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MATERIAL CHARACTERIZATION OF COMPOSITES FOR A VERTICAL WIND TUBRINE

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MATERIAL CHARACTERIZATION OF COMPOSITES FOR A
VERTICAL WIND TUBRINE
BY
ANTHONY MCQUEEN

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
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MASTER OF SCIENCE THESIS
OF
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Abstract

An experimental investigation was conducted to evaluate the performance of composite materials for a vertical wind turbine. The materials used were polyester resins with fiberglass reinforcement, corrugated aluminum core composite, and a polypropylene honeycomb core composite. Quasi-static tensile experiments were conducted using an Instron 5585 and following ASTM Standard D638. Tensile Modulus, Tensile Strength and other material characteristics were calculated using digital image correlation data acquisition and MATLAB. Blast experiments were conducted on the materials using a shock tube apparatus to investigate the dynamic response and performance. The 6.35mm Polyester Resin composite had the lowest deflection when normalized with thickness. This material had the highest tensile modulus and yield strength as well showing that of the materials tested it is the optimal choice for the wind turbine.

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Preface

This thesis is prepared in manuscript format.

Section 1 is an introduction for the reader to understand the background behind and previous research in the characterization of composite materials. This is given in order to conceptualize the differences between composites of varying materials and even those made of the same material.

Section 2 highlights the basic material properties as well as the experimental apparatuses used. This section includes initial properties observed of the tested material and a brief description of the procedure for tensile testing using an Instron and blast loading using a shock tube.

Section 3 outlines the results of tensile tests to determine quasi-static properties. The section also outlines the results of the blast loading experiment for each material.

Section 4 proposes the overall conclusion of the thesis.

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”Material Characterization of Composites for a Vertical Wind Turbine”

by

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1 Introduction

Impact response and mechanical behavior of honeycomb sandwiches and polypropylene honeycomb cores have been conducted within the past two decades. Honeycomb cores can be used in aircraft construction, as well as in a system trying to reduce weight while achieving similar structural strength [1]. The cores and faces are bonded to create a structure designed to handle tension, transverse shearing, compression and lateral stability while having a low density [2]. Polypropylene honeycomb cores have high strength to weight ratio and are also weather resistant [1]. Both characteristics make it a viable option for the vertical wind turbine. The compressive behavior of honeycomb cores is relatable to the density in that strength increases as density increases [2].

Mechanical properties of natural reinforced fiber composites were investigated by Gopinath et al., which can be used to understand the differences between varying glass fibre composites. Two composites were studied, jute fibre with polyester and jute fibre with epoxy. During tensile testing using ASTM D3039 standards were found to have Youngs Moduli of 0.811 GPa and 1.064 GPa respectively. [3]. The composites are found to be 83 and 65 times weaker than aluminum. When compared to different variations of jute fibre composite, chemically treated with 5% or 10%, the tensile strength was greater for the 5% by 16% and for polyester and resin compared to the 10%. Gopinath et al. found that these composites can be applied in the automotive field.

An investigation of the dynamic mechanical properties of glass/bamboo fiber reinforced unsaturated polyester resin composites was done in 2011. The investigation used a dynamic mechanical analyser, scanning electron microscope, to determine three parameters. The parameters were storage modulus, loss modulus and mechanical dampening. The investigation compared the parameters to the composition of glass/bamboo fibers. Pure resin had a lower storage modulus than glass/bamboo fiber

composite. Loss modulus was seen to decrease with an increase in bamboo fibers [4].

The mechanical performance of biofibre/glass reinforced polyester hybrid composite was studied at Ravenshaw College [5]. The composite was a matrix of pineapple leaf fibres (PALF), sisal fibres and glass fibres of varying weight percentage wt. %. The tensile test conducted met ASTM -D638 standard [6]. The total fibre content of the composite was kept equal to 25% while the glass fibre portion varied from 0% to 12.9%. Glass fibre wt.% of approximately 8.6% increase the ultimate tensile strength by 66% but at wt. % of 12.9% the composite lost tensile strength by 10%. Mishra et al found that at low wt.% the increase strength was due to the sisal fibre transferring load from the glass fibre. When the wt.% exceeds the amount that the sisal fibre can transfer loading out of the strength decreases.

Blicblau et al. at the Swinborne University of Technology in Australia experimented on raw wool and polyester resin composites. The experiment conducted used specimen of varying mass fractions from 0% to 55%. The tensile test was conducted with 36 specimen that were conditioned at 22 degrees Celsius for 24 hours. All tests were conducted on the Instron 1114 and showed that an increase in mass fraction yielded little change in strength. The tensile strength for 0% is 33.9 MPa while a mass fraction of 55% is 41.9 MPa. The modulus of elasticity for the two percentages was 0.9 MPa and 2.8 MPa respectively [7] The use of natural fibre may be environmentally friendly however, the reduction of strength does not seem to be a fair trade-off.

In 2011 a study was done on the impact response of polypropylene honeycomb cores without fiber metal laminate faces. The impact response was determined from low velocity impact tests using a drop tower. It was determined that low impact would only indent the specimen while the higher impact energies created delamination as well as core crushing and bending. There was also a range between the upper and lower limits of impact energy where energy absorption increases with an increase in

energy [1].

Encore in Leuven Belgium developed a production technology to manufacture high-end honeycomb structures at a lower cost. Previously honeycomb structures were primarily limited to aerospace applications but with changes in production technology the cost efficient applications can now include packaging, building and construction as well as automotive and much more. A redesign of the currently used twin walled corrugated composites was necessary due to the lack of mechanical strength in the transverse extrusion direction. The initial redesign was cup-shaped bubble cores, which only perform well at thickness of 3-5 mm. During the production process the material is stretched unevenly which result in negative effect on performance.

Continuous interlocking hexagons, honeycomb core sandwich panels results in higher uniform rigidity, flexural strength and compressive strength. The redesign allows for optimal mechanical performance for board of thickness 3-60 mm. At a thickness of approximately 10 mm Fluted board, twin wall corrugated composite, has a compression strength of 0.4 MPa at a weight of 2000 g/m². Honeycomb board with a weight of 1800 g/m² has a compressive strength of 0.5 MPa while honeycomb board with a weight of 2400 g/m² has a compressive strength of 1.1 MPa. The flexural modulus is where there is a large variation for the fluted board to the honeycomb board. The fluted board of weight 200 g/m² has a flexural modulus approximately 125 MPa for the transverse extrusion direction and approximately 437 MPa in the longitudinal extrusion direction. In comparison the honeycomb board of weight 1800 g/m² has a flexural modulus of approximately 562 MPa and 625 MPa in the transverse and longitudinal extrusion directions respectively. The honeycomb board of weight 2400 g/m² has a flexural modulus of approximately 875 MPa and 937 MPa for the transverse and longitudinal extrusion directions. The 1800 g/m² honeycomb board has a flexural modulus 4.4 times and 1.4 times greater than the fluted board in the transverse and longitudinal extrusion direction, emphasizing the increase in strength

of the composite structure. [8]

Wadley et al [9] conducted an impact response investigation of aluminum corrugated core sandwich panels. The investigation compared corrugated cores, corrugated cores with ceramic inserts and solid aluminum panels. A 52100 chrome steel sphere was used as projectile and impact velocity at penetration was analyzed to compare the panels. The solid aluminum panels had an impact velocity of 650-675 m/s while the corrugated core sandwich panels impact velocity ranged from 530-590 m/s, The corrugation resulted in a 20 % decrease in critical impact velocity.

Herbert investigated the performance of E-glass reinforced polymer resin sheets during shock wave loading and drop weight impact loading at the University of Rhode Island. Fiber areal weight as well as polymer type were compared. The urethane panel with the highest fiber areal weight out performed the lower fiber areal weights and the vinyl ester resin panels. The vinyl ester panel with the highest fiber areal weight out performed the the other materials in the shock tube test. The urethane high fiber areal weight had the best performance in the drop tower test and second best in the shock tube test. Urethane resin was thought to be strain rate sensitive and would offer better blast resistant in very high blast conditions [10].

At the University of Rhode Island in 1990 Butts tested the effects of bi-axial loading on impact performance of laminated composite materials. Butts testing 3.3 mm thick Scotchply Type 1002 E glass/epoxy laminate composites made by 3M. When the plates were impacted with no load applied to obtain the compressive strength of the material. The plates had a compressive strength of 193 MPa. During the testing, it was seen that an increase in projectile velocity causes the compressive strength to decrease. At 115 m/s the compressive strength dropped to 74 MPa, while for velocities under 50 m/s resulted in no decrease of compressive strength. When biaxial loading was applied and projectile velocity set a constant 70 m/s the residual strength decreased by 17 % and the area of the damage increase by 40% compared to

the unloaded plates. The ratio of vertical to horizontal loading was compared, during completely biaxial the compressive strength was 131.1 MPa and completely uniaxial loading the compressive strength was 169.7 MPa. [11]

Shillings et al [12] investigated the blast response of Carbon-Epoxy weathered composite materials. Non-weathered materials were also investigated as a comparative. The non weathered materials were blast loaded at approximately 0.8 MPa and when simply supported had an out of plane displacement of 20mm while returned to the original position. When blast loaded with a fixed support the non weathered composite experienced 5.57 mm of out of plane deflection. In the fixed support case the support allowed for the displacement to be restricted resulting in lower deflection than simply supported.

This study is an experimental investigation to evaluate the performance of composite materials for a vertical wind turbine. The materials tested were polyester resin with fiberglass reinforcement, corrugated aluminum core composite, and a polypropylene honeycomb core composite. Material characterization experiments were performed following the appropriate ASTM standards. Quasi-static tensile experiments were conducted using an Instron 5585 and following ASTM Standard D638 [6]. Tensile experiments were conducted for the following materials: LR, PT and PF. Blast experiments were conducted on the materials using a shock tube apparatus to investigate the dynamic response and performance.

2 Materials and Experimental Procedure

2.1 Material Description

The composite materials investigated in this study consisted of 12.7 mm polyester resin, 6.35 mm polyester resin, 5.08 mm polyester resin with ribbed protrusions (Safe Plank), 6.35 mm laminate veil with polyester resin, 8.509 mm corrugated alu-

minum sandwiched between two thin sheets of aluminum (Alumicore), and 25.4 mm polypropylene honeycomb composite. The interior structure of the Alumicore and Honeycomb composite can be seen in Figure 1a and 1b below. All the fiberglass resin composites were manufactured by Fiberglass Fabricators (Smithfield, RI). The polypropylene specimen was manufactured at Plascore Inc. (New Fairfield, CT). The aluminum composite was manufactured by Atlas International (Allentown, PA) and is a prototype material.

(a) Alumicore Interior

(b) Polypropylene Honeycomb Core Interior

Figure 1: Alumicore and Polypropylene Honeycomb Interior Cross-Section

The specimens were machined at the University of Rhode Island. Young's Modulus, yield strength, density, Poissons ratio and dimensions obtained for each material used in the blast loading and quasi-static test are given in Table 1.

Specimen	Material Type	Density (g/cm ³)	Thickness (mm)
PF	Polyester Resin	1.820	6.35
PT	Polyester Resin	1.767	12.7
LR	Laminate Resin Veil	1.527	6.35
AC	Alumicore	0.576	8.509
HC	Polypropylene Honeycomb	0.149	25.4
SP	Safe Plank	1.929	5.08

Table 1: Material Characteristics

2.2 Digital Image Correlation

Digital Image Correlation (DIC) is used to obtain full-field displacement measurements on a specimen surface through optical analysis. 3D DIC uses two cameras to capture the three dimensional response of the plates. Before data acquisition the cameras are calibrated and synchronized using a grid of dots with known relative locations. The grid was placed at the intended experimental location. The calibration grid was shifted in all degrees of freedom while recording the images. The coordinate locations of the dots allow for a correspondence of the coordinate system for each camera. The DIC is then performed on the image pairs that are recorded during the shock event. A high contrast random speckle pattern was applied to the composite plates by coating the specimen with white paint on one face, and randomly placing black dots approximately 2 mm in diameter throughout the coated area. The Photron FastCam SA1 cameras were set to record at 25,000 frames per second. The analyses of the high-speed images were performed using the commercially available VIC-3D 7 software by Correlated Solutions, Inc. located in Columbia, SC. The VIC-3D software matches common pixel subsets of the random speckle pattern between a reference undeformed image and the deformed images. 2D DIC uses the one camera to capture two dimensional response of the specimens. A known dimension of the specimen is input into the VIC-2D to define the original positions of the dots.

2.3 Material Characterization

Quasi-static tensile experiments were conducted using an Instron 5585 and following ASTM Standard D638. Tensile experiments were conducted for the following materials: LR, PT and PF. 2D DIC was utilized to obtain the strain data during the material characterization experiments.

2.4 Tensile Test

Quasi-static tensile experiments were conducted using an Instron 5585 and following ASTM Standard D638. Tensile experiments were conducted for the following materials: LR, PT and PF. The specimen were machined according to the ASTM D638 and clamped in the Instron. The testing speed was set to 5 mm/min and the data was recorded using the Instron load cells. One camera was setup for 2D DIC in order to get strain data.

2.5 Shock Tube Facility

A shock tube apparatus was used to generate a concentrated shockwave which provides a dynamic load on the composite specimens. The shock tube is 8 m in length and is composed of four separate sections: driver section, driven section, converging conical section, and a 38 mm diameter muzzle. A schematic of the shock tube is shown in Figure 2. The driver and driven sections of the shock tube are separated by a Mylar diaphragm, allowing for the pressurization of the driver section. When a critical pressure is reached, the diaphragm bursts, and the high pressure propagates down the length of the shock tube. The high pressure shock waves becomes a planar shock front and loads the specimen on the muzzle end.

When the shockwave meets the specimen, the shock wave is compressed and reflected back into the shock tube. The load that the specimen encounters is the

compressed reflected pressure. Three piezoelectric pressure transducers which are mounted flush to the shock tube muzzle collect the pressure data of the shock wave. The Pressure transducers are Piezoelectric PCB102A by PCB Piezotronics Inc. (Depew, NY). The specimen were simply supported and placed flushed to the muzzle end of the shock tube. The specimens were painted with a white coat, and black dots were randomly placed about the coated area to employ 3D DIC. The simply supported fixture clamped the specimen between two 12.7 mm wide aluminum plates that were approximately 457.2 mm apart. The first bolt was hand tightened down and the torque was measured to be 10 N*m which was then applied to every bolt for all of the following tests. For each experiment the specimen were placed flush against the shock tube. The DIC imaging was captured by two Photron FastCam SA1 cameras by Photron USA located in San Diego, CA. In order to ensure the specimen were properly illuminated two Super Sun-Gun SSG-400 from Frezzi Energy Systems Inc. located in Hawthorne, NJ. were used. 3D DIC was used to calculate the out-of-plane deflection of the panels.

Figure 2: Shock Tube Diagram

3 Experimental Results

3.1 Tensile Test

The Alumaticore and Honeycomb Polypropylene composites are not in conformance to any ASTM standard due to the fact that they are sandwich structures, with face-sheets and a core, which are bonded together by some adhesive. This results in a modulus that is a lumped parameter of both of these features which does not adhere to the test standard. Material properties obtained during the tensile test can be seen in Table 2

Specimen	PF	PT	LR
Young's Modulus (GPa)	19.88	8.97	12.032
Yield Strength (MPa)	299.6	111.3	147.4
Poisson's Ratio	0.3129	0.2549	0.2578
Failure Strain (%)	1.7124	1.5721	1.4472

Table 2: Material Properties

Figure 3: Tensile Test Specimen Postmortem

The 12.7 mm Polyester Resin began fracturing at the center of the specimen before fracturing vertically down through the specimen up to the edge of the gauge length. The 12.7 mm Polyester resin was found to have a Tensile Strength 111.25 MPa and a Poissons ratio of 0.25. The 6.35 mm Polyester Resin splintered vertically up the specimen but the sample did not fracture completely. The 6.35 mm Polyester Resin has half the thickness of the PT while having 2.69 times more tensile strength. 6.35 mm Polyester Resin had the largest deviation in its tensile strength of 66 GPa. The 6.35 mm Polyester Resin also splintered vertically during testing but did not completely fracture. The Laminate Resin Veil composite had similar fracture characteristics during this test. The effect of the tensile experiment can be seen in the postmortem documentation of the specimen in Figure 3.

3.2 Blast Loading

The requirement of the wind turbine is a material that can withstand a wind load of 0.0015 MPa. However, the minimum blast load achievable in the shock tube is 0.6 MPa (500 times the requirement). As shown in Table 1 at 500 times the required load, all materials, except for the Alumaticore meet, the maximum deflection requirement. The pressure profiles of each material can be seen in Figures 4,5,6,7,8and 9 below. The deflection data was normalized using the thickness of each material in order to accurately compare the results.

Figure 4: 6.35 mm Polyester Resin Pressure Profile

Figure 5: 12.7 mm Polyester Resin Pressure Profile

Figure 6: Laminate Resin Veil Pressure Profile

Figure 7: Alumaticore Pressure Profile

Figure 8: Polypropylene Honeycomb Pressure Profile

Figure 9: Safe Plank Pressure Profile

3.2.1 Polyester Resin

Both 12.7 mm and 6.35 mm Polyester Resins meet the test requirements and had no visible damage. The 12.7 mm Polyester Resin also had the lowest average deflection of all the materials. The 12.7 mm Polyester Resin has the lowest peak deflection/thickness also seen in Figure 10. The 6.35 mm Polyester Resin nominally deflected more than or as much as all the other material however, the non resin based material all experienced visible postmortem damage.

Figure 10: 12.7 mm Polyester Resin Deflection Profile

Figure 11: 6.35 mm Polyester Resin Deflection Profile

3.2.2 Alumaticore

Alumaticore deflects at the groove interfaces, and depending on side of impact, the corrugation causes a greater reduction of deflection. Figure 12 shows that normalized deflection of both when both sides are tested. The material strength would be dependent upon which direction the blast load occurs from.

Figure 12: Alumaticore Deflection Profile

3.2.3 Polypropylene Honeycomb

The Polypropylene Honeycomb also has visible damage and delamination of outer layer. For the first test using the Honeycomb Polypropylene the recording software misfired and specimen was then blast loading 5 additional times to correct the software issue. This pre-damaged specimen deflected less than an inch after 5 blast loads. Shown in Figure 13, the polypropylene honeycomb experienced less than 18 mm of out-of-plane displacement in the highest damaged induced test.

Figure 13: Polypropylene Honeycomb Deflection Profile

3.2.4 Laminate Resin Veil

The Laminate Veil had inconsistent thickness that contributed to the 13% error between tests. The Laminate Veil also had no visible damage.

Figure 14: Laminate Resin Veil Deflection Profile

3.2.5 Safe Plank

Due to the manufacturing process of the Safe Plank resulting in raised edges, seen in Figure 15, in the testing material this halted the shock tube from be flush with the specimen introducing error in the results. The Safe plank is the same material as the both polyester resin samples however, the difference is in how it was provided for testing.

Figure 15: Safe Plank

Figure 16: Safe Plank Deflection Profile

Figure 17: 6.35 mm Polyester Blast Loading Specimen

Figure 18: 12.7 mm Polyester Resin Blast Loading Specimen

Figure 19: Alumaticore Blast Loading Specimen

Figure 20: Polypropylene Honeycomb Blast Loading Specimen

Figure 21: Laminate Resin Veil Blast Loading Specimen

Figure 22: Safe Plank Blast Loading Specimen

4 Conclusion

The quasi-static and dynamic behaviors of the composite materials considered for the wind turbine application were determined under uniaxial tension and blast loading.

In order to determine the quasi-static tensile behavior, the specimens were placed in the Instron 5585 and ASTM D638 standard was used for testing. Under these conditions it was determined that 12.7 mm Polyester Resin, 6.35 mm Polyester Resin and the Laminate Resin Veil all have Young's Moduli 3.4 - 7.6 times lower than aluminum and 10 - 22.2 times lower than steel. However, the yield strength of all the resin composites is comparable to steel and aluminum. The 6.35 mm Polyester Resin is 2.7 times stronger than aluminum and only 1.34 times weaker than steel. The 12.7 mm Polyester Resin is equal to aluminum in yield strength and the Laminate Resin is 1.33 times stronger than Aluminum. 6.35 mm Polyester Resin has both the highest modulus and yield strength of the materials tested.

In order to determine the dynamic behavior of the composite materials, blast loading was conducted using the Shock Tube. At 500 times the desired wind load all of the specimen was within the acceptable range of < 25.4 mm deflection aside from the Alumaticore. The Alumaticore composite had the highest permanent deformation and was not reusable after the test. The HoneyComb composite suffered from delamination and a loss in structural rigidity. All of the Resin composite showed no visible damage after test. The 12.7 mm and 6.35 mm Polyester Resin composites deflected the least among the resin composites. The Laminate Resin composite fell within the acceptable range of < 25.4 mm deflection. However, the results varied the most for this material. The conclusion was that the unrefined surface finish which the fiberglass was easily visible resulted in varying thickness and affected the blast loading.

From the materials tested the 12.7 mm or 6.35 mm Polyester resin would be the best choice. The 6.35 mm Polyester Resin when cut into a 2133.6 mm x 2133.6 mm panel for the wind turbine would be weight 52.6 kg only half as much as the 12.7 mm Polyester Resin while still having a Young's Modulus 2.2 times higher and a yield Strength 2.7 times higher. The 6.35 mm Polyester Resin composite had the lowest

deflection when normalized with thickness. This material had the highest tensile modulus and yield strength as well.

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