Fiberglass Reinforced Plastics Recycling

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Background Information

Fiber reinforced plastics (FRP) products are a class of composite building materials consisting of a fibrous reinforcement encased in a polymer matrix. The polymer matrix is applied as a liquid resin and chemically cured to a solid. The reinforcing materials are typically glass fibers, but they can also be materials such as aramid (Kevlar) or carbon fibers. The fiber content of these composite materials can range from less than 5% to greater than 60% by weight.

Many manufacturing methods can be used to produce FRP products. These include hand lay-up, spray-up, closed-mold infusion, and compression molding. A majority of FRP manufacturers in Minnesota use hand lay-up, spray-up, or closed-mold infusion. Compression molding is more commonly used in high volume manufacturing plants such as automobile factories.

Solid waste is generated by all of these manufacturing methods. The waste is typically in the form of overspray, trimmings, or non-compliant parts. Currently, this solid waste is landfilled.

Motivation

A focus group conducted by MnTAP indicated that FRP fabricators are interested in recycling their scrap. FRP scrap costs fabricators in two ways: disposal costs and opportunity costs. Disposal costs are what people conventionally think of when the topic of waste cost is mentioned. Disposal costs include transport and landfill fees. An often overlooked scrap cost is the opportunity cost of materials thrown away that might have been used to produce a saleable product. The opportunity to capture revenue is lost every time scrap goes in the trash.

MnTAP encourages waste reduction as the best way to deal with waste. Because waste reduction lowers both disposal and opportunity cost, it tends to have a larger economic payback than end-of-pipe treatments like recycling.

However, even the best available FRP manufacturing technology still generates a certain amount of scrap.

To address the interest in scrap recycling, this document strives to summarize the current state of FRP recycling. This has been accomplished via a review of the relevant literature and through discussions with people who have tried to recycle FRP scrap in the past.

Problem Definition

Solid waste generated in the FRP manufacturing process is a matrix of cured polymer resin and fiber reinforcement material. The chemical structure of the polymers used, and the fiber and filler content of FRP scrap, make recycling more complex than typical thermoplastic recycling.

The first problem with FRP scrap recycling is the use of thermoset resins. Thermoset resins are liquids that cure to a solid through a chemical reaction that crosslinks the resin molecules. This curing reaction is non-reversible; the cured solid does not return to its original liquid form through heating as do thermoplastics. Unlike thermoplastics, the FRP scrap cannot be melted down and remolded, as is often done in plastic recycling. A useful analogy for comparing thermosets to thermoplastics would be to compare cooking an egg to freezing water. Like the frozen water, a thermoplastic material can be melted and "re-frozen," but the cooked egg (cured thermoset) cannot be transformed back to the raw state.

The second complicating factor in FRP recycling is the filler and fiber content of the scrap. Fillers are added to FRP resins to reduce the amount of resin needed to produce a part. This reduces cost and styrene emissions. Fillers can also be used to improve fire-resistance or affect appearance. Fibers are used in composite products to add strength. The physical properties of these fibers determine the strength of the finished part. Two of the critical fiber properties that contribute to strength are fiber length and the lack of surface defects in the fibers such as cracks and chips. Any reduction in fiber length or introduction of surface defects by a recycling system will reduce the value of the recycled material. A recycling system for FRP would have to be designed to recover and reuse the fiber and filler content of the scrap.

Third, most FRP products made in Minnesota use a room-temperature cure to reduce the capital cost of FRP manufacturing. Use of this method creates the potential for excess catalyst and promoters to exist in the scrap. The excess catalyst and promoter content of FRP scrap can cause safety and quality control problems in a recycling system. This most seriously impacts mechanical recycling and will be covered in more detail in that section of this report.

Fourth, the focus group participants suggested that their preferred way to handle scrap recycling was with a centralized processing facility. While this makes sense considering the specialized skills needed to successfully operate a recycling facility, it adds the significant problem of transportation and logistics.

Finally, any system that solves both the technical and logistic challenges presented by FRP scrap recycling must also have a market use for the recycled material of enough value to cover processing costs and compete with alternate waste disposal options. A number of potential end-products have been evaluated by different groups interested in FRP recycling, but a majority of the potential uses are low-value and would have to compete with established low-cost, high-quality products.

<u>Potential Solutions</u>

There are four basic classes of recycling covered in the literature: mechanical, incineration, thermal, and chemical. A description of each method follows.

Mechanical Recycling:
This method involves shredding and grinding of the scrap FRP material with subsequent use of the ground material in a new product. Previous attempts at mechanical recycling have focused on two size classes. The first size class is coarse “chips” that are ¼ to 1 inch square. These chips are used as filler and/or structural enhancers in a new plastic product, e.g. polyurethane foam board. The second size class is a finer ground product, less than 200 mesh or 75 µm, that could be used as a filler material to reduce the resin content of a part. Some FRP fabricators already use mineral fillers like calcium carbonate for this purpose.

Mechanical recycling is one of the simpler, and more technically proven methods, but it does have drawbacks. These include the safety hazards involved with mechanical recycling and the low value of the end-product.

Safety is a serious concern when grinding FRP scrap, and the primary safety issue is fire. Grinding any material increases the surface area exposed to air. FRP scrap can become more flammable, if not explosive, when ground. Adding to this problem is the fact that FRP cured at room temperature often contains excess catalyst. This catalyst, once released by the grinding process, can react with the freshly exposed polymer surfaces generating heat and potentially starting a fire. Any system designed to grind FRP scrap would need to account for these safety issues.

A second problem of mechanical recycling is the low value of the end-products. The coarse chips would have to compete with virgin structural reinforcing materials such as glass fibers. While the recycled material may be less expensive than virgin materials, it would undoubtedly have less reinforcing value. Also, the strength characteristics of the recycled material would have a much higher variability than virgin materials, again reducing their value to the fabricator.

Ground FRP finer than 200 mesh would have to compete with mineral fillers. The main disadvantage for the recycled product in this finer category would be the inconsistent chemical properties of the ground material. Specifically, the finely ground FRP product could contain varying amounts of catalysts and/or promoters. This would lead to difficulties if the ground material were to be added to a resin mixture affected by these chemistries (e.g. premature cure of resin in a mixing tank). In addition mineral fillers can provide fire-retardancy and other well-controlled and understood properties that would be difficult, if not impossible, to provide in a recycled filler. Mineral fillers also have established quality controls and make up a very small portion of FRP fabrication costs. It is unlikely that fabricators would be willing to assume the risk of adding recycled FRP fillers to their products when the economic reward for doing so would be so slight.

There may be some specific cases where mechanically processed FRP scrap could be used economically. No clear, outstanding examples were found in the literature or in conversations with people who have tried.

In general, the following questions should be asked when considering an end use for mechanically processed FRP scrap:

1. Can the scrap be processed in a safe manner?

2. Can the production process destined to consume the recycled material tolerate the physical and chemical property variations of the ground FRP scrap?

3. Is the cost of processing and handling the recycled product significantly lower than the cost of the material it intends to replace?

If a product and process can be identified for which both of these questions are answered "Yes," then mechanical recycling of FRP scrap would have a much better chance of being successful.

Incineration:

Combustion of FRP scrap with energy recovery is listed as a recycling method in some literature. Whether incineration strictly qualifies as a "recycling" technique is up for debate. Incineration does recover the energy content of the scrap materials whereas landfilling does not. Air pollution resulting from FRP scrap incineration is a drawback of this method. The fiber content of the material would still end up as landfilled waste, potentially becoming hazardous waste depending on chemical analysis of the ash. Some catalysts/promoters contain metals like cobalt. One incineration method that would utilize the glass fiber would be cement kiln fuel. In this case the polymer material would contribute to the energy input needed to produce portland cement, and the glass fiber would add silica to the mix – a raw material added to the process anyhow. Significant controversy surrounds the environmental impact of using cement kilns as a waste disposal strategy.

The incineration option appears to be most developed in Japan where landfilling is more expensive than in the U.S. Because most FRP products have a low resin-to-fiber ratio, the energy recovery probably doesn't justify the risks associated with this option.

Thermal:

Thermal recycling of FRP scrap, also known as pyrolysis, involves heating the material in an inert atmosphere to recover the polymer material as an oil. The inert atmosphere does not allow combustion, so the air pollution effects are lower for this process than incineration.

The fiber is also recoverable using pyrolysis, but thermal stresses introduce surface defects reducing the strength of the recovered fibers. The recovered oil can be used as fuel or it can be refined to regenerate resin feedstock chemicals. Some studies have shown the pyrolysis process to be thermally self-sustaining, meaning the gas product from the pyrolysis could be used to provide the process heat needed to recover the oil product. The oil product has been shown to have a relatively high gross calorific value with about 40% being similar to gasoline, and 60% like fuel oil. The U.S. Department of Energy has funded studies that attempt to refine these pyrolysis oils to add value.

Pyrolysis has also been proposed as a method for treating scrap tires, but several decades of effort have failed to demonstrate a commercially viable application of pyrolysis to tire recycling.

One company that is researching both the tire and composite pyrolysis options is Titan Technologies (in partnership with Adherent Technologies). In the area of composites this technology is most advanced with respect to carbon fiber products because of the high value of the recovered carbon fiber material.

Pyrolysis is a good technology to keep an eye on for the future. A lot of technical and economic hurdles need to be cleared before it becomes mainstream. Like most technologies, pyrolysis will prove itself out (or not) in the areas where paybacks will be highest and where the volume of material to be processed will be large enough to justify the capital cost of the technical plant. Because of these factors, FRP scrap recycling is unlikely to be a proving ground for pyrolysis in Minnesota. If the technology continues to advance, pyrolysis could become a potential recycling method for FRP scrap, perhaps in conjunction with other types of plastics recycling.

Chemical:
This method of recycling uses chemicals to dissolve the resin away from the fibers. The fibers retain most of their original strength using this method due to the absence of thermal stresses as in pyrolysis. However, this method typically requires granulating the scrap which reduces the fiber length, and using a lot of potentially hazardous solvents. Similar to pyrolysis, a chemical recycling plant would be capital intensive, and the disperse, relatively small quantities of FRP scrap generated in Minnesota are not likely to draw interest for this emerging technology.

Case studies

R. J. Marshall:

The R. J. Marshall Company had developed a pilot plant in Detroit that could mechanically process composite scrap. It was dismantled a couple years ago due to lack of demand from automotive companies. The FRP scrap in this case would have been thermally cured in compression molding tools, eliminating the problem of excess catalyst and promoters encountered in room-temperature processed material. Also, the volume of scrap in the Detroit area is high due to the concentration of automobile manufacturing in the region. This minimizes the transportation and logistics problems. Still, with all of these advantages the R. J. Marshall experience indicates that the economics of mechanical composites recycling is marginal at best. R. J. Marshall would be willing to look at FRP recycling again if the automotive companies were to push the issue, but the company representative I spoke with did not anticipate that happening anytime soon.

Seawolf Industries:

I spoke with the owner of Seawolf Industries regarding a recycling system they have developed for FRP scrap. The system grinds the material and reintroduces it as a dry spray. He said they have not had any problems with fires. The system costs $25,000 for a 1000 lb / hr grinder, and it costs about $4,500 for the hopper and spray gun. He said they can include about 25% scrap material in the new product. He has sold units in Brazil and Europe but none in the U.S. Both Europe and Brazil have stricter solid waste regulations for FRP than the U.S. resulting in higher disposal costs. The Royaline and Pearl Baths report funded by OEA in 1995, discussed in detail below, mentioned that spray gun clogging was an issue with this system.

Precision Fiberglass (Grove City) – John Bergstrom:

I spoke with John Bergstom, former CEO of Precision Fiberglass in Grove City, about past recycling attempts made at Precision. The process started by shredding the scrap material into pieces roughly 1” by 1” (1/8” thick). They then added these “chips” to virgin resin and compression molded sheets. In addition to problems with grinding (fires, etc.), the molded parts were very resin-rich making them brittle. No commercially successful products were made, and the process was abandoned.

Pearl Baths and Royaline Industries – Minnesota Technology Inc. Report:

A report for Minnesota Technology Inc. (MTI), funded by the Minnesota Office of Environmental Assistance (OEA), was written in 1995 covering the options for recycling FRP waste in Minnesota. The authors of the report concluded that FRP recycling technology was sufficiently mature to justify further testing. FRP trimmings and overspray were collected from Pearl Baths and Royaline Industries. The two waste products underwent mechanical size reduction at Jacobson Companies in Minneapolis. Post-grind size separation was performed, and selected size classes of material were reintroduced, along with virgin material, in two different spray up processes. The recycled products were then tested for physical properties and compared to standard products made without recycled content.

The results of the physical property testing showed that the smaller size fractions of ground material could displace a certain amount of filler without much physical property degradation. The test results also corroborated with the well understood relationship between the fiber content and fiber length to desired physical properties (break stress, stiffness etc.). The authors surmised that any recycling scheme should strive to minimize fiber fragmentation, but they did not indicate that they had discovered any such system. The main conclusion to draw from this work is that mechanically ground FRP scrap is most likely to replace filler materials as opposed to reinforcing materials. This is unfortunate because fillers are much less expensive than reinforcements.

In addition to the testing performed, the report analyzed the costs and benefits associated with mechanical FRP scrap recycling. The estimated cost of a facility capable of processing 3,400 lb/hr FRP scrap was just over $360,000 for the size reduction equipment, respray equipment, and associated facility costs. At this capacity point the authors estimated the facility would have to run nine hours per month to handle the waste from a manufacturing plant producing 1,500 lb of waste per day. The 1,500 lb / day of waste comes from the assumption that the average fabricator uses 6,000 lb of raw materials per day, and 25% of this goes to waste.

The economic analysis performed by the authors calculated a 2.3 year payback with just over $159,000 per year savings for this “average” facility. While the stated two-year payback on $360,000 may seem reasonable, closer inspection reveals an exaggerated benefit. The recycling benefit was calculated using the raw material price for recycled material. This inflates the calculated value of recycling since the recycled material does not have as much value, practical or economic, as virgin material.

To determine the benefit the authors calculated the cost of the raw materials and disposal costs as shown in Table 1.

	waste generation (lbs / day)	price ($ / lb)	annual cost ($ / yr)
resin	635.38	0.66	104,837
catalyst	9.53	1.60	3,812
fiberglass	216.03	1.00	54,007
filler	635.38	0.06	9,531
microspheres	3.69	5.00	4,606
disposal cost	1500	0.06	22,500
total	1500		**199,293**

Table 1: Base Case Cost of Waste

The authors continue by stating they could recycle 80% of the generated waste, and they claimed the full raw material price for each pound of material recycled as savings. This calculation, which is simple a multiplication of the values in Table 1 by 20% (except for prices), is shown in Table 2.

	waste cost (lbs / day)	price ($ / lb)	annual cost ($ / yr)
resin	127.08	0.66	20,967
catalyst	1.91	1.60	762
fiberglass	43.21	1.00	10,801
filler	127.08	0.06	1,906
microspheres	0.74	5.00	921
disposal cost	300	0.06	4,500
total	300		**39,859**

Table 2: Cost of Waste using Exaggerated Recycling Benefit

The problem with this analysis is that it assumes the recycled material can fully replace virgin materials, and it claims the virgin material price as savings for the recycled material. This is not the case physically or, as a result, economically. Physically, the resin content of the recycled material is already a solid, and it is cross-linked. FRP fabrication requires a liquid resin that has not been cross-linked. This difference in utility demands a difference in the price claimed when calculating a benefit. The same holds true for fiberglass. Virgin fiberglass consists of long, uncracked strands that give a lot of strength to a finished product. The fiber content of the recycled material consists of short, cracked fibers that may add some strength, but not nearly as much as virgin fibers. The recycled FRP only has the physical potential to replace filler. Again, the reduced physical utility of the recycled product demands a lower price when compared to virgin material when performing a cost-benefit analysis. A correct analysis of the cost structure after installation of recycling in shown in Table 3.

	waste generation (lbs / day)	price ($ / lb)	annual cost ($ / yr)
resin	635.38	0.66	104,837
catalyst	9.53	1.60	3,812
fiberglass	216.03	1.00	54,007
filler	0.00	0.06	0
microspheres	0.00	5.00	0
disposal cost	0	0.06	0
total	861		**162,656**

Table 3: Corrected Cost of Waste using Recycling

This analysis generously assumes the recycled scrap can replace all of the filler and microspheres, and it reduces the disposal costs to zero. The resin, catalyst, and fiberglass costs stay the same. In this case the net benefit of recycling is under $37,000 annually ($199, 293 base case - $162,656 recycling case). Even this overly-optimistic assumption yields a simple payback of nearly ten years on the $360,000 capital investment.

As opposed to the recycling case, pollution prevention does have the opportunity to claim the full cost of raw materials as benefits. This is because if the scrap isn't generated, the saved raw materials are still in virgin form. One of the best methods of pollution prevention in FRP manufacturing is the use of closed mold technology such as vacuum infusion or resin transfer molding. To illustrate the economic potential of closed molding, assume this fabrication technique could reduce per part material consumption by 5% as compared to open mold fabrication, a conservative estimate based on past experience. This means that for equal production (4500 lbs in this example) the pollution prevention techniques would require 5700 lbs of raw materials rather than the base case of 6000 lbs. This results in 1200 lbs of waste (5700 raw – 4500 product), as opposed to the case of 1500 lbs waste. Table 4 shows the closed mold waste cost calculation.

	waste generation (lbs / day)	price ($ / lb)	annual cost ($ / yr)
resin	508.30	0.66	83,870
catalyst	7.62	1.60	3,050
fiberglass	172.82	1.00	43,206
filler	508.30	0.06	7,625
microspheres	2.95	5.00	3,685
disposal cost	1200.00	0.06	18,000
total	1200		**159,435**

Table 4: Cost of Waste using Closed Molding

The base case waste cost (Table 1) was $199,293. Subtracting the total cost from the closed mold scenario shown in Table 3, $159,435, gives a net benefit of nearly $40,000. This cost reduction is roughly the same as the cost reduction calculated for the recycling scenario (see Table 2). The investment cost would be needed to calculate the payback for the closed mold scenario, but it is likely less than the ten year payback on $360,000 for the recycling case. In fact, case studies of FRP shops that have switched from open to closed molding have shown raw material savings closer to 10% and paybacks of around two years. Closed molding also has the benefit of vastly reduced air emissions which is not the case for the recycling scenario. Finally, pollution prevention does not require you to become an expert in recycling FRP scrap, it only requires some modifications to your existing manufacturing methods.

FRP scrap recycling may make sense in some cases. But, from an economic and environmental standpoint this option should be evaluated only after every effort to reduce waste generation has been exerted.

I recently had the opportunity to discuss FRP scrap recycling with one of the participants in the MTI study, Pearl Baths. It has also concluded that it makes more sense for the environment, and its bottom line to focus effort on pollution prevention rather than scrap recycling.

Larson Boats and Recycled Plastics Inc (RPI):

Following the research work conducted in the Minnesota Technology FRP recycling report, two grants were awarded by OEA to Larson Boats and Recycled Plastics Inc. to pursue FRP scrap recycling. The plan was to grind Larson FRP scrap and use it as reinforcement in polyurethane core board. This board would then be used in Larson boats. However, RPI found that the process to recycle scrap into board was labor intensive and they would have had to raise the board price to Larson so the project was cancelled.

Summary

There are three main issues to contend with when considering the recycling of FRP scrap:

1. technical processing issues
2. transport and logistics
3. economics

The technical methods needed to process thermoset materials, even those containing reinforcing fibers, have been tested and demonstrated at the laboratory and pilot level. Mechanical recycling appears to be the simplest, most developed option. FRP scrap cured at room temperature poses additional problems in mechanical recycling due to the safety hazards and unpredictability resulting from excess catalyst and promoters in the scrap.

Thermal and chemical treatments of the waste have the potential to produce a higher value end-product, but they also require greater capital investment. It is also uncertain that these alternative methods would be substantially better for the environment.

Transportation and logistics seem to pose another large problem, especially considering the case in Minnesota where FRP fabrication takes place across the state with no particular geographic concentration of scrap production. The centralized facility built and operated by R. J. Marshall Company in Detroit had a much higher geographic concentration of higher quality scrap, but it was still not successful due to lack of demand for the end product.

A sustainable FRP recycling scheme must be economically viable. FRP scrap recycling poses some unique challenges that can be overcome with technology, but this technology is not free. In certain circumstances scrap recycling could make sense for a given FRP shop, but it is important to fully understand the technical and economic difficulties that have prevented it from being widely used. It is also important to fully evaluate opportunities to prevent the generation of scrap in the first place because pollution prevention is generally better for the environment and your bottom line.

The Minnesota Technical Assistance Program is available to assist you in evaluating specific opportunities for pollution prevention or recycling in the FRP industry.

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