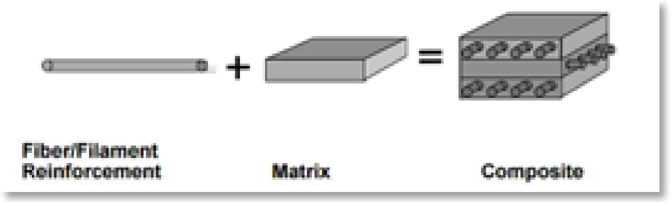
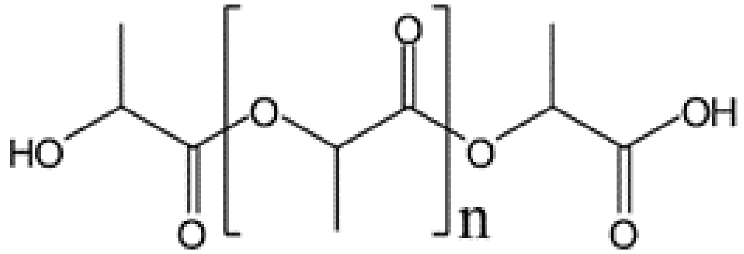
BEng (Hons) Mechanical Engineering with Composites



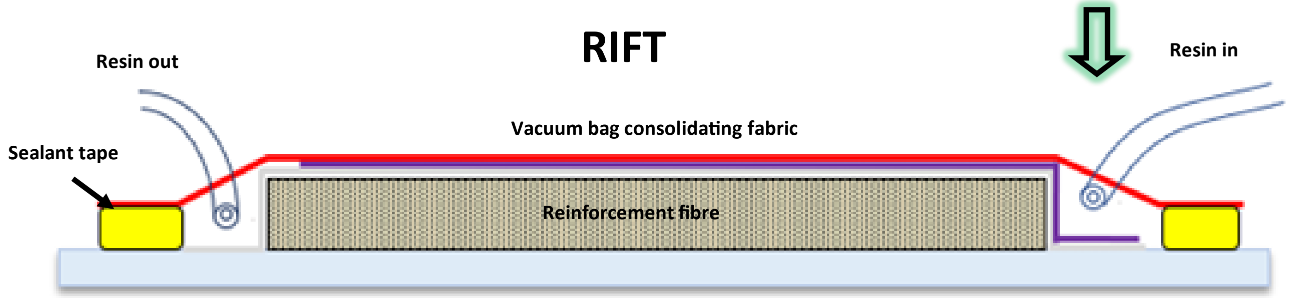
1. Fibre reinforced polymers have exceptional strength to weight ratios and resistance to corrosion. Consequently, they have been adopted for many marine applications.

2. The disposal of composite marine structures has become problematic though. Unlike other traditional materials, the heterogeneous/synthetic make-up of composite materials makes them difficult to dispose of.



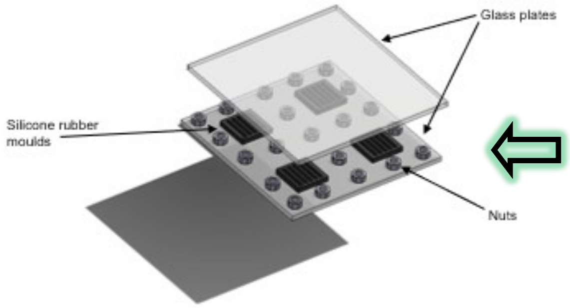
3. Plymouth University has been working with SeaBioComp to produce bio-based thermoplastic composite materials. Polylactic Acid, a bio-based thermoplastic, has shown to be a promising candidate for use with composites.

4. Glass fibre reinforced PLA has been successfully produced using resin transfer moulding (RTM). However, this process is limited to smaller composite components.



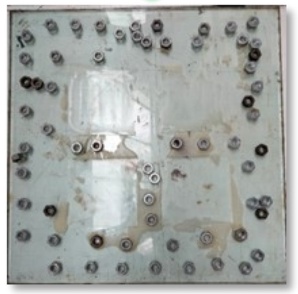
5. Resin Infusion Under Flexible (RIFT) is commonly used in industry to produce high quality composite structures. Unlike RTM, much larger structures can be manufactured using this process. However, during preliminary testing, PLA composites have shown to develop voids and porosity using this process — a common cause of reduced mechanical properties in composite materials. Thus, my project aim was to optimise the process to produce a high-quality PLA composite.

THE PROBLEM



6. Flexural testing specimens were manufactured in a makeshift vacuum chamber. This was done to better replicate the polymerization conditions of lactide (the monomer) to PLA (the polymer) during the RIFT process.

7. The first run was disastrous, resulting in a sludgy substance. Upon further consideration, it occurred to me that due to the loss of heating by convection, the rate of heat transfer to the moulds was much slower. Hence, after doing some calculations, the polymerisation oven cycle was increased.



8. This time the polymerization was "successful", but the specimens exhibited poor mechanical properties during flexural testing. Moreover, PLA had spilled over the moulds whilst in the oven — indicating that boiling had occurred.

$$ln\left(\frac{P_1}{P_2}\right) = -\frac{\Delta H_{vap}}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

Equation 1: *The Clausius-Clapeyron equation* (Winterbone Desmond, 1997)

$$Vacuum\ pressure = P_{Vac} = 40\ mbar = 4000\ Pa$$

$$T_1 = 150°C = 423.2\ K$$

$$\Delta H_m = 85\frac{kJ}{mol} = 85{,}000\frac{J}{mol}$$

$$P_2 = 10.3\ Pa$$

$$T_2 = 337.8\ K$$

Equation 2: *Vapor pressure for $_L$-lactide at T_1*

$$\therefore \boldsymbol{P_1 = P_2 e^{-\frac{H_{vap}}{R}\left(\frac{1}{T1}-\frac{1}{T2}\right)}}$$

$$\therefore P_1 = 4625\ Pa$$

9. Upon further reading, I discovered the Clausius-Clapeyron equation, which can be used to determine the boiling point of a substance at various pressures and temperatures.

THE SOLUTION

10. It was revealed that the boiling point of the lactide had been exceeded whilst being processed under vacuum. Thus, the likely cause of the problem, and an additional process control parameter has been established.

john.horrill@students.plymouth.ac.uk

Supervised by Professor John Summerscales

Optimisation of Monomer Infusion under Flexible Tooling using Polylactic Acid

UNIVERSITY OF PLYMOUTH