Floor Coating Formulations Obtained from 100% Natural, Renewable or Biobased Materials

Dong Tian, Keith T. Quisenberry, Mary Kate Boggiano, Larry W. Leininger
Susan L. Scheuering and Jeffrey S. Ross
Armstrong World Industries, Inc.
2500 Columbia Avenue, Lancaster, PA 17603

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Abstract

A variety of raw materials are used in so-called “greener” coating systems. This paper summarizes what this means for several “green” categories, and how to use these items to formulate floor coatings. Materials covered include: seed, nut, grass and softwood products; biofuel waste; modified small molecules; materials from enzyme catalyzed reactions; and renewable inorganic fillers. Also reviewed are selected commercially available “green” coating systems for flooring. Finally, performance of selected model systems is reported.

Introduction

Armstrong World Industries has a long-standing commitment to the environment. In the early 1900s, it recycled cork dust to manufacture linoleum flooring and in 1976 introduced the first UV floor coating. UV is considered environmentally friendly, since most of the solvents in inks, paints, adhesives and coatings can be eliminated when using UV curing methods. Today, radiation cure technology has been extensively used in Armstrong products. With a heritage of leadership in sustainability, Armstrong’s continued commitment to sustainability will propel us from managing environmental risk to developing innovative, environmentally sound strategies, to profitable and productive use of renewable resources. The key step in this approach is to integrate rapidly renewable materials (i.e., natural, biobased materials) into floor coating systems, thus reducing reliance on limited resources such as petroleum and fossil fuels. Armstrong believes it is essential to maintain focus on developing a more sustainable, long-term solution because it is the right and practical choice for both the environment and its customers. In this paper, the authors review and clarify some “green” concepts and commercially available “green” coating systems for flooring, and discuss the performance of a selected model system.

“Green” Labels

A variety of labels are used to describe the raw materials used in “greener” coating systems. Descriptions of some of those labels are included in the sections below. Several raw materials associated with various “green” labels have been summarized (Tables 1 and 4). The tables are intended to provide an introductory summary rather than an exhaustive list. In some cases, more than one label applies. For example, “renewable” and “biobased” labels are shared by many raw materials.

Natural

Natural is one of the less technical labels. In a broad sense, natural relates to the physical universe or material world. When used to describe materials, natural is generally attributed to systems that have not undergone extensive modification to derive value. Because of misuse in the marketplace, government agencies are being pressed to officially define what constitutes a natural material. Although the USDA is in the process of redefining natural at this time,[1] the FDA has yet to officially define natural.[2] The natural label is most often applied to consumer products. It appropriately applies to cork, bamboo, linoleum and wood flooring. Typically, the natural label does not refer to coating systems used on products, but the products themselves. For example, an advertisement may read, "Natural wood flooring protected with beautiful and durable high gloss, factory-applied polyurethane." Natural has been used to refer to coating compositions based on processed oils made from renewable sources. Examples include linseed oil, tall oil and soybean oil.

Renewable

Natural resources are generally defined as renewable when their rates of consumption are less than or equal to their rates of replacement by natural processes.[3] This balance of depletion and repletion enables the sustainability of renewable resources. Materials derived from sources such as trees, corn, soybeans, sugarcane and bamboo are considered renewable sources of organic carbon (Table 1) (cf. marine animals such as coral, shellfish, sea urchins and starfish are sources of renewable inorganic carbon, as they produce calcium carbonate).[4] In addition, environmental concerns over deforestation have led to the use of non-wood alternatives that are "rapidly renewable."[5]

Table 1. Sources of renewable materials.

Uses/example	**Renewable material**	**Renewable Source**
ethanol, biofuel, polymers	biomass material, sugars, fatty acids	corn, sugarcane, vegetable oils
bamboo flooring, particle board	bamboo, sunflower hulls, wheat straw	wheat, sunflower, bamboo
polymers (e.g., floor coating components)	seed oils	soybeans, sunflower, flax, vernonia, safflower
construction, flooring, energy source	wood, biomass	hardwood and softwood trees
cork, linoleum	cork tissue (from bark)	Cork Oak tree (*Quercus suber*)

The definition of "rapidly renewable" varies by different sources. "Green" building programs and others in the industry have set "years-to-harvest" time limits that are used to define "rapidly renewable" resources. In 1998 the U.S. Green Building Council (USGBC) initiated the Leadership in Energy and Environmental Design (LEED) program which outlines measures to be followed for developing sustainable buildings. LEED credits can be obtained for a variety of building practices that reduce or eliminate the negative environmental impact associated with a building and its construction. Ten years or less—from planting to harvest—is required to meet LEED guidelines for rapidly renewable materials.[6] As already stated, other sources vary. The Wood Floor Resource Group, LLC, defines rapidly renewable as any plant that grows to harvesting size within fifteen years.[7] Builders in Australia may follow Ecospecifier, a guide to eco-friendly materials, products and technologies, which stringently considers only plants with a harvesting cycle of three years or less to be rapidly renewable.[8]

Biobased

The Farm Security and Rural Investment Act of 2002 (FSRIA) requires federal agencies to establish preference programs for biobased products and to purchase such products that meet pricing, availability and performance criteria set forth in the legislation.[9] In response to the FSRIA, the US Department of Agriculture launched the Federal Biobased Products Preferred Procurement Program (FB4P).[10,11] The Secretary of Agriculture defined biobased products[12] as "composed in whole, or in significant part, of biological products or renewable domestic agricultural materials or forestry materials." For the purpose of determining biobased content of products, the USDA defines biobased content[10] as "the amount of biobased carbon in the product or material as a percent of the weight (mass) of the total organic carbon in the product."

This definition coincides with the one used by ASTM D6852-02 to determine biobased contents of products.[13] In practice, biobased materials include those that are produced using "biological" processing as opposed to methods based on more conventional chemical processing. Basically, biobased refers to products (or materials) that are originally derived from biological resources. Biological processes include fermentation, enzyme catalysis, or bacteriological processing. Corn-based ethanol derived from fermentation is thus both rapidly renewable and biobased. Another renewable, biobased material is glycerol, which is a byproduct from bio-diesel manufacturing. Sugar and corn starch are renewable materials but are not considered to be biobased products when used for food.[9]

Recycled and Recyclable

The Federal Trade Commission (FTC) Guides for the Use of Environmental Marketing Claims makes a clear distinction between labeling materials as recycled and recyclable: [14]

> A product or package should not be marketed as recyclable unless it can be collected, separated or otherwise recovered from the solid waste stream for reuse, or in the manufacture or assembly of another package or product, through an established recycling program…a recycled content claim may be made only for materials that have been recovered or otherwise diverted from the solid waste stream, either during the manufacturing process (pre-consumer), or after consumer use (post-consumer).

The amount of recycled material (pre- or post-consumer) must be substantiated if a material is labeled as recycled. Generally, the percentage of recycled content is printed on a product's package. Also, labels must be clear as to whether the "recycled" or "recyclable" label refers to a product or its package or both.

Biodegradable

The term biodegradable relates to a material that is capable of being broken down by micro-organisms (e.g., algae, fungi, bacteria) into substances that are found in nature. Biodegradable materials are broken down to carbon dioxide and/or methane, water and biomass, depending on whether the environment is aerobic or anaerobic.[15] Polymers can undergo several forms of degradation. Simple degradation can occur chemically through oxidation and hydrolysis, but stabilizers are often added to prevent unwanted polymer deterioration in a product. Polymers can also undergo biodegradation[16] or photo-degradation, a process in which sunlight directly induces polymer decomposition.[17] The American Society for Testing and Materials (ASTM) has even published a standard specifying biodegradable polymers as those designed to undergo significant structural change with subsequent property loss, resulting from actions of naturally-occurring organisms and the specific environmental conditions they create.[18]

When discussing biodegradable materials, a few aspects need to be considered: the disposal environment and the extent and rate of biodegradation.[14] First, will the material biodegrade in the environment where it is disposed? Composts are rich in air, water, nutrients and organisms that can degrade many materials in a reasonably short period of time. Many people mistakenly believe that landfills simply function as large compost heaps. By design and regulation, landfills are built to minimize contamination of the surrounding air and water by limiting exposure of the refuse to air, moisture and sunlight, thus slowing the degradation process.[19] Once the proper environment for biodegradation is taken into account, the extent and rate of biodegradation must be considered. In general, a material ought to be evaluated for recyclability before being discarded, even if it is biodegradable. For example, soy proteins can be reclaimed from biofuel wastes and modified for use as raw materials in the synthesis of adhesives. Glycerin is another examplebecause it is generated during biodiesel production. This biodiesel by-product can be converted into different chemicals[23] including propylene glycol, a building block for many materials with broad applications in the coating industry.

“Green”

“Green” is a concept that has many different meanings depending on the definition’s source. It has been used synonymously with eco-friendly and in conjunction with sustainable. In some instances, the label “green” alludes to a “natural” product, while in other instances, “green” evokes the idea that a product is somehow environmentally beneficial, or at least, less damaging in comparison with products that aren’t labeled so. In practice, a material is marketed as “green” if it meets at least one of the criteria generally associated with being eco-friendly (Table 2).[20]

Table 2. Criteria for “green” labeling of materials.

Criterion	Example
Material is made from eco-friendly material	salvaged material, agricultural waste, renewable resource or recycled material
Material is recyclable or certified	FSC* or SFI§
Material is manufactured using less environmentally intrusive methods	smaller environmental footprint vs. conventional methods
Material produces fewer negative effects on the environment	no VOC emission
Material is minimally processed	biobased
Material is exceptionally durable	coating that lasts the lifetime of a product

*FSC: Forest Stewardship Council
§SFI: Forestry Sustainable Initiatives

There are many national, regional and local U.S. “green” building programs that focus on eco-friendly construction, including the use of renewable materials (Table 3).[21] These programs encourage the practice of environmentally responsible construction and focus on environmental concerns like energy efficiency, water management, waste reduction, indoor air quality, recycling and the use of eco-friendly materials. Some “green” building programs have been criticized for endorsing certain materials for their specific attributes without considering the overall environmental effects of using those materials. However, others, like Green Globes,™ use life cycle assessments (LCA) to qualify “green” labels.

Table 3. Some U.S. “green” building programs.

LEED
Green Globes™
Seattle (King County) Built Green Program
Austin (Texas) Green Building Program
California Green Builder Program
Built Green Colorado Program
Wisconsin Green-built Program

Life cycle assessment is defined[22] in ISO 14040 as “a compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.” Careful consideration of all eco-effects of material usage through LCA provides the most thorough means of building “green” structures. Life cycle assessments of building materials have resulted in proposed changes to the LEED guidelines, allowing a biobased LEED credit in lieu of the rapidly renewable LEED credit.[21]

Formulations Principles

“Green” materials are formulated the same as “conventional” materials. However, the “green” formulator also considers target requirements reflecting a concern for manufacturing sustainability and end-of-life recovery or reuse. Materials used in “green” formulations include: seed, nut, grass and softwood products; biofuel waste; modified small molecules; materials from enzyme catalyzed reactions; and renewable inorganic fillers.

“Green” coating systems for flooring

A variety of “green” coating systems have been proposed for or used in flooring. This section reviews the commercially available systems of which the authors are aware, and also reports on performance attributes of some systems Armstrong currently uses or is developing. “Green” floor coating systems can be classified in a variety of ways including factory applied floor finishes (e.g., UV/EB cured finishes), site applied finishes intended as primary floor coatings, and floor care or “refinish” products. This review will first briefly cover site applied and refinish systems, followed by factory finish systems. Of particular interest is Armstrong’s model biobased, UV/EB curable coating system.

Although coatings can attain “green” labels by meeting any of the generally accepted criteria (Table 2), and there is an emergence of “green” coating systems available (e.g., low VOC and 100% solids UV coatings), this article focuses on coatings that comprise natural, renewable and/or biobased material. Floor coatings containing biobased polyols from seed oils usually merit the “green” label. Several seed oils have been extensively used in such coatings (Table 4). Fatty acids of seed oils may include several chemical functions that facilitate polymer synthesis, such as unsaturated carbon chains, hydroxyl groups, ester linkages and epoxy functions. A variety of synthetic routes have been implemented toward the manufacture of biobased coatings. [23]

Table 4. Seed oils used in floor coatings and main fatty acid components.

Seed Oil	Fatty Acid
castor oil	ricinoleic acid
linseed oil	linolenic, linoleic, oleic
soy oil	linoleic, oleic, palmitic
tall oil (pine oil)	palmitic, oleic, linoleic
tung oil	eleaostearic

Site Applied and Refinish Systems

Site applied and refinish systems can be generally classified by the type of solvent system used, whether the systems are ready to use (i.e., one-component system), or if the systems consist of two or more materials that must be mixed. One-component, site applied systems and refinish systems made from 100% natural, biobased or renewable materials have been surveyed (Table 5).

Table 5. Commercially available "green" site applied and refinish systems.

Manufacturer	System Name	Chemistry	Solvent System	Floor Products	Cure Method
Bonakemi	Bona Carl's Oil 90	hardening tall oil	solvent (10%)	wood	air dry
Klumpp	High Solid Oil-Wax	seed oils and waxes	100% solids	wood	air dry
Osmo	Osmo Polyx-Oil	sunflower, soybean and thistle oil, carnauba and candelilla waxes	solvent	wood, cork, laminates, tile	air dry
Tried and True Wood Finishes	Tried and True Oil Varnish Finish	polymerized linseed oil	100% solids	wood	air dry
BioShield	Hard Oil #9	linseed, castor, tung oils	solvent	wood, stone	air dry
EcoSafety Products	Eco-procote (Acri-Soy™)	soy esters and modified acrylics	water	wood, stone, tile	air dry
AFM	Safecoat AFM Naturals Oil Wax Finish	polymerized linseed, safflower, sunflower and soybean oils, carnauba wax	100% solids	wood	air dry
Vermont Natural Coatings™	PolyWhey™ Wood Finish	modified whey protein	water	wood	air dry
Waterlox	Waterlox Original Sealer & Finish	tung oil	solvent	all	air dry
Global Finishes, Ltd.	Lobasol® HS Azkent 100 Wax	modified vegetable oils and waxes	100% solids	wood	air dry
WOCA	WOCA Oil Refresher	modified vegetable oils	solvent	wood	air dry

Factory Finish Systems

Flooring products with factory finish coatings are segmented by market into several groups. The product attributes and factory finish coatings by market segment have been summarized (Table 6). Armstrong's total floor coating usage level is in excess of 10,000,000 lbs per year;[24] most of these coatings are UV/EB curable and comprise petroleum based raw materials. Clearly there is an opportunity to use renewable materials in UV/EB factory finish systems.

Table 6. Hard surface flooring products and factory finish systems.

Market Segment	Key Attributes	Typical Coating
Residential Sheet Vinyl	6–14 ft wide, rotogravure image, foam and felt carriers	UV, H_2O
Residential Vinyl Tile	12–24 inch squares, printed image, place and press adhesive on filled PVC base	UV, EB
Commercial Vinyl Tile	12 inch squares, filled inlaid & calendered PVC base & image	wax
Commercial Sheet Vinyl	typically 6 ft wide, calendered sheet, felt, glass or vinyl carrier	UV, H_2O
Linoleum	typically 2 meters wide, all natural calendered sheet, natural fiber carrier	UV
Wood Flooring	various sizes and thicknesses, solid or multi-ply construction	UV
Laminate Flooring	high pressure or medium pressure multi-ply product	melamine
Ceramic	oven fired clay or ceramic base with printed, fired ceramic slip image	oven fired glass or ceramic

Known factory finish systems made from 100% natural, biobased or renewable materials have been tabulated (Table 7). These systems were identified through a literature search for systems based on key words such as "green," as described above, and internally through Armstrong's research on biobased floor coatings. These systems were classified by manufacturer, the coating system name, the basic chemistry (if known), the products for which the coating is used, and the cure method. Armstrong's coating systems have been excluded from this summary since they are not commercially available.

Table 7. Commercially available "green" factory finish coating systems.

Manufacturer	System Name	Chemistry	Floor Products	Cure Method
Lott Lacke GmBH	naRoLa®	epoxidized linseed oil acrylate	wood, cork, linoleum	UV
WOCA	WOCA Oil System	modified vegetable oils	wood	IR or air dry

A Biobased Floor Coating Formula - Model System

We selected Polycin D-265 (Vertellus), a castor oil based polyol, in the floor model coating study, and Table 8 summarizes properties of D-265. A UV curable moiety must be introduced into this biobased polyol to obtain a UV curable floor coating. Two reactions were conducted to convert the caster oil polyol to UV curable material.

Table 8. Property of caster oil based polyols, D-265.

Acid #	OH #	Color, Gardner	Moisture, %	Viscosity, cP@25^{o}C	Functionality
1	265	1	0.02	375	2

Reaction 1: Partial Acrylation

Acrylic acid was used to convert 60% of the hydroxyl groups of Polycin D-265 into acrylates (A1). The FTIR spectra before and after acrylation indicate several changes (Fig. 1). Because the acrylation was only partial, the FTIR spectrum of A1 shows reduced OH absorption (around 3400cm^{-1}), and new absorption at 1636 cm^{-1} (C=C) and 1408cm^{-1} (=CH), suggesting double bond formation. Acid number, OH number and viscosity of the biobased polyols after acrylation indicated changes as well (Table 9).

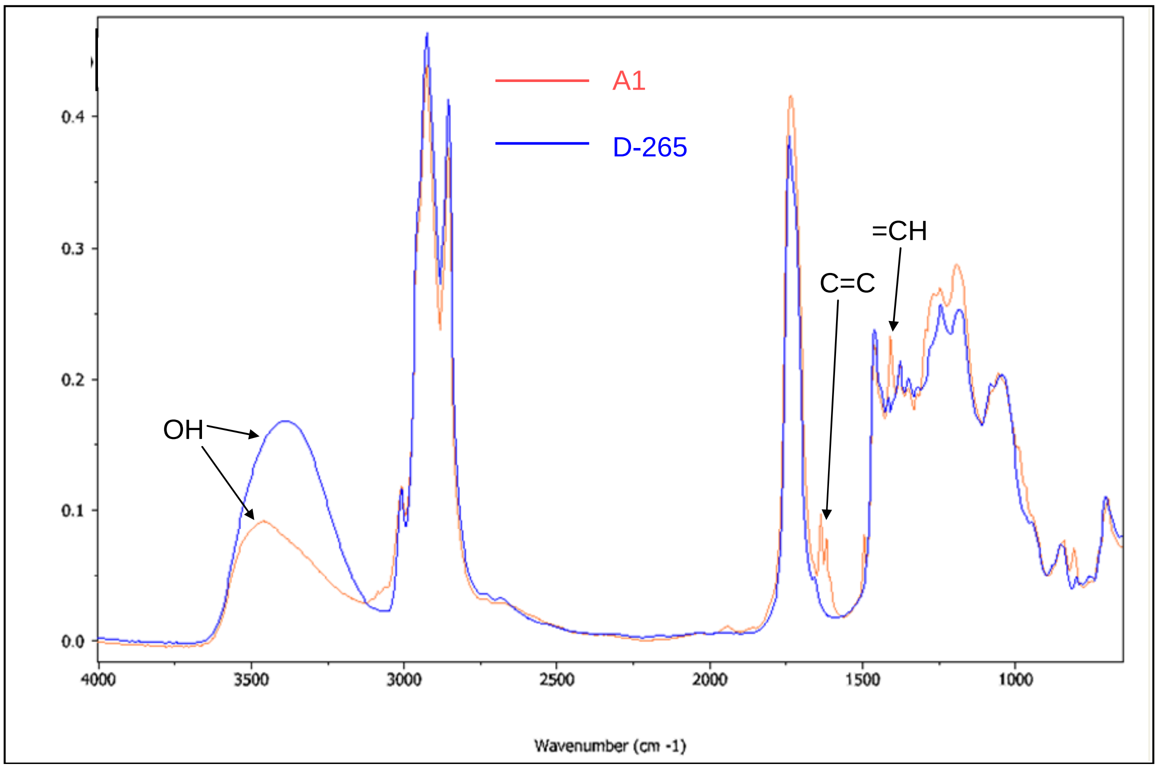

Figure 1. FTIR spectra of castor oil polyol (D-265) and partially acrylated castor oil polyol (A1).

Table 9. Partially acrylated castor oil polyols (A1)

Acid #	OH#	Viscosity, cP@22^{o}C
17	94	2510

Reaction 2: Urethane Acrylate

A biobased urethane acrylate (A2) was prepared by treating A1 with an aliphatic diisocyanate. In FTIR spectra, the NCO absorption gradually disappears with reaction time (Fig. 2a). The two peaks of NCO absorption and loss correspond to the two stepwise charges of diisocyanate into the reactor.

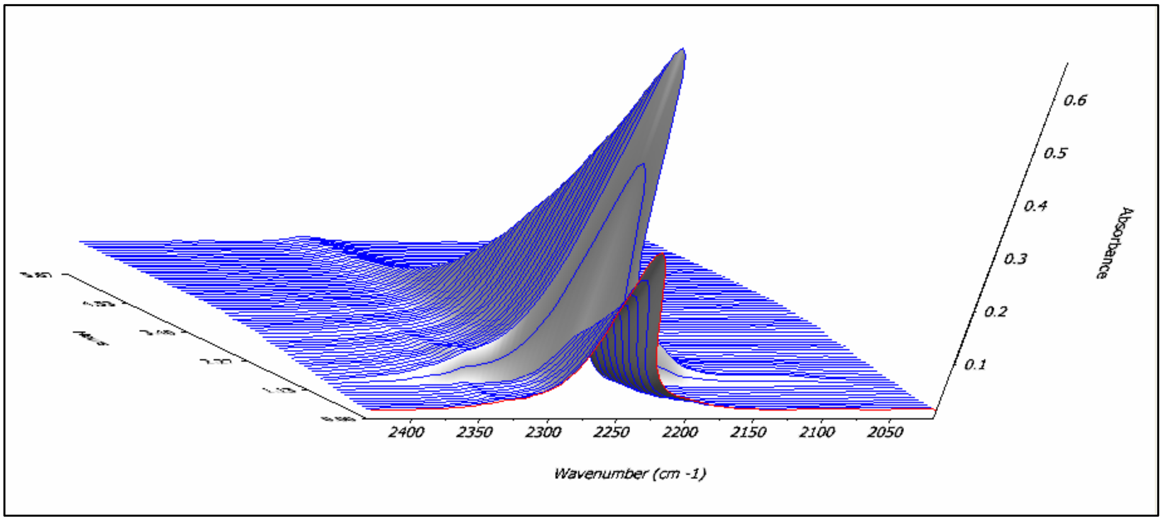

Figure 2a. FTIR spectra of urethane reaction, A1 with diisocyanate.

The FTIR spectra before and after the urethane reaction also indicated structural changes (Fig. 2b). The 3400cm^{-1} band shifts to lower wave numbers clearly indicating that the OH groups have fully converted into urethane linkages. This biobased urethane acrylate was formulated from a castor-based polyol into a radiation curable floor coating composition.

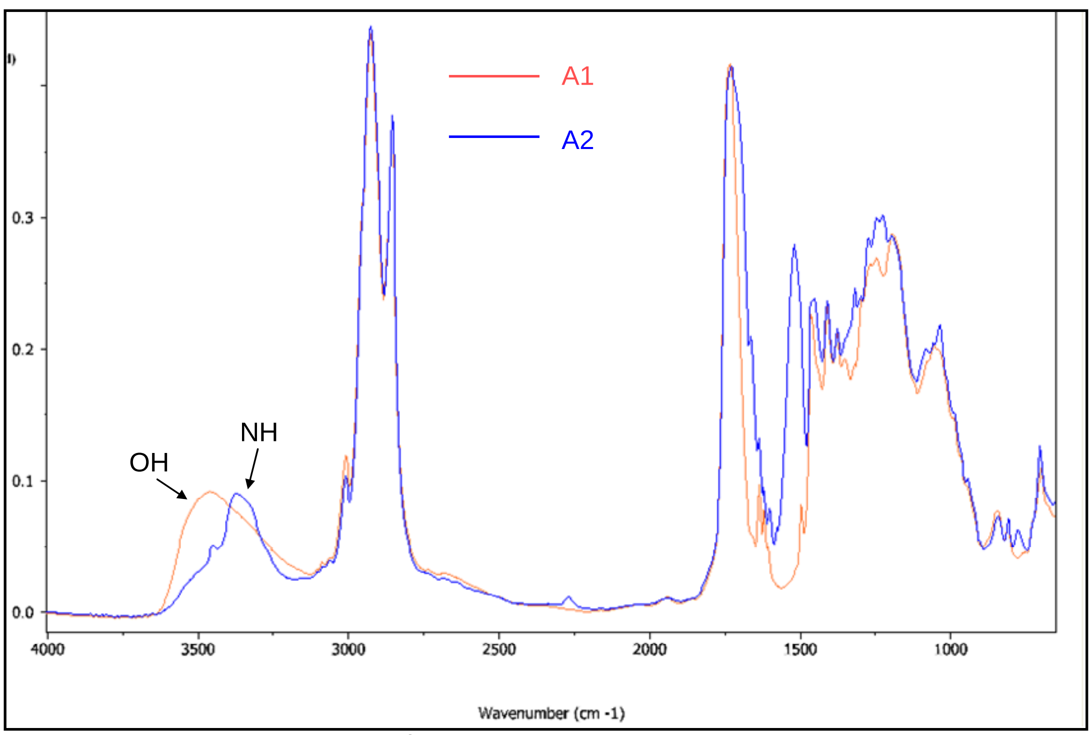

Figure 2b. FTIR spectra of A1 and castor oil based urethane acrylate (A2).

Model Formula

The model biobased floor coating was formulated as shown (Table 10). A control coating formula based on previously used petrochemicals[25] was also tested in the study as control.

Table 10. Coating formulations.

Coating ID	Control	Model Formula
Trade Name	Amount	Amount
HATPEC2[25]	126.28	0
A2	0	100.00
Triacrylate Monomers	139.54	56.26
Polyester	34.38	0
Isocyanate	87.41	0
Surfactant	1.00	0.40
Photoinitiators	14.54	5.86
Total	403.15	162.52

The coatings were applied to vinyl flooring and UV cured (2.0 J/cm^2 energy density; 0.60 W/cm^2 peak irradiance, measured by EIT UV Power Puck). Performance testing data for these coatings was summarized (Table 11). Performance of the biobased model coating was equivalent to that of the fossil fuel based coating. The calculated biobased content of the model coating is about 70% whereas there is 0% biobased content in the control coating. The effect of biobased content on coating performance and curing conditions will be evaluated as well. The introduction of renewable inorganic fillers like ground clam shells could provide another avenue toward increasing renewable content. These efforts are under way and will be reported in the near future.

Table 11. Coating properties.

Coating ID	Gloss	Color L*	Color a*	Color b*	Adhesion	Stain Resistance	Black Heel Scuffing Test
Control	89	87.55	-0.46	7.89	Pass	Pass	Pass
Model Formula	85	86.92	-0.16	6.96	Pass	Pass	Pass

Conclusions

Although the meaning of a "green" label may differ depending on its use, ultimately when consumers choose "green," they are implying that they subscribe to environmental stewardship and social responsibility. Legislation, government regulations and industrial guidelines regarding environmentally friendly practices have encouraged many industries to adopt sustainable manufacturing methods and to offer "green" products. The floor coatings industry is no exception. Through judicious selection of raw materials and innovative chemistry, the flooring coatings industry offers a variety of "green" coating options for eco-conscious consumers, ranging from coatings with reduced or zero VOC content, to those made from 100% natural, renewable or biobased materials. This paper introduces the latter. In summary, managing environment risk and reducing VOCs are not “green” enough for today’s “green” economy. The coatings industry will ultimately strive to utilize biobased materials derived from natural, renewable or biomass materials in UV coating systems. Armstrong created a model biobased system to demonstrate how to achieve this goal in light of the dearth of commercially available UV-cured biobased coatings in today’s market.

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