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Composite Materials

Composite materials are becoming more embedded in today's products, and are used in many industries including aerospace, automotive, construction, and recreational. A few examples include: small aircraft fuselages, aircraft thrust reverse flaps, automobile driveshafts, leaf springs, car bodies, bridges, I-beams, bathtubs, countertops, golf clubs, snow boards, boats, and bicycle frames (Strong, 2000; Richardson & Lokensgard, 1997; Rosato, 1997; Foreman, 1990).

A composite product is two or more materials combined to produce a new material having characteristics that were not present in either of the component materials (Foreman, 1990). Every polymeric composite material consists of a strong reinforcement material such as fiberglass (e-glass, s-glass, s2-glass, etc.), carbon or graphite, kevlar, or boron, embedded in a resin matrix material. The most common types of resin are epoxy and polyester, but vinyl ester, polyurethane, and others can also be used. All such resins are classified as thermoset plastics. This means that once the resin has undergone a chemical reaction that causes crosslinking of the long-chain polymer molecules, the resin is cured, and becomes solid. This crosslinking reaction cannot be reversed (Jones, 1998; Colling & Vasilos, 1995).

The long life of polymeric composites poses serious environmental problems. Once the product's useful life is complete, the product is usually disposed of in a landfill or junkyard. According to Rathje & Murphy (1992), since 1978, approximately 14,000 nationwide landfills have been closed due to being full, or because of environmental issues. Moreover, disposal of composites by incineration is not a desirable option. According to Strong (2000), ". . . the risks associated with incineration are real. All things considered, source reduction and recycling are preferred over incineration and regeneration (also potentially polluting) for managing solid wastes. Incineration, however, may be preferred over landfill" (p. 752).

Good corporate citizenship demands that the composite materials industry find alternative methods of reclaiming these products. Japan's Recycling and Treatment Council (RTC) is so concerned about the environmental effects of unusable composites that it has commissioned a committee to address ". . . technological and social problems regarding recycling thermoset composites wastes" (Kitamura, 1995, p. 101).

Researchers in the composite industry understand it is nearly impossible to recycle and reuse cured composite materials in the development of new products with equal or greater strength. Instead of trying to recycle composites into new high strength products, the focus should be directed toward their reuse in less exotic applications. Grinding the composite products into powder and using this as filler material is one potential application.

Thermoforming

Thermoforming is a molding process used to form sheets of plastic to a mold surface by using heat and force consisting of vacuum and/or pressure (Richardson & Lokensgard, 1997). Thermoformed products include large restaurant signs, children's swimming pools, small boat hulls, Halloween masks, disposable SOLO cups, ice cube trays, refrigerator door liners, cookie or donut trays, and Glad-Ware food containers. A few advantages of thermoforming are lower machine cost, large parts can be easily formed, and the required temperature can be up to 100 ^{0}F less than other plastics production processes. Another attractive characteristic of thermoforming is the ability to produce single parts, or low output prototype parts at relatively low cost. Material options for a thermoforming mold may vary when producing prototype molds. Molds can be made out of aluminum, wood, plaster, clay, plastic, or steel (Illig, 2000; Throne, 1999).

Purpose

The purpose of this study was to determine if recycled composite fiberglass powder could be used to develop an alternative material for making prototype thermoforming molds. Areas of interest were mold swelling or shrinkage, the effects of heat on the mold, and the surface quality of the thermoformed parts.

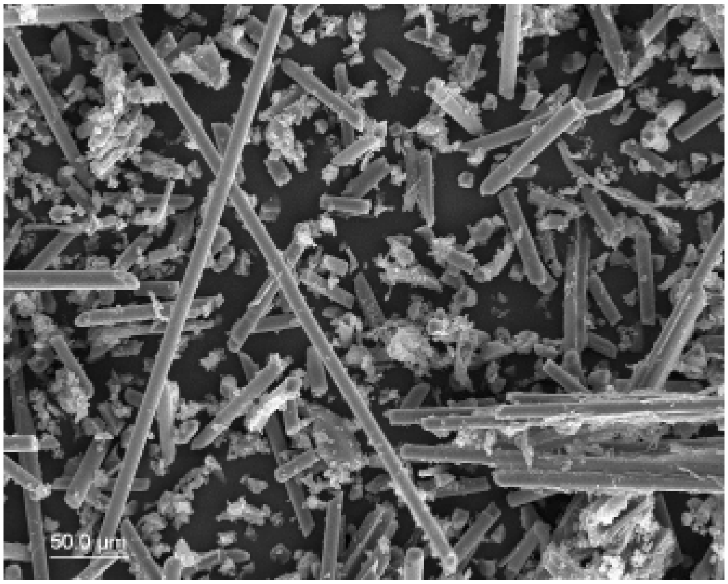
Methodology

Recycled Composite Powder

Cured composite products made of fiberglass were used to produce the recycled composite powder. The panels were ground into a powder using 36 grit sandpaper attached to a hand held die grinder. The powder was collected, filtered through a strainer to achieve a consistent powder, and stored in a sealed metal container. A sample of the powder was examined under an electron microscope (JEOL 840A SEM, 25Kv (accelerating voltage), 6x 10-11 probe current, sputter coated with 30nm Au) to determine the particle shape and size. The powdered fiberglass rods exhibited a very distinct diameter of 10 mm, and an average length of 60-80 µm with an overall distribution of 20-350 µm. The powdered epoxy resin is granular in shape with an average length of 5-10 µm and an overall distribution of 2-15µm (see Figure 1).

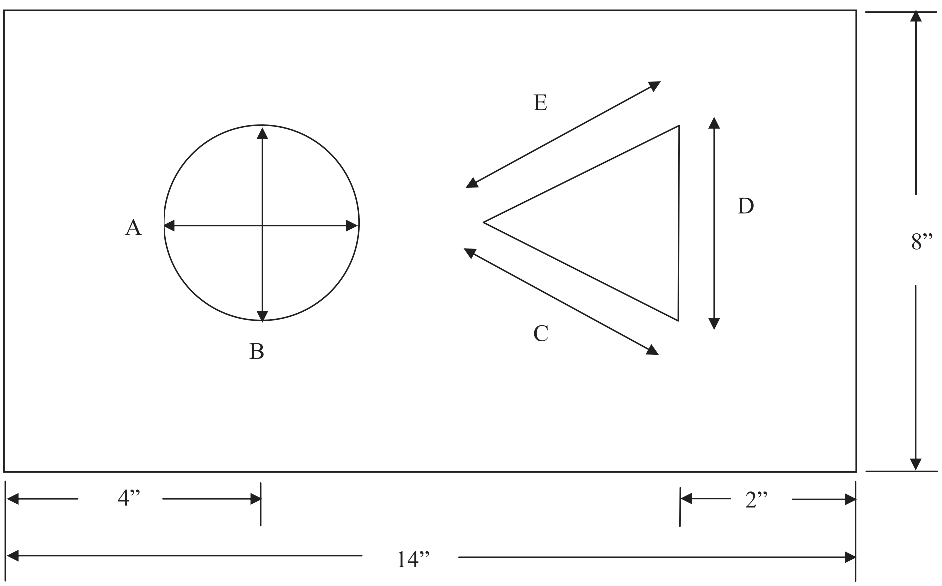
After experimenting with different filler percentage ratios of the recycled composite powder, a 70% filler-to-epoxy resin volume ratio was used to produce the tooling dough. Filler percentage ratios of 10%-60% were not viscous

Figure 1



A sample of the recycled fiberglass composite powder was examined under an electron microscope. The A-arrows represent examples of the long and short rods of the fiberglass. Three granular shaped examples of the epoxy resin are represented by the B-arrows. The C-arrows show the interface bond separation between the fiberglass rods and the epoxy resin (photo furnished by Central Michigan University's Electron Microscopy Facility).

Figure 2



Each mounting plate consisted of one four-inch circle and one four-inch equilateral triangle. Each letter (A-E) located by the arrow represents the diameter or side from where the measurements listed in Table 1 were taken.

enough and the 80% filler percentage ratio was dry, crumbly and unworkable. The powder/resin mixture was hand stirred and kneaded for seven minutes, one minute for each 10% of filler. The 70% ratio produced a mixture that was easy to work with; the consistency was similar to cookie dough.

Thermoforming Mold Design

Two geometric shaped thermoforming molds were made using the 70% filler dough. The first shape was a 4" diameter circle with a thickness of 1/2". The second shape was a 4" equilateral triangle with a thickness of 1/2". The filler dough was allowed 24 hours to cure after being shaped. Three samples using all new filler/resin batches were produced for each geometric shape. Three mounting boards were then developed using a circle and triangle on each board (see Figure 2). To allow for possible expansion or contraction of the filler dough molds, five-minute epoxy was only placed in the center of each geometric shape when being bonded to the boards.

Plastic Product

Ten sheets of polystyrene with the thickness of 0.020 inch were thermoformed to each mounting board. To avoid possible inconsistencies, manufacturing parameters were identified for each thermoformed part. Each 14" x 20" polystyrene sheet was heated for 10 seconds at 80% oven efficiency, thermoformed with vacuum, cooled for 45 seconds with the installed cooling fan, and then removed and given an identification number. Four solid colors of polystyrene were used. The same colors in the same order were used for each mounting board. Green was used to make parts 1-3, blue was used for parts 4-6, red for parts 7-9, and black for part 10.

Findings

Mold Characteristics

The recycled fiberglass powder filler dough was easy to mix and develop detailed shapes. After the solid mold had cured, it was easy to cut, machine, drill, and sand into shape. After producing ten prototype plastic products the molds still had the same color, texture, with no apparent heat damage. Since the molds were produced with epoxy resin, they should last for many months to years.

Molded Product Characteristics

The visual quality of the thermoformed part appeared to be an exact replica of the mold. All textures, scratches and fine details were transferred to the plastic part. The color of the plastic remained sharp throughout all parts. A six-inch digital caliper (resolution 0.0005 inch, accuracy 30 μm) was used to check for expansion or shrinkage of each final product's shape. The average and standard deviation were calculated for each shape to determine if the recycled dough could be used for prototype thermoforming molds (see Table 1). The measurements were taken from the plastic product rather than the mold, since it is the molded product that is used by the consumer, and not the mold.

Results

The results demonstrate that the recycled fiberglass filler dough has potential to be an excellent alternative for prototype thermoforming molds. There was almost no variation between the ten parts produced from each mold. Of fifteen molds, thirteen produced parts with dimensions having a standard deviation of less than 0.003 inch. No expansion or contraction of the parts was noted. Variation between each mold and each side of the mold was noted, and attributed to human error during the shaping and sculpturing of the geometric shapes. The results were used to accomplish the purpose of this study, which was to find an alternative material for prototype thermoforming molds using recycled thermosetting composite powder.

Implications

Engineers and designers need to have a visual and spatial representation of their ideas; hence, the capability to produce inexpensive prototype molds is essential in today's industries. This study has demonstrated the possibility of producing this type of prototype mold, while at the same time reducing the content of landfills by thousands of pounds. Not only can composite products be reclaimed and reused, but also there would be a reduction in the amount of petroleum needed to produce new thermosetting resins. In this study, only 10.8 ounces of new epoxy resin was needed to produce six thermoforming molds consisting of 70% recycled composite powder. To produce the same molds without filler would have consumed 36 ounces of new epoxy resin.

According to Kojima and Furukawa (1995), the disposal and recycling of these composite products have "constituted a great social problem, as there is no effective reusing system for it" (p. 137). The results of this study have demonstrated a workable alternative for the recycling and reuse of thermosetting composite products. However, further studies are needed to determine the commercial practicality of this recycling technique on a larger scale.

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Table 1. Plastic Product Measurement, Average and Standard Deviation (units in inches)

Part #	**A**	**B**	**C**	**D**	**E**
		Mounting Plate One			
1	4.034	4.037	4.001	3.999	3.829
2	4.030	4.048	4.000	3.995	3.824
3	4.033	4.032	4.003	4.001	3.832
4	4.030	4.035	4.005	3.999	3.824
5	4.037	4.037	3.998	4.001	3.822
6	4.031	4.037	4.003	4.001	3.825
7	4.036	4.036	3.999	4.000	3.824
8	4.036	4.038	3.998	4.003	3.823
9	4.037	4.032	4.001	4.000	3.825
10	4.035	4.036	4.003	4.000	3.824
Average	4.034	4.037	4.001	4.000	3.825
Standard Deviation	0.00277	0.00444	0.00238	0.00208	0.00301
		Mounting Plate Two			
1	3.956	4.062	3.853	4.005	3.855
2	3.958	4.068	3.859	4.000	3.858
3	3.954	4.065	3.858	4.006	3.853
4	3.961	4.067	3.857	4.007	3.856
5	3.955	4.067	3.854	4.004	3.851
6	3.955	4.069	3.858	4.006	3.854
7	3.954	4.067	3.855	4.006	3.853
8	3.955	4.068	3.854	4.005	3.855
9	3.958	4.068	3.854	4.005	3.855
10	3.959	4.068	3.859	4.003	3.853
Average	3.957	4.067	3.856	4.005	3.854
Standard Deviation	0.00237	0.00202	0.00233	0.00200	0.00195
		Mounting Plate Three			
1	4.048	4.065	3.985	3.955	4.130
2	4.047	4.068	3.984	3.957	4.134
3	4.048	4.067	3.985	3.959	4.130
4	4.046	4.065	3.983	3.955	4.128
5	4.048	4.070	3.983	3.956	4.130
6	4.047	4.067	3.985	3.955	4.135
7	4.046	4.064	3.980	3.954	4.131
8	4.046	4.068	3.985	3.954	4.132
9	4.049	4.062	3.983	3.952	4.131
10	4.050	4.066	3.983	3.953	4.130
Average	4.048	4.066	3.984	3.955	4.131
Standard Deviation	0.00135	0.00230	0.00158	0.00200	0.00208