can one use the material with full confidence. Furthermore, this knowledge would allow modification (redesign) of the resin in order to yield better physical properties, thus improving the performance of the whole composite material. The aim of this study is to bring chemistry and engineering together to achieve the similar level of understanding of the degradation processes of a sustainable epoxy resin system in a harsh marine environment as has taken place for conventional marine epoxy.

2. MATERIALS AND METHODS

A UV curable linseed oil based epoxy resin is the subject of this current research as it has already small scale applications in boat building [7] and with 97% bio-derived content is a attractive promising bio-alternative to the resins commonly in use [8].
A combination of experimental analytical methods (i.e. FT-IR, DSC, TGA, solid state NMR) is used that aims to make a significant contribution towards the understanding of sustainable composite ageing.
This project combines chemistry, physics and material science from the molecular to the ship scale. Primary experimental investigations include:

- hygrothermal ageing,
- resistance to black and grey water waste
- UV ageing.

The experiments conducted include: hygrothermal ageing in distilled water (DW) (accelerated ageing at 40^{o}C), UV ageing (4x 18W tube lamp, 230V, 50-60Hz (365 nm), 8h, 24h and 5 days), hygrothermal ageing in salty water (SW) (3.5% wt. NaCl, at 40°C) and the resistance of ELO resin to grey (waste) and black (foul) water (immersion in buffer solutions in the ranging between pH4 to pH10).

3. PRELIMINARY RESULTS

The gravimetric analysis revealed that the saturation has been reached after 36 days with a moisture uptake level around 6.3%. Despite water ingress, the difference in spectra from the FT-IR results, which describes changes in the molecular composition, suggests that the resin appears to be chemically stable. Based on the DSC (Figure 1) and TGA (Figure)

analyses it can be concluded that no free water molecules exist in the samples. In contrary to the conventional epoxy resin [9], the Tg value for the UV-L resin is constant despite different methods of ageing. Tg values might be improved by chemical modification of the resin to compete with traditional epoxy.
Analytical chemistry methods are useful complement to mechanical testing methods in the process of understanding long-term durability of composite materials operating in the harsh marine environment.

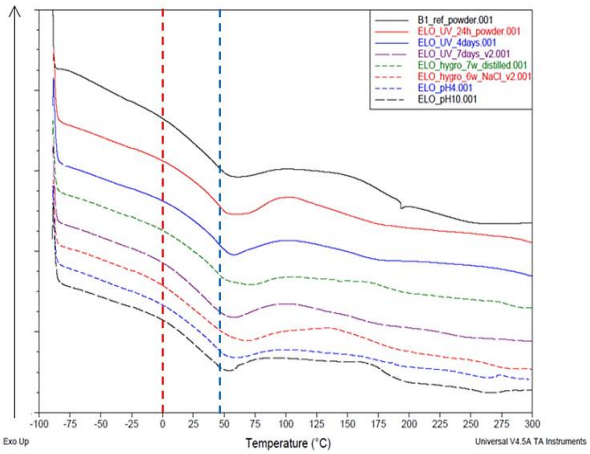

Figure 1 Differential Scanning Calorimetry (DSC) data showing heat flux as a function of temperature

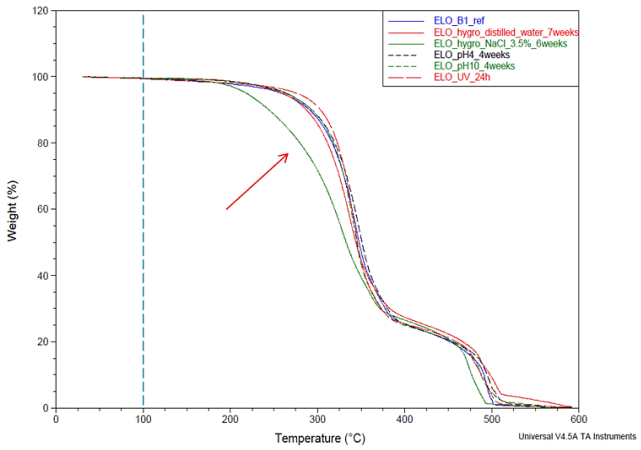

Figure 2 Thermogravimetric analysis (TGA) data showing weight loss of specimens as a function of temperature.

4. FUTURE WORK

To improve Tg values, the level of crosslinking needs to be higher. The increase of the crosslinking level might improve water resistance. In order to improve the physical properties the improvement of the curing process is necessary. Introduction of a post curing process – heating the resin up to approximately 45^{o}C (Tg) with additional UV exposure is being currently undertaken in order to achieve better level of curing. An addition of a sustainable catalyst to remove the remaining oxirane rings and improve the level of crosslinking is also planned.
If this would not yield a sufficiently satisfactory result, additional actions are being considered (e.g. adopting a different method of curing –addition of crosslinker)

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