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Flax/acrylic FLOW turbine blade manufactured by in situ polymerisation (ISP) monomer infusion under flexible tooling (MIFT)

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Flax/acrylic FLOW turbine blade manufactured by *in situ* polymerisation (ISP) monomer infusion under flexible tooling (MIFT)

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Abstract

A flax fabric reinforced acrylic thermoplastic matrix component has been manufactured as two half blades (front and back respectively) with the parts bonded together with a wood dust acrylic polymer to produce a component with the same thermoplastic polymer used for the composite matrix and the adhesive.

The mould profile is for a floating offshore wind (FLOW) turbine blade at scale 1:50. This model represents the NREL 5 MW reference wind turbine. The blades are not scaled geometrically, but instead have been adapted to produce Froude scaled thrust, in spite of much lower Reynolds numbers at reduced scale and when using Froude scaled wind.

The trimmed and faired blade weight weighs 395g. The profile surface has small areas of relative dryness, but the extent of the defect is similar to that seen in comparable synthetic fibre reinforced composite mouldings. The wood-filled adhesive appears to foam at some time after mixing: it may be that the exotherm takes the temperature to the boiling point of the monomer .There does appear to be some profile distortion, probably due to MMA vapour acting to soften the unsupported PMMA matrix (as a general rule in chemistry like dissolves like”).

Keywords:

Natural fibres; Thermoplastic; Acrylic monomer, Infusion; Demonstrator, Wind turbine blade.

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None.

List of abbreviations

FLOW	FLoating Offshore Wind
gsm	grams per square metre fabric areal density
ISP	*in situ* polymerisation
MIFT	Monomer Infusion under Flexible Tooling
MMA	Methyl MethAcrylate
PMMA	Poly (Methyl MethAcrylate)
SCRIMP^{TM}	Seeman Composites Resin Infusion Molding Process
VARTM	Vacuum-Assisted Resin Transfer Moulding

1. Introduction

For large composite marine structures (e.g. boat hulls or wind turbine blades), the most common technique for their manufacture is Resin Infusion under Flexible Tooling (RIFT). To reduce process times, it is common to flood one surface of the reinforcement fabric stack with resin in a flow medium (a.k.a. transport mesh) followed by through-thickness flow. The process is generally referred to as RIFT with a flow medium (RIFT II), or (in North America) Seeman Composites Resin Infusion Molding Process (SCRIMP^{TM}) or Vacuum-Assisted Resin Transfer Moulding (VARTM) [1-6]. However, while the use of thermosetting polymer systems permits manufacture at ambient temperature (plus an elevated temperature post-cure for optimum properties), there are few options for end-of-life disposal at a high level in the recycling hierarchy. Thermoplastic matrix composites could be recycled through a melt-form-cool cycle, but the melt viscosity is too high to permit infusion processes. SeaBioComp WP1.x seeks to develop in situ polymerisation (ISP) during Monomer Infusion under Flexible Tooling (MIFT). The selection of monomers for marine composites manufactured by ISP MIFT has been published [7].

The work undertaken in WP1 identified methyl methacrylate (MMA) as a "drop in" alternative to thermosetting resin systems. The polymer is MIFT processable at ambient temperatures. MMA is not yet available as a bio-based monomer, although it is anticipated that bio-based MMA [8], methacrylic acid [9] and similar materials [10] will be available soon after completion of this InterReg project. A second infusible, inherently bio-based, monomer is L-lactide although the system process temperatures are normally in the range 120-180°C. The elevated temperature may also require alternative materials for other process consumables (e.g. vacuum bag, flow media, peel ply and pipework).

2. Demonstrator component

The mould profile is for a floating offshore wind (FLOW) turbine blade at scale 1:50. This model represents the NREL 5 MW reference wind turbine. The blades are not scaled geometrically, but instead have been adapted to produce Froude scaled thrust, in spite of much lower Reynolds numbers at reduced scale and when using Froude scaled wind. The blade offsets and aerodynamic profiles have been published [11]. More detail will be available in Jessica Guichard's University of Plymouth PhD thesis shortly (subject to acceptance of post-viva corrections) where carbon fibre reinforced epoxy resin components were produced (Figures 1-3).

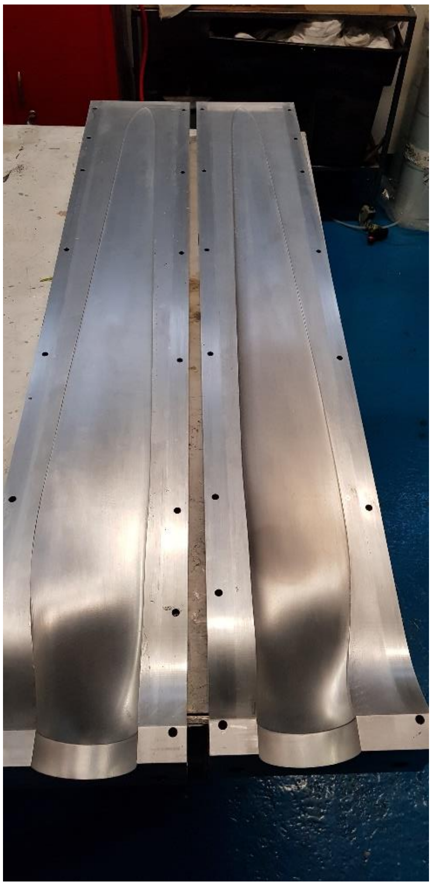

Figure 1 (left): Aluminium mould tool **Figure 2 (right): CFRP FLOW turbine blades**

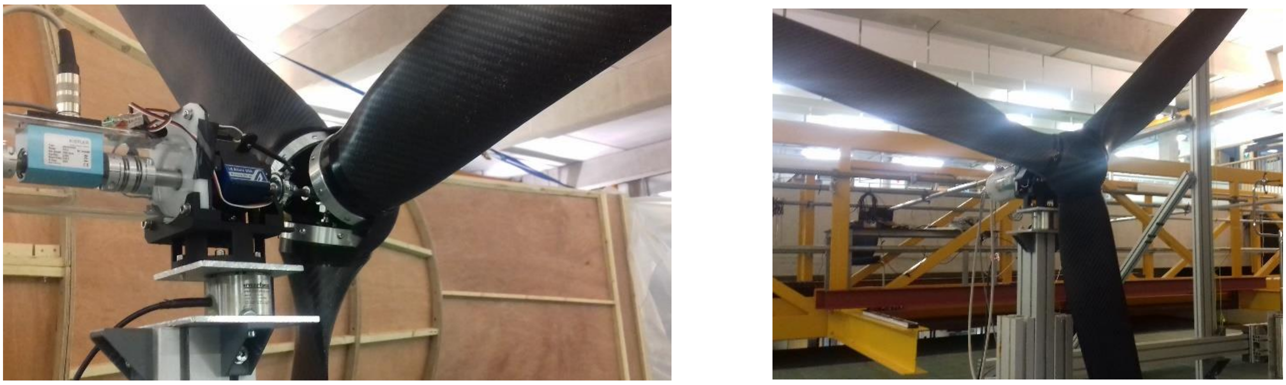

Figure 3: CFRP FLOW turbine blades installed in the University of Plymouth COAST Laboratory

3. Materials

The natural fibre reinforcement was 200 gsm 2x2 twill weave Biotex flax fibre supplied as a 1590 mm wide roll (EasyComposites, Stoke-on-Trent (UK) ~ no longer available, £13/m^2). The resin system was Arkema Elium® 188 XO (Arkema, Colombes (F), €24/kg) being 70-90% methylmethacrylate with other materials in the formulation [12]. The resin was catalysed with 2% benzoyl peroxide (Sigma-Aldrich, Germany). The mould tool was prepared with Frekote NC770 release agent. The peel ply and knitted flow mesh were unspecified laboratory stock supplied by Tygavac (Oldham UK) and Matrix Mouldings (Bristol UK) respectively. The bagging film was Easy Composites VB160. The tacky tape was Easy Composites ST150. The pipework was 6 mm internal diameter nylon.

4. Infusion

The fabric was laid up on the aluminium mould tool then degassed under the full vacuum for 20 hours before infusion. The Elium® monomer infusion was conducted on Tuesday 9 November 2021, following the procedure outlined in Appendix A. To achieve improved mechanical properties, the flax-Elium® composite was post-cured on the mould tool in an oven at 80 °C for 1 h (as recommended by the Elium® 188 XO technical data sheet).

5. Bonding

The two half-blade moulding were positioned in the respective mould tools (Figure 4) for bonding together on Tuesday 14 December 2021. Surfaces were primed with the acrylic resin catalysed with 2% benzoyl peroxide (Figure 5). Fine wood particles (saw dust) were mixed into the acrylic resin until it had the consistency of peanut butter. A bead of the wood/acrylic mix was created along the bond line before the two mould halves (Figure 6) were brought together and clamped (Figure 7).

Figure 4: The half-blade mouldings positioned in the mould tools.

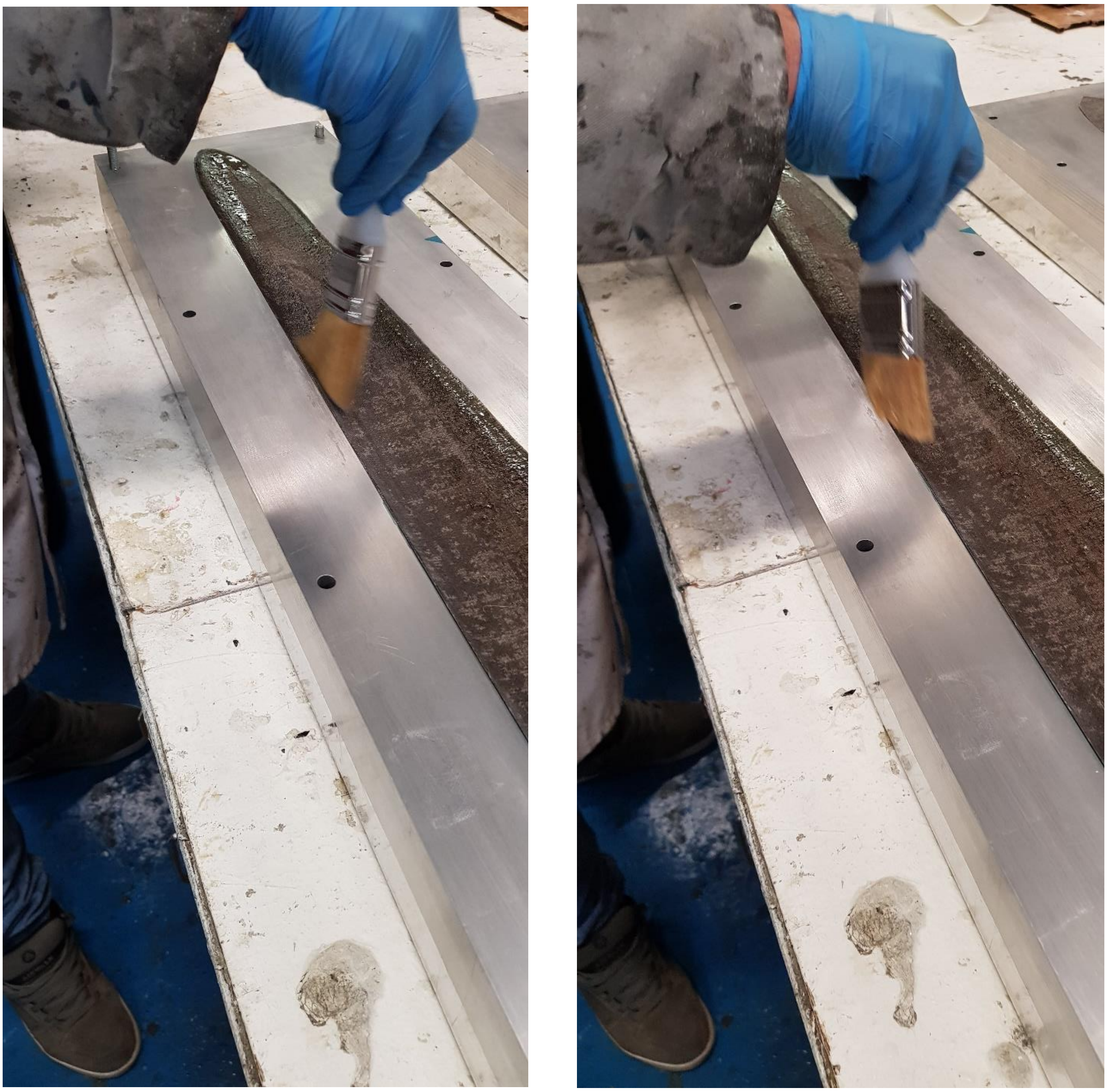

Figure 5: Priming the surfaces to be bonded.

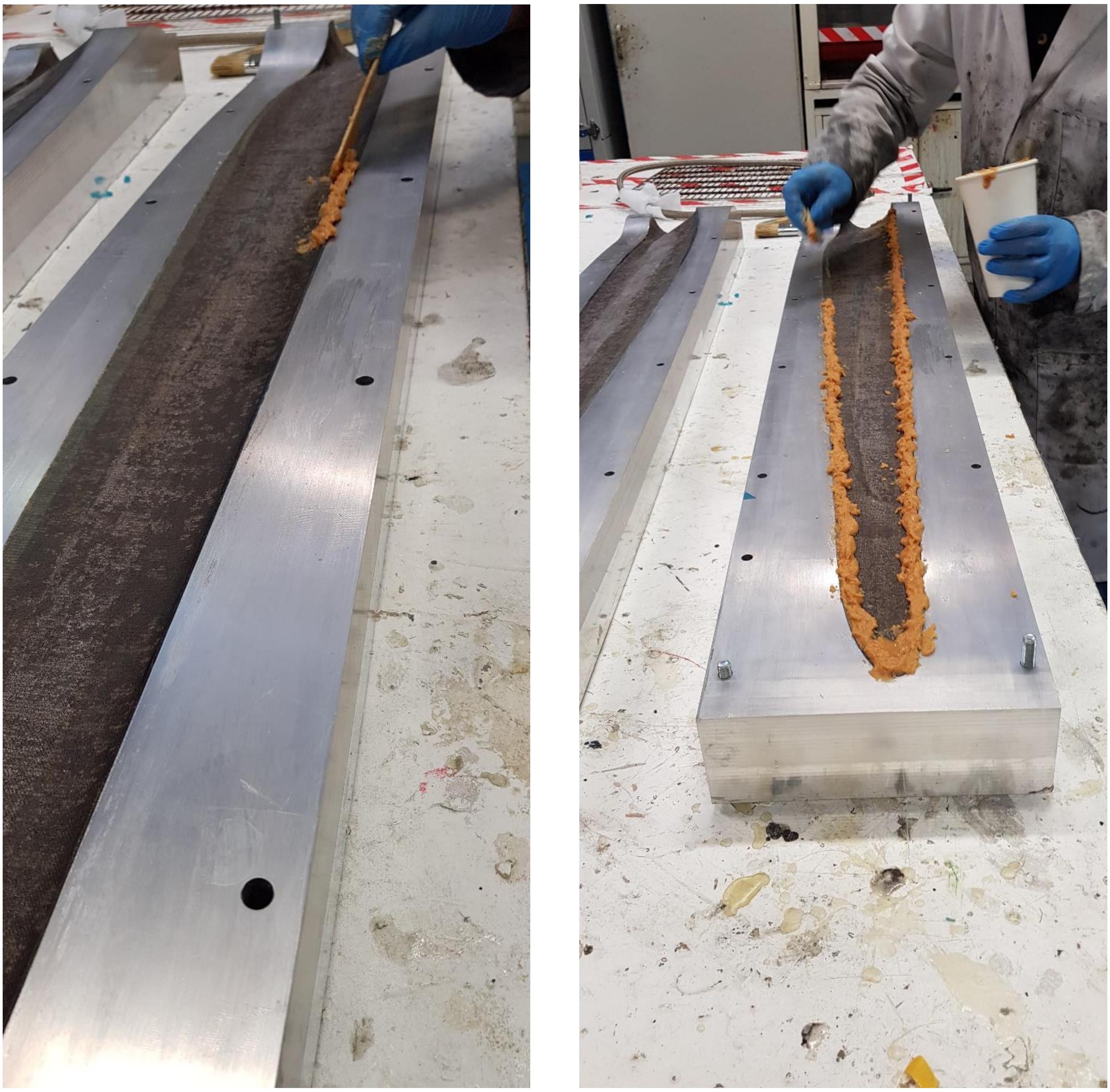

Figure 6: Application of wood-filled acrylic bonding medium

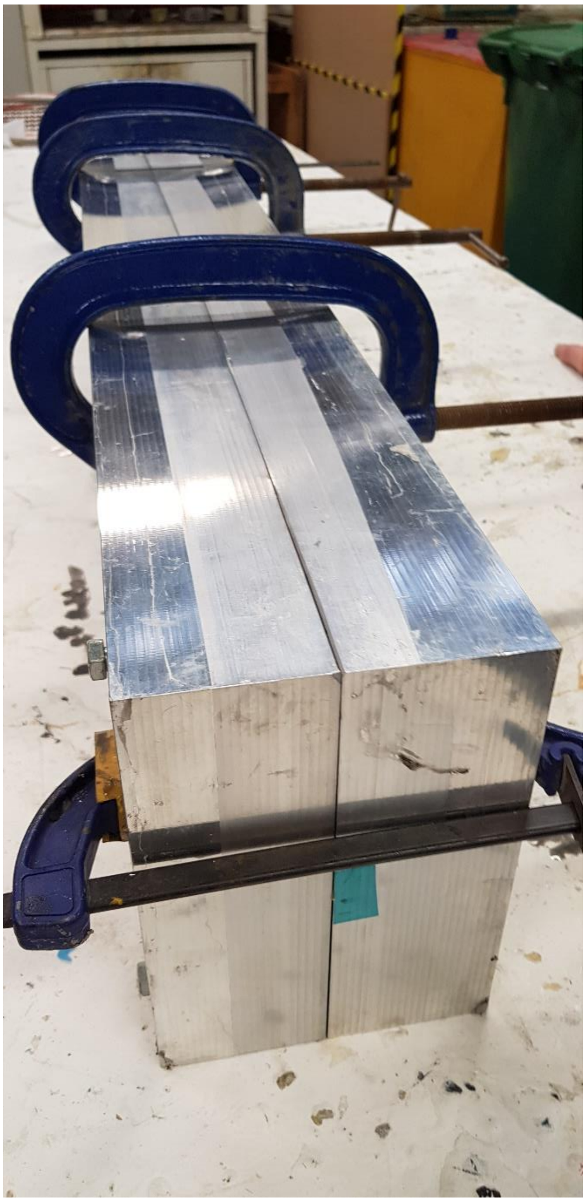

Figure 7: Mould tool halves clamped together during adhesive cure

6. Product

The trimmed and faired blade weight weighs 395g. The profile surface has small areas of relative dryness, but the extent of the defect is similar to that seen in comparable synthetic fibre reinforced composite mouldings. The wood-filled adhesive appears to foam at some time after mixing: it may be that the exotherm takes the temperature to the boiling point of the monomer .There does appear to be some profile distortion, probably due to MMA vapour acting to soften the unsupported PMMA matrix (as a general rule in chemistry like dissolves like”).

Figure 8: Four views of the completed FLOW turbine blade

7. Summary

A flax fabric reinforced acrylic thermoplastic matrix component has been manufactured as two half blades (front and back respectively) with the parts bonded together with a wood dust acrylic polymer to produce a component with the same thermoplastic polymer used for the composite matrix and the adhesive.

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The support of Interreg 2 Seas Mers Zeeën through the SeaBioComp, is gratefully acknowledged. The authors would also like to thank Martyn Hann for data on the mould tool and permission for its use. Further, [add names when appropriate] provided useful comments and insight provided during the drafting and review of this report.

References

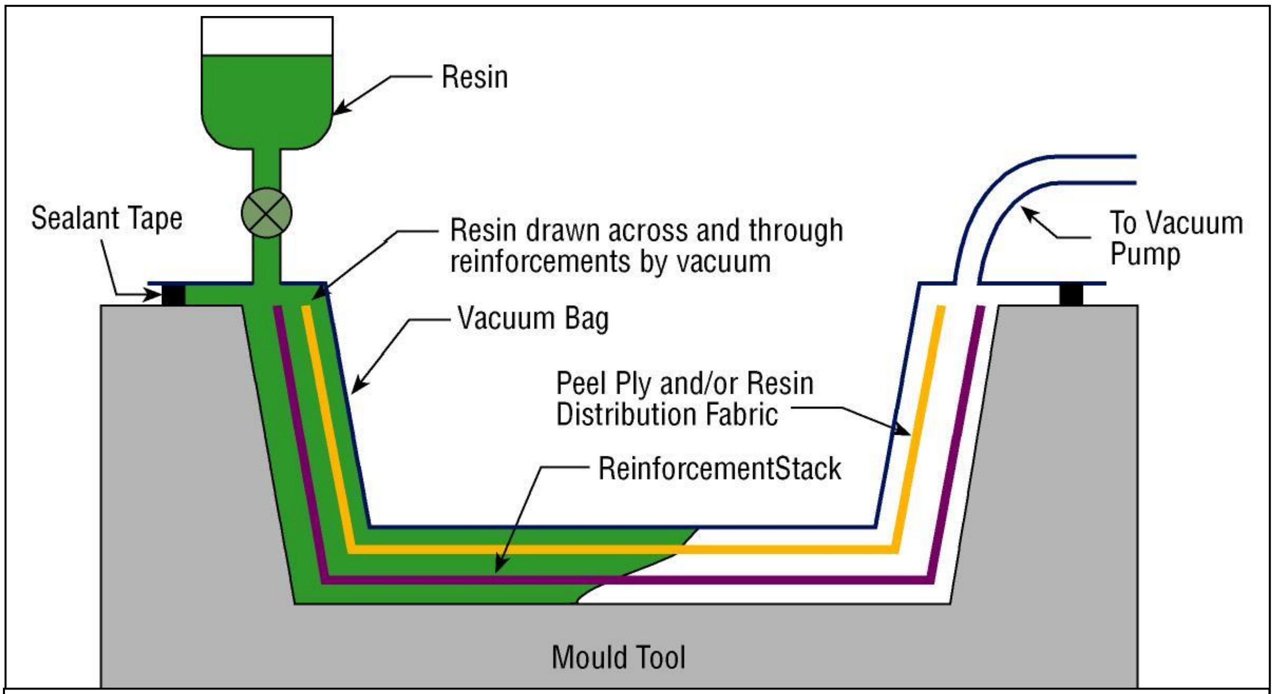
1. CD Williams, J Summerscales and SM Grove, Resin infusion under flexible tooling (RIFT) - a review, Composites Part A: Applied Science and Manufacturing, July 1996, A27(7), 517-524.
2. D Cripps, TJ Searle and J Summerscales, Open Mould Techniques, Chapter 21 in R Talreja and J-A Månson (editors): "Comprehensive Composite Materials Encyclopædia, volume 2: Polymer Matrix Composites", Elsevier Science, Oxford, July 2000, pp 737-761. ISBN: 0-08-043720-6.
3. J Summerscales and TJ Searle, Review: Low pressure (vacuum infusion) techniques for moulding large composite structures, Proc IMechE Part L: Journal of Materials: Design and Applications, February 2005, L219(1), 45-58.
4. SW Beckwith, Resin Infusion Technology * Part 1 - Industry highlights * Part 2 - Process definitions and industry variations * Part 3 - A detailed overview of RTM and VIP infusion processing, SAMPE Journal, 2007, 43(1), 61 and 43(3), 46 and 43(4), 6 & 66-70.
5. J Summerscales, Resin Infusion Under Flexible Tooling (RIFT) [88 references], Encyclopedia of Composites - second edition, John Wiley and Sons, 2012, 2648-2658.
6. VR Tamakuwala, Manufacturing of fiber reinforced polymer by using VARTM process: a review, Materials Today: Proceedings, 2021, 44(1), 987-993..
7. Y Qin, J Summerscales, J Graham-Jones, M Meng and R Pemberton, Monomer selection for *in situ* polymerisation infusion manufacture of natural-fibre reinforced thermoplastic-matrix marine composites, MDPI Polymers, 7 December 2020, 12(12), 2928.
8. A Bohre, K Avasthi, U Novak and B Likozar, Single-step production of bio-based methyl methacrylate from biomass-derived organic acids using solid catalyst material for cascade decarboxylation-esterification reactions, ACS Sustainable Chemistry and Engineering, 2021, 9, 7, 2902–2911.
9. J Lebeau, JP Efromson and MD Lynch, A review of the biotechnological production of methacrylic acid, Frontiers in Bioengineering and Biotechnology, 2020, 8, 207.
10. C Fang, X Zhu, Y Cao, X Xu, S Wang and X Dong, Toward replacement of methyl methacrylate by sustainable bio-based isobornyl methacrylate in latex pressure sensitive adhesive, International Journal of Adhesion and Adhesives, July 2020, 100, 102623.
11. R Kimball, AJ Goupee, MJ Fowler, E-J de Ridder, M Wageningen and J Helder, Wind/wave basin verification of a performance-matched scale-model wind turbine on a floating offshore wind turbine platform, 33rd International Conference on Ocean, Offshore and Arctic Engineering, ASME, San Francisco CA, USA, 8-13 June 2014, Paper No: OMAE2014-24166, V09BT09A025; 10 pages.
12. Elium® 188 XO Safety Data Sheet SDS 006828-001 (Version 1.0), Altuglas International/Arkema Group, La Garenne-Colombes (FR), 12 November 2018.

Appendix A: Composite plate manufacture by resin infusion

1. Select a glass plate and using a sharp blade remove any cured resin remaining on the surface and then wipe the plate clean with solvent.
2. Stick (white) tape around the edge of the plate where the tacky tape will eventually be placed.
3. Apply release agent to the plate and let it dry.
4. Record the time, temperature, pressure and relative humidity, and tows/m for the fabric.
5. Place the individual lamina onto the centre of the glass plate in the required stacking sequence.
6. Place a sheet of peel ply over the laminate
7. [only required for complex shapes] Place a sheet of porous release film over the peel ply.
8. Place the transport mesh/flow medium on top of the stack such that it is **>10 mm inside the laminate edge on both sides and along the length of the laminate**.
9. Cut a 800 mm length of inlet pipe and drill or cut holes at ~25 mm apart for the width of the laminate
10. Notch the end of the pipe which will go into the resin pot.
11. Wrap the (yellow) flow medium around the drilled inlet pipe.
12. Cut a 800 mm length of vacuum outlet pipe sufficient to connect to the resin trap and insert a small rolled piece of flow medium into the pipe end, and wrap any excess peel ply around the mesh.
13. Cut bagging film to size such that there is around 200 mm excess in both directions.
14. Stick a square border of tacky tape to the edges of the bagging film.
15. Remove (white protective) tape locally and adhere the corners of the bagging film to the glass plate.
16. Remove the (white) tape locally and stick the centres of each edge of the bagging film to the plate.
17. Make a tab of tacky tape around the pipes where they will exit the bag.
18. Complete the sealing of the bag to the glass plate.
19. Using a permanent marker, write the group name, laminate stacking sequence and an arrow indicating the resin flow direction onto the bag.
20. Record the time, temperature, relative humidity and pressure.
21. Attach a pressure meter to the inlet pipe.
22. Attach the outlet pipe to the resin trap and apply a vacuum to the bag, smoothing the bagging film away from the laminate area.
23. Identify any leaks in the bag and seek to achieve a vacuum level of ~20 mbar on the pressure gauge.
24. Isolate the vacuum (crimp the outlet pipes in a couple of places) and record the rate of pressure increase on the gauge.
25. Re-introduce the vacuum and continue to improve the seals of the bag until the rate of pressure drop is 1 mbar/minute or less.
26. Clamp the inlet pipe and remove the pressure gauge.
27. **Calculate the quantity of resin** (see below) required to fill the laminate, flow medium and feed pipe.
28. Mix the resin and hardener/catalyst/accelerator in the given proportions.
29. Fix the resin pot to a support, then insert the notched end of the pipe.
30. Unclamp the inlet pipe for just long enough that the resin rises to the clamp position, then reclamp.
31. After 30 seconds (to allow air displaced from the pipe to be evacuated from the bag), open the clamp and resin will flow into the bag.
32. It may be appropriate to record the progress of the flow front.
33. Once the flow front has reached the outlet pipe, and assuming the plate has filled, clamp the inlet pipe to stop further resin inflow.
34. If possible, with Unsaturated Polyester Resin reduce the vacuum level to ~500 mbar absolute and leave the moulding under vacuum until the resin gels.
35. Record the time, temperature, pressure and relative humidity
36. If required, postcure at the appropriate temperature for the required time in the oven.
37. The plate will be post-cured according to the resin manufacturer's recommendations.
38. Remove the laminate from the bag and transfer the data written on the bag to the plate.
39. The technician will cut the plate into samples for mechanical testing.

Volume of resin in laminate ≈ $(1-V_f) \times$ length $\times$ breadth $\times$ thickness *e.g.* $0.5 \times 20 \times 20 \times 0.2 = 40\ \text{cm}^3$
Volume of resin in flow medium (FM at 690g/m^2)= $(1-V_f) \times l \times b \times t$ *e.g.* $0.9 \times 18 \times 22 \times 0.1 = 36\ \text{cm}^3$
Volume of resin in 100 cm length of 0.6 cm internal diameter (r = 0.3 cm) pipe = $\pi r^2 l = 28\ \text{cm}^3$
Total volume of laminate, resin in FM and pipe = 104 cm^3, and assuming density of resin = 1.15 g/cm^3,
∴ required resin = 120 g and with a little extra for bottom of feed cup,
so mix ~170 g of combined (resin + hardener/catalyst)

Cite this document as: John Summerscales and Richard Cullen, Composite plate manufacture by resin infusion, University of Plymouth module MATS347 Appendix A, https://dle.plymouth.ac.uk/pluginfile.php/1800770/mod_folder/content/0/Appendix_A_RIFT.doc?forcedownload=1, accessed at <time> on <date>.



The above diagram is understood to be by **David Cripps of SP Systems** (now Gurit (UK) Limited)

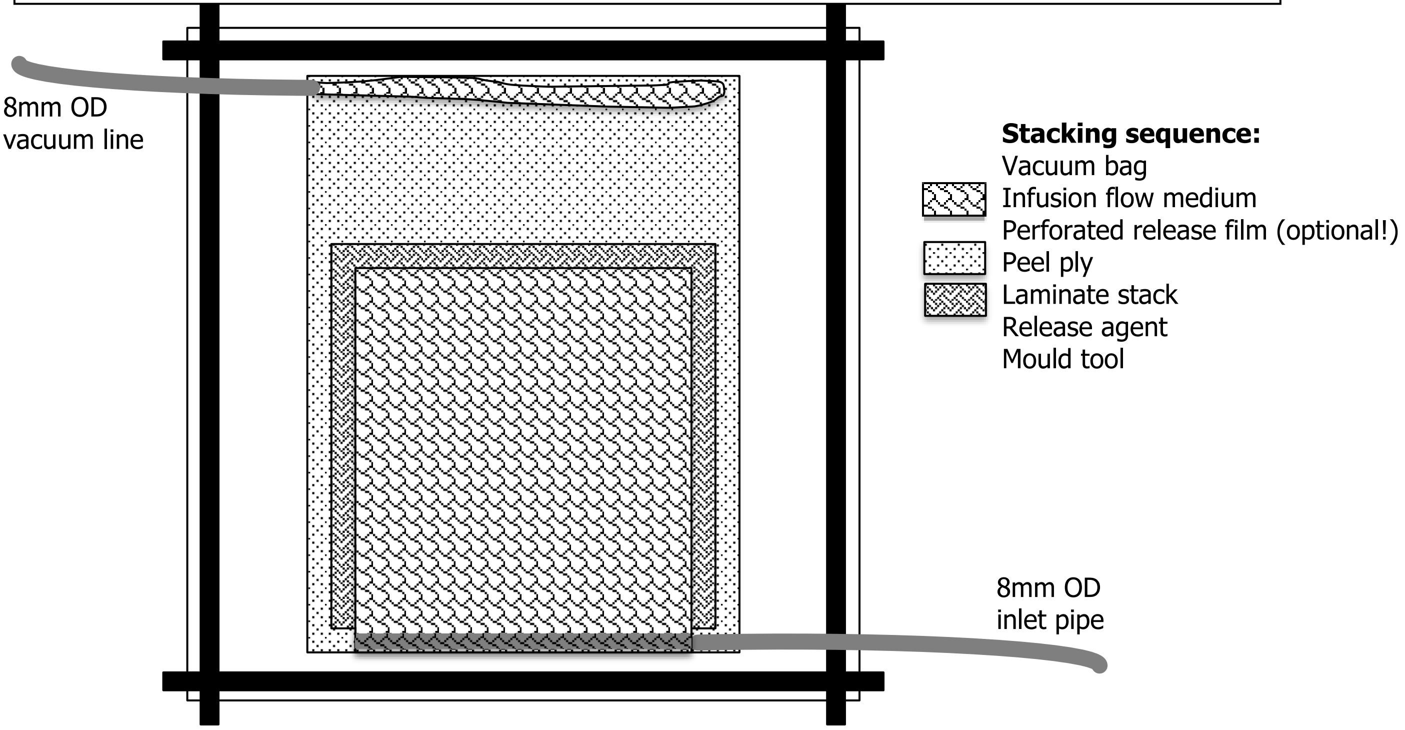


Figure A1: Schematic of the resin infusion process