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(54) **Titre : GRANULES DE COUVERTURE REFLECHISSANT BIEN LE RAYONNEMENT SOLAIRE ET UTILISANT DES
COMPOSANTS CARACTERISES PAR UNE FAIBLE ABSORPTION**
(54) **Title: HIGH SOLAR-REFLECTIVITY ROOFING GRANULES UTILIZING LOW ABSORPTION COMPONENTS**

(57) **Abrégé/Abstract:**

An uncolored roofing granule including a low solar absorption base and a low solar absorption and solar opaque coating presented on the base, the coating including a binder, a pigment, wherein the binder includes a curable component and a non-clay, thermally reactive curing agent.

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(54) Title: HIGH SOLAR-REFLECTIVITY ROOFING GRANULES UTILIZING LOW ABSORPTION COMPONENTS

(57) Abstract: An uncolored roofing granule including a low solar absorption base and a low solar absorption and solar opaque coating presented on the base, the coating including a binder, a pigment, wherein the binder includes a curable component and a non-clay, thermally reactive curing agent.



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**HIGH SOLAR-REFLECTIVITY ROOFING GRANULES UTILIZING LOW
ABSORPTION COMPONENTS**

FIELD

The present disclosure generally relates to roofing granules. More particularly, the present disclosure relates to high solar reflectivity roofing granules.

BRIEF SUMMARY

Features and advantages of this disclosure will be understood upon consideration of the detailed description, as well as the appended and claims. These and other features and advantages of the invention may be described below in connection with various embodiments of the present invention. This summary is not intended to describe each and all disclosed embodiments or every implementation of the present invention.

A feature and advantage of the present disclosure is the enablement of roofing having a total solar reflectivity ("TSR") of up to or even greater than 0.70 of the total solar spectrum, moderate to low cost, and sufficient ultraviolet ("UV") blocking for high durability. The subject matter of this disclosure, in its various combinations, either in apparatus or method form, may include the following list of embodiments:

1. An uncolored roofing granule comprising:
a low solar absorption base; and
a low solar absorption and solar opaque coating presented on said base, said coating comprising a binder, a pigment, wherein said binder comprises a curable component and a non-clay, thermally reactive curing agent.
2. The uncolored roofing granule of embodiment 1, wherein said coating is UV blocking.
3. The uncolored roofing granule of embodiment 1, wherein said curable component comprises a soluble silicate.
4. The uncolored roofing granule of embodiment 1, wherein said binder comprises less than about 15% by weight clay.
5. The uncolored roofing granule of embodiment 1, wherein said binder comprises less than about 5% by weight clay.
6. The uncolored roofing granule of embodiment 1, wherein said binder comprises less than about 1% by weight clay.

7. The uncolored roofing granule of embodiment 1, wherein said binder comprises about 0% by weight clay.

8. The uncolored roofing granule of embodiment 1, wherein said coating has high reflectivity to visible and infrared (IR) light.

5 9. The uncolored roofing granule of embodiment 1, wherein said base is transparent to much of the solar spectrum.

10 10. The uncolored roofing granule of embodiment 9, wherein said base is selected from the group consisting of recycled glass, engineered glass, quartz, and any combinations thereof.

11 11. The uncolored roofing granule of embodiment 1, wherein said base comprises high diffuse reflectivity and comprises a total solar reflectivity having a cup brightness of at least about 0.70 reflectivity.

12 12. The uncolored roofing granule of embodiment 11, wherein said base is selected from the group consisting of polycrystalline silicate, polycrystalline silica, glass ceramic, devitrified ceramic, phase-separated glass, polycrystalline fused oxide, white cement, and any combinations thereof.

13 13. The uncolored roofing granule of embodiment 11, wherein said base is white cement, said white cement comprising one or more fillers selected from the group consisting of recycled glass, engineered glass, quartz, alumina, titania, and any combinations thereof.

14 14. The uncolored roofing granule of embodiment 1, wherein said soluble silicate comprises mixed alkali silicate.

15 15. The uncolored roofing granule of embodiment 1, wherein said reactive curing agent comprises silica nanoparticles dispersed therein.

16 16. The uncolored roofing granule of embodiment 15, wherein said reactive curing agent further comprises a flux.

17 17. The uncolored roofing granule of embodiment 16, wherein said flux is selected from the group consisting of soluble borate, soluble phosphate, insoluble borate, insoluble phosphate, nanoparticles, and any combinations thereof.

18 18. The uncolored roofing granule of embodiment 1, wherein said pigment is selected from the group consisting of alumina, titania, zinc oxide, UV blocking powders, and any combinations thereof.

19 19. An uncolored roofing granule comprising:
a low solar absorption base; and
a coating presented on said base, said coating comprising a binder and a pigment, wherein said binder comprises a curable component and a non-clay, thermally reactive curing agent
35 comprising silica nanoparticles dispersed therein.

20. The uncolored roofing granule of embodiment 19, wherein said binder comprises less than about 15% by weight clay.

21. The uncolored roofing granule of embodiment 19, wherein said binder comprises less than about 5% by weight clay.

5 22. The uncolored roofing granule of embodiment 19, wherein said binder comprises less than about 1% by weight clay.

23. The uncolored roofing granule of embodiment 19, wherein said coating has high reflectivity to visible and infrared (IR) light.

10 24. The uncolored roofing granule of embodiment 19, wherein said base is transparent to much of the solar spectrum.

25. The uncolored roofing granule of embodiment 24, wherein said base is selected from the group consisting of recycled glass, engineered glass, quartz, and any combinations thereof.

15 26. The uncolored roofing granule of embodiment 19, wherein said base comprises high diffuse reflectivity and comprises a total solar reflectivity having a cup brightness of at least about 0.70 reflectivity.

27. The uncolored roofing granule of embodiment 26, wherein said base is selected from the group consisting of polycrystalline silicate, polycrystalline silica, glass ceramic, devitrified ceramic, phase-separated glass, polycrystalline fused oxide, white cement, and any combinations thereof.

20 28. The uncolored roofing granule of embodiment 26, wherein said base is white cement, said white cement comprising one or more fillers selected from the group consisting of recycled glass, engineered glass, quartz, alumina, titania, and any combinations thereof.

29. The uncolored roofing granule of embodiment 19, wherein said soluble silicate comprises mixed alkali silicate.

25 30. The uncolored roofing granule of embodiment 19, wherein said reactive curing agent further comprises a flux.

31. The uncolored roofing granule of embodiment 30, wherein said flux is selected from the group consisting of soluble borate, soluble phosphate, insoluble borate, insoluble phosphate, nanoparticles, and any combinations thereof.

30 32. The uncolored roofing granule of embodiment 19, wherein said pigment is selected from the group consisting of alumina, titania, zinc oxide, UV blocking powders, and any combinations thereof.

35 33. A roofing article comprising a substrate and a plurality of roofing granules according to any of the previous embodiments presented on said substrate, said article further comprising an overcoat presented on said substrate and roofing granules.

34. The roofing article of embodiment 33, wherein said overcoat comprises fluorinated polyurethane silane with nanosilica particles dispersed in said fluorinated polyurethane silane.

35. The roofing article of embodiment 33, wherein said overcoat further comprises
5 pigment selected from the group consisting of alumina, titania, zinc oxide, UV blocking powders, and any combinations thereof.

36. The roofing article of embodiment 33, wherein said overcoat further comprises a binder.

37. The roofing article of embodiment 33, wherein said overcoat comprises a second
10 polymer.

38. The roofing article of embodiment 33, wherein said second polymer comprises an acrylic.

39. The roofing article of embodiment 33, wherein said overcoat comprises a first layer comprising acrylic and a second layer presented on said first layer, said second layer
15 comprising fluorinated polyurethane silane with nanosilica particles dispersed in said fluorinated polyurethane silane.

40. The roofing article of embodiment 33, wherein said overcoat comprises a mixture of acrylic and fluorinated polyurethane silane with nanosilica particles dispersed in said fluorinated polyurethane silane.

20 In one aspect, the present invention provides an uncolored roofing granule comprising: a low solar absorption base selected from the group consisting of recycled glass, engineered glass, quartz, and any combinations thereof; and a low solar absorption and solar opaque coating on said base, said coating comprising a binder, a pigment, wherein said binder comprises a curable component and a non-clay, thermally reactive curing agent.

25 In another aspect, the present invention provides an uncolored roofing granule comprising: a low solar absorption base selected from the group consisting of recycled glass,

engineered glass, quartz, and any combinations thereof; and a coating on said base, said coating comprising a binder and a pigment, wherein said binder comprises a curable component and a non-clay, thermally reactive curing agent comprising silica nanoparticles dispersed therein.

5

BRIEF DESCRIPTION OF THE DRAWINGS

The disclosure may be more completely understood, and those having ordinary skill in the art to which the subject invention relates will more readily understand how to make and use the subject invention, in consideration of the following detailed description of various exemplary embodiments of the disclosure in connection with the accompanying drawings, in
10 which:

Figure 1 is a graph depicting reflectivity of various numbers of coatings by base rock versus L^* (whiteness on the CIE LAB scale). As more coatings are added the Nova Scotia base and the Raw Rock base approach the same level on the L^* scale, but the Nova Scotia base has higher reflectivity by ~10% (0.10 TSR).

15 Figure 2 is a graph depicting A1 Doped ZnO particle size distribution showing effects of sonication causing deagglomeration.

Figure 3 is a graph depicting A1-Doped ZnO Peak fit summary.

Figure 4 is a graph depicting Kadox 911 ZnO particle size distribution showing effects of sonication causing deagglomeration.

20 Figure 5 is a graph depicting Kadox 911 ZnO Peak fit summary.

Figure 6 is a graph depicting AA-TiO₂ particle size distribution showing no significant change in response to sonication.

Figure 7 is a graph depicting Kronos-TiO₂ particle size distribution showing no significant change in response to sonication but exhibiting a bi-modal distribution.

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DETAILED DESCRIPTION

In the following description, reference is made to the accompanying drawings that forms a part hereof, and in which are shown by way of illustration several specific embodiments. It is to be understood that other embodiments are contemplated and may be made without departing from the scope or spirit of the present disclosure. The following detailed description, therefore, is not to be taken in a limiting sense.

10

All scientific and technical terms used herein have meanings commonly used in the art unless otherwise specified. The definitions provided herein are to facilitate understanding of certain terms used frequently herein and are not meant to limit the scope of the present disclosure.

15

The term “uncolored,” such as in reference to granules or roofing granules, can be essentially white granules that are not designed to have specific absorption in the visible region of the solar spectra, as would be used to create a desired color appearance other than white.

The term “low solar absorption” can refer to materials that primarily reflect or transmit a large fraction of the total solar spectrum. Such a material would therefore primarily reflect or transmit most of the visible and near IR spectrum. In embodiments, a functional amount of a low solar absorption material (such as a layer of granules of base rock or coated base rock, or a thin layer of a granule coating material) would absorb less than 50%, preferably less than 30%, and optimally less than 20% of the total solar spectrum.

20

A solar opaque material is one that has low transmission of the total spectra. When a material is both solar opaque and has low solar absorption, it has high total reflectivity of the solar spectrum. Preferably, a functional amount of a solar opaque material (such as a layer of granules of base rock or coated base rock, or a thin layer of a granule coating material) would transmit less than 60%, more preferably less than 40%, and optimally less than 30% of the total solar spectrum.

25

Unless otherwise indicated, all numbers expressing feature sizes, amounts, and physical properties used in the specification and claims are to be understood as being modified in all instances by the term “about.” Accordingly, unless indicated to the contrary, the numerical parameters set forth in the foregoing specification and attached claims are approximations that can vary depending upon the desired properties sought to be obtained by those skilled in the art utilizing the teachings disclosed herein.

30

The recitation of numerical ranges by endpoints includes all numbers subsumed within that range (e.g. 1 to 5 includes 1, 1.5, 2, 2.75, 3, 3.80, 4, and 5) and any range within that range.

As used in this specification and the appended claims, the singular forms “a”, “an”, and “the” encompass embodiments having plural referents, unless the content clearly dictates otherwise. As used in this specification and the appended claims, the term “or” is generally employed in its sense including “and/or” unless the content clearly dictates otherwise.

Higher performance white granules can be used for commercial bitumen roofs. Granules that enable roofs with an initial TSR value of at least 0.70 of the total solar spectrum can meet new building energy rating requirements, resulting in considerably increased value of the roofing product. The granules themselves optimally have extremely high reflectivity, as there can be losses from granule post treatments and incomplete coverage of bitumen surface. Granule cup reflectivity requirements can be as high as about 78% to about 85%.

Three characteristics of ultra-white granules can include sufficiently high scattering power, sufficiently low absorption, and high UV blocking. Scattering power can be controlled by refractive index contrast and particle size. Titania can be an ideal pigment based on its high refractive index and low absorption. However, due to cost considerations, titania can be present in an amount which typically does not exceed two to three 10 – 30 μm pigment layers with moderate to high titania loading. This can be inadequate to fully hide a conventional baserock granule. Transparent granules can enable better coating utilization, but do not contribute additional scattering or UV absorption. Optimum utilization of titania can result from particle / aggregate size tailored to the solar spectrum and uniform distribution on the granules.

Other approaches to enhanced scattering include the development or trapping of light scattering pores, lowering the refractive index of the binder matrix, or using lower cost pigments (such as, for example, alumina) that enhance overall scattering due to the ability to use larger quantities, trap small pores, or promote uniform coatings. Sufficiently low absorption opaque base rock can contribute to total scattering power, either in combination with coatings or as a monolithic granule if sufficiently reflective. Other approaches to white opaque base include bonded alumina, devitrified glass, white marble, and white cement.

Light can be lost to absorption in the pigment layer, the granule, or in the bitumen after transmission through the granule. The latter can be controlled by scattering power as described above. The former can be minimized by eliminating light absorbing components such as, for example, standard clay. Colloidal silica has been shown to be an alternate heat curing agent to clay. Pigment subtleties, such as, for example, the presence of an organic surface treatment, can lead to absorption after heat treatment. Absorbing base rock can be replaced with transparent or low absorption opaque granules, unless the coating essentially fully hides the granule.

UV blocking can be accomplished by absorption in the baserock for conventional granules. For high TSR granules, UV reflection can be preferred versus absorption, although both could be used. Generally, an optimum particle size for UV scattering is smaller than for the remaining solar spectra, so inclusion of and/or preferential location of small particles in an outer layer can improve the fraction scattered. The use of pigments that are both good scatterers and UV absorbers (such as, for example, titania) is beneficial. Certain pigment, such as, for example, zinc oxides are moderately good scatterers and more UV absorbing in certain wavelength ranges (340 – 380 nm) than titania. Including UV absorbers in the base rock enables scattering from the coating followed by absorption of remaining UV light. Synthesized granules, such as, for example, custom glass, glass-ceramic, bonded alumina, or white cement based materials, allow for the incorporation of UV absorbers. With multiple coats of applied pigmented metal silicate/clay ceramic coatings, the UV transmission of a high silica granule can be cut down to lower levels. In the first two examples below, the light transmission is cut below the 5% threshold after 2 or 3 coats (depending on the composition of the coating) and the TSR of these granules is higher than the same formulation on a more absorptive standard raw rock.

Example 1 – Ultra White Roofing Granules

In this example, each coat was mixed and fired to 870° F onto quartz base rock from Black Bull Resources (Shelburne, Nova Scotia, Canada) using the formulation described in Table 1. The comparative samples fired on 3M raw rock used the same formulation with the slight difference in the first coat using 5 lbs/ton less titanium dioxide. The resulting color (as measured using a LabScan XE with a D65 light source and a 10 degree CIE standard observer) and TSR is listed in Tables 2 and 3 and plotted in Figure 1. Table 2 also gives the light transmission results. TSR was measured using a Devices and Services Solar Spectrum Reflectometer (v5) using 1.5 air mass setting. The Light Transmission was measured using a full spectrum flood lamp with a 5850 light filter (for wavelengths ~330 nm to ~480 nm). Individual granules are placed in a 10 by 10 array and film was exposed with any light that is transmitted through the granules. In this example, acceptable light transmission is achieved after the 2nd coat.

Table 1: Formula used on Black Bull quartz base rock for each coating. The formula used on the 3M raw rock is the same except that the 1st coat used 15 lbs/ton titanium dioxide instead of 20 lbs/ton.

Coating Formulation

RM 11-Digit No.	RM Name	lbs/ton
11-0000-7234-5	PD sodium silicate	63.00
	Water	20.00
11-0002-6169-0	CR800 titanium dioxide	20.00
11-0002-9619-1	Borax 5 Mol	3.00
11-0000-7240-2	B-3 Bag Clay	30.00

Table 2: Color and TSR results for each coat on the Black Bull quartz base (results reported are an average of 4 samples).

Sample	L*	a*	b*	Reflectivity %	Light Transmission
Raw					
Rock	85.32	0.73	5.12	72.1	93%
1 Coat	80.13	1.36	5.85	63.1	59%
2 Coats	79.67	0.99	4.35	60.7	4%
3 Coats	79.80	0.66	3.56	59.5	2%

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Table 3: Color and TSR results for each coat on the 3M raw rock samples (3 replicates).

Sample 1	L*	a*	b*	Reflectivity %
1 Coat	66.08	-0.44	-0.35	30.5
2 Coats	75.45	-0.63	0.40	42.4
3 Coats	78.23	-0.44	1.75	48.7
4 Coats	79.85	-0.27	2.52	53.0

Sample 3	L*	a*	b*	Reflectivity %
1 Coat	65.50	-0.51	-0.70	29.7
2 Coats	75.18	-0.65	0.32	42.2
3 Coats	78.30	-0.45	1.65	48.8
4 Coats	79.79	-0.30	2.45	52.6

Sample 11	L*	a*	b*	Reflectivity %
1 Coat	66.73	-0.54	-0.66	31.1
2 Coats	75.80	-0.69	0.35	42.8
3 Coats	78.61	-0.45	1.80	49.5
4 Coats	79.70	-0.20	2.64	52.8

Further Examples:

Coating components

Pigment	Manufacturer	Location	Grade	Part. Size Dist. (μm)	% Primary Oxide	Phase	Surface Coating
TiO ₂	Kronos	Houston, TX	3025	0.3-100	99	Rutile	None
TiO ₂	Dupont	Wilmington, DE	R101	0.32	97	Rutile	1.7 wt% Al ₂ O ₃
TiO ₂	Precolor	Prague, CZ	R200M	0.45	99.5	Rutile	Organic
ZnO	Kadox	Monaca, PA	911	0.12	99.9	Wurtzite	None
Al ₂ O ₃	Alcan	Saguenay-Lac-St-Jean, QC	AC34	0.5-70	99.6	NaAl ₂ O ₃	None
AlSiI	20 Microns	Vadodara, Gujarat, India	ZX	-325 Mesh	100	AlSi Extender	None

Component	Manufacturer	Location	Grade	Part. Size Dist. (μm)	% Primary Oxide	Phase
Coll. SiO ₂	Nalco	Naperville, IL	1130	0.008	30	nano
Coll. SiO ₂	Nalco	Naperville, IL	2326	0.005	15	nano
Coll. SiO ₂	Nalco	Naperville, IL	2327	0.02	40	nano
Kaolin	Laguna	City of Industry, CA	B-3	0.1-30	100	clay
NaSi	PQ Corp	Valley Forge, PA	PD	3.22 SiO ₂ /Na ₂ O	39	Sol
KBF4	Glenn Corp	Lake Elmo, MN	-	-	100	-

White Pigments: Light Scattering Analysis:

Understanding the effect of particle size and particle state on scattering is critical to achieve maximum TSR. Below are examples of particle size measurements for light scattering techniques.

Al Doped ZnO –Sonication causes the larger agglomerated particles between 4 and 10 μm to break into particles in the 200nm size range. The graph in Figure 3 summarizes the peak fit for the two modes in the Al doped ZnO after 1 minute of sonication. The sample has a peak at about 260nm and at about 4 μm. The Kadox 911 exhibits very similar behavior to that of the Al-doped ZnO sample see Figures 4 and 5). Note that the peak fit data is for the sample after 2 minutes of sonication and the separation between the two modes is less distinct.

The TiO₂ samples exhibit a much larger overall particle size distribution. Sample AA-TiO₂ exhibits a normal single mode distribution that is unaffected by sonication (see Figure 6). The Kronos TiO₂ sample also appears to be generally unaffected by sonication but exhibits a

distinct bi-modal distribution (Figure 7). The major mode is at about 1.4 μm with a somewhat smaller mode at about 34.5 μm .

Base Rock Materials

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Minerals

Sample ID	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃ *	MgO	MnO	CaO	TiO ₂	Na ₂ O	K ₂ O	P ₂ O ₅	LOI	Ba
	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	ppm
96-11GL-W	70.26	13.93	2.94	0.63	0.04	1.33	0.49	3.90	3.74	0.02	1.88	>800
96-11GL-B	50.63	11.62	11.36	8.92	0.18	11.08	0.93	1.73	0.43	0.07	0.55	105.00
96-11GL-C	69.93	13.78	3.86	0.82	0.07	2.84	0.43	3.43	3.20	0.05	0.46	>800
96-11GL-L	62.42	18.10	3.44	0.78	0.18	1.89	0.96	6.31	6.05	0.16	0.73	>800

Sample ID	Sample Description
96-11GL-W	Wausau: 11-grade granule, crushed in the geology lab, from plant production November 1996
96-11GL-B	Belle Mead: 11-grade granule, crushed in the geology lab, from plant production November 1996
96-11GL-C	Corona: 11-grade granule, crushed in the geology lab, from plant production November 1996
96-11GL-L	Little Rock: 11-grade granule, crushed in the geology lab, from plant production November 1996

*Note: Total iron (FeO and Fe₂O₃) reported as Fe₂O₃

Analyses completed by ACTLABS, Inc., Wheat Ridge, Colorado, November 19, 1997 by the ICP method.

Quartz

T-Grade Quartz is left over stock from 3M's color quartz production.

Recycled Glass

8 grade recycle glass was broken clear bottle glass obtained from E-Cullet (Saint Paul, MN) and crushed/sieved at bldg. 30. Abrasive G14 glass is crushed light bulb glass obtained from NC Minerals of Lakeville, MN.

Marble

9 grade commercially available marble roofing granules were obtained from Imerys (Roswell, GA).

Custom Fused Materials

1200 frit has standard 3M bubble glass chemistry. The glass is melted, fritted, and then devitrified in a belt furnace at temps ranging from 850-950°C for 1-4 min at a time. <0.5 wt% fumed silica is added to prevent the fritted parts from sticking together.

Coated granules were prepared by blending coatings components, then applying to granules in a rotating laboratory furnace.

Coating Notes: Colloidal silica and sodium silicate react to form a sheer thinning gel that the standard mixer blades only stir the bottom of making pigment distribution difficult. An air prop with a jiffy mixer attachment is used instead for the mixing so that the coating slip can be more controllably mixed. Clay based binders made by both methods are identical.

Other sample types were made as needed to analyze optical and chemical properties of the various components of interest. These included (coated slides, granules comprised of only coating material, actual shingles)

Performance of Roofing Materials Based on Ultra-white Granules

Performance is affected by several factors that are difficult to experimentally separate. For high TSR (total solar reflectivity), key factors include low absorbance (vis and IR), high scattering power (vis and IR), UV blocking (scattering or absorption), and good bitumen coverage (granule shape and size). Measurements and experiments to characterize and optimize these functions are described below. It is believed the materials and experiments below provide a path to a commercial granule bitumen roof with the desired TSR (0.70 of the total solar spectrum). Laboratory shingles do not necessarily meet this target due to non-optimum shingle coverage and packing, non-optimum granule surface treatment, or other factors.

Coatings on slides – as a function of thickness, these help determine scattering power via identification of the required thickness to provide maximum reflection. At sufficient thickness – they also provide information on relative absorption. However the maximum reflectivity differs from the entitlement value for coated granules, because the rough surface formed by granules has more bounces for absorption, and therefore a lower maximum TSR than for thickly coated slides.

Cup brightness values – These can be measured for base granules, coated granules, and granules fabricated from coating materials (granules of coating). Cup brightness provides a TSR value that is influenced by relative absorption with the appropriate magnification caused by roughness. For coated granules with absorptive base rock, primarily the top layer scatters light, so the result is very similar to shingle properties. For white granules with clear or white base rock, cup TSR is often enhanced because multiple granule layers counter act the absence of sufficient scattering power.

Granule mono-layers (shingles or black tape) – these samples are closest to real functional performance, since the surface has real world roughness, and lack of scattering power causes light loss to the black backing. Granule packing, size, and shape influence this test (and real world performance) however, so the tests above are often needed to separate materials performances from granule shape factors.

Performance of Coatings

A. Examples of low loss binder systems:

Clay Binder System

RunOrder	DOE 1	DOE 11	DOE 13	DOE 14	DOE 15	8-29-11-6E
3025 lb/ton	45.00	90.00	50.63	60.00	56.25	135.00
RCL9 lb/ton	0.00	0.00	28.13	15.00	11.25	0.00
ZnO 911 lb/ton	22.50	0.00	5.63	15.00	11.25	0.00
AlSil lb/ton	22.50	0.00	5.63	0.00	11.25	0.00
B3 clay	30.00	30.00	30.00	30.00	30.00	15.00
PD sodium silicate	63.00	63.00	63.00	63.00	63.00	50.00
water	20.00	20.00	20.00	20.00	20.00	20.00
amt /1 kg rock	203.00	203.00	203.00	203.00	203.00	220.00

Colloidal SiO₂ System

RunOrder	DOE 1	DOE 11	DOE 13	DOE 14	DOE 15	8-29-11-6E
3025 lb/ton	45.00	90.00	50.63	60.00	56.25	135.00
RCL9 lb/ton	0.00	0.00	28.13	15.00	11.25	0.00
ZnO 911 lb/ton	22.50	0.00	5.63	15.00	11.25	0.00
AlSil lb/ton	22.50	0.00	5.63	0.00	11.25	0.00
2326 Nalco	200.00	200.00	200.00	200.00	200.00	100.00
PD sodium silicate	63.00	63.00	63.00	63.00	63.00	50.00
water	0.00	0.00	0.00	0.00	0.00	0.00
amt /1 kg rock	353.00	353.00	353.00	353.00	353.00	285.00

TSR	DOE 1	DOE 11	DOE 13	DOE 14	DOE 15	8-29-11-6E
Clay Flat Black	0.650	0.615	0.636	0.644	0.647	0.677
2326 Flat Black	0.675	0.625	0.678	0.655	0.666	0.639
2326 % Improvement	3.74	1.68	6.71	1.71	2.89	-5.52

Clay Cup	0.768	0.750	0.760	0.758	0.760	0.785
2326 Cup	0.831	0.770	0.815	0.816	0.830	0.799
2326 % Improvement	8.29	2.67	7.28	7.70	9.26	1.83

B. Examples of transparent baserock and cup brightness properties

Table 6: Cup TSR and Color for transparent base rocks

Sample	CO raw rock	White G18	Green G18	T-Grade	1200 1 Pass	1200 Multipass
TSR	0.111	0.574	0.271	0.604	0.625	0.680
L*	41.14	81.4	62.63	78.01	83.723	89.267
a*	-0.6	-0.46	-3.92	1.41	-3.050	-4.103
b*	1.97	4.52	18.92	5.92	0.397	-0.213

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C. Examples of monolithic granules / opaque baserock and cup brightness properties:

Table 7: Cup TSR values of monolithic granules

Sample	1200 850C 1 Pass	1200 850C Multipass	Marble
Avg TSR	0.625	0.680	0.594
L*	83.74	-3.09	0.37
a*	86.59	-3.53	0.10
b*	86.59	-3.53	0.10

Table 8: TSR values of monolayers of granules on tape

Avg TSR		Black Tape	White Tape		
		0.059	0.807		
Marble on White	Marble on Black	Quartz on Black	Quartz on White	Abra G14 on Black	Abra G14 on White
0.666	0.425	0.268	0.727	0.199	0.730
Abra G14 on Black	Abra G14 on White	1200 1Pass Black	1200 1Pass on White	1200 Multi Pass Black	1200 Multi Pass White
0.199	0.730	0.244	0.750	0.335	0.755

1200 frit is bubble glass that has been partially nucleated at 850 OC for 1-3 minutes. Multipass is 6 passes varying in length from 1-3 minutes. Black is 3M 610 Vinyl Tape while White is TSSD TiO₂ loaded patch brightness tape.

5 D. Examples of coated granules

Table 9: Comparison of TSR values of high TSR granules using different TiO₂ pigments

	R101 Corona	R101 Abrasive G14	R200M Abrasive G14	Kronos 3025 Abrasive G14	R200M Abrasive G14
10/25/2011	10-25-11-7	10-25-11-9	10-25-11-10	10-25-11-11	10-25-11-12
PD NaSi	44.3	44.3	44.3	44.3	22.0
2326 Coll. SiO ₂	66.5	66.5	66.5	66.5	44.1
DI H ₂ O	0.0	0.0	0.0	0.0	4.4
TiO ₂	45.0	45.0	45.0	45.0	59.5
Batch Applied	155.7	155.7	155.7	155.7	130.0
% Solids	0.46	0.46	0.46	0.46	0.58
%Binder	0.18	0.18	0.18	0.18	0.12
NaSi:React Ratio	1.750	1.750	1.750	1.750	1.311
Coatings as batched	Corona	Abrasive G14	Abrasive G14	Abrasive G14	Abrasive G14
10/25/2011	10-25-11-7	10-25-11-9	10-25-11-10	10-25-11-11	10-25-11-12
PD NaSi	64.0	64.0	64.0	64.0	38.1
2326 Coll. SiO ₂	96.0	96.0	96.0	96.0	76.3
DI H ₂ O	0.0	0.0	0.0	0.0	7.6
TiO ₂	65.0	65.0	65.0	65.0	103.0
Batch Weight	225.0	225.0	225.0	225.0	225.0
TiO ₂ g per Coat	45	45	45	45	59.51014752
Avg. TSR 3 Coats	0.544	0.611	0.511	0.735	0.735
	7	9	10	11	12
L*	82.61	83.28	77.88	88.87	89.78
a*	-0.62	-0.28	-0.21	-0.55	-0.32
b*	1.08	1.64	0.90	5.51	3.42

Table 10: Comparison of TSR values of high TSR granules using different TiO₂ pigments (cub brightness TSR)

TiO ₂	Kronos 3025	Kronos 3025	Kronos 3025	Kronos 3025	Kronos 3025
Granule	Marble	T-Quartz	Abrasive G14	T-Quartz	T-Quartz
12/22/2011	12-22-11-3	12-5-11-1	10-25-11-11	8-29-11-6D	8-29-11-6E
PD NaSi	88.5	88.5	88.6	50	50.0
Kaolin B-3	0.0	0.0	0.0	0.0	0.0
2326 Coll. SiO ₂	132.9	132.9	133.0	100	100.0
DI H ₂ O	0.0	0.0	0.0	10.0	10.0
ZnO LS	0.0	0.0	0.0	67.5	33.8
TiO ₂	90.0	90.0	90.0	67.5	101.3
Batch	311.4	311.4	311.6	295.0	295.1
Amount of H ₂ O	166.6	166.6	166.7	125.3	125.3
Amount of Binder	54.8	54.8	54.9	34.7	34.7
NaSi:React Ratio	1.750	1.750	1.750	1.313	1.313
Total Applied	103.82	155.72	155.80	147.50	147.55
AVG 3 Coat TSR	0.719	0.67	0.735	0.775	0.779

Table 11: Comparison of TSR values and alkalinity of low dust formulations blending multiple metal-silicate solutions with different colloidal silica levels on Corona

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4/12/2012	1	2	3	4	5	6	7	8
TiO2	22.5	33.8	45.0	22.5	22.5	22.5	22.5	22.5
Alsil	22.5	11.3	0.0	22.5	22.5	22.5	22.5	22.5
NaSi	63.0	63.0	63.0	63.0	63.0	63.0	28.0	28.0
Kasil 6	0.0	0.0	0.0	0.0	0.0	0.0	35.3	35.3
Nalco 2327	75.0	75.0	75.0	37.5	37.5	37.5	37.5	75.0
Water	0.0	0.0	0.0	0.0	10.0	20.0	0.0	0.0
Total	183.0	183.0	183.0	145.5	145.5	145.5	145.8	183.3
APPLY	91.5	91.5	91.5	72.8	72.8	72.8	72.9	91.7
Apply	91.5	91.5	91.5	72.8	72.8	72.8	72.9	91.7
Batch	1	2	3	4	5	6	7	7
TiO2	18.0	27.0	36.0	18.0	18.0	18.0	18.0	18.0
Alsil	18.0	9.0	0.0	18.0	18.0	18.0	18.0	18.0
NaSi	50.4	50.4	50.4	50.4	50.4	50.4	22.4	22.4
Kasil 6	0.0	0.0	0.0	0.0	0.0	0.0	28.2	28.2
Nalco 2327	60.0	60.0	60.0	30.0	30.0	30.0	30.0	60.0
Water	0.0	0.0	0.0	0.0	8.0	16.0	0.0	0.0
Total	146.4	146.4	146.4	116.4	116.4	116.4	116.6	146.6
Apply	91.5	91.5	91.5	72.8	72.8	72.8	72.9	91.7
	Corona	Corona	Corona	Corona	Corona	Corona	Corona	Corona
4/12/2012	1	2	3	4	5	6	7	8
Alkalinity	3.624	3.736	4.722	4.502	4.188	3.814	4.58	4.018
Washed Alk	3.342	3.288	3.764	3.386	3.746	3.648	4.622	3.544
Cup: -16 +20	0.302	0.320	0.342	0.309	0.303	0.301	0.292	0.298
Flat: -16 +20	0.259	0.273	0.295	0.260	0.261	0.261	0.244	0.253
Flat: Full	0.261	0.278	0.296	0.273	0.264	0.281	0.253	0.280
Flat: Full	0.881	0.905	0.900	0.911	0.894	0.921	0.901	0.919
Flat: -16 +20	0.872	0.852	0.862	0.861	0.864	0.875	0.836	0.860
L *	63.88	65.85	67.40	64.14	63.63	63.51	62.48	63.35
a *	0.26	0.13	0.06	0.28	0.30	0.32	0.27	0.23
b *	2.07	2.20	2.15	2.29	2.35	2.39	2.31	2.07

Table 12: Comparison of TSR values and alkalinity of low dust formulations blending multiple metal-silicate solutions with different colloidal silica levels on Silmer white (0.78 TSR) base.

	4/17/2012	MiniGrain 1	1	2	3	4	5	6	7	8	9	10
TiO2 3025			22.5	22.5	22.5	22.5	22.5	22.5	22.5	0.0	0.0	0.0
TiO2 RCL 9			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	22.5
Alsil			22.5	22.5	22.5	22.5	22.5	22.5	22.5	0.0	0.0	22.5
NaSi			28.0	28.0	63.0	28.0	63.0	28.0	63.0	28.0	63.0	28.0
Kasil 5			37.5	37.5	0.0	35.3	0.0	35.3	0.0	35.3	0.0	35.3
Nalco 2327			37.5	37.5	37.5	75.0	75.0	37.5	37.5	37.5	37.5	37.5
Total			145.8	145.8	145.5	183.3	183.0	145.8	145.5	100.8	100.5	145.8
APPLY			72.9	72.9	72.8	91.7	91.5	72.9	72.8	50.4	50.3	72.9
Apply			72.9	72.9	72.8	91.7	91.5	72.9	72.8	50.4	50.3	72.9
Batch			1	2	3	4	5	6	7	8	9	10
TiO2			18.0	18.0	18.0	18.0	18.0	18.0	18.0	0.0	0.0	0.0
TiO2 RCL 9			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.3
Alsil			18.0	18.0	18.0	18.0	18.0	18.0	18.0	0.0	0.0	11.3
NaSi			22.4	22.4	50.4	22.4	50.4	22.4	50.4	22.4	50.4	14.0
Kasil 5			35.3	35.3	0.0	28.2	0.0	35.3	0.0	35.3	0.0	17.7
Nalco 2327			30.0	30.0	30.0	60.0	60.0	30.0	30.0	30.0	30.0	18.8
Total			116.6	116.6	116.4	146.6	146.4	116.6	116.4	80.6	80.4	72.9
Apply			72.9	72.9	72.8	91.7	91.5	72.9	72.8	50.4	50.3	36.5
Alkalinity	0.604		Sil. MGO 9.36	Sil. MGO -	Sil. MGO 9.706	Sil. MGO 7.656	Sil. MGO 9.136	2095 5.342	2095 3.802	Sil. MGO 10.386	Sil. MGO 12.804	Sil. MGO 8.426
Washed Alk			8.404	-	9.136	7.12	7.978			9.646	12.482	8.006
1x Coat	Flat: Full		0.599	0.614	0.623	0.589	0.568	0.446	0.464	0.569	0.591	0.600
	Flat: -16 +20		0.563	0.590	0.620	0.588	0.573	0.409	0.429	0.566	0.571	0.574
	Cup: -16 +20	0.789	0.728	0.771	0.726	0.723	0.739	0.602	0.627	0.758	0.764	0.750
1x Coat	L*	91.08	88.71	90.55	88.88	88.23	88.75	77.68	79.21	89.53	89.94	90.08
	a*	0.47	0.14	0.30	0.22	0.19	0.24	3.52	3.42	0.71	0.68	0.03
	b*	1.09	3.49	2.86	3.42	3.60	3.62	9.90	9.65	1.83	1.62	2.57
1x Pack	Flat: Full		0.890	0.916	0.887	0.840	0.821	0.867	0.855	0.822	0.845	0.860
	Flat: -16 +20		0.835	0.862	0.916	0.858	0.832	0.773	0.785	0.824	0.816	0.828
	Est 95% pack	0.752	0.694	0.735	0.692	0.689	0.705	0.574	0.598	0.722	0.728	0.715
3x Coat	Flat: Full		0.616		0.613	0.603	0.612					
	Flat: -16 +20		0.586		0.584	0.569	0.581					
	Cup: -16 +20		0.712		0.727	0.705	0.717					
3x Coat	L*		87.62		88.46	86.70	87.44					
	a*		-0.02		-0.07	0.12	0.02					
	b*		4.34		4.38	4.56	4.67					

TSR cup, shingle, flat black

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Table 13: Comparison of TSR values of high TSR granules in different constructions

Sample	6D1	6D2	6E1	6E2
Granule Cup TSR	0.794		0.792	
Gran. + PT Cup TSR	0.738		0.736	
Shingle TSR	0.613	0.630	0.630	0.635

The post treatment required to adhere the granules to the asphalt has absorptive components that lower granule TSR values.

Table 14: Comparison of TSR values of high TSR granules in different constructions

Sample	PolyFlake	Firestone	Al ₂ O ₃	8-29-11-6D P.T.
Cup TSR	?	0.811	0.859	0.738
Flat Black TSR	?	0.653	?	?
Flat Black Packing %	?	85.0	?	?
Shingle TSR	0.660	0.705	0.703	0.613
Shingle Packing %	96.6	92.5	84.0	87.3

The polyflake and firestone materials were made by a manufacturing process that yields higher packing density than lab hand spreads are capable of achieving. Granule packing on shingle hand spreads is not easily controlled leading to lower construction TSR values than production processed shingles.

Data on granule durability: boil test, tumble test

Table 15: 6 hour boil test to judge coating solubility

Sample	8-29-11-5C	5C 6 Hour Boil		8-29-11-7F	7F 6 hr boil
	0.699	0.686		0.767	0.76
	0.707	0.693		0.772	0.76
	0.708	0.694		0.775	0.751
TSR Avg	0.705	0.691	TSR Avg	0.771	0.757
	% Loss	1.94		% Loss	1.86

Samples show a minimal amount of TSR drop after 6 hours in rapidly boiling water.

Table 16: Tumble test data on Corona rock and na-silicate infiltrated alumina

	On -30 mesh
NaSiAl	0.9g
Corona Rock	0.5g

Na-silicate infiltrated shaped alumina particles retain enough shape after firing to pass the granule tumble test.

Coating

In embodiments, a roofing article includes a substrate and a plurality of roofing granules presented on said substrate. The article can further include a coating presented on the substrate and roofing granules. Such coating can include, for example, the following materials:

Substrates. High-performance roof coating material, obtained as "SCOTCHKOTE Poly-Tech CSM 658" and Scotchkote Poly-Tech UV both available from 3M Company, St. Paul, MN.

Fluoro-materials. Material 1: 15% aqueous fluoro-urethane silane dispersion available from 3M Company as Trade name SRC220.

Silica Nanoparticles. Nanoparticle: A 40% aqueous colloidal spherical silica dispersion (stabilized with ammonium ion, Mean Particle Diameter = 20 nm), available as NALCO 2327 from NALCO Chemical Company;

The present invention should not be considered limited to the particular examples described herein, but rather should be understood to cover all aspects of the invention as fairly set out in the attached claims. Various modifications, equivalent processes, as well as numerous structures to which the present invention can be applicable will be readily apparent to those of skill in the art to which the present invention is directed upon review of the instant specification.

CLAIMS:

1. An uncolored roofing granule comprising:

a low solar absorption base selected from the group consisting of recycled glass, engineered glass, quartz, and any combinations thereof; and

5 a low solar absorption and solar opaque coating on said base, said coating comprising a binder, a pigment, wherein said binder comprises a curable component and a non-clay, thermally reactive curing agent.
2. The uncolored roofing granule of claim 1, wherein said coating is UV blocking.
3. The uncolored roofing granule of claim 1 or 2, wherein said curable component comprises
10 a soluble silicate.
4. The uncolored roofing granule of claim 3, wherein said soluble silicate comprises mixed alkali silicate.
5. The uncolored roofing granule of any one of claims 1 to 4, wherein said binder comprises less than 15% by weight clay.
- 15 6. The uncolored roofing granule of any one of claims 1 to 4, wherein said binder comprises less than 5% by weight clay.
7. The uncolored roofing granule of any one of claims 1 to 4, wherein said binder comprises less than 1% by weight clay.
8. The uncolored roofing granule of any one of claims 1 to 4, wherein said binder comprises
20 about 0% by weight clay.
9. The uncolored roofing granule of any one of claims 1 to 8, wherein said coating has high reflectivity to visible and infrared (IR) light.
10. The uncolored roofing granule of any one of claims 1 to 9, wherein said base is transparent to much of the solar spectrum.

11. The uncolored roofing granule of any one of claims 1 to 10, wherein said base comprises high diffuse reflectivity and comprises a total solar reflectivity having a cup brightness of at least 0.70 reflectivity.
12. The uncolored roofing granule of claim 11, wherein said base is selected from the group consisting of polycrystalline silicate, polycrystalline silica, glass ceramic, devitrified ceramic, phase-separated glass, polycrystalline fused oxide, white cement, and any combinations thereof.
13. The uncolored roofing granule of claim 11, wherein said base is white cement, said white cement comprising one or more fillers selected from the group consisting of recycled glass, engineered glass, quartz, alumina, titania, and any combinations thereof.
14. The uncolored roofing granule of any one of claims 1 to 13, wherein said reactive curing agent comprises silica nanoparticles dispersed therein.
15. The uncolored roofing granule of claim 14, wherein said reactive curing agent further comprises a flux.
16. The uncolored roofing granule of claim 15, wherein said flux is selected from the group consisting of soluble borate, soluble phosphate, insoluble borate, insoluble phosphate, nanoparticles, and any combinations thereof.
17. The uncolored roofing granule of any one of claims 1 to 16, wherein said pigment is selected from the group consisting of alumina, titania, zinc oxide, UV blocking powders, and any combinations thereof.
18. An uncolored roofing granule comprising:

a low solar absorption base selected from the group consisting of recycled glass, engineered glass, quartz, and any combinations thereof; and

a coating on said base, said coating comprising a binder and a pigment, wherein said binder comprises a curable component and a non-clay, thermally reactive curing agent comprising silica nanoparticles dispersed therein.

19. The uncolored roofing granule of claim 18, wherein said binder comprises less than 15%
5 by weight clay.

20. The uncolored roofing granule of claim 18, wherein said binder comprises less than 5%
by weight clay.

21. The uncolored roofing granule of claim 18, wherein said binder comprises less than 1%
by weight clay.

10 22. The uncolored roofing granule of any one of claims 18 to 21, wherein said coating has
high reflectivity to visible and infrared (IR) light.

23. The uncolored roofing granule of any one of claims 18 to 22, wherein said base is
transparent to much of the solar spectrum.

15 24. The uncolored roofing granule of any one of claims 18 to 23, wherein said base comprises
high diffuse reflectivity and comprises a total solar reflectivity having a cup brightness of at
least 0.70 reflectivity.

25. The uncolored roofing granule of claim 24, wherein said base is selected from the group
consisting of polycrystalline silicate, polycrystalline silica, glass ceramic, devitrified ceramic,
phase-separated glass, polycrystalline fused oxide, white cement, and any combinations
20 thereof.

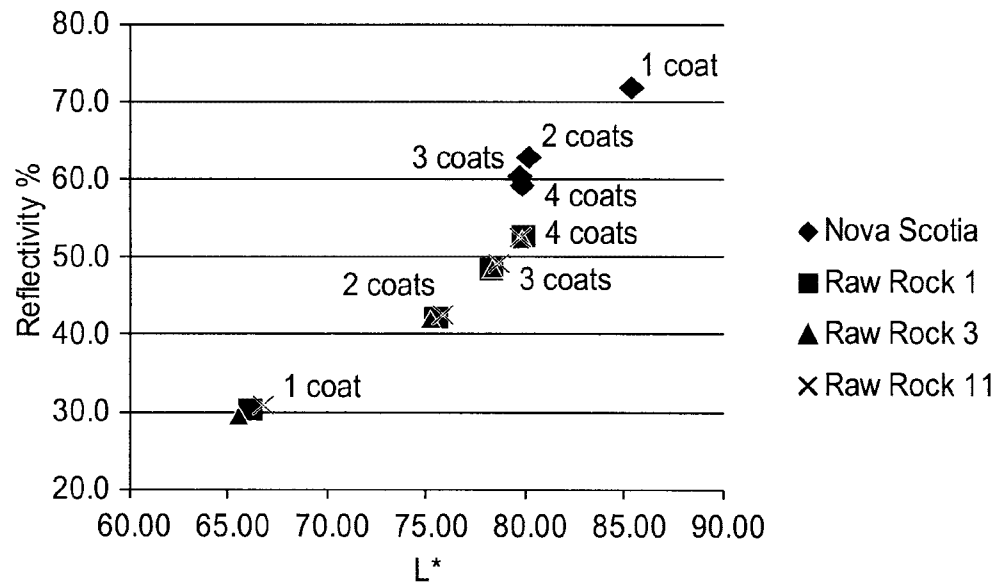
26. The uncolored roofing granule of claim 24, wherein said base is white cement, said white
cement comprising one or more fillers selected from the group consisting of recycled glass,
engineered glass, quartz, alumina, titania, and any combinations thereof.

27. The uncolored roofing granule of any one of claims 18 to 26, wherein said reactive curing
25 agent further comprises a flux.

28. The uncolored roofing granule of claim 27, wherein said flux is selected from the group consisting of soluble borate, soluble phosphate, insoluble borate, insoluble phosphate, nanoparticles, and any combinations thereof.
29. The uncolored roofing granule of any one of claims 18 to 28, wherein said pigment is
5 selected from the group consisting of alumina, titania, zinc oxide, UV blocking powders, and any combinations thereof.
30. A roofing article comprising a substrate and a plurality of roofing granules according to any one of claims 1 to 29 on said substrate, said article further comprising an overcoat on said substrate and roofing granules.
- 10 31. The roofing article of claim 30, wherein said overcoat comprises fluorinated polyurethane silane with nanosilica particles dispersed in said fluorinated polyurethane silane.
32. The roofing article of claim 30 or 31, wherein said overcoat further comprises pigment selected from the group consisting of alumina, titania, zinc oxide, UV blocking powders, and any combinations thereof.
- 15 33. The roofing article of any one of claims 30 to 32, wherein said overcoat further comprises a binder.
34. The roofing article of any one of claims 30 to 33, wherein said overcoat comprises a second polymer.
35. The roofing article of claim 34, wherein said second polymer comprises an acrylic.
- 20 36. The roofing article of any one of claims 30 to 35, wherein said overcoat comprises a first layer comprising acrylic and a second layer on said first layer, said second layer comprising fluorinated polyurethane silane with nanosilica particles dispersed in said fluorinated polyurethane silane.

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37. The roofing article of any one of claims 30 to 36, wherein said overcoat comprises a mixture of acrylic and fluorinated polyurethane silane with nanosilica particles dispersed in said fluorinated polyurethane silane.

*FIG. 1*

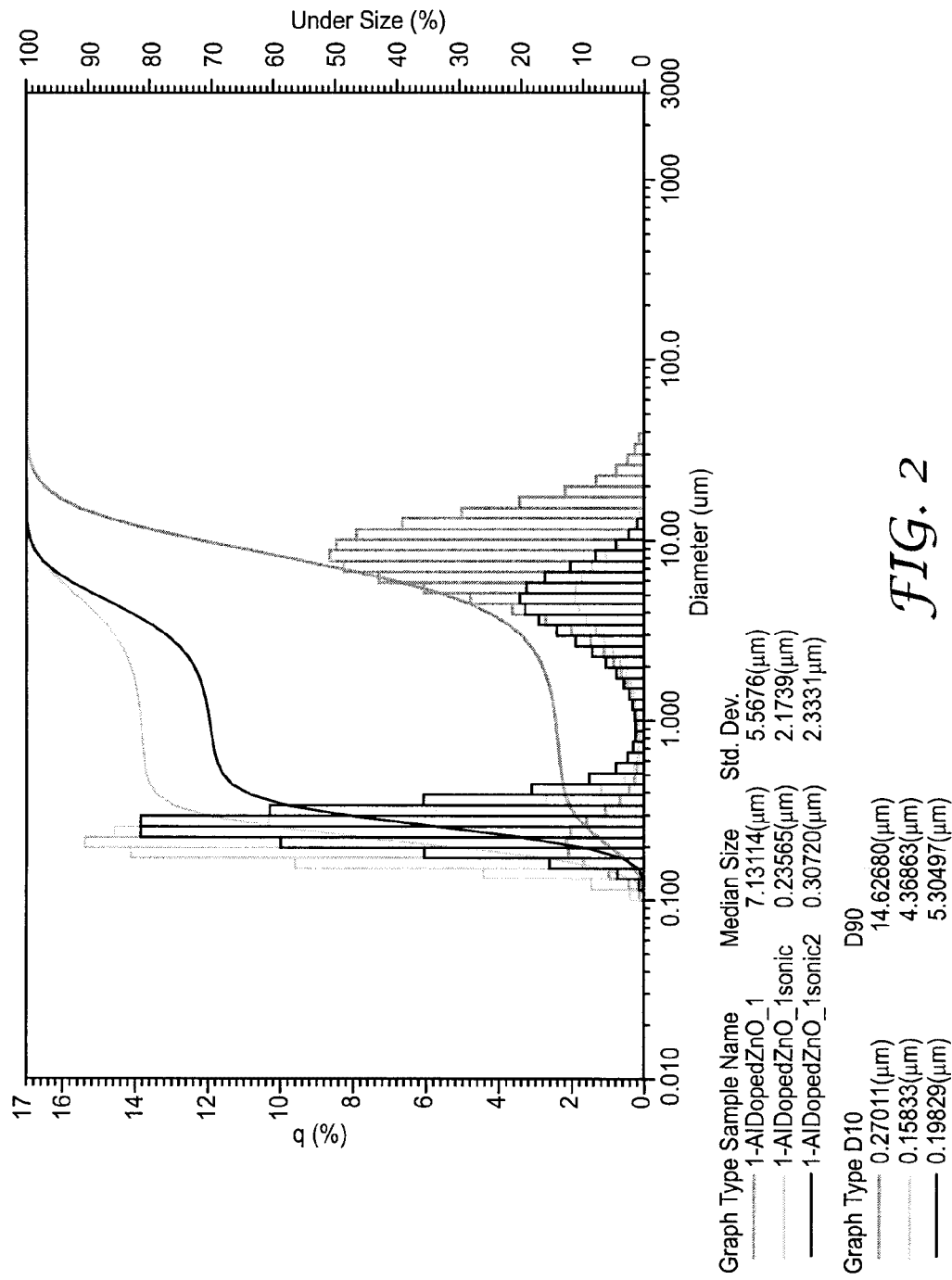


FIG. 2

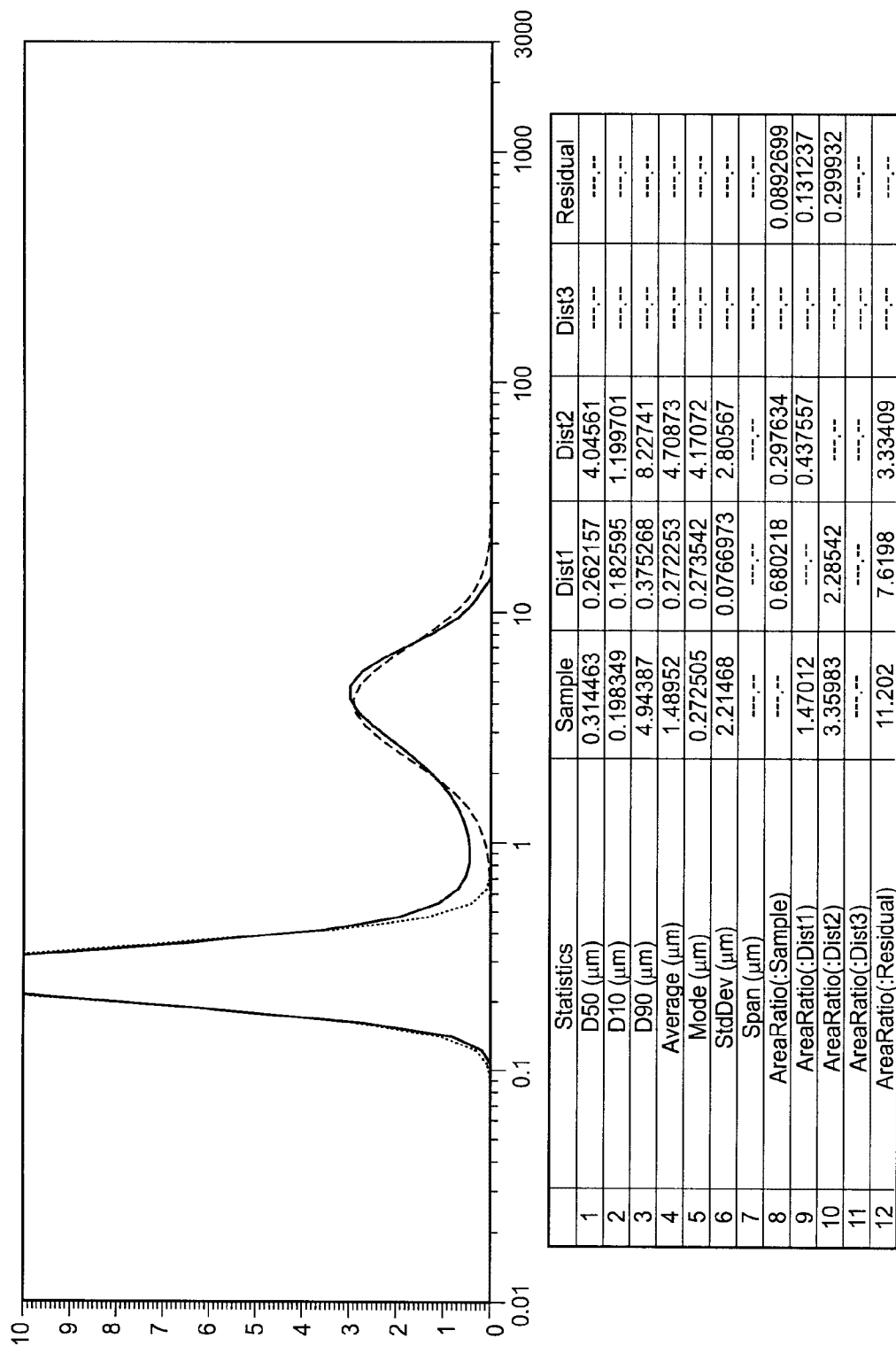


FIG. 3

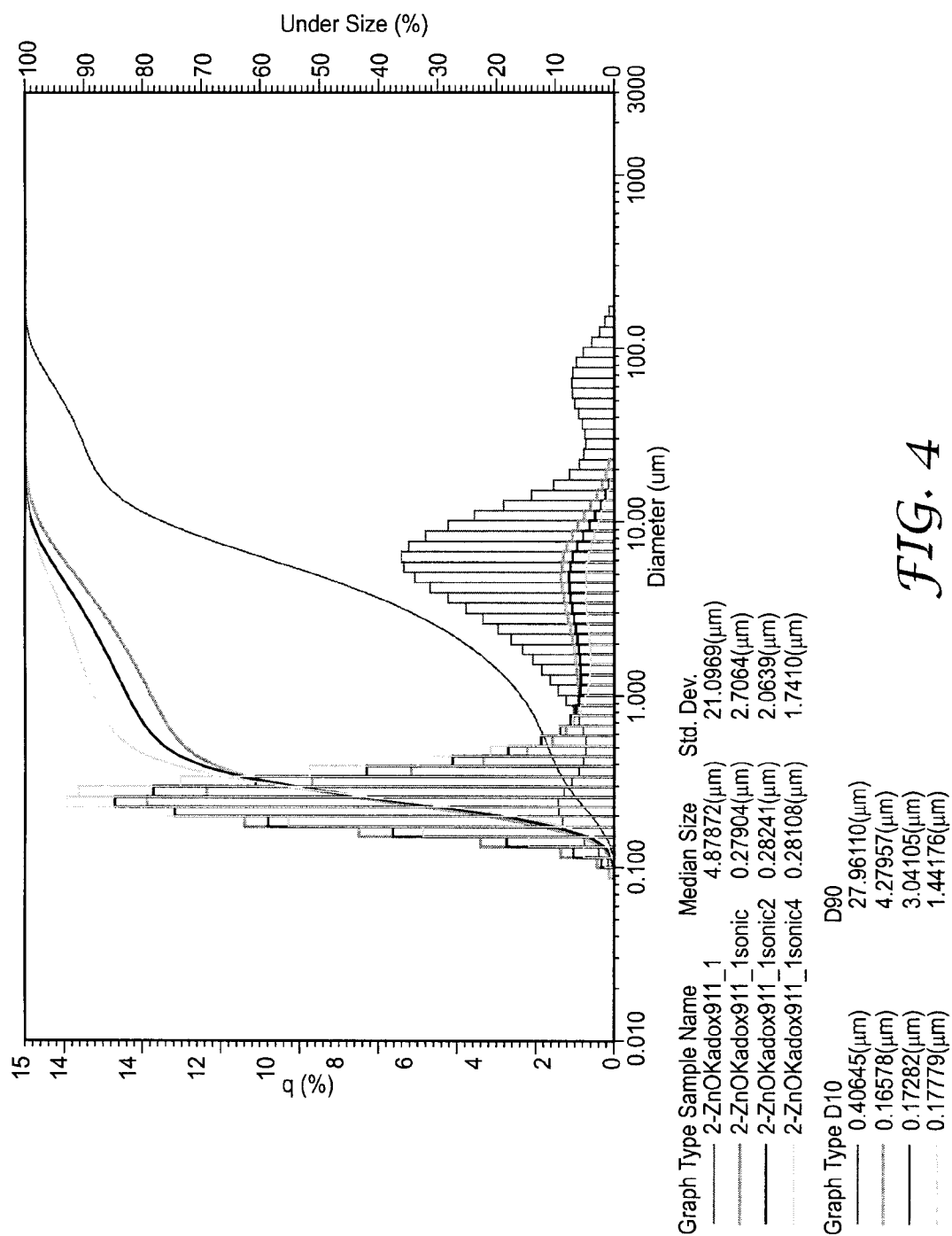
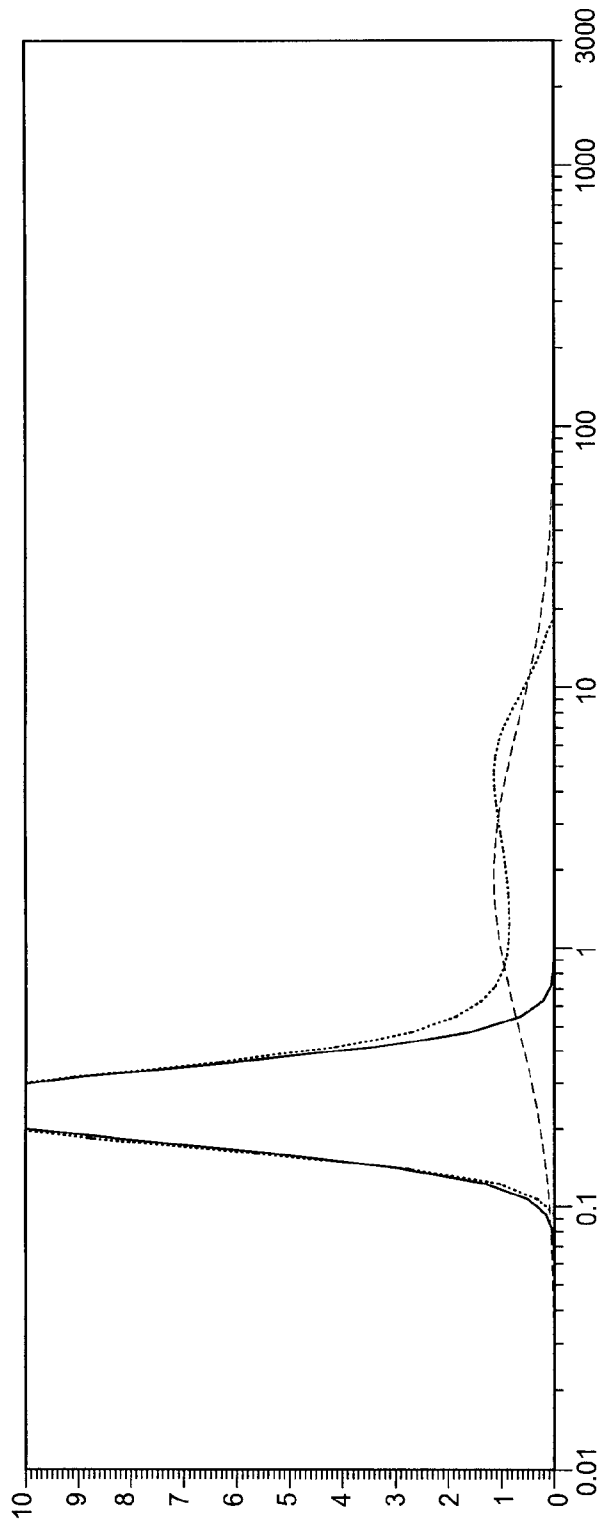


FIG. 4



	Statistics	Sample	Dist1	Dist2	Dist3	Residual
1	D50 (µm)	0.282407	0.245399	1.91714	---	---
2	D10 (µm)	0.172818	0.160135	0.354615	---	---
3	D90 (µm)	3.04105	0.375469	10.36	---	---
4	Average (µm)	1.02071	0.259063	4.55735	---	---
5	Mode (µm)	0.242334	0.242227	1.85149	---	---
6	StdDev (µm)	2.06388	0.0874631	9.81929	---	---
7	Span (µm)	---	---	---	---	---
8	AreaRatio(:Sample)	---	0.73867	0.278041	---	0.0946179
9	AreaRatio(:Dist1)	1.35378	---	0.376408	---	0.128092
10	AreaRatio(:Dist2)	3.59659	2.65669	---	---	0.340302
11	AreaRatio(:Dist3)	---	---	---	---	---
12	AreaRatio(:Residual)	10.5688	7.80688	2.93857	---	---

FIG. 5

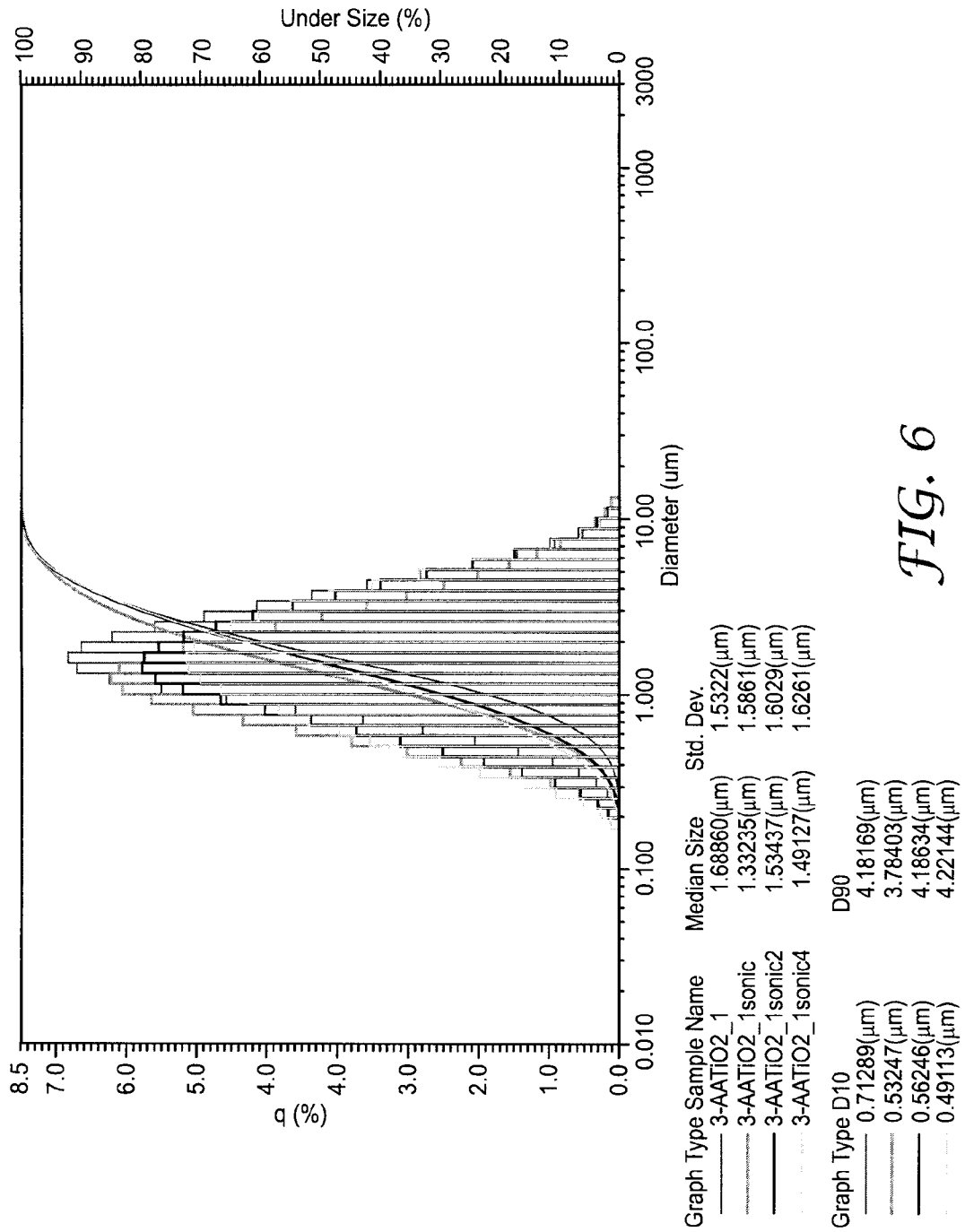


FIG. 6

