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Industrial Resilient Floor Tiles made from Post-Consumer Carpet Waste: Processability and Performance

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Chelsea Center for Recycling and Economic Development Technical Research Program

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1. Abstract

RepTile™ is a resilient floor tile made from a blend of post-industrial, flexible PVC and post-consumer carpet waste by SelecTech, Inc. The RepTile is a 24" x 24" x 0.2" thick, interlocking floor tile that is ideal for use in high traffic and production areas that require durability and ease of maintenance. RepTiles are installed by interlocking the tiles together without glues. The interlocking edges and the weight of the tiles keep the tiles in place. This alleviates a lot of cost, labor and subfloor preparation that is normally found with conventional glue-down flooring.

During early production and sale of this product, several problems were discovered that were related to distortion of the tiles in the field. This project was designed to determine the cause of these problems and modify both the process and the material formulation to overcome the problems.

During the project, it was discovered that high percentages of post-consumer carpet waste in the final product increased the severity and occurrence of tile distortion. It was determined that the level of mixing of the material blend also affected the level of distortion and that by increasing the level of blending, distortion could be eliminated even at higher carpet concentrations.

2. Background

2.1 Creating a Beneficial Use for Waste Vinyl-Backed Carpet

The problem of disposing of old carpeting has become a public issue, fueling the movement toward recycling. One type of carpeting, vinyl-backed carpet tiles, is not readily recycled and has become a problem for the companies that collect old carpeting. SelecTech's partner in this endeavor, DuPont Flooring Systems, collects all the old carpeting that is removed during a remodeling job and recycles most of what is collected. The vinyl-backed carpet, however, is a problem because it consists of a vinyl backing, a fiberglass reinforcing sheet, and nylon or polyester face fiber. These three materials are incompatible with one another and are too costly to separate.

The vinyl-backed carpet waste can be used to make dark colors (black, gray, hunter green), but cannot be used to make bright colored tiles. For these tiles, virgin flexible PVC is mixed with bright colored pigments (red, yellow, blue, beige) and powdered carpet backing from DuPont Flooring Systems nylon carpet recycling operation. During the recycling of conventional nylon carpeting, DuPont separates the backing from the nylon face fibers. This backing consists primarily of calcium carbonate and latex and, after the recycling operation, is left in a powder form. This powder is a byproduct of the nylon carpet recycling operation. This test program also investigated the use of adding this byproduct powder to the RepTile to increase the post-consumer content of brightly colored tiles.

SelecTech has created a patent-pending method for compounding post-industrial and virgin PVC with post-consumer carpet waste in a way that leaves the fiberglass, nylon, and polyester intact as fibers that reinforce the finished product. These fibers will clog conventional plastics manufacturing machinery and could even cause expensive damage. SelecTech's equipment is specifically designed to handle these fibers and allows them to be used in the product for added

value. Preparing this material for use in SelecTech's equipment, however, is difficult. Conventional carpet recycling relies on shredding which tears the carpeting apart and produces a very fluffy end-product that is hard to mix and convey in SelecTech's equipment.

2.2 Project Goals

SelecTech has just developed the RepTile and still has to improve the efficiency of the manufacturing process, which should lead to an increase in the post-consumer carpet content of the product. This project is intended to resolve these inefficiencies and make the RepTile more cost competitive with a higher recycled-content.

Old Process

As shown below, RepTiles were originally made using a mixture of shredded, vinyl-backed carpet tiles, post-industrial, flexible PVC, and proprietary additives to create a blend of material that incorporates the benefits of flexible PVC with the strength of glass, nylon, and polyester fibers. This mixture is processed using SelecTech's innovating injection molding technology, which is ideally suited for using co-mingled, dirty waste plastics. This device melts the mixed plastics and then injects them under high pressure into a mold that forms the shape of the RepTile. The hot plastic then cools and hardens to yield the finished tile.

For most of SelecTech's products, this system works well. For the RepTile, however, the mixture of shredded carpet, post-industrial PVC, and proprietary additives is so clumpy that it does not feed uniformly. As a result, the finished tile has variations that affect quality.

Prior to this project, SelecTech did not have the proper equipment to shred and homogenize the material. Instead, the mixture of PVC, post-consumer carpet material, and proprietary additives was hand-fed into the injection molding machine, and made into tiles that were not adequately consistent. These tiles were then granulated and the resultant granulated plastic was dry-blended for uniformity and re-fed into the injection-molding machine to make new tiles. This process, shown in Figure 1, is obviously inefficient and costly.

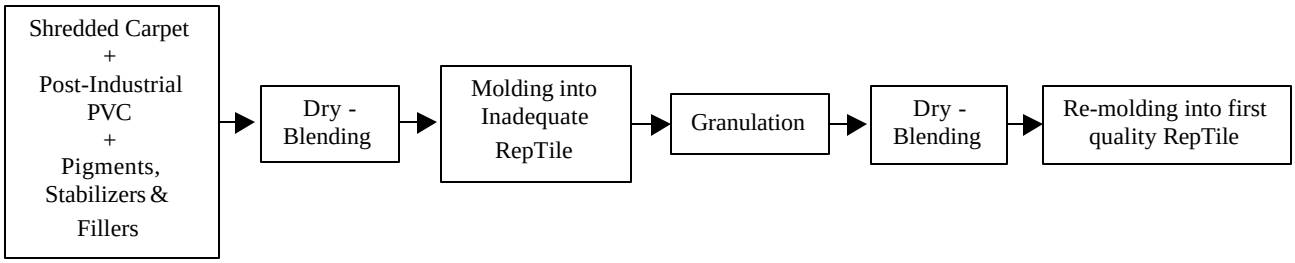

Figure 1

New Process

The new process, developed as part of this project, is described in Figure 2. It removes the inefficiencies of the existing process by eliminating the costly steps of hand feeding, re-grinding and double running.

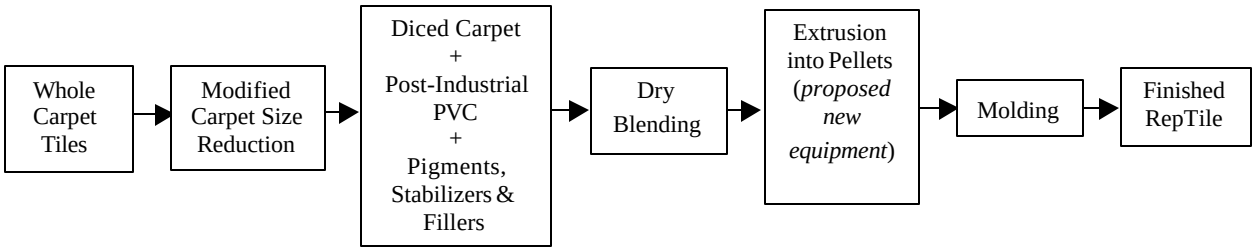

Figure 2

In this new system, whole carpet tiles (roughly 18" x 18" square x ¼" thick) are sorted from other carpet waste at DuPont's Carpet Reclamation Facility in Calhoun, GA. These sorted tiles are then sent to Conigliaro Industries in Framingham, MA where they are shredded/granulated in a modified, low-speed granulator that reduces the carpet into a more uniform size that is easier to handle and mix. The diced material is dry-blended to create a homogenous material. The blended material is fed into an extruder that melts and further homogenizes it and extrudes the molten mixture into a strand that is cooled and chopped into relatively uniform pellets. These pellets are fed to the injection-molding machine to create the finished RepTile.

2.3 Potential use/diversion from waste stream

The market for resilient flooring is approximately 1.5 billion square feet per year. Resilient flooring is typically sold into commercial facilities such as factories, warehouses, hotels, hospitals, schools, municipalities, and office buildings. The RepTile, because of its quality, performance, and cost advantage has the potential to capture a significant share of this market. Moreover, because of its unique features, the RepTile has the potential of creating new applications to further expand the market. Each RepTile weighs 6.25 lbs and covers approximately 4 square feet (1.6 pounds per square foot). The potential market for this material, therefore, is approximately 2.4 billion pounds per year. This represents a substantial outlet for a problem material.

The ability to compete in this market is based on quality and price. The RepTile has been tested to be superior in quality to competing resilient floor tiles made with virgin materials. SelecTech has created the ability to manufacture this unique product, but still has some technical hurdles to overcome to bring its costs down to levels that will allow a 40% price savings (versus competing virgin-content tiles) to the customer. This project would allow SelecTech to meet this challenge. This, in turn, will create a large, viable outlet for the problem of disposal for vinyl-backed carpet tiles.

SelecTech introduced this product during the last fiscal quarter and consumed approximately 64,000 pounds of post-consumer vinyl-backed carpeting. SelecTech's goal is to increase market penetration through cost and price reduction and thereby increase carpet use to more than 350,000 pounds per quarter by the end of 1999.

2.4 Potential end markets

As mentioned above, the market for resilient flooring is very large. SelecTech will market this product through the existing DuPont Flooring Systems distribution channel which includes nearly 100 offices located throughout the U.S. and Canada. These DuPont branches sell and

install flooring to commercial customers. They are a recognized leader in the industry and are, therefore, an ideal outlet for this product.

2.5 Scope of Work

This project included testing a variety of mixtures under a variety of conditions to determine the cause of tile distortion during use and to perfect the material formulation that maximizes post-consumer carpet content while eliminating this performance problem.

3. Description of Approach

Generally, RepTile is 24" × 24" with a thickness of 0.22" and a weight of six pounds. In this work, size and weight of RepTile were chosen as control factors and measured precisely. Size was represented by three dimensions and measured by a stainless steel ruler with one 64th inch precision. Two of the dimensions are the lengths of a pair of parallel edges of a tile. The third length was measured parallel to the two edges at the center of the tile. Tile weight was measured using an electronic scale with 0.01 pound precision.

This work was divided into four parts as follows:

- Part 1 – The effect of carpet concentration on the size and weight of the RepTile.
- Part 2 – Repeatability of injection molding process
- Part 3 – Weathering tests
- Part 4 – Effect of compounding methodology on tile performance

In the first part of the program, the effect of carpet concentration on the weight and size of a tile were investigated. For black and gray RepTiles, the carpet regrind was composed of irregularly shaped pieces with projected areas of from 0.25 to 5 square inches. According to the new system developed in this project, whole vinyl-backed carpet material was collected by DuPont Flooring Systems and then shipped to Conigliaro Industries in Framingham, Massachusetts, where it was chopped using a special, low-speed granulator to produce the particles. For colored (yellow in this test) RepTiles, powdered carpet backing was used as the post-consumer carpet content. This powdered carpet backing is a byproduct of DuPont Flooring Systems' nylon carpet recycling operation located in Chatanooga, TN. The formulations are shown in Table 1.

Table 1

Experimental trials	Color	Carpet Concentration (Weight %)	Flexible PVC
1B	Black	10%	90%
2B		20%	80%
3B		30%	70%
4B		40%	60%
1G	Gray	10%	90%
2G		20%	80%
3G		30%	70%
4G		40%	60%
1Y	Yellow	5%	95%
2Y		7.5%	92.5%
3Y		10%	90%

All trials were conducted under the same processing conditions which consisted of:

- Melt Temperature 170 °C
- Mold Cooling Temperature 34 °C
- Injection Pressure 150 bar
- Mold Clamp Pressure 200 Metric Ton
- Cooling Time 60 seconds

Fifty tiles were made in each trial and 20 tiles were randomly chosen from them to represent the trial. After measuring the sizes and weights, 12 tiles were interlocked with each other to form a 3×4 unit and placed outdoors to see if the tiles would distort under high heat and humidity. Past problems with distortion at customer locations were always exacerbated with rises in temperature and humidity. The roof of SelecTech's factory, during the time of this study, provided an ideal location to expose the tiles to both high temperature and humidity.

In the second part of the program, the repeatability of the injection molding process was investigated. A trial manufacturing run was conducted to produce tiles with 20% post-consumer carpet content. During this production run of 500 tiles, 41 RepTiles were chosen randomly. The sizes and weights of these tiles were measured. These tiles were made in the new system, developed as part of this project.

In the third part of the program, the effect of weathering on the weight and size of tiles was investigated. As mentioned above, increases in heat and humidity apparently increase the likelihood that the tiles will distort after installation. During this part of the program, the intention was to determine if exposure to heat and humidity actually caused changes in the tiles as measured by weight and size. Tiles were exposed to two months of direct sunlight on a black surface. In this environment, tile surface temperatures were measured to be as high 150 °F. Ten 30% carpet filled gray tiles were then selected from the exposed batch and measured for size and weight. Again, these tiles were manufactured by the new process.

In the fourth part of the program, using the newly developed system, material was run from one to three times through the new extruder. Material that was not extruded first was also tested as a benchmark. Tiles were then manufactured using these materials and compared for performance and uniformity.

4. Results

Part 1 – The effect of carpet content on the size and weight of the RepTile

The effect of carpet content on the size and weight of RepTile was investigated. Results are reported in Table 2.

Table 2

Color	Carpet content (%)	Right Edge (in)	Middle (in)	Left Edge (in)	Weight (lbs)
Black	10	24.00 (0.01)	24.00 (0.01)	24.00 (0.01)	5.93 (0.01)
	20	24.04 (0.01)	24.02 (0.01)	24.04 (0.01)	5.97 (0.02)
	30	24.08 (0.02)	24.05 (0.01)	24.08 (0.01)	6.11 (0.07)
	40	24.10 (0.02)	24.07 (0.01)	24.09 (0.01)	6.30 (0.03)
Gray	10	24.03 (0.01)	24.02 (0.01)	24.03 (0.01)	5.99 (0.02)
	20	24.09 (0.01)	24.07 (0.01)	24.09 (0.01)	6.06 (0.03)
	30	24.09 (0.02)	24.07 (0.01)	24.09 (0.01)	6.06 (0.01)
	40	24.12 (0.02)	24.10 (0.01)	24.12 (0.01)	6.09 (0.03)
Yellow	5	23.99 (0.01)	23.98 (0.01)	23.98 (0.01)	5.69 (0.03)
	7.5	23.99 (0.01)	23.98 (0.01)	23.98 (0.01)	5.74 (0.03)
	10	24.00 (0.02)	23.99 (0.01)	23.99 (0.02)	5.80 (0.02)

Values given are averages. Standard deviations are presented in parenthesis.

The increase in carpet content led to an increase in both the size and weight of the tiles. When the carpet content increased from 10% to 40%, the size of tiles increased about 0.07 to 0.1 inches, and the weight increased about 0.1 to 0.3 pounds. More significantly, variations in the sizes and weights from tile to tile (as measured by standard deviation), also increased. This means that the higher carpet content contributes to reduced homogeneity of the final product. Finally, higher carpet content decreased the processability of the material. When the carpet content was increased to 40%, the material would not completely fill the mold. With this increase, melt viscosity also increased, making it more difficult to push the blend into the cavities of the mold under the same processing conditions.

When tiles were placed outdoors in the direct sun on a black surface, 40% carpet-content tiles showed a great distortion at the interlocking joints, which caused the tiles to rise off the floor at this intersection (referred to as “peaking”). Moreover, gaps in the interlocks were observed due to this deformation. Almost every joint shows the peaking on a 3×4 tiles unit (6 joints). The height of peaking joints were ¼" to ½" above the flat surface. When carpet content decreased to 30%, the number and height of peaking joints decreased accordingly. When carpet content decreased to 20%, 10%, 7.5%, and 5%, there was no peaking. It is clearly shown that carpet content affects the tile quality regarding the peaking problem. When carpet content is below 20%, tiles perform well; above 30%, tiles show distortion.

Finally, tiles were sliced to determine if there was any visual difference within the tiles. When tiles were cut, it revealed agglomerates of post-consumer carpet within the tile. Tiles made from increased carpet concentrations showed increases in these agglomerates. Because the thermal

expansion rates of these agglomerates and the surrounding PVC resins are different, when temperature increases, the size of the carpet and PVC increase differently. This difference creates tension within the tile, which, in turn, can cause peaking.

Part 2 – Repeatability of injection molding process

In the second part, the repeatability of the injection molding process was investigated. The size and weight of 41 randomly chosen tiles of a 500-tile production run is reported in Table 3.

Table 3

	Size (in)			Weight (lbs)
	Right edge	Middle	Left edge	
Maximum Value	24.11	24.11	24.13	6.21
Minimum Value	24.08	24.06	24.06	6.01
Average Value	24.09	24.08	24.09	6.10
Standard Deviation	0.01	0.01	0.01	0.05

The size variation was measured to be approximately 0.07 inches and the standard deviation is 0.01. This variation is not big enough to cause the peaking, which is a quarter of inch to half an inch high and appears at almost every joint. From this, it was concluded that peaking is not caused by size variation from part to part. It was also concluded that the injection molding process to make RepTiles is repeatable and reliable and does not contribute to the peaking problem.

Part 3 – Weathering test

The third part of the program consisted of a weathering test to measure any changes in the tiles size and weight due to weathering. This was done to see if there were any physical changes occurring within the tiles due to exposure to heat and humidity that would lead to distortion. The size and weight of tiles before and after two months exposure outdoors are reported in Table 4.

Table 4

	Size (in)						Weight (lbs)	
	Right edge		Middle		Left edge			
	Before	After	Before	After	Before	After	Before	After
Maximum value	24.14	24.13	24.11	24.08	24.14	24.11	6.09	6.18
Minimum value	24.08	24.06	24.05	24.05	24.08	24.06	6.04	6.09
Average value	24.09	24.09	24.07	24.06	24.09	24.09	6.06	6.13
Standard derivation	0.02	0.02	0.01	0.01	0.01	0.02	0.01	0.03

It was found that the weight of the tile increased after two months weathering. Before the weathering test, the weight ranged from between 6.04 to 6.09 pounds. After that, the weight increased slightly to a range of 6.09 to 6.18 pounds. This weight gain is considered to be small and possibly the result of dirt sticking to the surface and moisture absorbed into the tile. From this work, it cannot be concluded whether dirt or absorbed moisture contributes more to weight gain.

With regard to sizing, the tile did not change due to the weathering. Even in the tiles that distorted at corners, overall dimensions did not change. From this, it can be concluded that the

problem with peaking is “built-in” to the tile as it manufactured and not “created” due to the weathering of the tile.

It was also noticed that the number and height of peaking joints were greater on a hot day than on a cool day. From this, it was concluded that the peaking is a result of a non-uniform expansion in the tile due to temperature changes. The larger the temperature change, the more the non-uniformity. It is theorized that this non-uniform expansion is a result of the incomplete mixing of the material.

Part 4 – Effect of compounding on tile performance

In the fourth part of the program, tiles were made using materials that had been compounded through the extruder process 0, 1, 2, and 3 times. In all cases, tiles were made from a consistent blend of 40% post-consumer carpet content and 60% post-industrial vinyl which was purchased from a re-processor. The tiles were then exposed to direct sunlight on a black surface and monitored for peaking. Tiles made from uncompounded material and from material that had been compounded once all showed peaking, though those made from material that was compounded once peaked less than tiles made from uncompounded material. Tiles that were made from material that had been compounded two and three times did not peak.

This test helped to re-affirm that the level of compounding (and thus, the homogeneity of the material in the tile) affects the performance of the tile and that peaking is most likely a result of material that is not fully homogenous.

5. Lessons Learned

The following general lessons were learned during the program:

- The occurrence of distortion in the finished RepTiles is directly related to the carpet concentration in the tiles. The higher the concentration, the more likely the tiles will distort. Moreover, increasing carpet concentration leads to a corresponding increase in the size and weight of the finished tile and to the variations in size and weight from tile to tile.
- Increasing the carpet content reduces the processability of the material. When carpet content is increased beyond 30%, material does not consistently fill the mold resulting in reject product. RepTiles showed the peaking at interlocking joints.
- The repeatability of the injection molding process to make RepTiles is good. The peaking was not caused by variations in the molding process.
- The effect of weathering on the size and weight of tiles was not significant.
- The peaking was related to variations in thermal expansion caused by variations (inconsistent blending) in the materials.
- Increased compounding increases the homogeneity of the final product (as measured by consistency in tile weights and sizes and lack of distortion in the field), and allows for higher post-consumer carpet content.

6. Transferability of this Research

This project demonstrated a method of mixing post-consumer vinyl-backed carpet waste for creating a resilient floor tile. Moreover, the testing showed the effect that the post-consumer carpet has on the performance properties of the material and of the final product. These results can be extended to the use of this material for making other products both within and outside of the flooring industry.

In general, this project perfected material formulations with the following characteristics:

- Vinyl-based material
- Increased strength due to fiber addition
- Injection moldable
- Useful in a range of temperature and weather conditions

7. Recommendations for Future

Sliced sections of RepTiles showed agglomerates of carpet. Tiles made from increased carpet concentrations showed increases in these agglomerates. Because the thermal expansion rates of these agglomerates and the surrounding PVC resins are different, when temperature increases, the size of the carpet and PVC increase differently. This difference creates tension within the tile, which, in turn, can cause peaking.

In this work, the effect of running material multiple times through the new extruder to reduce the level of agglomerate was studied. This method, although technically effective, is not cost effective. With the extruder configuration as developed in this work, it was determined that tiles could be made using up to 20% carpet content. Future work will focus on improving the compounding capability of the existing extruder to effect a higher level of mixing on just one pass and allow for higher use of post-consumer carpet.

8. Conclusions

From the lessons learned, it was concluded that the new system does improve the processability of the material and the performance of the final product. With this system, we are capable of producing consistent tiles that perform in the field using up to 20% post-consumer carpet content. Using this formulation and process conditions, SelecTech can now economically offer a high-quality product to the market and thereby create a reliable outlet for post-consumer vinyl-backed carpet waste.

The concentration of post-consumer carpet content is currently limited by the level of mixing and homogeneity that is achieved by the system. If this can be improved, then the concentration of post-consumer carpet could be increased to both lower costs of the final product and, potentially, improve performance.

9. Appendices

A. Part 1 The effect of carpet content on the size and weight of RepTiles

Tile Batch: RepTile coin black 1B (10% carpet)

Sample #	Right Edge (in)	Middle (in)	Left Edge (in)	Weight (lbs)	Comments
1	23.98	23.97	23.98	5.93	
2	23.98	23.97	23.98	5.91	
3	24.00	24.00	24.00	5.92	
4	24.00	24.00	23.98	5.91	
5	24.00	24.00	23.98	5.93	
6	24.00	23.98	24.00	5.92	
7	24.00	24.02	24.02	5.92	
8	24.00	24.00	23.98	5.93	
9	24.00	23.98	24.00	5.94	
10	24.00	24.00	23.98	5.93	
11	24.00	23.98	24.00	5.91	
12	24.00	23.98	24.00	5.92	
13	24.00	24.00	23.98	5.94	
14	23.98	24.00	23.98	5.94	
15	24.00	24.00	23.98	5.94	
16	24.00	24.00	24.00	5.93	
17	24.00	23.98	23.98	5.91	
18	24.00	24.00	24.02	5.96	
19	24.03	24.02	24.03	5.95	
20	24.02	24.02	24.02	5.91	
Average	**24.00**	**24.00**	**24.00**	**5.93**	
STDEV	**0.01**	**0.01**	**0.01**	**0.01**	

Tile Batch: RepTile coin black 2B (20% carpet)

Sample #	Right Edge (in)	Middle (in)	Left Edge (in)	Weight (lbs)	Comments
1	24.06	24.05	24.05	5.97	
2	24.05	24.02	24.05	5.97	
3	24.03	24.02	24.02	5.96	
4	24.05	24.02	24.05	5.95	
5	24.05	24.02	24.03	5.94	
6	24.03	24.02	24.03	5.95	
7	24.05	24.02	24.03	5.98	
8	24.05	24.03	24.05	5.95	
9	24.06	24.03	24.05	6.00	
10	24.03	24.03	24.05	5.98	
11	24.02	24.03	24.02	5.96	
12	24.05	24.03	24.03	5.97	
13	24.05	24.03	24.05	5.99	
14	24.05	24.02	24.06	6.00	
15	24.05	24.03	24.05	5.99	
16	24.05	24.00	24.03	5.99	
17	24.05	24.03	24.05	5.95	
18	24.05	24.02	24.03	5.95	
19	24.05	24.05	24.05	5.96	
20	24.03	24.02	24.03	5.96	
Average	**24.04**	**24.02**	**24.04**	**5.97**	
STDEV	**0.01**	**0.01**	**0.01**	**0.02**	

Tile Batch: RepTile coin black 3B (30% carpet)

Sample #	Right Edge (in)	Middle (in)	Left Edge (in)	Weight (lbs)	Comments
1	24.09	24.05	24.08	6.05	
2	24.08	24.06	24.08	6.04	
3	24.09	24.05	24.08	6.06	
4	24.08	24.05	24.08	6.03	
5	24.11	24.05	24.08	6.03	
6	24.06	24.06	24.08	6.05	
7	24.08	24.05	24.08	6.05	
8	24.05	24.03	24.05	6.06	
9	24.08	24.03	24.06	6.07	
10	24.06	24.05	24.08	6.07	
11	24.08	24.03	24.08	6.08	
12	24.05	24.05	24.08	6.08	
13	24.08	24.05	24.08	6.12	
14	24.06	24.03	24.08	6.13	
15	24.08	24.06	24.08	6.17	
16	24.08	24.05	24.08	6.15	
17	24.06	24.05	24.09	6.25	
18	24.08	24.06	24.08	6.25	
19	24.09	24.06	24.08	6.18	
20	24.06	24.06	24.06	6.20	
Average	**24.08**	**24.05**	**24.08**	**6.11**	
STDEV	**0.02**	**0.01**	**0.01**	**0.07**	

Tile Batch: RepTile coin black 4B (40% carpet)

Sample #	Right Edge (in)	Middle (in)	Left Edge (in)	Weight (lbs)	Comments
1	24.13	24.06	24.13	6.32	
2	24.11	24.09	24.09	6.32	
3	24.09	24.09	24.11	6.31	
4	24.13	24.09	24.11	6.29	
5	24.13	24.08	24.11	6.30	
6	24.13	24.08	24.11	6.35	
7	24.08	24.06	24.09	6.30	
8	24.08	24.06	24.08	6.25	
9	24.08	24.05	24.06	6.27	
10	24.09	24.06	24.09	6.34	
11	24.08	24.05	24.08	6.34	
12	24.09	24.06	24.09	6.31	
13	24.09	24.06	24.09	6.32	
14	24.08	24.08	24.08	6.29	
15	24.08	24.06	24.09	6.33	
16	24.11	24.06	24.09	6.24	
17	24.09	24.08	24.08	6.28	
18	24.08	24.08	24.09	6.24	
19	24.09	24.08	24.09	6.35	
20	24.09	24.06	24.09	6.32	
Average	**24.10**	**24.07**	**24.09**	**6.30**	
STDEV	**0.02**	**0.01**	**0.01**	**0.03**	

Tile Batch: RepTile coin gray 1G (10% carpet)

Sample #	Right Edge (in)	Middle (in)	Left Edge (in)	Weight (lbs)	Comments
1	24.02	24.02	24.02	6.00	
2	24.02	24.00	24.02	5.99	
3	24.02	24.00	24.03	6.01	
4	24.03	24.03	24.02	6.01	
5	24.03	24.03	24.03	6.00	
6	24.03	24.02	24.03	6.01	
7	24.03	24.02	24.03	6.01	
8	24.02	24.02	24.03	6.00	
9	24.05	24.03	24.03	5.98	
10	24.03	24.03	24.05	6.00	
11	24.05	24.02	24.03	6.00	
12	24.03	24.03	24.05	5.99	
13	24.03	24.03	24.05	6.00	
14	24.03	24.03	24.05	6.00	
15	24.03	24.02	24.03	6.01	
16	24.03	24.02	24.03	5.98	
17	24.03	24.02	24.05	5.98	
18	24.03	24.03	24.03	5.99	
19	24.03	24.03	24.02	5.92	
Average	**24.03**	**24.02**	**24.03**	**5.99**	
STDEV	**0.01**	**0.01**	**0.01**	**0.02**	

Tile Batch: RepTile coin gray 2G (20% carpet)

Sample #	Right Edge (in)	Middle (in)	Left Edge (in)	Weight (lbs)	Comments
1	24.09	24.08	24.08	5.99	
2	24.09	24.08	24.08	6.05	
3	24.08	24.06	24.09	6.06	
4	24.09	24.08	24.09	6.06	
5	24.08	24.06	24.09	6.08	
6	24.09	24.06	24.08	6.08	
7	24.09	24.06	24.09	6.08	
8	24.09	24.08	24.09	6.05	
9	24.08	24.06	24.09	6.05	
10	24.08	24.08	24.08	6.07	
11	24.09	24.08	24.08	6.01	
12	24.09	24.06	24.09	6.04	
13	24.09	24.09	24.09	6.09	
14	24.08	24.05	24.08	6.09	
15	24.08	24.06	24.08	6.07	
16	24.09	24.06	24.09	6.08	
17	24.09	24.06	24.09	6.07	
18	24.09	24.06	24.08	6.06	
19	24.09	24.08	24.08	6.06	
20	24.08	24.08	24.08	6.08	
Average	**24.09**	**24.07**	**24.09**	**6.06**	
STDEV	**0.01**	**0.01**	**0.01**	**0.03**	

Tile Batch: RepTile coin gray 3G (30% carpet)

Sample #	Right Edge (in)	Middle (in)	Left Edge (in)	Weight (lbs)	Comments
1	24.08	24.06	24.09	6.08	
2	24.14	24.11	24.14	6.08	
3	24.11	24.08	24.09	6.09	
4	24.08	24.08	24.08	6.06	
5	24.11	24.08	24.09	6.06	
6	24.09	24.08	24.09	6.06	
7	24.09	24.08	24.09	6.06	
8	24.09	24.08	24.09	6.07	
9	24.11	24.08	24.09	6.04	
10	24.11	24.09	24.11	6.04	
11	24.08	24.06	24.09	6.04	
12	24.11	24.06	24.09	6.04	
13	24.09	24.06	24.08	6.05	
14	24.08	24.06	24.09	6.06	
15	24.09	24.06	24.09	6.06	
16	24.08	24.05	24.08	6.04	
17	24.09	24.06	24.09	6.05	
18	24.08	24.06	24.09	6.04	
19	24.09	24.06	24.09	6.05	
20	24.08	24.06	24.09	6.06	
Average	**24.09**	**24.07**	**24.09**	**6.06**	
STDEV	**0.02**	**0.01**	**0.01**	**0.01**	

Tile Batch: RepTile coin gray 4G (40% carpet)

Sample #	Right Edge (in)	Middle (in)	Left Edge (in)	Weight (lbs)	Comments
1	24.11	24.09	24.13	6.12	
2	24.11	24.09	24.11	6.13	
3	24.09	24.08	24.13	6.09	
4	24.13	24.09	24.14	6.16	
5	24.14	24.13	24.13	6.08	Short
6	24.11	24.08	24.13	6.08	Short
7	24.09	24.09	24.13	6.06	Short
8	24.13	24.09	24.14	6.07	Short
9	24.14	24.09	24.14	6.09	Short
10	24.09	24.09	24.13	6.09	Short
11	24.16	24.13	24.09	6.12	Short
12	24.09	24.09	24.13	6.03	Short
13	24.09	24.09	24.13	6.06	Short
14	24.13	24.09	24.11	6.07	Short
15	24.13	24.09	24.11	6.08	Short
16	24.13	24.09	24.14	6.07	Short
17	24.13	24.09	24.13	6.09	Short
18	24.13	24.11	24.11	6.08	Short
19	24.13	24.11	24.11	6.07	Short
20	24.14	24.11	24.13	6.08	Short
Average	**24.12**	**24.10**	**24.12**	**6.09**	
STDEV	**0.02**	**0.01**	**0.01**	**0.03**	

Tile Batch: RepTile coin yellow 1Y (5% carpet)

Sample #	Right Edge (in)	Middle (in)	Left Edge (in)	Weight (lbs)	Comments
1	24.00	23.97	23.98	5.72	
2	23.98	23.97	23.98	5.75	
3	24.00	23.98	23.97	5.73	
4	23.97	23.97	23.97	5.66	
5	23.98	23.97	23.98	5.66	
6	23.98	23.97	23.98	5.70	
7	23.98	23.97	23.97	5.70	
8	23.97	23.97	23.97	5.66	
9	23.98	23.98	23.97	5.67	
10	23.98	23.97	23.97	5.67	
11	23.98	23.97	23.98	5.68	
12	23.98	24.00	23.98	5.66	
13	24.00	23.98	23.97	5.64	
14	23.98	23.98	23.98	5.68	
15	24.00	23.98	24.00	5.68	
16	24.00	24.00	23.98	5.69	
17	24.00	23.98	24.00	5.68	
18	24.00	24.00	23.98	5.68	
19	24.02	24.00	24.00	5.72	
Average	**23.99**	**23.98**	**23.98**	**5.69**	
STDEV	**0.01**	**0.01**	**0.01**	**0.03**	

Tile Batch: RepTile coin yellow 2Y (7.5% carpet)

Sample #	Right Edge (in)	Middle (in)	Left Edge (in)	Weight (lbs)	Comments
1	23.98	23.97	24.00	5.77	
2	24.00	23.98	23.98	5.76	
3	23.98	23.98	23.97	5.76	
4	24.02	24.00	24.02	5.80	
5	23.98	23.98	23.98	5.74	
6	24.00	23.97	23.98	5.72	
7	23.98	23.98	23.97	5.74	
8	24.02	23.97	23.98	5.74	
9	24.00	24.00	24.00	5.73	
10	23.98	23.98	23.97	5.73	
11	23.98	23.97	23.98	5.73	
12	24.00	23.97	23.97	5.76	
13	23.98	23.98	23.97	5.73	
14	24.00	23.98	24.00	5.71	
15	23.98	23.97	23.98	5.73	
16	24.00	23.98	24.00	5.69	
17	23.98	23.98	23.97	5.67	
18	24.00	23.98	23.98	5.71	
19	24.00	24.00	23.98	5.74	
20	23.98	23.98	23.98	5.74	
Average	**23.99**	**23.98**	**23.98**	**5.74**	
STDEV	**0.01**	**0.01**	**0.01**	**0.03**	

Tile Batch: RepTile coin yellow 3Y (10% carpet)

Sample #	Right Edge (in)	Middle (in)	Left Edge (in)	Weight (lbs)	Comments
1	23.98	24.00	23.97	5.78	
2	24.00	24.00	23.98	5.82	
3	24.02	23.98	23.98	5.82	
4	24.00	23.98	23.97	5.83	
5	23.97	23.97	23.97	5.82	
6	23.98	23.97	23.97	5.81	
7	24.00	23.98	23.98	5.79	
8	24.00	23.98	24.00	5.79	
9	24.03	24.00	24.00	5.77	
10	24.00	23.98	23.97	5.78	
11	24.00	23.97	23.98	5.78	
12	24.00	23.98	24.00	5.80	
13	24.00	24.02	24.02	5.77	
14	24.02	24.00	24.02	5.79	
15	24.00	23.98	23.98	5.79	
16	24.00	23.98	24.00	5.79	
17	24.02	24.00	23.98	5.83	
18	24.03	24.00	24.02	5.81	
19	24.00	24.02	23.98	5.81	
20	23.98	23.98	24.02	5.79	
Average	**24.00**	**23.99**	**23.99**	**5.80**	
STDEV	**0.02**	**0.01**	**0.02**	**0.02**	

B. Part 2 Repeatability of injection molding process test

Tile Batch: RepTile coin gray 2G(20% carpet) One from each of 41 boxes

Sample #	Right Edge (in)	Middle (in)	Left Edge (in)	Weight (lbs)	Comments
1	24.11	24.11	24.13	6.13	
2	24.11	24.09	24.09	6.17	
3	24.09	24.08	24.09	6.16	
4	24.09	24.09	24.09	6.17	
5	24.11	24.09	24.11	6.18	
6	24.11	24.09	24.09	6.17	
7	24.08	24.09	24.09	6.19	
8	24.11	24.09	24.09	6.20	
9	24.09	24.08	24.09	6.17	
10	24.09	24.08	24.09	6.21	
11	24.09	24.09	24.09	6.09	
12	24.09	24.08	24.09	6.08	
13	24.11	24.09	24.09	6.11	
14	24.08	24.11	24.09	6.09	
15	24.09	24.09	24.08	6.09	
16	24.08	24.08	24.09	6.04	
17	24.09	24.08	24.08	6.08	
18	24.09	24.08	24.08	6.10	
19	24.09	24.09	24.08	6.09	
20	24.11	24.08	24.11	6.07	
21	24.09	24.06	24.08	6.06	
22	24.08	24.06	24.09	6.07	
23	24.11	24.11	24.11	6.06	
24	24.09	24.09	24.09	6.05	
25	24.08	24.06	24.06	6.04	
26	24.08	24.08	24.08	6.07	
27	24.09	24.08	24.09	6.05	
28	24.09	24.09	24.08	6.07	
29	24.09	24.08	24.08	6.09	
30	24.09	24.08	24.08	6.05	
31	24.09	24.09	24.09	6.06	
32	24.11	24.09	24.11	6.09	
33	24.11	24.08	24.11	6.09	
34	24.09	24.08	24.09	6.08	
35	24.09	24.08	24.09	6.06	
36	24.09	24.08	24.08	6.10	
37	24.08	24.08	24.08	6.10	
38	24.08	24.06	24.09	6.05	
39	24.09	24.08	24.09	6.05	
40	24.09	24.08	24.08	6.04	
41	24.08	24.06	24.06	6.01	
Average	**24.09**	**24.08**	**24.09**	**6.10**	
STDEV	**0.01**	**0.01**	**0.01**	**0.05**	

C. Part 3 Weathering test

Tile Batch: RepTile coin gray 3G (30% carpet) (before the weathering)

Sample #	Right Edge (in)	Middle (in)	Left Edge (in)	Weight (lbs)	Comments
1	24.08	24.06	24.09	6.08	
2	24.14	24.11	24.14	6.08	
3	24.11	24.08	24.09	6.09	
4	24.08	24.08	24.08	6.06	
5	24.11	24.08	24.09	6.06	
6	24.09	24.08	24.09	6.06	
7	24.09	24.08	24.09	6.06	
8	24.09	24.08	24.09	6.07	
9	24.11	24.08	24.09	6.04	
10	24.11	24.09	24.11	6.04	
11	24.08	24.06	24.09	6.04	
12	24.11	24.06	24.09	6.04	
13	24.09	24.06	24.08	6.05	
14	24.08	24.06	24.09	6.06	
15	24.09	24.06	24.09	6.06	
16	24.08	24.05	24.08	6.04	
17	24.09	24.06	24.09	6.05	
18	24.08	24.06	24.09	6.04	
19	24.09	24.06	24.09	6.05	
20	24.08	24.06	24.09	6.06	
Average	**24.09**	**24.07**	**24.09**	**6.06**	
STDEV	**0.02**	**0.01**	**0.01**	**0.01**	

Tile Batch: RepTile coin gray 3G (30% carpet) (after the weathering for two months)

Sample #	Right edge (in)	Middle (in)	Left edge (in)	Weight (lbs)	Comments
1	24.06	24.06	24.09	6.09	
2	24.13	24.06	24.08	6.12	
3	24.09	24.06	24.11	6.10	
4	24.09	24.06	24.11	6.13	
5	24.09	24.06	24.08	6.16	
6	24.09	24.08	24.08	6.14	
7	24.06	24.05	24.06	6.18	
8	24.09	24.05	24.08	6.11	
9	24.08	24.05	24.11	6.11	
10	24.13	24.08	24.09	6.13	
Average	**24.09**	**24.06**	**24.09**	**6.13**	
STDEV	**0.02**	**0.01**	**0.02**	**0.03**	