Recycling Advanced Composites

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Recycling Advanced Composites

FINAL REPORT

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RECYCLING ADVANCED COMPOSITES

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1.0 ABSTRACT

The purpose of this project was to explore recycling applications for finely ground composites. Development of uses for scrap advanced composite laminates and pre-preg materials is important because of the potential for recovering the reinforcing fibers, such as Kevlar, graphite or glass fibers, from the expensive composite materials and because of the almost infinite life of the scrap material when disposed in landfills. Because the cost of virgin reinforcements is prohibitive, by developing uses for ground composite materials as reinforcement for plastic resin systems that currently do not use reinforcement (e.g., thixotropic additives for sealants and adhesives), this waste stream can be diverted to a value added recycled raw material.

The recycled composites consisted of scrap edge trimmings from molded composites and cured pre-preg composites generated as waste during cut-out operations from the aerospace industry. Pre-preg is a unidirectional or woven Kevlar, graphite or glass fiber impregnated with epoxy resin. This material then is formed to the desired shape, and the resin system is cured under heat and pressure. Because of the outstanding weight-to-strength ratio of these materials, they are used in the aerospace industry. The cost of these materials is \$50 per yd^2 for the Kevlar, and \$60 per yd^2 for the graphite. Both Kevlar and graphite fibers were evaluated during this project. This project explored the use of the ground composite material as a low cost reinforcing additive for epoxy compression molding compounds and for rigid polyurethane foam.

After both edge trimmings and cured scrap pre-preg materials were ground, formulations of the epoxy compounds were made using varied fiber lengths, different fiber types (Kevlar vs. graphite), and different percentages of fiber additions. The epoxy was then molded over a urethane form to simulate use in an application such as water ski manufacturing. The material was then strength tested. Kevlar fiber was added to the polyurethane foam, formed into test specimens, and tested for bend strength.

Test results for the epoxy compression molding compound showed that with the addition of 1% of Kevlar with a fiber length of less than 0.5 mm, strength was increased by 16% when compared to

epoxy with no fiber additions. The addition of 1% of graphite fibers with length less than 0.5 mm increased strength by over 20% when compared to epoxy with no fiber additions. For rigid polyurethane foam, the addition of 0.5% recycled Kevlar with fiber lengths less than 0.5 mm increased bend strength by 14% when compared to foam with no fiber additions.

This work has shown the increase in strength of two different plastic systems when recycled advanced composites are added. Tests indicating these increases in strength demonstrate the potential for value-added processing of recycled composites for additions to plastics. Their market potential is derived from their use as a low-cost substitute for virgin fiber, which can cost as much as $14 per pound.

2.0 PROJECT OVERVIEW

2.1 BENEFITS OF RECYCLING COMPOSITES

Development of uses for scrap advanced composite laminates and pre-preg materials is important because of the potential for recovering the reinforcing fibers, such as Kevlar, graphite or glass fibers, from the expensive composite materials, and because of the almost infinite life of the scrap material when disposed in landfills.

The use of ground composite material as an additive in the manufacturing of other materials can have two purposes. The first is as a filler material. Because the cured composite material is relatively inert, finely ground material could possibly be added as a substitute for common fillers such as calcium carbonate or silica. Because these filler materials are low cost and the cost to process composite material adds expense, grinding composite material for filler applications would be cost prohibitive. The second purpose for adding ground composite material would be as a reinforcement. The focus of this project was to explore the performance of ground composite materials when added as a reinforcement to improve strength in epoxy molding compounds.

Because the cost of virgin reinforcements is prohibitive, by developing uses for ground composite materials as reinforcement for plastic resin systems that currently do not use reinforcement, as thixotropic additives for sealants and adhesives, this waste stream can be diverted to a value added recycled raw material.

2.2 PROJECT OBJECTIVE

The objective of the first phase of this project involved researching the equipment industry to locate size reduction equipment to grind the composite material. Because some of the composite materials collected for recycling are edge trimming with lengths up to 4 feet and widths up to 2 feet, the initial step in grinding involves shredding the composite material into pieces smaller than 2 in^2 (5 mm^2). The second step in grinding is to reduce the shredded material to fiber lengths less than 2 mm. From the information gained in this phase an estimated cost to process was calculated to compare to virgin fiber costs.

The objective of the second phase of this project was to test applications that would benefit from the addition of the fibers as reinforcement. Epoxy compression molding compounds were targeted. Based on the results of initial testing, rigid polyurethane foam was also included in the formulation development and strength testing.

3.0 INDUSTRY RESEARCH

3.1 MATERIAL FOR RECYCLING

Obtained cured graphite and Kevlar pre-preg and edge trimming from cured molded parts from Heath Tecna Aerospace in Kent, Washington. This type of waste material is generated in aerospace manufacturing companies producing composite parts. The pre-preg material is scrap material that is generated when patterns are cut-out of the sheets of pre-preg material. The pre-preg is sandwiched between two thin sheets of polyethylene which must be removed prior to curing. The edge trim material consists of layers of pre-preg material combined with other structural components that may include urethane foam, polyester mat, and honeycomb material. This combination of materials has been cured and the trim is generated when the molded part is cut to final size.

3.2 EQUIPMENT FOR GRINDING

In researching companies to perform grinding experiments and production of samples for testing Jacobson Companies in Minneapolis, Minnesota was chosen. Some manufacturers of grinding and shredding equipment could perform either grinding or shredding, but Jacobson Companies could part perform all tasks required for this project. Jacobson equipment is used by the molders of vertical and horizontal Sheet Molding Compound (SMC) panels for the auto industry to recycle the waste and rejected parts. Jacobson Companies was chosen to perform shredding and grinding trials because of their fully equipped lab, its team of experienced engineers, and their complete line of Size Reduction Systems, including Shredders, Particle-izers, Hammermills and Pulverizers. Approximately 150 pounds combined weight, were shipped to be processed to three different fiber lengths: a) 0.1-0.5 mm, b) 0.5-1.0 mm, c) 1.0-2.0 mm.

The first operation was to put the cured pre-preg through the Jacobson Model HTS Shredder, with 30 RPM cutter speed and 3/4" cutter thickness. The odd size pre-preg pieces, 18"x 6"x 1/16" and alike, were reduced in size to 1-1/4"x 3/4"x 1/16".

Further size reduction requires the use of the Hammermill or Particle-izer. The Jacobson Commander Half-Circle Hammermill, Model 24 D, was selected to use for the test. The Hammermill works on the principle that it grinds the material until all goes through the specific screen placed in the machine for a specified fiber length. The ground pre-preg from the Hammermill goes to the Baghouse Fiber Collection System where the fibers are separated from the dust (epoxy resin) and placed into storage containers. With the Hammermill, the smallest particle size that can be achieved is 0.1-0.5 mm. The shredded material first has to be ground to 3-4 mm with the Particle-izer before it can be processed to a smaller size. The second operation was to place the 3-4 mm material back into the Hammermill with the proper screen installed for the specified fiber lengths evaluated in these trials. The smaller the particle size, the longer it takes to process, and the higher the cost.

The estimated grinding cost of the Kevlar, graphite and fiberglass pre-pregs is based on a system that grinds 10 tons per month as shown in Appendix I.

4.0 MATERIAL FORMULATION AND TESTING

4.1 EPOXY COMPRESSION MOLDING COMPOUNDS

Epoxy compression molding compounds were formulated to meet the sporting goods manufacturers' processing requirements for snow skis and water skis. One of the most important material characteristics that must be controlled is the resin viscosity which affects molding properties.

Epoxy resin with recycled pre-preg fibers were formulated by varying the amount (0.25% -1.0%), length (1.0-2.0 mm, 0.5-1.0 mm, and less than 0.5 mm), and type of fibers (Kevlar and graphite). The viscosity of these compounds ranged from 14,000 cps of the clear epoxy to 95,000 cps of the 1%, 1-2 mm fiber length kevlar-filled epoxy.

	FIBER LENGTH		
	0.1 - 0.5 mm	0.5 -1.0 mm	1.0 - 2.0 mm
	VISCOSITY		
Epoxy Resin with 1% Kevlar	51 - 52,000 cps	67 - 68,000 cps	94 - 95,000 cps
Epoxy Resin with 1% Graphite	44 - 45,000 cps	59 - 60,000 cps	94 - 95,000 cps

Compounds with the viscosity over 55,000 cps were discarded due to their handling difficulty and poor wet-out properties. Wet-out is the ability of the resin to completely surround the fiber (wet the fiber) resulting in a stronger resin to fiber bond. One of the processes used to produce a composite laminate is to uniformly impregnate or wet-out the dry Kevlar, graphite or glass fiber reinforcement with the resin compound. The 1-2 mm fiber length filler was difficult to mix into the epoxy resin to obtain a homogenous compound, and was also difficult to evenly wet-out the reinforcement. These conditions resulted in a reduction of the strength of the molded product.

The best result was achieved with the:

- 0.5 mm fiber length Kevlar filled epoxy with 52,000 CPAs viscosity, and
- 0.5 mm fiber length graphite filled epoxy with 43,000 CPAs viscosity.

4.3 POLYURETHANE FOAM

Additional testing was conducted to determine the effect of the recycled fiber additive on the rigid polyurethane foam. This product is widely used in the snow ski, snowboard, water ski, wakeboard, kneeboard, wall and pipe insulation, and packaging industries.

For the test, a clear 4 lb/ft^3 and a clear 6 lb/ft^3 density foam (non-reinforced) were used as control specimens. Adding 0.5% of recycled 0.5 mm Kevlar fibers to the 4 lb/ft^3 density foam for the first formula, and 0.5% of virgin 0.5 mm Kevlar fibers for the second formula, showed approximately 15% improvement against failure under load.

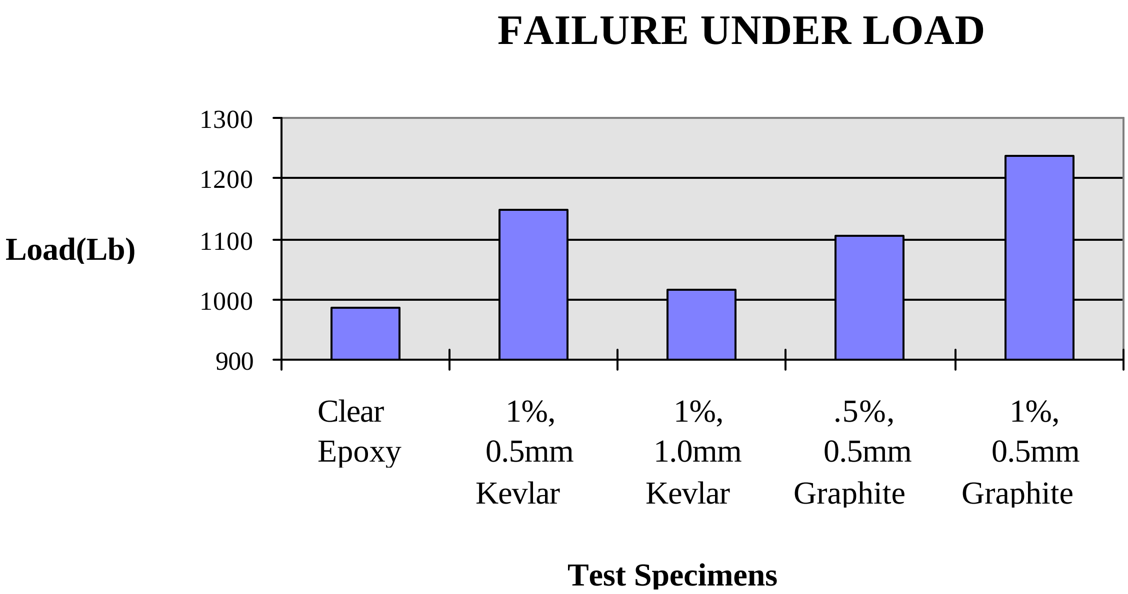
5.0 PRODUCT TESTING

5.1 EPOXY COMPRESSION MOLDING COMPOUNDS

In order to obtain meaningful test results of new materials for the ski industry, a method had to be developed where a compression molded " torsion box " ski structure could be duplicated and tested in a laboratory environment. The "torsion box " structure consists of a lightweight core material and a fiber reinforced epoxy composite that is molded around the core material.

A mold was designed and built to produce test specimens to meet dimensional requirements for the tensile strength testing procedure 401 MIL Standard, and to follow the "torsion box " ski concept.

See Appendix II for a diagram of the Test Procedure where a test specimen is supported in two places 8 inches apart and the load is applied at the center until specimen failure. The Failure Under Load test results of five different epoxy compounds are shown below



5.2 POLYURETHANE FOAM TESTING

Tensile strength tests were performed on standard un-filled polyurethane foam and compared to the reinforced foam material. The preliminary test shows that by adding 0.5% of pure or recycled kevlar to the foam, the property of the foam to resist bending was increased by 9-14%. These results mean that a lower density foam can be used for certain applications at lower material cost, and less usage of the Isosyanate, a toxic substance. A 4 lb/ ft^3 density foam with 0.5% Kevlar additive approaches the property of a 6 lb/ft^3 density clear foam.

See Appendix II. for a diagram of the Test Procedure and Appendix III. for the Product Improvement test results chart.

6.0 INTERPRETATION OF RESULTS

From phase one of the project, it was determined that the equipment to process the waste composite material into fibers required a two-step operation consisting of pre-shredding and then processing the shredded material through a hammermill. The production of the shorter fibers required multiple passes through the hammermill, which reduced the throughput. The cost to process this material is estimated to be less than $2 per pound.

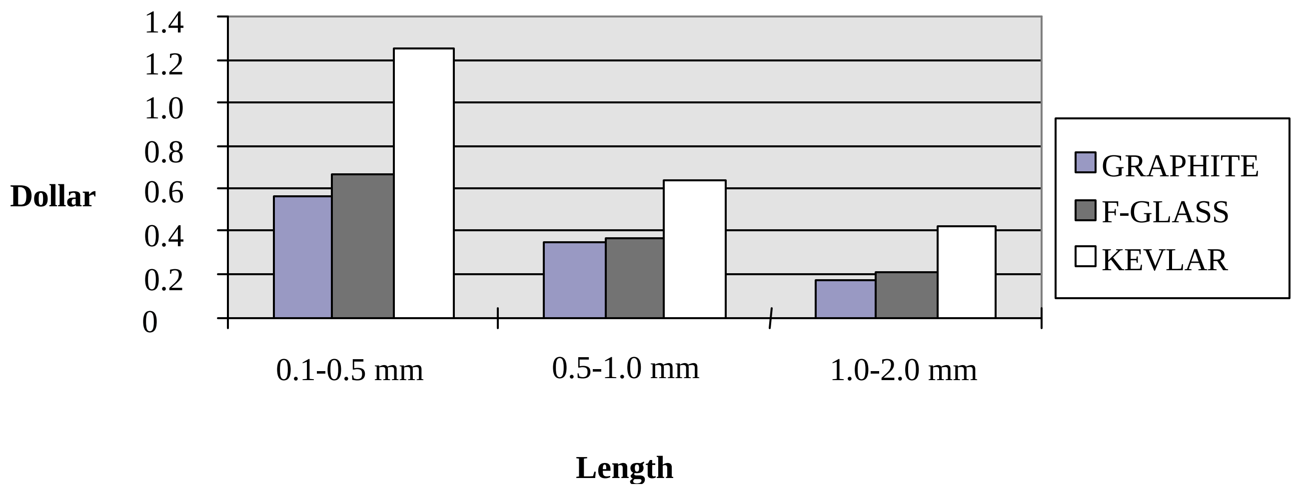
From phase two of the project, it was determined that the maximum of 1% addition of fibers could be made to the epoxy resin before the viscosity increased to unacceptable levels. The length of the fiber also affected the viscosity, with longer fibers increasing the viscosity of the resin. The addition of fibers to urethane foam resin was limited to 0.5% before the viscosity reached unacceptable levels.

In phase three the results showed the strength of the epoxy resin was increased by 16% with the addition of 1% fibers with fiber lengths less than 0.5 mm. The fibers with length less than 0.5 mm produced not only higher strengths when compared to fibers greater than 0.5 mm, but also produced a lower viscosity resin with the same percent addition. The urethane foam strength was increased by 14% with addition of 0.5% fibers with lengths less than 0.5 mm.

The results demonstrate the potential value of the recycled fibers as reinforcement additives to two different resins. Even with relatively small percentage additions, significant strength improvements were achieved at a relatively low cost compared to virgin fibers. This work opens up opportunities to explore other resin systems that might benefit from fiber additions for reinforcement. This work also opens possible opportunities to process and recover fibers from waste composite materials from boat manufacturing, tub and shower manufacturing, and other composite manufacturing operations.

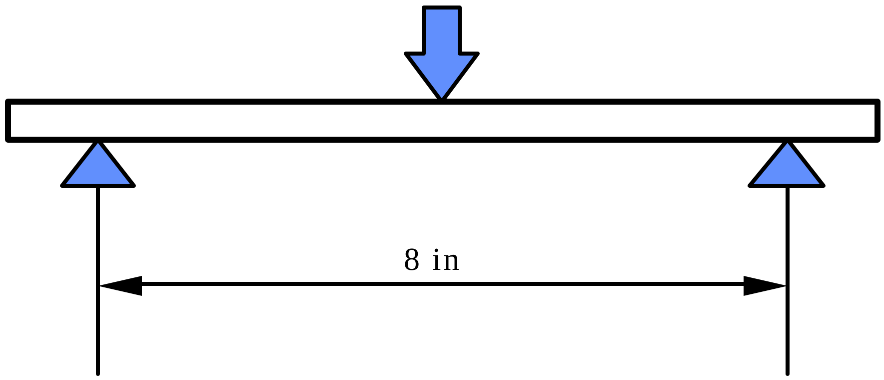
APPENDIX I

COST / LB / FIBER-LENGTH



APPENDIX II

THREE-POINT LONG BEAM FLEX TEST



1) LOAD VS DISPLACEMENT
2) LOAD TO DESTRACT

APPENDIX III

PRODUCT IMPROVEMENT FAILURE UNDER LOAD TEST RESULTS