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Publisher's version / Version de l'éditeur:

Journal of Testing and Evaluation, 16, 3, pp. 322-327, 1988-05

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Granule Embedment on Shingles and Roofing Membranes

by O. Dutt

ANALYZED

Reprinted from
ASTM
Journal of Testing and Evaluation, JTEVA
Vol. 16, No. 3, May 1988
p. 322-327
(IRC Paper No. 1553)

NRCC 29216

RÉSUMÉ

On a soumis à des essais des échantillons de bardeaux et de membranes bitumineuses modifiées revêtus de granules de pierre, de laitier ou d'ardoise pour déterminer la quantité de granules appliqués et la surface de bitume couverte. Le degré d'enrobage des granules à l'état sec et après mouillage a été évalué au moyen de 50 passages d'une brosse d'acier sur les échantillons. Cinq échantillons représentatifs, sur les treize choisis, ont également été soumis à l'essai de frottement prolongé, au cours duquel on a porté le nombre de passages de la brosse à 150 (par séquences) pour évaluer la rétention. Les résultats montrent des écarts importants entre les échantillons.

La plupart des normes prescrivent une limite maximale de perte de granules. Bien que cette façon de faire convienne pour le contrôle de qualité, la perte devrait être proportionnelle à la quantité de granules appliqués plutôt que soumise à une limite fixe. Pour bien vérifier l'adhérence des granules, il faut contrôler les paramètres suivants : perte de granules à l'état humide, surface couverte initialement par les granules, et tendance des granules à se détacher sous l'action d'un frottement prolongé.

Granule Embedment on Shingles and Roofing Membranes

Authorized Reprint 1988 from Journal of Testing and Evaluation, May 1988
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REFERENCE: Dutt, O., "Granule Embedment on Shingles and Roofing Membranes," *Journal of Testing and Evaluation*, JTEVA, Vol. 16, No. 3, May 1988, pp. 322-327.

ABSTRACT: Samples of shingles and modified bituminous membranes covered with stone, slag or slate granules were tested for the amount of granules applied and the coverage provided to the bitumen. The granule embedment in the as-received condition and after wetting was measured by scrubbing the samples with 50 strokes of a steel wire brush. Five representative samples out of the thirteen were also subjected to an extended scrub test, where the number of scrub strokes was increased to 150 (in intervals) to evaluate the retention. The results showed significant variations between samples.

The requirement of a fixed amount of granule loss exists in most standards. Although this is adequate for quality control, the loss should be proportional to the quantity of granules applied, rather than a fixed amount. Proper assessment of granule adhesion requires testing for wet granule loss, for the initial granule coverage and for the tendency for granules to detach under extended scrubbing.

KEY WORDS: adhesion of granules, bituminous surface, granule embedment, modified bituminous membrane, roofing granules, scrub test, shingles, slag granules, slate granules

Mineral granules are commonly used as surfacing material for many bituminous roofing products such as shingles and roll roofing, as well as many new modified bituminous membranes. In general, the base product is one or more layers of reinforcement saturated and coated with bitumen. The granules applied to the base are of stone, slate, or slags from copper, nickel and steel and blast furnaces. The bitumen is the waterproofing component, and it must retain its integrity for the roof to perform in all kinds of inclement weather conditions. Solar radiation and oxygen are particularly harmful, as they cause photo-degradation of bitumen. This and the effect of weathering, in general, lead to lowered adhesion of the granules.

Practically, all bituminous roofing membranes, whether prefabricated, built-up, or cold- or hot-applied liquid, are protected with suitable surfacing such as mineral granules and aggregates, paint, aluminum foil, tiles, concrete, mineral stabilizers, or reinforcing fibers incorporated in the top coating or with insulation boards in the inverted roofing system [1,2].

The principal functions of granules are to shield the bitumen from solar radiation, to reduce surface temperature, to improve impact resistance from foot traffic, hailstones and dropped ob-

jects, and to provide improved fire resistance to the surface. They also add to the weighing down of shingles and membranes against wind uplift. On sloping roofs, granules offer excellent non-slip and non-stick walking surfaces during roof application, inspection and repair. In bundles or rolls of roofing materials for shipment, the granules act as an anti-stick medium between layers. Colored granules enhance the aesthetics and influence the temperature of roofing.

Suitable grading of granules is necessary to provide maximum coverage of the bitumen. Complete coverage is only theoretically possible [3]. In practice, many other factors affect coverage, such as the irregular shape of granules and their random distribution on the surface and excessive granules. The granules drop through chutes onto the top surface of fast-moving coated sheets in a roofing plant and are embedded in the coating as the sheet passes through rollers. The embedment is affected by the thickness of the top coating, roller pressure and the temperature and viscosity of bitumen at the point of granule application, as well as the quantity, type, size, shape and surface texture of the granules.

The granule loss test is a standard method for determining adhesion of granules and is frequently used as a part of the quality control program in roofing plants. The test involves clamping the specimen in an apparatus (Fig. 1a) and scrubbing the surface with a steel wire brush (Fig. 1b). The total mass of the brush and holder is 2.27 kg (5.0 lb), putting a pressure of 28 kPa (4.15 psi) on the rectangular area encompassing the 22 clusters of wires. The essential function of the apparatus is to provide a back-and-forth movement

FIG. 1a—Granule embedment test apparatus.

Manuscript received 4/6/87; accepted for publication 9/25/87.

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FIG. 1b—Standard steel wire brush.

of the brush through 171 mm (6 3/4 in.), while the 50 by 250 mm (2 by 10 in.) test specimen is held in position by clamps. In some machines, the brush is stationary and the tray holding the specimen moves back and forth. The net area of surface scrubbed is computed as 5300 mm² (8.22 in.²) (Fig. 2). The test method and equipment [4] have been progressively developed since the early 1930's through modifications of a brush and machine used to test sandpaper.²

In the standard test, the mass of granules removed by 50 full-cycle (back-and-forth) strokes of the brush is determined by weighing the specimen before and after scrubbing. If the loss of granules does not exceed the specified limit, the embedment is considered adequate. These conditions and the requirement for maximum amount of granules removed differ in the various standards (Table 1). The fixed approach is easier for quality control and is realistic when comparing like materials. The test provides a measure of the degree of embedment of the granules. This does not, however, predict accurately the retention of adhesion of granules, which depends on various environmental and production factors.

The durability of granule adhesion and maximum coverage for the protection of bitumen are vital to the performance of roofing. None of the standards (Table 1) makes any reference to them. Both these aspects are examined in the present study of shingles and modified bituminous membranes surfaced with granules of stone, slag and slate. The samples were tested for the amount of granules applied, the area of covered bitumen, and the detachment of granules resulting from 50 full cycle scrubs in both the dry and wet condition. Selected samples were also subjected to an increasing num-

FIG. 2—Extreme left and right positions of the brush during scrubbing in granule embedment test (net scrubbed area = 5300 mm²).

TABLE 1—Standards requirements for mass of granules applied and/or removed in embedment test.

No.	Standard ^a	Minimum Granules Applied, g/m ²	Max. Loss of Granules By Scrubbing, When	
			Dry	Wet
1	CSA Standard A123.1-M1979 for asphalt shingles surfaced with mineral granules	900	1.0 g	...
2	ASTM D 225, Asphalt shingles surfaced with mineral granules	903	...	...
3	ASTM D 249, Asphalt roll roofing (organic felt) surfaced with mineral granules	1171	...	...
4	ASTM D 3462, Asphalt shingles made from glass felt and surfaced with mineral granules	1221	...	...
5	ASTM D 3909, Asphalt roll roofing (glass felt) surfaced with mineral granules	1170	...	...
6	CGSB Standard 37-GP-56M for modified bituminous prefabricated and reinforced membrane for roofing	...	2.0 g	...
7	UEAtc Nos. 30 and 31, special directives for the assessment of reinforced waterproof coverings in APP and SBS modified bitumens, respectively	...	30%	50%
8	UL 55B Class C asphalt, organic-felt sheet roofing and shingles	...	1.0 g	...

^aASTM - American Society for Testing and Materials
 CGSB - Canadian General Standards Board
 CSA - Canadian Standards Association
 UEAtc - European Union of Agrément
 UL - Underwriters Laboratories

²Personal communication with 3-M company personnel concerning the granule industry (Feb. 1984).

ber of scrubs to a maximum of 150, in intervals. This has been called the "Extended Scrub Test," as it provides information about the trend to lose adhesion as shown in a hypothetical situation in Fig. 3. This trend is based on various factors, stated earlier, which affect the initial embedment of granules.

Experimental Procedure

Sample Preparation

A minimum of five specimens each for dry and wet tests and three specimens each for extended tests were cut in the machine direction from each sample of shingle and modified bituminous membrane. They were 50 mm wide and 250 mm long, for mounting in the test machine. They were conditioned for the dry, wet and extended scrub tests as follows:

(a) For dry and extended tests, samples were kept at a temperature of $23 \pm 2^\circ\text{C}$ ($73.5 \pm 3.5^\circ\text{F}$) and $50 \pm 5\%$ relative humidity for 24 h.

(b) For wet tests, samples were soaked in distilled water at 21°C (71°F) for 24 h followed by mopping up the water with a paper towel and drying the surface with light air jet.

Descriptions of samples and their designations are given in Table 2.

Two specimens having a total area of approximately 300 cm^2 were cut from each sample and tested for (1) the area of exposed bitumen using the linear traverse method described in the Coverage of Bitumen section, and (2) the amount of granules adhered to the surface, described in the Granules section.

FIG. 3—Extended scrub test of two hypothetical samples Z_1 and Z_2 .

TABLE 2—Description of samples tested.

Designation	Granules	Roofing Product
A1	stone	organic felt shingle
A2	stone	organic felt shingle
B1	stone	glass mat shingle
B2	stone	glass mat shingle
C1	stone	prefabricated modified bituminous membrane
C2	stone	prefabricated modified bituminous membrane
D1	slate	prefabricated modified bituminous membrane
D2	slate	prefabricated modified bituminous membrane
D3	slate	prefabricated modified bituminous membrane
D4	slate	prefabricated modified bituminous membrane
E1	slag	organic felt shingle
E2	slag	organic felt shingle
E3	slag	organic felt shingle

Granules

The granules were removed by soaking the specimens of shingles and membranes in xylene overnight, washing the granules with the solvent, and drying them in an air circulating oven. The quantity obtained from each specimen was weighed after removing fine mineral matter passing a No. 60 ($246\text{ }\mu\text{m}$) sieve and then sieved for particle size distribution in accordance with ASTM Method for Sieve Analysis of Granular Mineral Surfacing for Asphalt Roofing Products (D 451) using sieve sizes in accordance with the industry's existing practice. The sieve analysis values for a typical sample of each granule type are given in Table 3.

The surface area of each specimen from which granules were obtained was measured and the mass of granules adhered per unit area was computed and recorded (Table 4).

Coverage of Bitumen

The surface of each sample was examined to measure the percentage area of exposed bitumen; this was subtracted from 100 to obtain the coverage provided by the granules. For this purpose, ASTM Practice Microscopical Determination of Air-Void Content and Parameters of the Air-Void System in Hardened Concrete (C 457) was adapted to the measurement of the bitumen exposed through intergranular spaces [5]. This test, which is generally labor intensive, was particularly so in the case of slag or other dark-colored granules because of their poor contrast with bitumen. The resulting values of the coverage on the samples are given in Table 4, along with the results from the scrub test.

TABLE 3—Sieve analysis of three types of granules.

Standard Sieve			% Mass of Granules Retained on Sieves			
Tyler No.	U.S. No.	Opening, mm	Stone	Slag	Slate	Industry's Standard for Stone
8	8	2.362	0	0	0	0-trace
10	12	1.651	5.3	5.2	2.5	4-10
14	16	1.168	35.3	30.6	26.2	30-45
20	20	0.833	32.4	33.8	37.6	25-37
28	30	0.589	19.9	18.6	26.4	14-24
35	40	0.417	5.5	7.0	5.2	2-9
Pan	...	...	1.6	4.8	2.1	0-2

TABLE 4—Granule coverage of bituminous surfaces and the scrub test results.

Sample No.	Granule Type/Surface ^a	Quantity of Granules Adhered to Surface, g m ²	Area of Bitumen Covered Before Test, %	Loss of Granules in 50 Scrub Cycles							
				Dry				Wet			
				Mean Value		No. of Specimens Tested	Standard Deviation, g	Mean Value		No. of Specimens Tested	Standard Deviation, g
				g	%			g	%		
A1	Stone/OS	1338	87.2	0.41	6	8	0.15	1.14	16	5	0.26
A2	Stone/OS	1387	89.4	0.82	11	7	0.25	1.10	15	5	0.25
B1	Stone/GS	1703	90.5	1.42	16	10	0.22	3.5	39	5	0.30
B2	Stone/GS	1470	83.6	0.21	3	6	0.06	0.39	5	5	0.07
C1	Stone/MB	1351	92.0	1.19	17	7	0.37	6.75	94	5	0.24
C2	Stone/MB	1385	88.9	1.29	18	5	0.44	1.78	24	8	0.30
D1	Slate/MB	757	91.6	1.26	31	5	0.42	1.35	34	5	0.35
D2	Slate/MB	873	94.6	1.29	28	5	0.32	1.94	42	5	0.21
D3	Slate/MB	716	96.0	3.35	88	5	0.11	3.54	93	5	0.32
D4	Slate/MB	707	96.4	0.77	21	5	0.11	1.13	30	5	0.13
E1	Slag/OS	1362	92.5	0.37	5	6	0.14	1.31	18	5	0.29
E2	Slag/OS	1338	88.5	0.16	2	5	0.04	0.55	8	5	0.12
E3	Slag/OS	1726	82.6	0.68	7	5	0.07	0.90	10	5	0.14

^aOS—Organic felt shingle; GS—Glass-fibre mat shingle; MB—Modified bituminous membrane.

Scrubbing of Samples

(a) *Dry Testing*—Specimens from various samples, listed in Table 2, were scrubbed in the dry (as-received) condition on the granule embedment tester. The amount of granules removed by 50 full-cycle strokes of the steel brush was determined for at least five specimens of each sample. Their mean and standard deviations are given in Table 4.

In the scrubbing of modified bituminous membranes the following problems were encountered that required additional work:

- (i) In the case of comparatively thinner membranes and cap sheets of modified bitumen, the specimens tended to stretch and wrinkle as the weighted steel brush moved back and forth, because of the supple nature of the material. This increased the amount of granules removed. To overcome this anomaly, the specimens were adhered with double-sided tape to a hard substrate such as rigid plastic sheet or cardboard and the assembly was weighed before and after scrubbing. This solved the problem.
- (ii) Because of the softness of modified bitumen (as compared to the harder asphalt on shingles), the granules kept leaning backward and forward with the scrub strokes and finally broke off with bitumen particles sticking to them, thereby increasing the mass loss. A sample of granules removed was washed with xylene to remove bitumen, dried in the air-circulating oven and then reweighed. This component (bitumen particles) was found to be 2 to 3% of the mass of granules removed. This percentage was used to correct the granule loss in the test.
- (iii) The abrasion of slate granules stuck flat to the membranes caused mass loss but no additional exposure of bitumen. This dust was found to be between 1 and 2% of the mass of the detached granules.

These differences were taken into account when computing the final loss of granules, the mean values and standard deviations. In cases where granule loss from different specimens of a sample showed considerable deviations from the mean value, additional

specimens were tested and others rejected on the basis of the significance level of the differences.

(b) *Wet Testing*—The test was conducted on the wet specimens that had been soaked in water for 24 h. The surfaces were mopped with paper towel and dried with a light air jet.

In testing wet specimens, it was considered that moisture evaporated during the test could introduce an error in the mass of granules lost. Accordingly, in each case a duplicate specimen was soaked in water, mopped, surface dried, and weighed right after the test specimen was weighed. This loss of moisture from the control specimen was subtracted from the loss of the test specimen, excluding the error due to evaporation. Also, the detached granules carried some absorbed or surface moisture that added to their mass. The mass of water was determined for each type of granule. Both errors were found to be 3 to 5% of the mass lost. The corrected means and standard deviations are given in Table 4.

(c) *Extended Scrub Testing*—Three specimens each of selected samples, conditioned at room temperature and humidity, were subjected to extended scrubbing to determine if there was a trend to greater granule loss. They were scrubbed and weighed at intervals of 5, 10, 25, 50, 100 and 150 scrub cycles, or a similar set of numbers of cycles, to determine the granule loss. The plotted mean values of granule loss at each interval are shown in Fig. 4.

Results and Discussion

The sieve analysis was done to investigate if the grading of different samples of granules was within the normal range specified by the granule manufacturers. As seen in Table 3, the slate granules, which are generally found on imported roofing materials, have somewhat different grading than those of the stone and slag manufactured in North America. Amount of coverage of bitumen provided by granules is closely related to the grain size distribution of granules [5].

The results for the quantity of granules adhered to various samples of shingles and modified bituminous membranes, the amount of coverage provided by them, and the loss of granules in the stan-

FIG. 4—Granules removed in extended scrub test of various samples (see Table 2 for designations).

dard embedment test (Table 4) show a significant variation amongst the different samples. This is attributed to numerous factors resulting from conditions during manufacture of the roofing materials, such as the thickness of the top coating, filler content, the temperature and viscosity of the stabilized asphalt at the point of granule application, the roller pressure, the sheet tension, and the type, size, shape and amount of granules. Variation is partly attributable to the segregation of granules that occurs during their transportation, storage, and passage through the application chutes. It is easily distinguishable as patches of smaller or larger sizes that affect the precision of tests.

In the case of modified bituminous membranes, the viscosity of the blend at the point of granule application is an important factor in the embedding of granules because the properties of modified bituminous coating at high temperature are different from those of the conventional asphalt coating. The difference in this respect is seen in the comparatively larger amount of granules lost by the modified bituminous membrane in the dry scrub test, as in Samples C1 and C2 compared with Samples A and E (Table 4).

The quantities of stone or slag granules applied on shingle samples A, B, and E (Table 4) are, in all cases, more than the minimum specified in some standards (Table 1). In the other standards for shingles and modified bituminous membranes, there is no such requirement. It is reasonable to assume that some manufacturers prefer to use more granules, which are less expensive than bitumen and felt; this provides greater coverage of bitumen and, in turn, causes greater loss of granules in the test, as seen in Sample B1.

It was observed during the microscopic examination of samples that in some cases a slightly thicker coating or an excess pressure on the roller due to tension of the sheet during manufacture had embedded larger granules deeper and squeezed the hot bitumen up through the intergranular spaces, resulting in greater exposure of bitumen. This condition of increased embedment in turn reduced

the coverage and loss of granules by scrubbing (this can be seen by comparing Samples B2 with A2 and E3 with B1 [Table 4]).

Slate granules found only on modified bituminous membranes (Samples D1 to D4 [Table 4]) were tested. Being thin and flaky, they provide a much larger coverage per unit mass than the stone granules, so the quantity applied is less. Of more importance, the slates tend to adhere to the bitumen that squeezes out of intergranular spaces, forming a top layer that partially overlaps the lower layer. These top granules are easily removed in the scrub test, but those in the lower layer that lie flat are much harder to detach and are only abraded by the steel wire brush, which removes slate dust without exposing more bitumen. Some granules that are embedded on edge bend with the initial strokes of the brush because of the flexibility of modified bitumen. As the scrubbing continues, they are removed along with adhering bitumen, giving a comparatively higher mass loss in the scrub test. Stone granules on MB membranes (Samples C1 and C2 [Table 4]) do not exhibit any unusual difference in the amount of coverage and loss of mass by scrubbing, but they do carry adhered bitumen particles when detached from the membrane. This difference was accounted for in the results presented in Table 4.

The wet granule-covered surface shows a higher granule loss after scrubbing than the dry surface (Table 4). The difference in granule loss between the two test conditions varies, in general, from 2 to 22%, except in the case of Sample C1, which shows an abnormally high difference of 77% (the test for this sample was repeated to check possibility of an error and found to be correct). The reduction of adhesion of granule to bitumen due to wetness may be attributed to the stripping of the asphalt. This aspect, however, needs further research. Nevertheless, the UEAtc recognizes the wetness factor, as is evident from the requirement in the applicable standard (Table 1). This factor has potential for further investigation.

Conclusions

1. The non-uniformity in the placement of different types of granules and their embedment in bituminous coating is inherent in the conditions during manufacturing, such as:

- Thickness of coating.
- Temperature and viscosity of bitumen at the point of granule application.
- Segregation of granules in transportation, storage and application.
- Speed of coated sheet.
- Sheet tension or roller pressure.

2. The amount of granule loss determined with the standard embedment test is higher than the actual loss, due to the bitumen sticking to the granules. On the other hand, dust caused by the abrasion of granules that remain embedded is removed without affecting the coverage. These anomalies are significant in the case of modified bituminous membranes. They should be taken into account when setting limits in standards.

3. Scrubbing of a granule covered surface when wet causes much greater loss of granules compared to the original dry condition. This is recognized in the European UEAtc Directives (Table 1). Accordingly, the wet storage of shingles becomes a critical factor in this regard. It also suggests that walking on a wet shingled roof could cause considerable loss of granules.

4. The initial coverage of bitumen as well as the amount of gran-

ules removed by scrubbing are related to the total granules applied and their embedment, both of which vary with the manufacturer. In order to get a complete picture of granular protection:

- (a) Granule loss in the scrub test should be based on a percent of the mass of granules applied, rather than a fixed quantity.
- (b) The extended test should be conducted, since this is indicative of the retention of adhesion.
- (c) Initial coverage of bitumen by granules should be determined, since this is related to the principle function of granules.

Acknowledgments

The author acknowledges with thanks the assistance of G. A. O'Doherty and D. A. Neely in conducting the laboratory tests. This paper is a contribution from the Institute of Research in Construction, National Research Council of Canada.

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