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COMPARATIVE MECHANICAL PROPERTIES STUDY OF RESIN INFUSION VERSUS HAND LAMINATING FOR THE CONSTRUCTION OF 12-FT FISHING BOAT

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ABSTRACT

Resin Infusion is widely used to produce fiber-reinforced materials. In the process, the resin enters a close mold containing the dry fiber performed by pressure difference. This study is about finding the comparison of the tensile strength, compression strength and flexural strength between resin infusion technique and conventional hand laminating for the construction of a 12-feet fishing boat. Both boat were applied with the same composite matrices. All testing was done in accordance to the standard ASTM D3039, D3039M, ASTM D695-02a and ASTM D790-07. The result showed that the resin infusion technique produced better result upon ultimate tensile strength (27% better) but slightly less satisfactory for in compressive stress (12% lower) and flexural stress (34% lower). Even though resin infusion was only better in tensile strength, physically the product is more lightweight with a better resin-to-fiber ratio.

Keywords: resin infusion, composite, hand laminating, fiberglass.

INTRODUCTION

Fiberglass has been used in the traditional boat building industry in Malaysia since the 1980s [1]. Fiberglass boat is much more attractive due to its strength such as light weight, high vibration damping capability, high impact resistance, low construction costs, ease of fabrication, ease of maintenance and repair. The manual hand laminating technique has undergone several evolutions since its introduction in the 1970s [2]. Several new technologies have been developed since then, such as Resin Transfer Molding [3-5], Seeman Composites Resin Infusion Molding Process (SCRIMP) [6], Resin Infusion under Flexible Tooling (RIFT), [7-9] and Vacuum Assisted Resin Transfer Moulding (VARTM) [10-14].

Hand lay-up refers to the manual method where the application of resin and reinforcement is done by hand onto a suitable mold surface. Glass or other reinforcing mat or woven fabric or roving is positioned manually in the open mould, and resin is poured, brushed, or sprayed over and into the glass plies. On the other hand, the vacuum infusion process is a technique where vacuum pressure is used to drive resin into a laminated layer of fiber mat. Materials are laid dry into the mould and the vacuum is applied before resin is introduced. Once a complete vacuum is achieved, resin is literally sucked into the laminate via carefully placed tubing.

This study was conducted to find out the comparison of selected mechanical properties i.e. ultimate tensile strength, compressive stress and flexural stress between these two methods of construction fiberglass boat.

THE EVOLUTION OF FIBREGLASS BOAT BUILDING METHOD

Fiberglass boat construction has expanded over the years with the various methods for the sole purpose of improving the techniques and skills for the boatbuilding process. The objective in the fiberglass boatbuilding is to achieve lightness in weight, vibration damping, corrosion resistance, and impact resistance, low construction cost and ease of construction. The boatbuilding industry methods can be divided into single skin construction, sandwich construction, resin development, unidirectional and stitched fabric reinforcement, advanced fabrication technique, alternate reinforcement materials and infusion method.

Hand laminating

Hand lay-up is a simple method for composite production. A mould must be used for hand lay-up parts unless the composite is to be joined directly to another structure. The mould can be as simple as a flat sheet or complex as infinite curves and edges. For some shapes, moulds must be joined in sections so they can be taken apart for part removal after curing. Before lay-up, the mould is prepared with a release agent to ensure that the part will not adhere to the mould.

Reinforcement fibres can be cut and laid in the mould. It is up to the designer to organize the type, amount and direction of the fibres being used. Resin must then be catalyzed and added to the fibres. A brush, roller or squeegee can be used to impregnate the fibres with the resin. The lay-up technician is responsible for controlling the amount of resin and the quality of saturation. Other fabrication processes such as vacuum bagging, vacuum resin transfer moulding and compression moulding can be used with hand lay-up to improve the quality of the finished part. In addition it also saves time.

Infusion and vacuum technique

Resin infusion is a specialized advanced laminating technique that greatly improves the quality and strength of fiberglass parts as opposed to conventional hand layup. Applying laminate engineering and resin infusion technology simultaneously allows for the optimization of the parts in terms of strength and weight. The use of resin infusion will likely become the standard in yacht construction and has been in use since the 1960s. From the inside of the mould, after the usual mould release wax is applied, the gel coat and skin coat of thin fiberglass reinforcement are applied in the conventional manner and allowed to cure. From here on everything differs. Next, in the infusion process, the outer skin of the fiber reinforcement fabrics is carefully fitted into the mould over the top of the skin coat. These are put to dry and held in place with a spray contact adhesive.

As the technicians are not hurried and concerned with the narrow resin curing period as would be in conventional layup, attention can be paid to quality and the conscientious cutting, fitting and orientation of the fabrics fibers and core. Next, in the case of a cored part, the structural core materials are cut and fitted, and glued into place. Then the inner skin of reinforcement fabrics is carefully fitted over the core to form a sandwich.

METHODOLOGY

Experimental

This experiment has been divided into two phases: (1) to conduct the selected mechanical test of conventional hand laminating composite boat, and (2) to conduct the selected mechanical test of resin infusion composite boat. The experiment was conducted for 12-feet fishing boat as shown in Figure-1. Same mould has been used for both techniques; hand laminating and resin infusion. The experiment was conducted in controlled environment.

Figure-1. Mould for the experimental setup.

Hand lay-up refers to the manual method where the application of resin and reinforcement was done by hand onto a suitable mold surface. Reinforcements were laid into a mold and manually wet out using brushes and rollers. Table-1 shows the laminating schedule applied to the construction of 12-feet boat.

Table-1. Laminate schedule for construction of a 12-feet GRP boat.

Layers	Mat
1st layer	Tissue mat
2nd layer	CSM 300
3rd layer	WR 600
4th layer	CSM 600

The general setup of resin infusion using the same principle of vacuum pressure was used to drive resin into a laminated layer of fiber mat. The same basic setup has been described in [12-15]. The setup is shown in Figure-2 below.

Figure-2. Resin infusion setup.

Mechanical properties testing

All the testing were done at CTL Asia Sdn. Bhd. Three types of mechanical testing were chosen to test the material. All the testing were using ASTM standard as reference. The standards are:

a) ASTM D3039, D3039M Tensile Testing of Polymer Matrix Composite Materials. ASTM D3039 Tensile Testing is to measure the force required to break a polymer composite specimen and the extent to which the specimen stretches or elongates to that breaking point.
b) ASTM D695-02a Compressive Properties of Rigid Plastics. Compressive properties testing describe the behavior of a material when it is subjected to a compressive load. Loading is at a relatively low and uniform rate. Compressive strength and modulus are the two most common values produced.
c) ASTM D790-07 Flexural Properties of Unidirectional and Reinforced Plastics and Electrical Insulating Materials. The flexural test measures the force required to bend a beam under three point loading conditions. The data is often used to select materials for parts that will support loads without flexing. Flexural modulus is used as an indication of materials stiffness when flexed.

Testing equipment and methodology

The specimen was tested using the Universal Testing Machine Model: Instron 5582 with a load capacity of 100kN and well calibrated. The test was conducted in accordance to the standard.

a) Tensile test (ASTM D3039 / D3039M-08)

Each specimen was gripped by using mechanical grips and an extensometer was used to measure modulus. The test speed can be determined by the material specification or time to failure (1 minute to 10 minutes). Testing speed was set at the rate of 2.0mm/min.

b) Compression test (ASTM D695-02a)

The specimen was placed between compressive plates parallel to the surface. The specimen is the compressed at a uniform rate. The maximum load was recorded along with the stress-strain data. All specimens were tested at the rate of 1.3mm/min. An extensometer was attached to the specimens to measure their modulus.

c) Flexural test (ASTM D790-07)

The speed of the test varied depending on support span and the thickness of the specimens. Most commonly the specimen lies on a support span and the load is applied to the center by the loading nose producing three points bending at a specific rate. The parameters for this test are the support span, the speed of the loading and the maximum of the deflection for the test. Based on the standard, this test is stopped when the specimens reaches 5% deflection or the specimens breaks before 5%.

RESULTS AND DISCUSSIONS

All the testing were done at CTL Asia Sdn. Bhd. Three types of mechanical testing were chosen to test the material. Figure-3 and Figure-4 show the fracture sample of hand lay-up and vacuum infusion method for 12-feet fiberglass boat. It was observed that both failed at the same behavior but comparing the thickness of samples, it was noted that the product by hand laminating produced almost double the thickness of resin infusion.

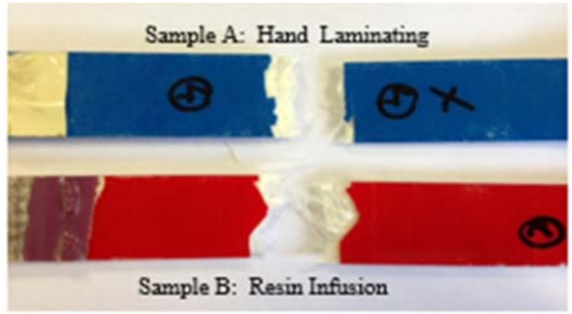

Figure-3. Fracture specimens of composite fabricated using 2 different methods.

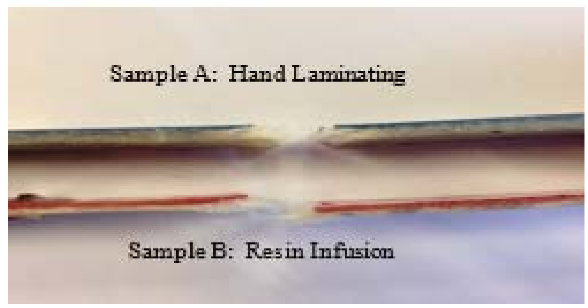

Figure-4. Fracture specimens of composite fabricated by hand lay-up method (top) and resin infusion method (bottom).

Tables 2 and 3 show a comparison of tensile strength of composite with different manufacturing methods which were vacuum infusion and hand lay-up. It was clearly observed that the sample fabricated by vacuum infusion had a higher tensile strength than hand lay-up method.

Table-2. Tensile strength and modulus data for hand laminating process.

	Width (mm)	**Thickness** (mm)	**Failure load** (kN)	**Ultimate tensile strength** (Mpa)	**Chord modulus** (0.001-0.003) mm/mm (Gpa)
1	24.890	3.650	6.364	70.054	6.622
2	24.850	3.780	6.639	70.680	6.341
3	24.950	3.680	7.079	77.102	6.761
4	24.960	3.660	6.862	75.115	6.647
5	24.910	3.630	5.617	62.124	6.317
Mean	24.912	3.680	6.512	71.015	6.538
SD	0.04	0.06	0.57	5.79	0.20

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Table-3. Tensile strength and modulus data for resin infusion process.

	Width (mm)	**Thickness** (mm)	**Failure load** (kN)	**Ultimate tensile strength** (Mpa)	**Chord modulus (0.001-0.003) mm/mm** (Gpa)
1	24.930	2.850	6.587	92.703	7.583
2	24.900	2.740	6.835	100.177	7.103
3	24.890	2.954	6.304	85.745	8.604
4	24.850	2.425	5.890	97.746	9.324
5	24.790	2.570	6.909	108.445	8.222
Mean	24.872	2.708	6.505	96.963	8.167
SD	0.05	0.21	0.42	8.47	

The tensile strength testing for hand laminating and also resin infusion process was done using the universal testing machine (Instron 5582). This specification for this testing was based on ASTM D3039. The quantity of the specimens for this kind of testing that was taken from the panel of hand laminating was 5 specimens and resin infusion was 5 specimens. The temperature and also humidity must be kept constant for both process which was 24 °C and 55 % respectively. The speed rate for this testing was 2.00 millimeters per minute. Tables 4 and 5 show the comparison of compression strength of composite with different manufacturing method which were vacuum infusion and hand lay-up. It was observed that the sample fabricated by the hand lay-up method had higher compression strength than that of vacuum infusion.

Table-4. Compressive strength and modulus data for hand laminating process.

	Width (mm)	**Thickness** (mm)	**Compression at failure** (kN)	**Compressive stress at maximum comp. load** (Mpa)
1	12.754	3.751	5.376	112.374
2	12.731	3.774	5.518	114.846
3	12.743	3.645	5.439	117.108
4	12.750	3.891	5.491	110.677
5	12.751	3.741	5.365	112.476
Mean	12.746	3.760	5.438	113.496
SD	0.01	0.09	0.07	2.51

Table-5. Compressive strength and modulus data for resin infusion process.

	Width (mm)	**Thickness** (mm)	**Compression at failure** (kN)	**Compressive stress at maximum comp. load** (Mpa)
1	12.774	2.396	3.431	112.104
2	12.763	2.628	3.248	96.833
3	12.721	2.566	3.157	96.722
4	12.743	2.557	3.516	107.919
5	12.762	2.606	3.035	91.261
Mean	12.753	2.551	3.278	100.968
SD	0.02	0.09	0.20	8.68

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The compression strength testing for hand laminating was done using the universal testing machine (Instron 5582). The specification for this testing was based on ASTM D695-02a. The quantity of the specimens for this kind of testing that was taken was 5 specimens each from the panel of hand laminating and resin infusion. The temperature and also humidity must be kept constant for both processes which was at 23 °C and 55 %. The speed rate for this testing was 1.3 millimetres per minute. Table 6 and 7 show the comparison of flexural strength of composite with different manufacturing method which was vacuum infusion and hand lay-up. It was clearly observed that the sample fabricated by the hand lay-up method has higher compression strength than the vacuum infusion.

Table-6. Flexural strength data for hand laminating process.

	Width (mm)	**Thickness** (mm)	**Max. Load** (N)	**Flexural stress** (Mpa)
1	17.368	3.464	347.593	137.600
2	17.136	3.596	375.270	144.797
3	17.358	3.770	365.278	133.255
4	17.368	3.918	434.529	154.018
5	17.262	4.041	389.351	134.672
Mean	17.298	3.758	382.404	140.869
SD	0.10	0.23	32.87	8.59

Table-7. Flexural strength data for resin infusion process.

	Width (mm)	**Thickness** (mm)	**Max. load** (N)	**Flexural stress** (Mpa)
1	12.858	2.435	119.898	92.002
2	12.936	2.411	124.955	97.211
3	12.772	2.599	125.736	91.818
4	12.473	2.635	118.207	85.991
5	12.679	2.679	138.786	98.372
Mean	12.744	2.552	125.517	93.079
SD	0.18	0.12	8.08	4.95

The flexural strength testing for the resin infusion was done using the universal testing machine (Instron 5582). This specification for this testing was based on ASTM D790-07. The quantity of the specimens for this kind of testing that was taken was 5 specimens each from the panel of hand laminating and resin infusion. Similar to the other materials, the temperature and also humidity must be kept constant at 24 °C and 57% for both processes. The speed rate for this testing varied depending on support span and thickness of the specimen.

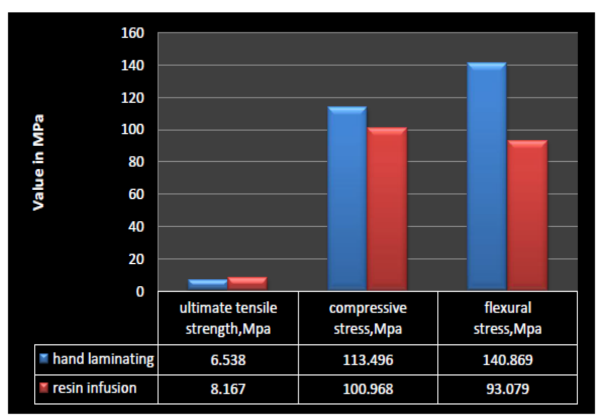

Figure-5. The comparison between three (3) types of mechanical testing for hand laminating method and resin infusion method.

From Figure-5, it can be concluded that the hand laminated specimens had a higher value than the resin infusion process. The hand laminating specimens were not as strong enough as resin infusion process in terms of tensile stress testing. The compressive stress value for compressive strength testing and the specimens from the hand laminating process stated higher values than of the resin infusion process. The mechanical testing proved that the hand laminating specimens had better strength enough compared to resin infusion specimens in terms of compressive strength testing. For the flexural strength testing, the flexural stress for hand laminating was higher compared to resin infusion. Therefore hand laminating specimens had better strength compared to the resin infusion specimens in this experiment.

CONCLUSIONS

This study has successfully shown the differences in the methods of constructing 12-feet fishing boats between hand laminating process and resin infusion process. The results were attained using tensile strength testing, compressive strength testing and flexural strength testing methods. Although the facilities and resources were limited, the paper had proven the best construction process to be used which could contribute to a better quality of the fishing boat itself. The findings be obtained by conducting three testing methods, for the tensile strength testing, the specimens taken from resin infusion product yielded a higher value of ultimate tensile strength compared to the specimens taken from resin infusion process. For the compressive strength testing, the specimens taken from the hand laminating product had higher value of compressive stress compared to the value of specimens taken from the resin infusion. For the flexural testing, the data for the specimens taken from hand laminating product was higher than the value from the specimens taken from resin infusion. This research has proved that the resin infusion method is better than the hand laminating method in term of tensile strength.

RECOMMENDATION

The research may be applied to another type of testing such as physical and also chemical testing. All the humidity and temperature must be controlled strictly and all the infusion setup bagging should be leak-proof. The research also can be expanded to the other type of construction method for the fiberglass boat and also from the testing results; the data can be used to producing standards of the fiberglass boatbuilding.

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REFERENCES

[1] Shamsuddin, M. Zawahid, 2003, A Conceptual Design Of a Fibre Reinforced Plastic Fishing Boat For Traditional Fisheries In Malaysia. The United Nations University Fisheries Training Program, Available at www.unuftp.is/static/fellows/document/samsuddin03prf.pdf. Accessed 2013 Jul 23.

[2] Market Development," CI on Composites, SPI Composites Institute, New York, NY, Aug/Sep 1994, pp. 10-11

[3] Beckwith SW, Hyland CR. Resin transfer molding: a decade of technology advances. SAMPEJ 1998; 34(6):7–19.

[4] Potter K. Resin transfer moulding. London: Chapman & Hall; 1997. ISBN 0-412-72570-3.

[5] Benjamin WP, Beckwith SW. Resin transfer moulding. SAMPE Monograph 3. Covina (CA); 1999. ISBN 0-938-99483-2.

[6] SCRIMP technology. Available at http://www.seemanncomposites.com/index.php?option=com_content &view=article&id=26&Itemid=26. Accessed 2013 Jul 23

[7] Williams CD, Summerscales J, Grove SM. Resin infusion under flexible tooling (RIFT): a review. Compos Part A Appl Sci Manuf 1996 July; 27A(7):517-524.

[8] Beckwith SW. Resin infusion technology; (a) Part 1-industry highlights. SAMPE J 2007; 43(1): 61; (b) Part 2-process definitions and industry variations. SAMPE J 2007; 43(3):46; (c) Part 3-a detailed overview of RTM and VIP infusion processing. SAMPE J 2007; 43(4):6, 66-70.

[9] Cripps D, Searle TJ, Summerscales J. Open mould techniques for thermoset composites. In: Talreja R, Månson JA, editors. Comprehensive composite materials encyclopaedia. Volume 2, Polymer matrix composites. Oxford: Elsevier Science; 2000. pp. 737-761. Set ISBN: 0-08-043720-6. Volume ISBN: 0-08-043725-7. Chapter 21.

[10] M.S. Koefoed, Modeling and Simulation of the VARTM Process for Wind Turbine Blades, Industrial Ph.D. Dissertation, Aalborg University, 2003

[11] N.C. Correia, F. Robitaille, A.C. Long, C.D. Rudd, P. Simacek, S.G. Advani, Use of Resin Transfer Moulding Simulation to Predict Flow, Saturation and Compaction in the VARTM Process, Journal of Fluids Engineering ASME 126 (2004) 210-215

ARPN Journal of Engineering and Applied Sciences

[12] Ragondet A. Experimental Characterization of the Vacuum Infusion Process. PhD thesis, 2005, University of Nottingham.

[13] Hoebergen A, van Herpt E, Labordus M. The manufacture of large parts using the vacuum injection technique: practical injection strategies for boatbuilding used in the manufacture of the Contest 55. In: 20th Jubilee International Conference 1999 Apr 13-15. Paris: SAMPE Europe.

[14] Vacum Infusion How to Guide. Available at http://www.fibreglast.com/product/vacuum-infusion-brochure. Accessed 2013 Jul 23.