THE IMPLEMENTATION OF RECYCLED THERMOSETTING COMPOSITE POWDER IN ROTATIONAL CASTING

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Abstract

Is it possible to grind up used or damaged composite products into powder and use it as filler in rotational casting? Rotational casting is a good candidate for this research method, since the percentage of recycled powder can be confirmed and maintained during this process. The exact amount of virgin plastic and recycled powder is placed directly into the mold and then closed, allowing all of the material to stay in the mold. The approach in this current study was not to return the fiberglass with polyester resin back to pre-mixed conditions, but to grind a used composite product into powder and use it as a filler. This concept could have a positive impact in two areas: it could reduce the amount of composite products in landfills or junkyards, and it can reduce the amount of virgin material needed to produce each new part. The samples with filler were evaluated using three methods: observational, drop test, and compression test.

Introduction

Rotational casting, also known as rotational molding or rotomolding, is a plastics manufacturing process that uses thermoplastic powder to produce hollow products. The powder is placed into a hollow mold and rotated on both major and minor axes. This allows the plastic to tumble inside the mold cavity allowing it to adhere to the mold as it is heated [1, 2]. To produce fiberglass composite products, fiberglass reinforcement must be saturated with resin to make the final part structurally rigid. Two of the primary functions of the resin are to transfer stress to the individual strands of fiberglass and to hold the fibers in the proper orientation (including geometrical shape). The most common types of resin are polyester, epoxy, vinyl ester, and urethane; all four are thermosetting (or thermosets) resins. Once a thermosetting resin has chemically cross-linked, or cured, it is virtually impossible to reverse or recycle. Once a composite product has cured, it will not chemically "reset" back to a premixed liquid resin.

As a result, there are composite products in landfills across the country that will never decompose. Examples include boats, showers, bathtubs, car bumpers, aircraft parts, campers, and canoes. This is a growing problem and will continue to increase until alternative solutions can be found in reusing the disposed composites. According to Thomas et al. [3], "Recycling of thermosetting polymers is regarded as one of the urgent problems to be settled because of its technological difficulty." Currently, fiberglass/resin composite recycling can be divided into mechanical, conventional pyrolysis, microwave pyrolysis, and chemical and electrical fragmentation-based processes [3, 4]. However, these methods can be time consuming and extremely costly. According to Lopez et al. [5], "The recycling of these composites is not, at present, profitable in economic terms, because obtained fibers present lower mechanical properties than the original ones, and cannot be employed in the manufacture of structural materials. Therefore, most of the waste glass fiber composites are stored in landfills or buried. This causes serious environmental problems, due to this kind of wastes are usually non-biodegradable and very bulky."

Rotational casting products can be classified into many areas, including toys, agricultural products, automotive products, boats, kayaks, road safety, industrial products, lighting, and furniture [1, 6]. Various shapes and sizes of kayaks are great examples of rotational casting. Polyethylene (PE) is the industry standard plastic for producing kayaks. Using recycled thermoplastics (including PE) in the rotational casting process has been successfully practiced since the 1980s [7]. Thermoplastics are significantly different from thermosetting plastics, because they can be easily re-melted and re-used. Unfortunately, thermosetting plastics are not commonly used in rotational molding. However, if a small percentage of recycled fiberglass/polyester powder could be used in the manufacturing process, it would reduce that amount of virgin PE material needed.

Table 1 gives a breakdown of how a company can reduce virgin PE. For example, if a company can make 500 kayaks a day, and each weighs 30 pounds, 1500 pounds of PE will be needed per day. Is it possible to remove a damaged one-piece fiberglass/polyester bathtub/shower unit, weighing approximately 120 pounds, from a landfill and grind it up into a powder? This recycled powder could then be used, in small percentages, in producing kayaks. There would be two major benefits. It would reduce the amount of virgin PE material, while eliminating a large damaged fiberglass product out of landfill. If 10 percent filler were possible, it would reduce the PE amount by 150 pounds per day. This appears to be minimal, but would save 4000 pounds in a year. The more significant benefit would be the elimination of 1.25 damaged fiberglass bathtub/showers each day, or over 450 bathtub/showers a year.

Table 1. Weight Analysis Using the Kayak Example: Manufacturing 500 Kayaks per Day Using 30 Pounds of High-Density Polyethylene (HDPE) per Kayak Recycled Fiberglass/Polyester (F/P) Powder Filler

% of F/P Powder	HDPE Usage (lb)		F/P Powder (lb)		Bathtub Reduction	
	Daily	Yearly	Daily	Yearly	Daily	Yearly
0%	1500.0	547,500	n/a	n/a	n/a	n/a
2.5%	1462.5	533,813	37.5	13,688	0.31	114.06
5%	1425.0	520,125	75.0	27,375	0.63	228.13
7.5%	1387.5	506,438	112.5	41,063	0.94	342.19
10%	1350.0	492,750	150.0	54,750	1.25	456.25

A cost analysis using virgin HDPE and recycled fiberglass/polyester powder as a filler was completed. The average price for HDPE powder is approximately $0.60 per pound, when buying a minimum of 2205 pounds [8]. The cost of the fiberglass/polyester powder was more difficult to calculate. After looking at various parameters (labor, time, equipment, etc.) a cost of $0.38 per pound was determined as shown in Table 2.

Table 2. Cost of Recycled Fiberglass/Polyester Powder

Item	Cost	Notes
Labor	$20 per hour	Manual labor for one operator
Equipment	$150 per hour	Includes equipment, maintenance, facilities, utilities, etc.
Collection Fee	($20 per hour)	Companies can charge $100 to collect 2000 pounds of damaged fiberglass. Cost per pound ($0.05) multiplied by one hour of work (400 pounds) equals $20 per hour
Production Cost	$150 per hour	Labor + Equipment – Collection Fee
F/P Powder Production	400 pounds per hour	Takes ½ hour to grind 400 pounds; must grind material twice to reduce fiberglass rods into powder
Final Cost	$0.38 per pound	$150 ÷ 400 pounds = $0.375 rounding up to $0.38

Spent fiberglass products are readily available and can be obtained free. In fact, there are recycling companies that are charging a collection fee to haul away damaged fiberglass boats. These prices range from $325 to $2400 depending on the size of the fiberglass boat [9]. Eco-Wolf, Inc. sells equipment that can grind over 800 pounds of cured fiberglass an hour. The amount of fiberglass that can be chopped per hour is impressive; unfortunately, substituting the chopped fiberglass powder (rod length of 3175-25400 µm, or 0.3175-2.54 cm) for the recycled fiberglass/polyester powder (rod length of 50-150 µm) would not be acceptable [9]. This discrepancy in rod length could be resolved by running the chopped fiberglass rods through the grinding equipment twice and then using a strainer to remove any remaining larger rods from the new powder.

Table 3 shows how a company can save $12,045 per year by implementing 10% recycled fiberglass/polyester powder into their products. Not only can a company achieve an annual savings of 3.67%, they will also have a positive impact on the environment by reducing the amount of virgin materials used (i.e., natural resources), while eliminating damaged composite products from the landfills.

Table 3. Cost Analysis Using the Kayak Example from Table 1: Based on High-Density Polyethylene (HDPE) at $0.60/pound and Recycled Fiberglass/Polyester (F/P) Powder at $0.38/pound

% of F/P Powder	Daily Cost		Total Cost (HDPE + F/P powder)		Total Savings ($)
	HDPE	F/P powder	Daily	Yearly	Yearly
0%	$900.00	n/a	$900.00	$328,500.00	n/a
2.5%	$877.50	$14.25	$891.75	$325,488.75	$3011.25
5%	$855.00	$28.50	$883.50	$322,477.50	$6022.50
7.5%	$832.50	$42.75	$875.25	$319,466.25	$9033.75
10%	$810.00	$57.00	$867.00	$316,455.00	$12045.00

Material and Sample Preparation

The powder was produced by using a die grinder to grind up composite panels consisting of fiberglass with polyester resin. Once the powder was collected, it was sifted through a food strainer twice to reduce the particle size to the approximate size of the virgin high-density polyethylene (HDPE) powder commonly used in rotational casting. The recycled fiberglass/polyester powder was analyzed under a scanning electronic microscope (SEM). Figures 1-3 clearly show that, during the grinding process, the polyester resin separated cleanly from the fiberglass rods. The polyester resin became like small granular rocks, with the majority being between 10-150 µm. The fiberglass rods broke relatively smoothly, with the majority of the rods being 7-10 µm in diameter and 50-150 µm in length.

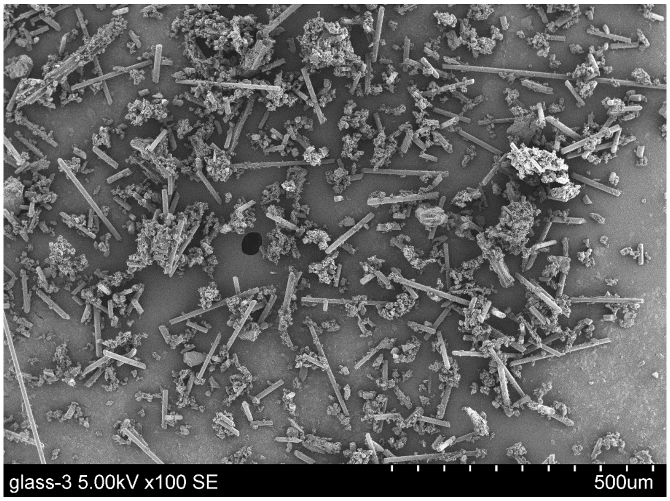

Figure 1. Scanning Electron Microscope (SEM) Image of Recycled Fiberglass/Polyester Powder (500 µm)

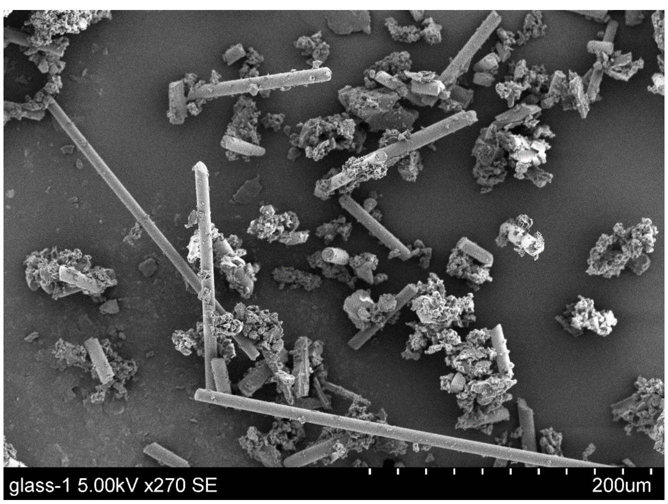

Figure 2. Scanning Electron Microscope (SEM) Image of Recycled Fiberglass/Polyester Powder (200 µm)

After producing a few trial samples (8.5 cm hollow balls), the authors decided to use recycled fiberglass/polyester powder at 2.5% increments up to 10% filler. The trial sample piece at 12.5% filler was getting "clumpy" and the recycled powder wanted to cling to itself, making noticeable imperfections in the final product. By using increments of 2.5%, there were slightly noticeable differences in texture and color; smaller percentage increments did not appear to produce any differences. A control group (samples with zero percent recycled powder) was created to have a standard for comparison to the parts with the various percentages of recycled powder. Table 4 gives a breakdown of the amount of HDPE and fiberglass/powder used for each sample piece.

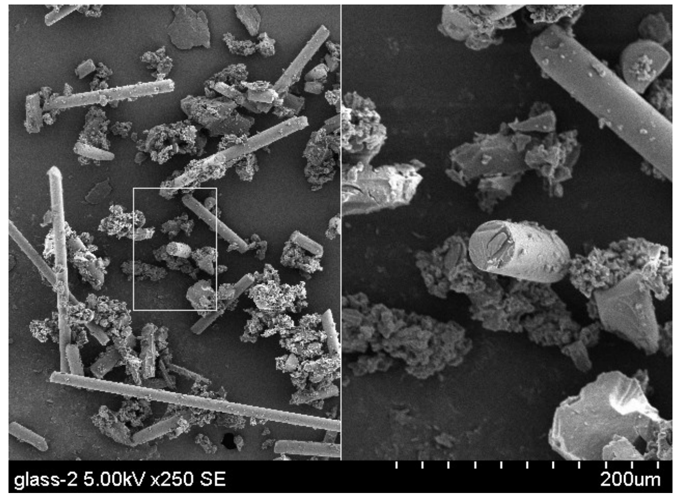

Figure 3. Scanning Electron Microscope (SEM) Image of Recycled Fiberglass/Polyester Powder (image on the right is a high-magnification shot of the area inside the rectangle)

The fiberglass/polyester (F/P) powder was weighed using a digital scale capable of measuring to 0.0000g. For each rotational casting product, the virgin material and recycled powder ratios were weighed individually to maintain accuracy. The recycled powder was then added to the virgin material and stirred for two minutes before being poured into the rotational mold. To maintain control standards, the same procedures were used for making all 25 sample pieces. The premixed F/P powder was poured into a 350°F preheated mold. The temperature was then increased to 400°F while the mold was being rotated around the major axis at 15 rpm for 30 minutes. The mold rotated for another 30 minutes with the heat turned off and the oven door opened, allowing the plastic ball to cool. After cooling, the sample was removed from the mold and labeled.

Testing and Results

Observational

Besides collecting data, a visual inspection was done on each test piece. Each ball was visually inspected for color and surface texture. With the increase in recycled fiberglass/polyester filler, there were obvious changes in color and surface porosity. The color of the sample pieces become noticeably darker. The samples that had zero percent filler were an opaque white color, but with each additional increase in filler percentage, the samples became noticeably darker or "dirtier." Figure 4 shows how the sample colors went from white, off-white, beige, tan, and dark tan, respectively.

Table 4. High-Density Polyethylene (HDPE) and Fiberglass/Polyester (F/P) Powder Material Usage

Sample Piece #	Filler Percentage	HDPE	F/P Powder
1	0%	60.00 g	--
2	0%	60.003 g	--
3	0%	60.004 g	--
4	0%	60.003 g	--
5	0%	60.002 g	--
6	2.5%	58.501 g	1.504 g
7	2.5%	58.501 g	1.502 g
8	2.5%	58.502 g	1.502 g
9	2.5%	58.502 g	1.503 g
10	2.5%	58.502 g	1.502 g
11	5%	57.002 g	3.002 g
12	5%	57.002 g	3.002 g
13	5%	57.001 g	3.003 g
14	5%	57.002 g	3.001 g
15	5%	57.002 g	3.001 g
16	7.5%	55.502 g	4.501 g
17	7.5%	55.501 g	4.502 g
18	7.5%	55.502 g	4.501 g
19	7.5%	55.502 g	4.502 g
20	7.5%	55.502 g	4.502 g
21	10%	54.002 g	6.002 g
22	10%	54.002 g	6.002 g
23	10%	54.002 g	6.001 g
24	10%	54.001 g	6.001 g
25	10%	54.002 g	6.002 g

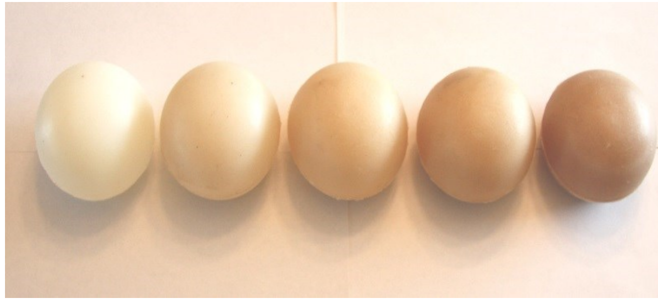

Figure 4. Samples Produced with 0%, 2.5%, 5%, 7.5%, and 10% Fiberglass/Polyester Powder (left to right)

Figures 5-7 show that the surface porosity for the samples with 0%, 2.5%, and 5% filler looked virtually the same. This demonstrates that small percentages of fiberglass/polyester powder, when distributed evenly in the samples, would fuse with the HDPE.

Figure 5. Samples with 0% Filler

Figure 6. Samples with 2.5% Filler

Figure 7. Samples with 5% Filler

Figure 8 shows that, for the samples with 7.5% filler, there were small pinhole voids on the entire surface of the ball, along with one or two small pockets of clumped fiberglass. The voids were in the top skin-surface only, and did not go completely through the part.

Figure 8. Samples with 7.5% Filler and Having Small Pinhole Voids over Their Entire Surface

Figure 9 shows that balls with 10% filler had two obvious quality issues. There were small pinhole voids over the entire surface, just like the samples with 7.5% filler. The second issue was the amount of noticeable small pockets of clumped fiberglass over the entire surface of the ball. If a company wanted to have a greater impact on the environment, this could still be an option if the products were painted or used in an unseen location.

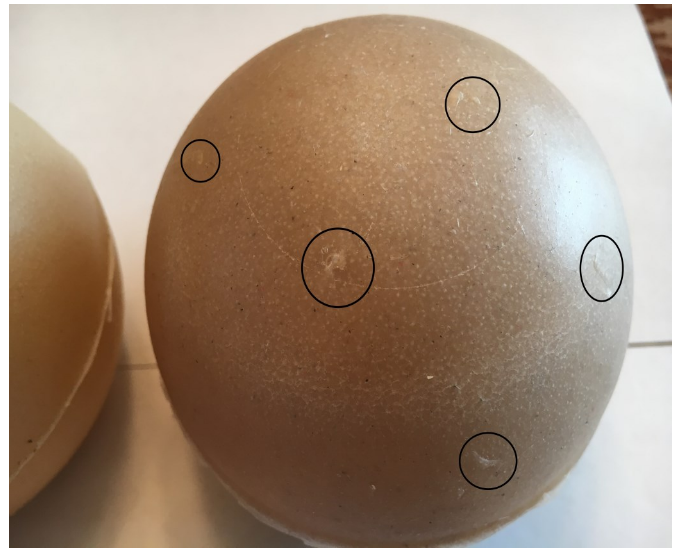

Figure 9. Samples with 10% Filler and Having Small Pinhole Voids and Numerous Pockets of Clumped Fiberglass/Polyester Powder (located inside the circles) over Their Entire Surface

Drop Test

The second test performed was a two-meter drop test. Each ball was placed in a container with a sliding bottom. The bottom of the container was quickly pulled, causing the ball to drop down and bounce off the concrete floor. A large cardboard ruler with horizontal lines was used as the backdrop to determine the bounce height. Table 5 shows the data collected for the drop test, which was completed in one setting. During a trial run to determine drop height, it was determined that two meters produced the best consistency of the ball bouncing. At one meter, the balls had minimal bounce; at three meters, the balls would bounce at inconsistent and random angles. Each sample piece (ball) was dropped from the same height without a guide system. Using a tube or pole for a guide would have caused the ball to skip off the tube, causing a reduction in true speed.

Table 5 shows that all five balls from the control group (0% filler) bounced over 100 cm. For all of the test pieces with filler, only three balls (out of 20) bounced over 100 cm, and none of the filler percentages had more than one ball that bounced over 100 cm. The control group had the best standard deviation (1.483) followed by 2.5% filler (3.912). The standard deviation for 5% filler would have been the lowest if not for one ball, since the other four balls with 5% filler bounced to 88cm ± 1cm. The balls using 5%, 7.5%, and 10% filler, were very similar in bounce average and also had the highest three standard deviations. Based solely on the drop test data, the best sample of balls were the control group (0% filler); however, balls with 2.5% filler presented a viable option. The balls with 2.5% filler only had an 8.615% reduction in bounce at three meters and had the second best standard deviation. Figure 10 shows the averages of the bounce height for each sample set, which tended to decrease when higher percentages of filler were used.

Table 5. Drop Test (Bounce) Results

Test Piece #	Filler Percentage	Bounce Height	Average (Std. Dev.)
1	0%	107 cm	
2	0%	107 cm	
3	0%	105 cm	
4	0%	109 cm	106.8 cm (1.483)
5	0%	106 cm	
6	2.5%	98 cm	
7	2.5%	92 cm	
8	2.5%	103 cm	
9	2.5%	97 cm	97.6 cm (3.912)
10	2.5%	98 cm	
11	5%	89 cm	
12	5%	87 cm	
13	5%	104 cm	
14	5%	88 cm	91.2 cm (7.190)
15	5%	88 cm	
16	7.5%	84 cm	
17	7.5%	101 cm	
18	7.5%	87 cm	
19	7.5%	90 cm	89.4 cm (6.877)
20	7.5%	85 cm	
21	10%	87 cm	
22	10%	91 cm	
23	10%	90 cm	
24	10%	93 cm	91.8 cm (4.087)
25	10%	98 cm	

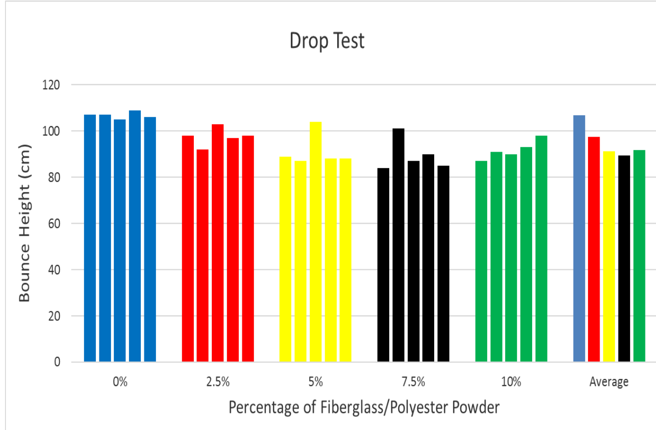

Figure 10. Drop-Test Results Using Various Ratios of Recycled Fiberglass/Polyester Powder

Compression Test

The third, and final test, was the compression test. An Instron Model 5582 with a load cell of 100 kN was used to test the balls. Each ball was placed on the bottom fixture mount, while a flat steel plate attached to the top fixture was used to apply the compression load. The compression load was applied at 2.5 cm per minute. Table 6 shows the data collected for the compression test, which was completed in one setting.

The 2.5% filler group had the best compression load average (4.208 kN), followed by the 0% group (4.098 kN). Balls with 0% and 2.5% filler had four out of five results above 4.0 kN. The 2.5% filler group had three out of the four highest compression results of all the balls. The group with 7.5% filler had the most inconsistent results, with three results above 4.0 kN, and also had the lowest two compression results for all percentage groups. Averages of the compression load tests for each sample set tended to decrease when higher percentages of filler were used.

All five sample groups had low standard deviations, ranging from 0.107 (0% filler) to 0.525 (7.5% filler). Table 6 shows that the balls with 2.5%, 5%, and 10% had similar standard deviation results of 0.234, 0.235, and 0.289, respectively. Based solely on the compression test, the balls with 2.5% filler performed the best. The 2.5% samples had the highest compression load average (4.208 kN) along with a relatively low standard deviation (0.289). The second choice would be the control group (0% filler), based on the second highest compression result (4.098 kN) and the lowest standard deviation (0.107). Figure 11 shows that the samples with 0% and 2.5% filler had higher compression maximum load results, while fillers with 5%, 7.5% and 10% tended to have lower results.

Table 6. Compression Test Maximum Load Results

Test Piece #	Filler Percentage	Maximum Load	Average (Std. Dev.)
1	0%	4.12 kN	
2	0%	4.19 kN	
3	0%	4.03 kN	
4	0%	3.95 kN	4.098 kN (0.107)
5	0%	4.20 kN	
6	2.5%	4.31 kN	
7	2.5%	3.72 kN	
8	2.5%	4.42 kN	
9	2.5%	4.18 kN	4.208 kN (0.289)
10	2.5%	4.41 kN	
11	5%	4.37 kN	
12	5%	3.85 kN	
13	5%	3.83 kN	
14	5%	3.82 kN	3.952 kN (0.235)
15	5%	3.89 kN	
16	7.5%	3.16 kN	
17	7.5%	4.09 kN	
18	7.5%	4.01 kN	
19	7.5%	4.28 kN	3.750 kN (0.525)
20	7.5%	3.21 kN	
21	10%	3.82 kN	
22	10%	3.46 kN	
23	10%	4.04 kN	
24	10%	3.62 kN	3.774 kN (0.234)
25	10%	3.93 kN	

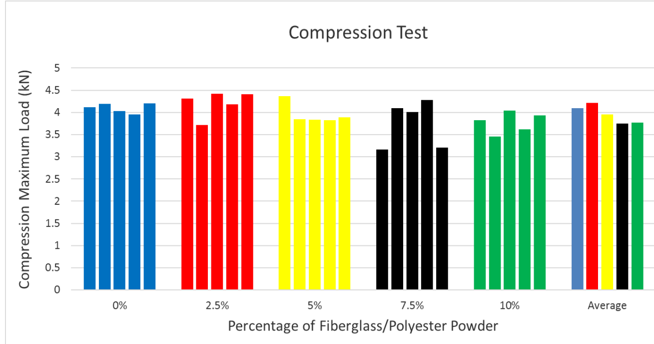

Figure 11. Compression-Test Results Using Various Ratios of Recycled Fiberglass/Polyester Powder

Conclusions

A study was conducted in order to determine if recycled fiberglass/polyester (F/P) powder could be implemented in rotational casting. Various filler percentages (0%, 2.5%, 5%, 7.5%, and 10%) were added to virgin high-density polyethylene (HDPE) powder to produce round, hollow balls. The balls were then evaluated by general observation, drop testing, and compression testing. After manufacturing, testing, and analyzing the results, the control group (0% filler) performed the best overall. It had the best color, highest drop test bounce results (106.8 cm), and was second in the compression test. The balls with 2.5% filler also performed well, with color being slightly darker; they were second in the drop test (97.6 cm) and best in the compression test (4.208 kN). A company willing to have less than a 10% reduction in bounce could advertise a ball with recycled fiberglass/polyester filler as an environmentally friendly or "green" product.

According to Tables 1 and 3, using the kayak and bathtub examples, even a small substitution using only 2.5% filler could help reduce the size of landfills by 114 bathtubs and save $3011.25 in virgin HDPE per year. Based on the overall results, the three higher filler percentages (5%, 7.5%, and 10%) were similar to each other. These sample pieces were darker, had less bounce, and had lower compression strengths. The higher filler percentages did not have ideal results, but could still be considered a viable option, depending on the use and geometric shape of the product, or if the customer wants an environmentally friendly product.

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Biographies

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