Industrial Resilient Floor Tiles From Post-Consumer Carpet Waste

Material and Product Testing to Aid in the Development Of an Industrial Resilient Floor Tile Made from Post-Consumer Carpet Waste

FINAL REPORT

Prepared for:

CWC
A division of the Pacific NorthWest Economic Region (PNWER)
2200 Alaskan Way, Suite 460
Seattle, WA 98121

May 2000

Prepared by:

Thomas Ricciardelli
Ming Lu

SelecTech, Inc.
15 Fourth Street
Taunton, MA 02780

This recycled paper is recyclable

Copyright © 2000 CWC. All rights reserved. Federal copyright laws prohibit reproduction, in whole or in part, in any printed, mechanical, electronic, film or other distribution and storage media, without the written consent of the CWC. To write or call for permission: CWC, 2200 Alaskan Way, Suite 460, Seattle, Washington 98121, (206) 443-7746.

Disclaimer
CWC disclaims all warranties to this report, including mechanics, data contained within and all other aspects, whether expressed or implied, without limitation on warranties of merchantability, fitness for a particular purpose, functionality, data integrity, or accuracy of results. This report was designed for a wide range of commercial, industrial and institutional facilities and a range of complexity and levels of data input. Carefully review the results of this report prior to using them as the basis for decisions or investments.

REPORT NO. IBP-00-1

ACKNOWLEDGEMENTS

CWC is a nonprofit organization providing recycling market development services to both businesses and governments, including tools and technologies to help manufacturers use recycled materials. CWC is an affiliate of the national Manufacturing Extension Partnership (MEP) – a program of the US Commerce Department's National Institute of Standards and Technology. The MEP is a growing nationwide network of extension services to help smaller US manufacturers improve their performance and become more competitive. CWC also acknowledges support from the US Environmental Protection Agency and other organizations.

This project, performed by SelecTech Inc., was partially funded by:

- CWC's Recycling Technology Assistance Partnership (ReTAP), through a grant from the U.S. Environmental Protection Agency, with supporting funds from the National Institute of Standards and Technology Manufacturing Extension Partnership (NIST MEP).
- Chelsea Center for Recycling and Economic Development
- Massachussetts Department of Environmental Protection's Recycling Investment Research Credit (RIRC), which funded part of the equipment purchase.

EXECUTIVE SUMMARY

RepTile™, manufactured by SelecTech Inc., is a resilient floor tile made from a blend of PVC and mixed post-consumer carpet waste. During early production of this product, problems arose with respect to processing efficiency, and distortion (or peaking) of the tiles at the four mating corners. This project was designed (1) to modify the existing production process in order to improve efficiency and reduce cost; and (2) to determine the cause of peaking distortion, and to modify the process and/or the material formulation to overcome the problem.

Phase 1 of the project focused on designing and installing a custom extruder system capable of feeding and homogenizing a mixture of post-consumer carpet, post-industrial PVC, and proprietary additives, to produce a suitable feedstock for use in finished tiles. The production process was modified to incorporate the revised feedstock material.

Phase 2 of the project focused on testing to determine the impact of feedstock formulation and production process with respect to final product quality. Tests included (1) the effect of recycled post-consumer carpet concentration on the length and weight of the tiles; (2) measurements of length and weight from a sample production run to determine the repeatability of the modified injection molding process; (3) measurement of tile length and weight before and after weathering exposure to heat and humidity for a two month period; and (4) an observation test to determine the relationship between peaking and blending efficiency (i.e. recycled carpet content particle size and distribution).

Phase 1 resulted in the design and installation of a customized extruder system that successfully combined three existing process steps (Molding Into Prep Tile, Granulating Prep Tile, and Dry Blending) into one revised process step (Extrusion into Nuggets). The nuggets are then used as a pellet feedstock for the tile injection molding process.

Phase 2 testing results indicated that the revised processing and production system could repeatably produce injection-molded tiles that show no evidence of peaking at recycled

© CWC 2000

carpet concentrations as high as 20%. Weathering observations on a 30% recycled carpet concentration batch indicated a trend for the length and weight of the tiles to increase slightly, however, the data was insufficient to draw conclusions with respect to the potential relationship of the increases with respect to peaking. In an observation test of the relationship between peaking and blending efficiency, it was noted that tiles made with a concentration of 40% post-consumer carpet content did not exhibit peaking in response to weathering if the material passed through the blending/extrusion process more than once. Note that all tiles made at 40% concentration (with a single pass through the blending/extrusion process) had demonstrated peaking in previous tests. This indicates that it is possible to maintain product quality (i.e., resistance to peaking) at post-consumer recycled content concentrations above 20% if the grinding/blending process can be sufficiently improved.

© CWC 2000

1.0 BACKGROUND

The market for resilient flooring is approximately 1.5 billion square feet per year. Resilient flooring is typically sold to commercial facilities such as factories, warehouses, hotels, hospitals, schools, municipalities, and office buildings. The market is currently dominated by products manufactured from virgin materials.

Some recyclers, such as DuPont Flooring Systems, have the infrastructure to both collect used carpeting from remodeling and demolition projects, and to recycle most of what is collected. However, in many areas of the country, used carpeting still goes into landfills.

The many different types of resins and materials used in carpeting and carpet backing make this recovered material stream very non-homogenous, and thus difficult to recycle without costly separation. One type of carpet in particular, vinyl-backed carpet tile, is a problem stream for recycling. Vinyl-backed carpet tile consists of a vinyl backing, a fiberglass reinforcing sheet, and nylon or polyester face fiber. These tiles are too costly to separate for recycling, and when ground in an attempt to use as a typical re-grind feedstock, the fibers clog conventional plastics manufacturing machinery and can cause equipment damage.

SelecTech has developed a patent-pending method for producing an industrial-grade resilient floor tile, by re-using mixed carpet waste, including vinyl-backed carpet, in a process that retains the fiberglass, nylon, and polyester intact as fibers to reinforce the finished product. The resilient floor tile, known as RepTile™, is manufactured from a commingled mixture of shredded vinyl-backed carpet tiles, post-industrial PVC, and proprietary additives. The blend combines the flexibility of PVC with the strength of glass, nylon, and polyester fibers.

Each RepTile weighs 6.25 lbs and covers an area of approximately 4 square feet (1.6 pounds per square foot). The potential market for this material, in pounds, is therefore 2.4 billion pounds per year. It is clear that even a small percentage of market share represents the potential for a substantial diversion of carpet waste from landfills.

© CWC 2000

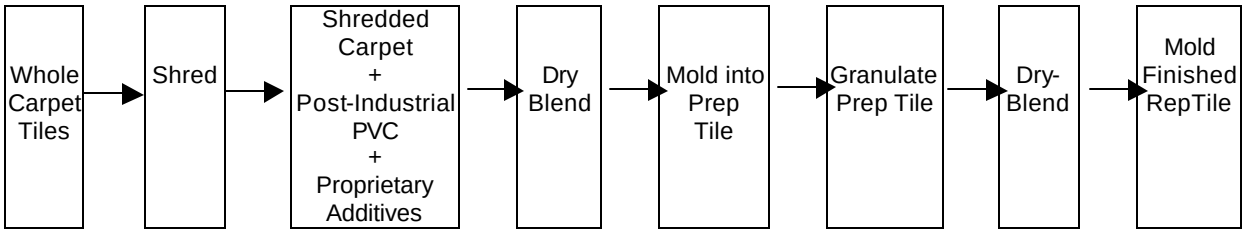
The ability to compete in the resilient flooring market is based on quality and price. Testing has shown the RepTile to be comparable or superior in quality to competing resilient floor tiles made with virgin materials. At present, the critical stage of development in the product depends upon increasing efficiency and reducing production costs, while maximizing recycled content.

1.1 ORIGINAL PROCESS DESCRIPTION

SelecTech's original process equipment was specifically designed to handle the fiberglass, nylon, and polyester fibers and utilize their beneficial properties in a value-added final product. The tiles are molded in an innovative injection molding technology that is ideally suited for processing commingled waste plastics.

The original process is shown in Figure 1. Whole carpet tiles were shredded, then mixed with post-industrial PVC and proprietary additives. The clumpy mixture was then dry-blended and hand-fed into the injection molding machine to be molded into a preparatory (or intermediate) tile. The preparatory tile was granulated, and then dry-blended. The blended mixture was then fed into the injection molding unit, where the blend was melted and then injected under high pressure into a mold that forms the RepTile. The tile was then cured by cooling.

Figure 1: Original Process Flowchart

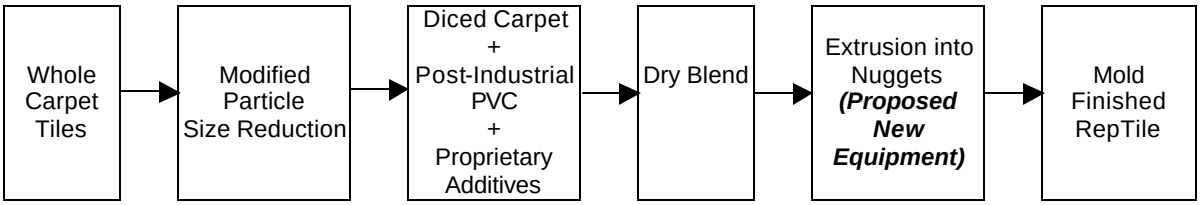


1.2 REVISED PROCESS DESCRIPTION

Phase 1 resulted in the design and installation of a customized extruder system that successfully combined three existing process steps (Molding Into Prep Tile, Granulating

Prep Tile, and Dry Blending) into one revised process step (Extrusion into Nuggets), thus eliminating the inefficiencies of the old process.

Figure 2: Revised Process Flowchart



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 and granulated in a modified, low-speed granulator that reduces the carpet into a more uniform size that is easier to handle and mix. The blended material is then fed into an extruder that further homogenizes the blended material and forms the mixture into relatively uniform nuggets. These nuggets can then be automatically fed into the injection molding machine to create the finished RepTile.

2.0 PHASE I: SYSTEM REDESIGN

The goal of the Phase 1 of this project was to develop an extruder system that could homogenize the carpet/PVC mixture sufficiently for the desired product. The critical requirements for the system were:

- the ability to feed a non-uniform, fluffy feedstock; and
- the ability to break-up and disperse carpet clumps in the mixture.

The final system is shown in Figure 3-1. As shown, this system consists of the following components:

- Feed Hopper Bin
- 6" Screw Feed Conveyor
- 4 ½ Cram Feeder

© CWC 2000

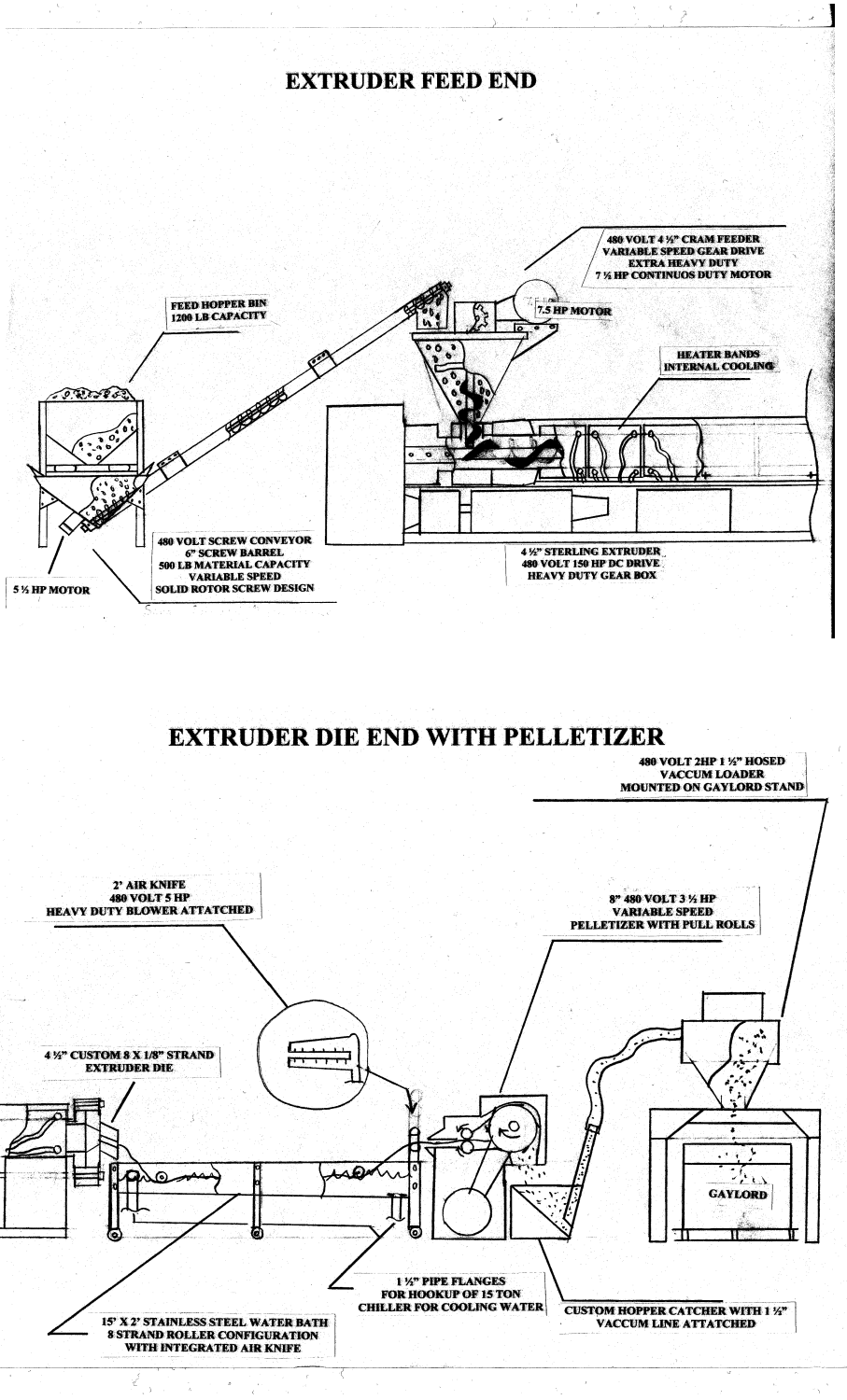
- 4 ½ Extruder
- 4 ½ Custom Extruder Die
- Stainless Steel Water Bath with Air Knife
- 8” Pelletizer with Pull Rollers
- Custom Hopper Catcher
- Vacuum Loader Mounted on Gaylord Stand

Because the waste carpeting/PVC blend is unconventional, many of these components are not standard auxiliaries used for conventional plastic compounding. This system has been specifically designed to handle the hard-to-convey mixture of PVC and carpeting, and individual components were modified to ensure that the material feeds positively into the extruder. The die on the end of the extruder and the cutting system was designed to ensure maximum throughput of this particular feedstock.

© CWC 2000

Figure 3-1

Extruder System Design



© CWC 2000

3.0 PHASE 2: PRODUCT TESTING

Phase 2 of the project focused on testing to determine the impact of feedstock formulation and production process with respect to final product quality.

3.1 Approach

Typically, RepTile has a size of 24L × 24W × 0.22T inches and a weight of six pounds. In this project, size and weight of RepTile were chosen as the 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 testing was divided into four parts as follows:

- Part 1 – Effect of recycled carpet concentration on the length and weight of the tile.
- Part 2 – Repeatability of the injection molding process.
- Part 3 – Effect of weathering on length, weight, and shape of the tile.
- Part 4 – Effect of blending efficiency on tile distortion or peaking.

3.2 Part 1 – Effect of recycled carpet concentration on the tile length and weight

In Part 1, the effect of recycled carpet concentration on the weight and length of a tile was investigated. For black and gray RepTiles, the carpet regrind was composed of irregularly shaped particles with projected areas of from 0.25 to 5 square inches. This chopped vinyl-backed carpet material was collected by DuPont Flooring Systems in whole form and then shipped to Conigliaro Industries in Framingham, MA where it was chopped using a special, low-speed granulator to produce the particles as described above. For colored (yellow in this test) RepTiles, powdered carpet backing was used as

© CWC 2000

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 showed below.

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

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

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

Fifty tiles were made in each trial and 20 tiles were randomly chosen from the fifty to represent the trial. After measuring the sizes and weights of the twenty tiles, 12 tiles were interlocked with each other to form a 3× 4 unit and placed outdoors to test for weathering.

Past problems with distortion or peaking at customer locations were known to be exacerbated with rises in temperature and humidity. When interlocked tiles distort due to material inconsistencies, they bump up at the corner where the four tiles come together. This "bump" resembles a little peak. The primary reason for placing the 3 x 4 unit outdoors was to to evaluate the distortion or peaking under high heat and humidity.

© CWC 2000

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. During the trials, actual weather conditions were not recorded. The weather varied over the time period, from warm and rainy to extremely hot and humid, thus exposing the tiles to a wide variation in temperature and humidity.

3.3 Part 2 – Repeatablity of the injection molding process

In Part 2, the repeatability of the injection molding process was investigated. A test 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 lengths and weights of these tiles were measured.

3.4 Part 3 – Effect of weathering on length, weight, and shape of the tile.

In Part 3, the effect of weathering on the weight and length of the tiles was investigated. It is known that increases in heat and humidity increase the likelihood that the tiles will distort or "peak" after installation. To determine if exposure to heat and humidity actually caused changes in the weight and length of the tiles, tiles were exposed for two months of direct sunlight on a black surface (roof of the Selectech facility). In this environment, tile surface temperatures were measured to be as high 150 °F. During the trials, actual weather conditions were not recorded. The weather varied over the time period, from warm and rainy to extremely hot and humid, thus exposing the tiles to a wide variation in temperature and humidity.

Ten 30% carpet-filled, gray tiles were then selected at random, from the exposed batch and measured for size and weight.

3.5 Part 4 – Effect of blending efficiency on tile peaking.

In Part 4, tiles were manufactured using materials that had been processed through the extruder (homogenized) from 0 to 4 times to observe the "peaking" behavior of the tiles in a field environment as a function of the degree of compounding or blending.

4.0 RESULTS

4.1 Part 1 Results – Effect of recycled carpet concentration on the length and weight of the tile

In Part 1, the effect of recycled carpet content on the length and weight of RepTile was investigated. Data are provided in the Appendices, and summarized in Table 1 below.

Increasing recycled carpet content led to an increase in both the length and weight of the tiles. When the carpet content increased from 10% to 40%, the tile length increased approximately 0.07 to 0.1 inches, and the weight increased approximately 0.1 to 0.3 pounds. More significantly, variations in the sizes and weights (as measured by standard deviation), from tile to tile, also increased. This indicates that the higher carpet content contributes to reduced homogeneity of the final product. Finally, it should be noted that 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. As carpet content increased, melt viscosity increased accordingly, making it more difficult to push the blend into the cavities of the mold under the same processing conditions.

© CWC 2000

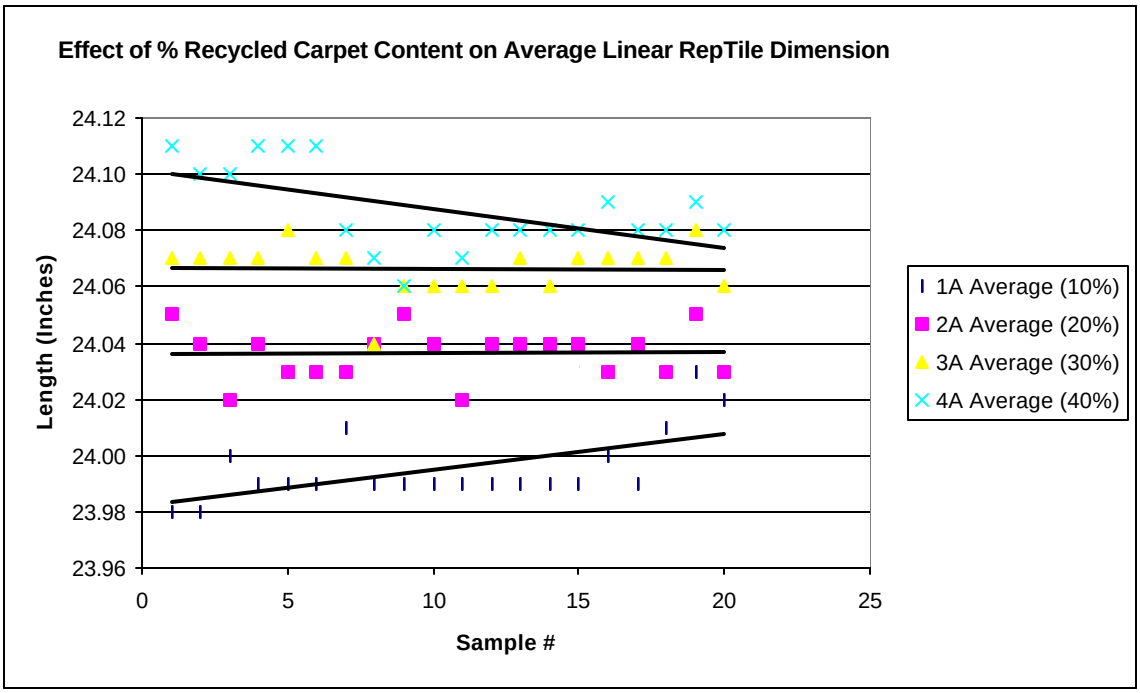
TABLE 1 - Effect of recycled carpet concentration on the length and weight of the tile

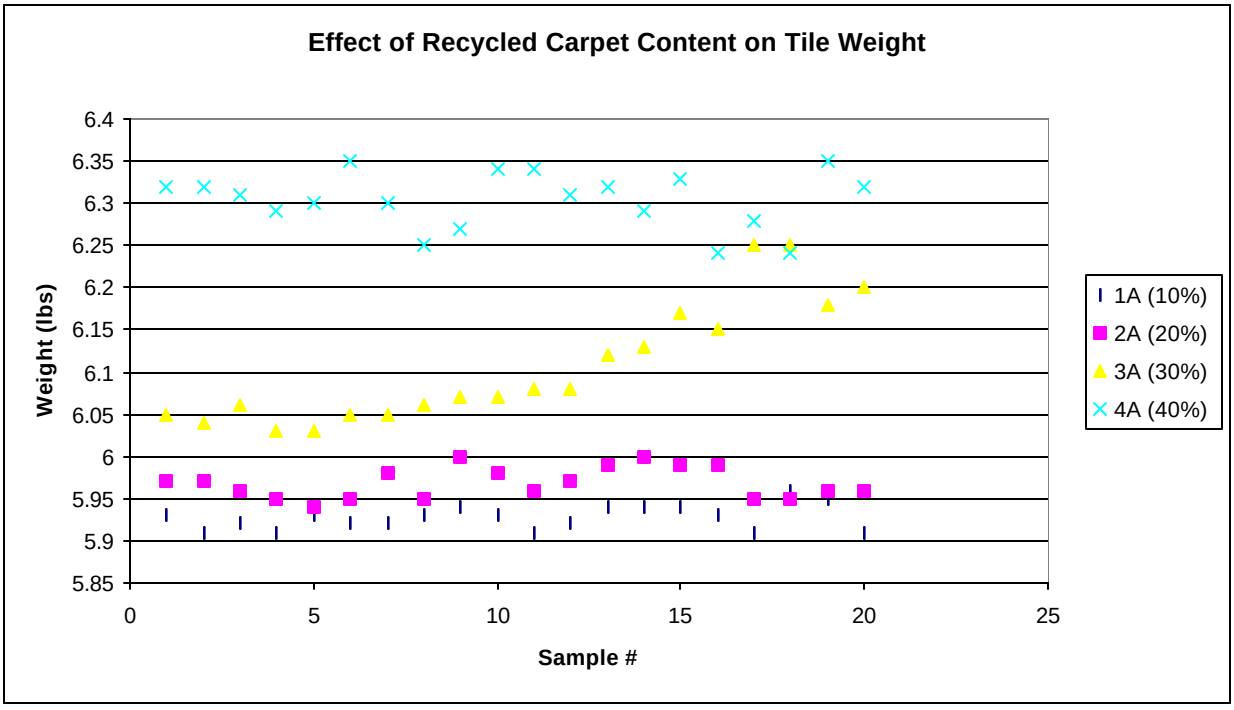
Color	Carpet content (%)	Right Edge (in)	*Middle* (in)	Left Edge (in)	Weight (lbs)
Black	10	24.00 (0.01)	24.00 (0.01)	24.00 (0.01)	5.93 (0.01)
	20	24.04 (0.01)	24.02 (0.01)	24.04 (0.01)	5.97 (0.02)
	30	24.08 (0.02)	24.05 (0.01)	24.08 (0.01)	6.11 (0.07)
	40	24.10 (0.02)	24.07 (0.01)	24.09 (0.01)	6.30 (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 two charts that follow provide a graphic representation of the trends observed with respect to the effect of the percentage of recycled carpet content on the average tile dimensions and weight. It is clear that the length and weight of the tiles increased as the percentage of recycled carpet content increased, and these increases in length and weight were relatively consistent throughout the sample.

© CWC 2000





When tiles were placed outdoors in the direct sun on a black surface, the 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 showed peaking on the 3×4 tiles mat (6 joints). The height of peaking joints was a quarter of inch to half an inch above the flat surface. When carpet content decreased to 30%, the amount and height of peaking joints decreased accordingly. When carpet content decreased to 20%, 10%, 7.5%, and 5%, no peaking was observed. This indicates that carpet content affects the tile quality with respect to the peaking problem. It was generally observed that when carpet content is below 20% tiles perform well; and above 30%, tiles show distortion.

Finally, tiles were sliced to determine if there was any visual difference within the tiles. When tiles were cut, the cross-sections revealed agglomerates of post-consumer carpet within the tile. Tiles made from increased carpet concentrations showed increases in the presence of these agglomerates. Because the thermal expansion rates of these agglomerates and the surrounding PVC resins are different, when the temperature increases, stresses are generated within the tile that result in peaking.

4.2 Part 2 Results – Repeatability of Injection Molding Process

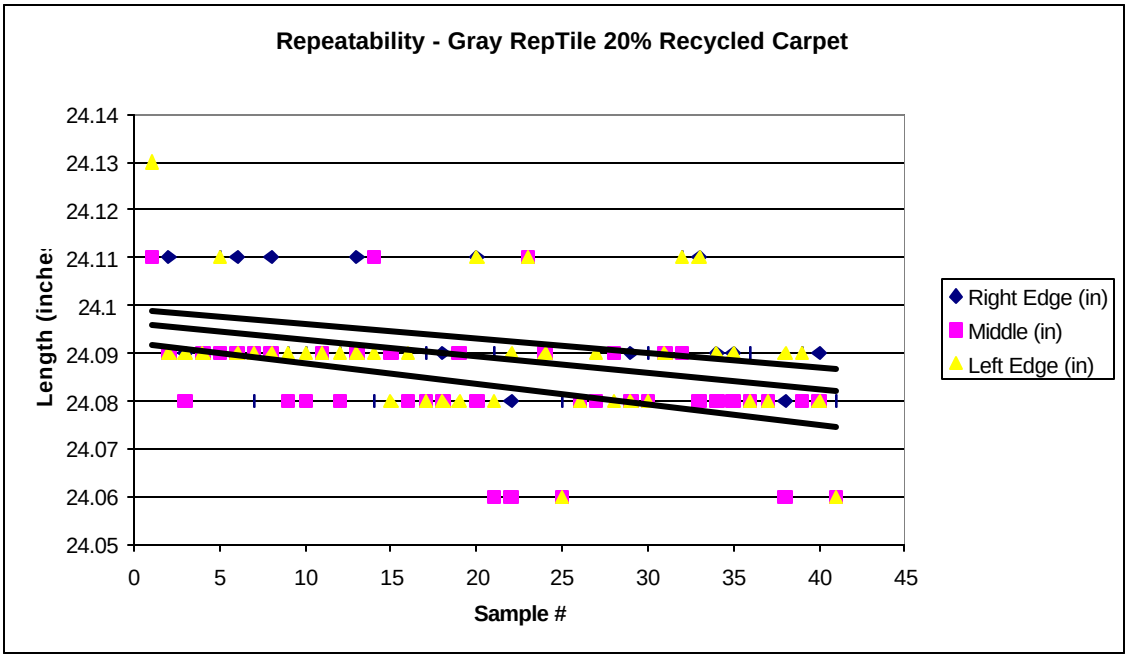
In Part 2, the repeatability of the injection molding process was investigated. The length and weight of 41 randomly chosen tiles, from a 500 tile production run with a 20% recycled carpet concentration, is provided in the Appendices. Table 2 provides a summary of this data.

Table 2 – Repeatability of Injection Molding

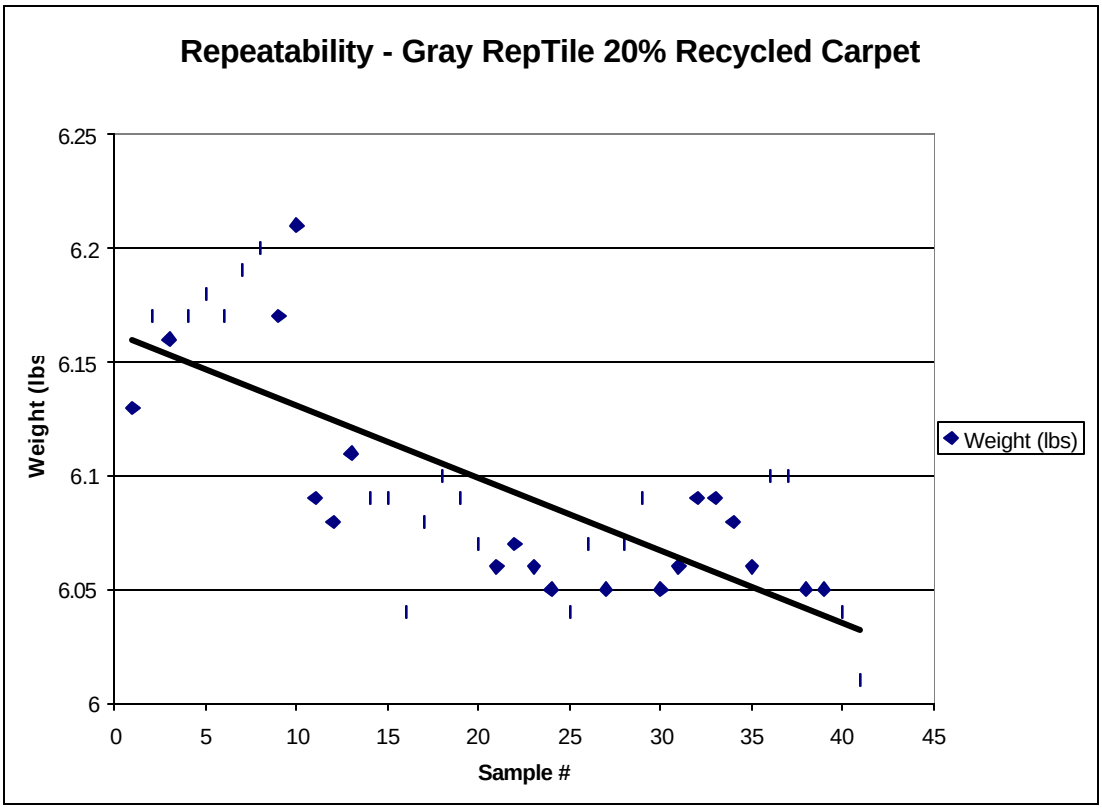
	Size (in)			Weight (lbs)
	Right edge	Middle	Left edge	
Maximum Value	24.11	24.11	24.13	6.21
Minimum Value	24.08	24.06	24.06	6.01
Average Value	24.09	24.08	24.09	6.10
Standard Derivation	0.01	0.01	0.01	0.05

© CWC 2000

The length variation was found to be approximately 0.07 inches with a standard deviation of 0.01. The weight variation was found to be approximately 0.20 pounds with a standard deviation of 0.05. Referring to the scatter plots of length and weight, with linear trend lines shown below, it can be seen that the injection molding process to make RepTiles is repeatable within acceptable production limits.



© CWC 2000



4.3 Part 3 Results – Effect of weathering on length, weight, and shape of the tile.

Part 3 consisted of a weathering test to observe distortion, and measure changes in the tile's length and weight due to exposure to heat and humidity. The size and weight of 10 tiles before and after two months exposure outdoors are provided in the Appendices. Table 3 below summarizes the weathering data.

Table 3 – Effect of Weathering on Length and Weight

	Size (in)						Weight (lbs)	
	Right edge		Middle		Left edge			
	Before	After	Before	After	Before	After	Before	After
Maxim 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

© CWC 2000

It was found that the weight of the tile increased only slightly 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. Weight measurements were not done after cleaning the tiles, or after drying the tiles, and thus it cannot be concluded whether dirt or absorbed moisture contributed more to weight gain. With regard to size, average tile length did not change significantly due to the weathering. Even in the tiles that distorted visibly at corners, overall dimensions did not change substantially.

It was also noticed that the amount and height of peaking joints were greater on a hot day than that on a cool day, indicating that the peaking is a result of non-uniform expansion of the non-homogeneous tile components due to temperature changes.

4.4 Part 4 Results – Effect of blending efficiency on tile peaking.

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. 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. Tiles 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 indicates that the level of compounding (i.e., 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 blended.

© CWC 2000

5.0 CONCLUSIONS

The following conclusions resulted from this project:

- The occurrence of distortion or "peaking" in the field applications of finished RepTiles is directly related to the degree of blending, or homogeneity, of the recycled carpet concentration in the tiles. The higher the concentration, the more likely the presence of agglomerates that will cause the tiles to distort when subjected to temperature changes.
- Increasing the recycled carpet concentration leads to a corresponding increase in the weight of the finished tile.
- Increasing the carpet content, without thorough blending, reduces the processability of the material. When carpet content is increased beyond 30% using standard in-process blending, the material does not consistently fill the mold resulting in reject product.
- The injection molding process for the tile production is repeatable within typical manufacturing limits. The peaking was not caused by size variations inherent in the molding process.
- The peaking is related to variations in thermal expansion of the feedstock materials. Peaking is exacerbated when insufficient blending results in the presence of agglomerates.
- Increased compounding efficiency increases the homogeneity of the final product and allows for higher post-consumer carpet content without end-product distortion.

This project resulted in the design and implementation of a revised system that is capable of economically producing consistent field-quality tiles using up to 20% 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 further improved, then the concentration of post-consumer carpet could be increased to both lower costs of the final product and, potentially, improve performance.

© CWC 2000

APPENDIX A

PART 1: The effect of carpet content on the size and weight of Rep Tiles

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

Tile Batch: Reptile coin black 1A (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**	**23.99**	**5.93**	
STDEV	**0.01**	**0.02**	**0.02**	**0.01**	

Tile Batch: Reptile coin black 2A (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	**24.05**	**24.03**	**24.04**	**5.97**	
STDEV	**0.01**	**0.01**	**0.01**	**0.02**	

Tile Batch: Reptile coin black 3A (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 4A (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**	**0.02**	**0.03**	

Tile Batch: Reptile coin gray 1B (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	
20	24.02	24.02	24.03	6.00	
Average	**24.03**	**24.02**	**24.03**	**5.99**	
STDEV	0.008	0.009	0.011	0.020	

Tile Batch: Reptile coin gray 2B (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	**0.00**	**0.01**	**0.01**	**0.03**	

Tile Batch: Reptile coin gray 3B (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 4B (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**	**24.13**	**6.09**	
STDEV	**0.02**	**0.01**	**0.01**	**0.03**	

Tile Batch: Reptile coin yellow test 1 (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	
20	23.98	23.98	23.98	5.67	
Average	**23.99**	**23.98**	**23.98**	**5.69**	
STDEV	0.013	0.011	0.01	0.028	

Tile Batch: Reptile coin yellow test 2 (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 test 3 (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**	**0.02**	**0.02**	**0.02**	

APPENDIX B

Part 2: Repeatability of Injection Molding Process Test

B. Part 2 Repeatability of Injection Molding Process Test

Tile Batch: Reptile coin gray (20% carpet) One from each 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**	

B. Part 3 Weathering Test

Tile Batch: Reptile coin gray 3B (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 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**	