BioBased Tile® --
A Non-PVC Flooring Made with Rapidly Renewable Resources

December 30, 2011

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Recent Milestone

In January 2008, BioBased Tile was launched with great customer acceptance, at a million square feet in sales that year. In 2009, sales of BioBased Tile quadrupled over the previous year, with sales increasing substantially each subsequent year. Armstrong will be offering its second BioBased Tile product in January 2012 with enhanced features for customer acceptance, including formats designed for schools.

Eligibility Statement

This nomination is neither eligible for the award in the academic category, nor the small business category.

Focus Area Statement

The primary focus area of the nominated technology is the design of greener chemicals.
The secondary focus area of the nominated technology is the use of greener synthetic pathways.

Statement of Activities in the United States

All research, development, scale-up and commercial production of BioBased Tile flooring has taken place in the United States.

Abstract

Historically, resilient flooring has been manufactured using binders derived from fossil-based sources. The primary binder used in resilient flooring is polyvinyl chloride (PVC). The binder combines a matrix of plasticizers, processing aids, stabilizers, limestone and pigments. In 2008, Armstrong commercialized BioBased Tile, a revolutionary new flooring product that uses natural limestone and a proprietary binder made from rapidly renewable materials. BioBased Tile was developed specifically to provide a PVC- and phthalate-free alternative to vinyl composition tile (VCT) for the K-12 education market. The development of Armstrong's polyester binder marks a significant achievement, as it is the first biobased binder developed for hard surface flooring products in over 100 years. The new polyester binder helped create a new category of floor tile, which couples indoor air quality and environmental benefits with improved performance. The polymer binder contains ingredients from rapidly renewable, domestic corn, resulting in reduced reliance on fossil fuels, and a lower carbon footprint. It was built on previous Presidential Green Chemistry Award winning technologies of renewable chemicals, *i.e.* polylactic acid and biobased 1,3-propanediol, to replace phthalate-plasticized PVC. Development of the polyester binder and BioBased Tile flooring followed important principles of green chemistry, life cycle assessment, and Design for the Environment. The consumer product also contains 10-percent pre-consumer recycled limestone. Replacing VCT with BioBased Tile flooring could annually avoid the use of 140 million pounds of virgin limestone, eliminate 336,000 pounds of volatile organic compounds (VOCs) from manufacturing, reduce energy consumption equivalent to 475 billion BTUs (or 56 million pounds CO_2), plus capture 44 million pounds CO_2 from the atmosphere in biobased components. BioBased Tile flooring is certified by Floor Score, with no detectable levels of VOCs, including no materials listed in the table of Chronic Reference Exposure Levels (CRELs), established by the California Office of Environmental Health Hazard Assessment (OEHHA). For green building initiatives, BioBased Tile contributes up to four points toward LEED certification and will be NSF 332 certified in January 2012.

Goal: Develop and commercialize a vinyl composition tile (VCT) alternative without using PVC or phthalate plasticizers, and meets customers' needs for cost and performance, while providing environmental and health benefits.

Analysis of current resilient flooring technology:

1. VCT is the largest category of resilient flooring sold today. Low cost and ease of maintenance has propelled VCT to become a billion square foot market, and the primary choice for flooring in the K-12 education environment. This product provides excellent impact resistance, chemical resistance and ability to withstand deflection.[1]
2. Until now, there were only two resilient hard surface flooring products derived from renewable resources: linoleum and natural rubber flooring. Unfortunately with these alternatives, the costs to the manufacturer and to the end-user are higher than other conventional flooring options due to long production cycles and low production volumes, contributing to limited consumer acceptance of green flooring.
3. Many alternate materials have been proposed to replace PVC in resilient floor products, including polyolefins,[2] polyacrylates & polymethacrylates,[3] ethylene vinyl acetate,[4] and ionomers.[5] Among these binder systems, only polyolefins have been successfully commercialized, but their manufacture still relies entirely on fossil sources.

Solution: Armstrong's BioBased Tile resilient flooring provides enhanced environmental and health benefits, improved performance, a classic look and affordability to replace phthalate-plasticized PVC in resilient commercial flooring.

Brief Technology Description: BioBased Tile flooring is Armstrong's revolutionary new product made with rapidly renewable resources and recycled content. It is the first consumer product that is built on previous Presidential Green Chemistry Award winning technologies of renewable chemicals, *i.e.* polylactic acid and 1,3-propanediol, to replace phthalate-plasticized PVC for flooring applications. To facilitate customer acceptance, especially in school environments, BioBased Tile was designed to perform at least as well as traditional VCT. While the relative amounts of filler, binder and pigments are nearly identical in VCT and BioBased Tile flooring (Figure 1), BioBased Tile avoids the use of PVC, as well as the additives required to make a high-performing PVC floor, including heavy-metal stabilizers and phthalate plasticizers. The binder component of BioBased Tile flooring consists solely of our proprietary biobased polyester.[6]

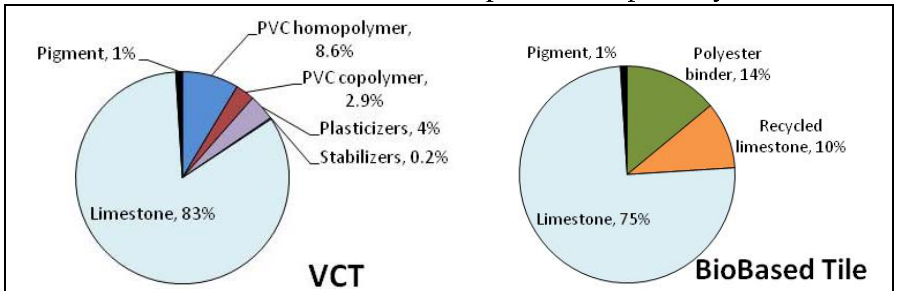

Figure 1. Relative composition of VCT and BioBased Tile flooring components.

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[1] ASTM Standard F 1066, 2004, "Standard Specification for Vinyl Composition Tile," ASTM International, West Conshohocken, PA, www.astm.org.

[2] (a) US Patent 6224804. (b) US Patent 6287706. (c) US Patent 5700865. (d) US Patent 5824727.

[3] (a) US Patent 7175904. (b) US Patent 5391612.

[4] (a) US Patent 5407617. (b) US Patent 4614556. (c) European Patent Application 0721829.

[5] US Patent 4083824.

[6] (a) US Patent Application 20080081158. (b) US Patent Application 20080081875. (c) US Patent Application 20080081882. (d) US Patent Application 20080081898. (e) US Patent Application 20080227951.

1. Science and Innovation

The identification of a biobased resin was required to produce a biobased floor product identical to VCT. Armstrong underwent an exhaustive development project, applying Design of Experiments in the synthesis, formulation, compounding and testing of binder systems synthesized from renewable sources. In addition to including renewable materials in the design of our new resilient flooring, Armstrong also required the inclusion of recycled materials and an affordable finished product. To eliminate the potential environmental and financial impact of building a new manufacturing facility, Armstrong stipulated using existing facilities and processes. Finally, the new product needed to perform at least as well as VCT to meet our customers' expectations.

The Armstrong research team reviewed all available biobased and renewable polymers as potential binders for this product (Figure 2). We also reached out to leading universities, in an effort to identify new biobased resins that would suit our application.[7] Some of these biobased options provide attractive alternatives in other existing products, but our extensive experimental work indicated that these materials' properties were not appropriate to replace PVC & phthalates as a binder for VCT flooring. Looking one step back in the supply chain, we developed our own flooring binder, using available monomers from renewable sources.[8]

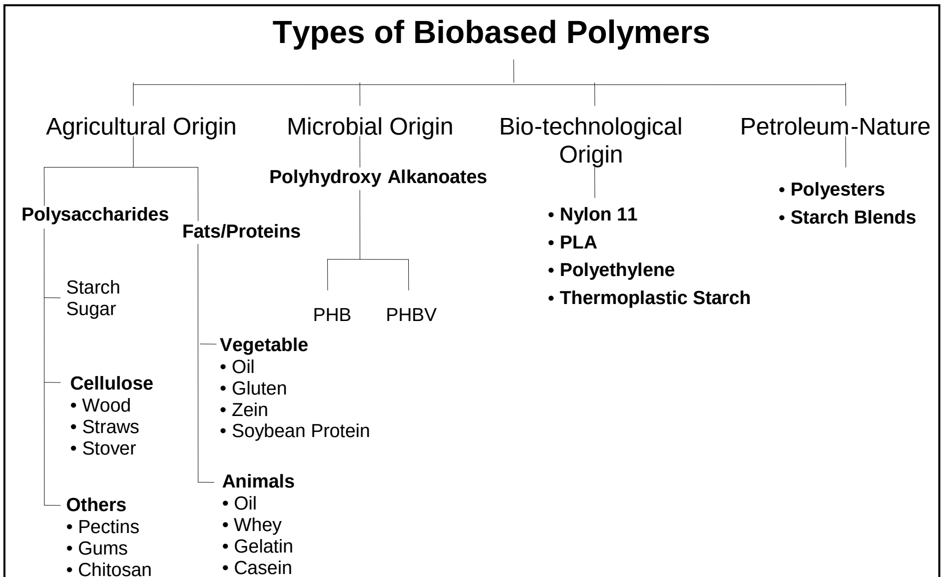

Figure 2. All biobased polymers available at the start of the BioBased Tile product development.

Although the available selection of renewable monomers and polymers continues to grow, the Armstrong technical team recognized that some fossil fuel-based raw materials would be needed initially to achieve a product with the required performance attributes. Future generations of the binder material will contain increased biobased content as additional feedstocks become available.

The Principles of Green Chemistry[9] were carefully considered during the binder development. The Armstrong technical team specifically selected a polyester because its synthesis has a high degree of atom economy (Figure 3). By doing so, we showed that simple, well-known chemistry

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[7] (a) US Patent 7196124. (b) European Patent 1581577. (c) US Patent 6869985. (d) European Patent 1361039. (e) US Patent 7354656.

[8] (a) Tian, D; Boggiano, MK; Quisenberry, KT; Ross, JS; "Biobased Routes to UV Curable Materials;" presentation at RadTech International UV & EB Conference, 2008. (b) Werpy, T; Petersen, G; "Top Value Added Chemicals from Biomass: Volume I;" EPA Publication; 2004. (c) Voith, M; Chem. Eng. News, 2010, 88 (29), pp 25–26.

[9] Anastas, PT; Warner, JC; Green Chemistry: Theory and Practice, Oxford University Press: New York, 1998.

can be applied to create a new green product family that can be 'dropped in' to an established high-volume market. The reaction is run in the absence of solvent, and water is the only byproduct. Also, the polyester developed is exempt under TSCA exemption criteria of 40 CFR 723.250(e).

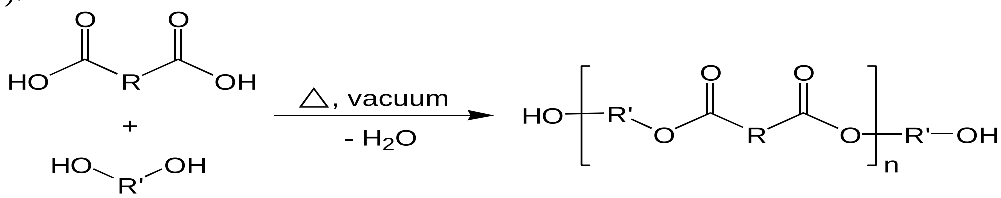

Figure 3. Polyester synthesis used for Armstrong's polyester binder for flooring tile. R and R' comprise aliphatic or aromatic hydrocarbon chains or rings. The diacid and diol may be derived from biobased feedstocks.

Table 1. Thermal and mechanical properties of a few polyester candidates synthesized for BioBased Tile, and typical values for plasticized PVC in VCT.

Polyester ID	1100	1027	1038	3658	Plasticized PVC
Reagents	1,3-propanediol Sebacic acid	1,3-propanediol Terephthalic acid	1,3-propanediol Sebacic acid Isophthalic acid Terephthalic acid	Proprietary	Polyvinyl chloride Phthalate plasticizers
Biobased content	100%	27%	38%	13%	0%
T_g (°C)	-11	60	26	16	21
T_m (°C)	62	228	N/A	125	degrades
Elongation at break		3%	>1500%	250%	116%
Break stress (PSI)		123,000	109	3,000	1,800

A major challenge in the design and development of our biobased polyester was to match the performance of plasticized PVC as a binder, using a class of polymers that typically have dramatically different molecular weights, properties and applications. Due to these differences, polyesters are rarely considered to replace plasticized PVC. However, with the available toolbox of diacids and diols from renewable sources, we challenged ourselves to take this approach to remove PVC and phthalates from a VCT-like product. The chemical properties we optimized are directly related to the floor product properties; a few of these properties are shown (Table 1). The relationship of polymer composition, structure and properties was not a simple linear relationship, with wide-ranging variations. Polyester 1100 contains a full 100% biobased content, but its melting point of 62°C is too low to meet the dimensional stability needed in tile. Polyester 1027 has excellent break stress, but its melting point of 228°C is too high for processing with current production equipment, and its elongation at break is insufficient. Polyester 1038 is amorphous, has very high elongation at break, and has a T_g very close to that of PVC, but its poor break stress indicates that a product made from this resin would crack in a high traffic environment. After numerous experiments, polyester 3658 was found to have acceptable biobased content and better mechanical properties than traditional plasticized PVC binders. BioBased Tile made from this polyester provides equal or better performance than VCT. For example, BioBased Tile has much better impact and crack resistance than VCT because the polyester 3658 has better break elongation and break stress than plasticized PVC used in VCT.

Additionally, VCT has a 30-50 year use life and BioBased Tile must be designed to have a similarly long use life. Evaluating a new product and projecting its long-term performance is another challenge for designing the new product. Often, materials supplied with short-term test information are used to project long-term performance. Because polymers are viscoelastic, they exhibit behavior during deformation and flow that is both temperature and time dependent. The Armstrong technical team used the method of time-temperature superposition to project the long-term performance of the newly designed system, and used this projection as feedback to improve the design.[10] The method of time-temperature superposition comes from the observation that the time scales of the molecular motions of a polymer are affected by temperature. The motions or relaxations occur at shorter times at higher temperatures. The modulus curve of a polymer over time, at all temperatures, can be superimposed onto a single mastercurve, using a suitable shift on the time scale. This provides a convenient technique for predicting long-term behavior of the material while running short-term tests. The time-temperature superposition mastercurves of VCT and BioBased Tile (Figure 4) indicate that the BioBased Tile has better long-term performance than VCT over the product lifetime.

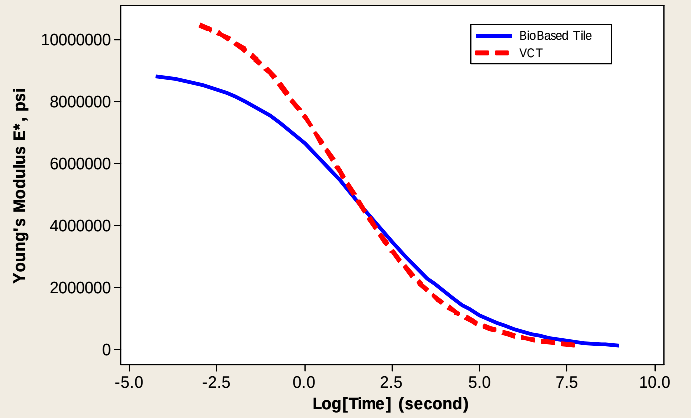

Figure 4. Time-temperature superposition mastercurve of VCT and BioBased Tile.

Other product properties were concurrently optimized through formulation and processing changes, including resistance to chemical attack, heat and light stability, and ability to be maintained with polish, etc. We required that all properties of BioBased Tile needed to achieve levels at least as good as VCT to deliver a product to our customers.

2. Human Health and Environmental Benefits

Indoor Air Quality Improvement. Recent concerns over the impacts of indoor air quality have driven construction industry specifiers to scrutinize the volatile emissions of the products they select. BioBased Tile flooring has been proven to not contain any toxic or carcinogenic volatile organic compounds (VOCs), as listed in table of Chronic Reference Exposure Levels (CRELs) established by the California Office of Environmental Health Hazard Assessment (OEHHA). Further, as part of Floor Score™ certification, BioBased Tile has been shown to emit non-detectable levels of total VOCs, based on California Department of Public Health (CDPH) Standard Method V1.1, 2010.[11] It also contributes up to four credits toward the US Green Building Council's LEED program.[12] In contrast, the other biobased floors, linoleum and natural rubber flooring, contain VOCs listed in the table of CRELs established by California OEHHA, although both of them meet the FloorScore™ indoor air quality specifications.

VOC Reduction. Additionally, our lab analysis indicates that BioBased Tile products emit 89%

[10] Ferry, JD; Viscoelastic Properties of Polymers, 3rd ed., Wiley, New York, 1980.

[11] California Integrated Waste Management Board: http://www.ciwmb.ca.gov/greenbuilding/Specs/Section01350.

[12] LEED credits possible include EQ4.3 (low-emitting materials), MR4.0 (recycled content), MR6.0 (rapidly renewable resources) and, depending on location, MRS.O (local materials).

less VOCs than VCT during the manufacturing process. Replacement of VCT with BioBased Tile flooring could reduce 336,000 pounds of VOCs each year, equivalent to the total annual VOC emissions from 13,570 cars in the U.S.[13]

Eliminated High Priority Chemicals. Biobased Tile contains biobased polyester as sole binder. We completely eliminate the need for stabilizers and phthalate plasticizers, which are often needed to process PVC-based products. Some stabilizers and plasticizers have been shown to have negative effects on human health, and the absence of these classes of materials in BioBased Tile eliminates the possibility of any harm that could come from them. This is particularly important in the K-12 education sector.

Recyclability. The lack of heavy-metal stabilizers, phthalate plasticizers or other processing additives in the BioBased Tile formula follows a Principle of Green Engineering to minimize material diversity and promote value retention of the raw materials.[14] The formula simplification and the use of a reprocessable thermoplastic binder enable ease of recyclability of BioBased Tile at the end of its useful life. The lifetime of this highly durable product is greater than 30 years, so large-scale facilities for recycling have not yet been developed. We have, however, successfully recycled BioBased Tile into other Armstrong flooring products.

Renewable Feedstocks. Inclusion of biobased content in the binder system dramatically reduces the carbon footprint of BioBased Tile products. A higher biobased content in the polyester binder is desired, but this is limited by performance attributes and available raw materials. The polyester binder, as currently produced, contains 13% biobased content, equal to 22 lbs of CO_2 converted from the atmosphere for every 100 lbs of binder synthesized. The biobased content will be increased as appropriate feedstocks become available. Based on the market size, 44 million pounds of CO_2 could be captured from the atmosphere through the use of rapidly renewable materials in the binder.

Recycled Content. Armstrong developed a tile formulation to include this pre-consumer recycled content. By including third-party-certified 10% recycled limestone in BioBased Tile, a significant amount of virgin material is saved. Considering the VCT market size, BioBased Tile could avoid using 140 million pounds of virgin limestone annually.

Reduced Energy Consumption. The new polyester binder allows lower processing temperatures which directly reduces energy consumption in the factory, up to 28 billion BTU per year. Additionally, by substituting VCT with BioBased Tile, we estimate that BioBased Tile manufacturing could reduce energy consumption equivalent to 475 billion BTU per year, or 56 million pounds of CO_2.[15]

Existing Facilities. Armstrong targeted existing manufacturing facilities to produce BioBased Tile to eliminate the environmental impact of building a new plant. Not only has this allowed BioBased Tile to reach the market faster, but it also avoids the environmental changes and

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[13] An average car in 2002 was responsible for emission of 30.8 g of VOC per day. U.S. DOT Federal Highway Administration. Sources of Vehicle Emissions. Viewed October 16, 2009: http://www.fhwa.dot.gov/environment/aqfactbk/page15.htm.

[14] Anastas, PT; Zimmerman, JB; *Envir. Sci. Technol.* **2003**, *36*, 94A.

[15] Calculation is based on DOE published conversion factors: http://tonto.eia.doe.gov/energyexplained/index.cfm?page=about_btu; http://www.eia.doe.gov/oiaf/1605/coefficients.html.

resources needed in constructing a new facility.

3. Applicability and Impact

Affordability. Biobased Tile is priced affordably. This allows customers to specify a green flooring product that is significantly more economical than other existing biobased flooring available. This is particularly important in the K-12 education sector, where healthy and environmentally-friendly options are highly desired, but budgets are often limited. Also, BioBased Tile is designed with the classic look of traditional VCT, which is well-accepted in the market. Accordingly, BioBased Tile is priced similar to VCT, with a 20% premium that is eclipsed by the average 600% improvement in performance.

Performance. Not only does Armstrong's BioBased Tile have environmental benefits compared to VCT, but this product also performs at least as well as VCT for every property specified in ASTM F1066. In fact, the absence of PVC resin is the only reason BioBased Tile does not meet this ASTM standard. While VCT is a proven and reliable product, BioBased Tile outperforms VCT on impact resistance (10 times better), and crack resistance from uneven subfloors (2.5 times better). These properties add value that the end user can appreciate.

Customer Acceptance. BioBased Tile has been shown to have the same long product life as other resilient flooring materials. Additionally, BioBased Tile can be installed in the same fashion as VCT with conventional adhesives and installation techniques. It has the same maintenance requirements as VCT, and does not require new training, equipment, or maintenance materials. A minimal learning curve in the installation and use of BioBased Tile has facilitated its acceptance in the marketplace. Multi-million-square-foot sales, with year-on-year increases during the current economic crisis, indicates exceptional customer acceptance.

Summary

A non-PVC, non-phthalate commercial floor tile product, suitable for K-12 schools has been developed at Armstrong. This product looks identical to the existing, well-accepted VCT, but contains a proprietary biobased resin. Its performance has been tested, demonstrated and accepted by the customer. Armstrong's BioBased Tile flooring carries measureable health and environmental advantages over the existing VCT product, including:

1. improved indoor air quality;
2. reduced VOC emissions during the manufacturing process;
3. eliminated high priority chemicals, phthalates and stabilizers;
4. a new biobased binder that reduces reliance on petrochemical feedstocks and captures CO_2 from atmosphere;
5. reduced energy consumption and CO_2 emissions during manufacturing;
6. recycled content, that minimizes waste;
7. use of existing manufacturing facilities, which reduces environmental impact; and
8. a familiar design, enhanced performance and affordable price that aids customer acceptance of this "greener" alternative.