Net Adsorption Test for Chip-Sealing Aggregates and Binders

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The net adsorption test (NAT) (M-001) developed for the SUPERPAVE mix design procedure is of interest to those concerned with selecting binders and chippings for chip seals (surface dressings). The relevance of the NAT, which is performed on the fine aggregate fraction, for assessing the adhesion performance of chipping sizes of 14 mm (0.55 in.) used for chip seals and the behavior of bitumen emulsions is evaluated. Since the surface chemical composition of 14-mm (0.55-in.) chippings was not found to be statistically different from the composition of the fine aggregate fraction from the crushed chippings, it was accepted that NAT results were indicative of the adhesion performance of the chippings with the binder used in the test. In testing bitumen emulsions the prior removal of the water phase by evaporation was necessary. Results obtained with aggregate-bitumen combinations used for chip sealing in Ireland corresponded to the Strategic Highway Research Program (SHRP) findings that aggregate type has a dominating influence on binder-aggregate adhesion. However, with aggregate-emulsion combinations the emulsion source had a major effect, and the influence and type of emulsion surfactant was assumed to be responsible for the very specific affinity of these binders for aggregates. This is consistent with results of SHRP studies on the effect of antistripping agents on bonding energies. If the percentage net adsorption is determined on the basis of the total binder in the test solution, an overall expression of the binder-aggregate affinity and resistance to moisture damage is provided.

The Strategic Highway Research Program's (SHRP's) net adsorption test (NAT) is based on the physical chemical adsorption of a solute (bitumen) from a solution onto a solid (road aggregate). The test provides a fundamental quantitative measure of the affinity between bitumen and aggregate and a means of measuring quantitatively the effects of factors such as moisture, bitumen additives, and so forth on the bond.

Previous research, since 1950, has indicated the importance of the influence of aggregate type and properties on the aggregate-binder adhesion bond. Hallberg (*1*) conducted experiments, from 1950 to 1958, on the influence of aggregate petrography on the aggregate-binder adhesion bond and indicated statistically that the adhesion performance of the bond was better with basic (low silica content) as opposed to acidic (silica content > 66 percent) rocks.

The SHRP study (*2*) indicates that the mechanism of stripping is failure within the aggregate (*3*) and not separation of binder and aggregate at the interface. This is because of dissolution, particularly of silica, which is relatively soluble at high pH (<9) levels (*4*). A series of NATs on 11 aggregates and 3 bitumens confirmed that the aggregate type has a greater influence on adhesion than variations in bitumen type. Each bitumen exhibited high and low levels of adsorption: for example, high adsorption with limestone and low adsorption with granite, but the magnitude of the differences among the aggregates for each bitumen was quite large.

A routine NAT procedure was developed as a preliminary screening method (M-001) for aggregate-binder combinations in the SHRP SUPERPAVE mix design method (*5*). If this can be used to evaluate aggregate-binder combinations for chip-sealing operations, it would be very useful, as chip sealing (surface dressing) is a major road maintenance procedure throughout the world. The purpose of this paper is to describe the results of an investigation involving aggregates and binders used in chip sealing in Ireland.

ADSORPTION ISOTHERMS

The NAT, as previously mentioned, is based on the phenomenon of adsorption and the SHRP investigation liquid adsorption isotherms that were studied, as indicated in Figure 1. The figure indicates the influence of aggregate type on adsorption of bitumen over a range of bitumen solution concentrations.

Adsorption studies were also used to assess the adsorption affinity of various bitumen components. For example, compounds with polar functional groups (sulfoxides, carboxylic acids, and nitrogen bases) were found to be more adsorptive and formed much stronger adhesion bonds than less-polar compound types (ketones and nonbasic nitrogen groups). However, desorption studies indicated that sulfoxides and carboxylic acids were most susceptible to stripping, whereas the ketones and basic nitrogen groups were most resistant (*2*).

OBJECTIVES

The purpose of this investigation was to determine whether the net adsorption procedure could be used to assess the affinity of aggregate-binder combinations for chip sealing.

The M-001 procedure uses the fine aggregate fraction, 4.75 to 0.0 mm (0.18 to 0.0 in.), of an aggregate grading. However, in chip sealing, only single-sized aggregates are used, usually 10- and 14-mm (0.39- to 0.55-in.) sizes, although even 16-mm (0.63-in.) or larger sizes are used in some circumstances. The NAT is not practical with the aggregate sizes used in chip sealing, since to maintain the same ratio of solvent volume to aggregate used in the research investigation, a large quantity of the solvent would be required.

In addition, the method must be applicable to the most common type of surface-dressing binder, which is bitumen emulsion.

The specific goals therefore were (*a*) to determine whether results obtained on the fine aggregate fraction are applicable to the performance of size chippings, and (*b*) to evaluate bitumen emulsion binders by the NAT procedure.

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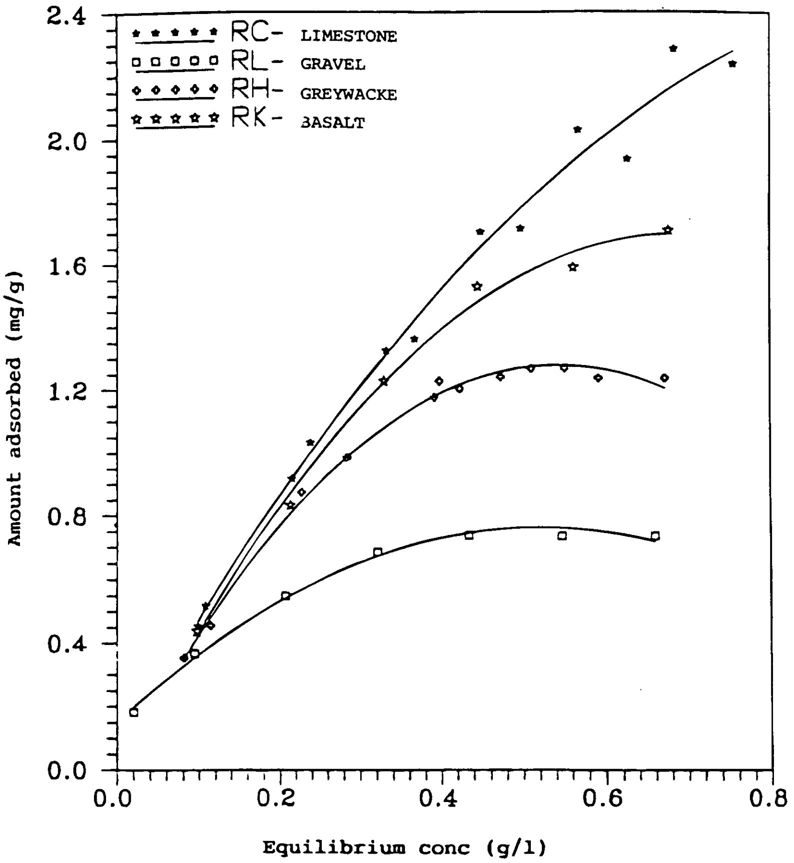

FIGURE 1 Adsorption of bitumen onto four aggregates (*2*).

NET ADSORPTION TEST

The NAT determines (*a*) the affinity between bitumen and aggregate (initial adsorption), and (*b*) the moisture sensitivity of the aggregate-binder bond (net adsorption, or the amount of bitumen remaining on the aggregate after water is added).

Procedure

The test is completed within 24 hr and is carried out in four main steps:

1. Three test flasks are set up for each aggregate-binder combination and a fourth flask is set up as a control. The control is carried through the entire procedure to ensure that there is no material on the surface of the aggregate that will interfere with the test.
2. A bitumen-toluene solution of known concentration is prepared; approximately 1 g of bitumen to 1 L of toluene.
3. Fifty grams of the prepared graded aggregate is added to each of the flasks including the control flask; 140 mL of toluene is added to the control flask and 140 mL of the bitumen-toluene solution is added to each of the other three test flasks. The flasks are subsequently placed on a mechanical shaker and are shaken for 6 hr.
4. After this time, 2 mL of water is added to each flask and shaking is continued for a further period of 16 to 17 hr.

Calculation and Evaluation

In order to calculate both the initial and net adsorption, three measurements on the solution of bitumen in the solvent (toluene) are carried out:

1. Initial concentration of bitumen-toluene solution, A_1;
2. Solution concentration after 6 hr in contact with the aggregate, A_2; and
3. Solution concentration after addition of water to the aggregate-bitumen solution, A_3.

The solution concentrations are determined by a spectrophotometer technique at 410 nm.

The initial adsorption is given by

$$A_i = \frac{VC(A_1 - A_2)}{WA_1}$$

where

V = volume of solution = 140 ml;
C = concentration of bitumen-toluene solution;
A_1, A_2 = solution concentration measurements; and
W = weight of aggregate sample to nearest 0.001 g.

TABLE 1 Criteria Suggested (SHRP) for Aggregate-Binder Adhesion Performance

Percent Net Adsorption	Aggregate/binder bond performance
>70	Good
55-70	Marginal
<55	Poor

The net adsorption is given by

$$A_n = \frac{VC(A_1 - A_3)}{WA_1}$$

where volume at this stage is 136 mL.

$$\text{Percentage net adsorption} = \frac{A_n}{A_i} \times 100$$

These calculations are used in the standard procedure (M-001) and criteria for performance were suggested (*2*) as indicated in Table 1.

The authors found that the precision of the method was excellent using the graded fine aggregate fraction indicated in Table 2. This is the grading used in the SHRP research investigations and unlike the grading used in M-001 it contains no passing 75-µm fraction. Otherwise, the fractions are in proportion with the standard asphalt concrete grading ASTM D3515. The use of a standard grading minimizes variations in surface area, which SHRP indicated to have a major influence on the results of the test. On repeat testing of a number of aggregate-binder combinations, the standard deviation was < 0.05 mg/g compared with the value of 0.08 mg/g as reported by SHRP. All results presented in this report are the means of measurements carried out in triplicate.

TABLE 2 Grading Used for NAT

Sieve Size	Percent Retained	Weight Retained (g)
2.36 mm	8.0	4.3
1.18 mm	25.0	13.5
600 µm	17.0	9.1
300 µm	23.0	12.4
150 µm	14.0	7.5
75 µm	6.0	3.2
		Total 50

Expressing the results as the percentage net adsorption, although effective in illustrating the moisture sensitivity of the bond, does not take into account differences in the amount of bitumen initially adsorbed by the aggregate. For example, in Table 3 of the two aggregates tested with Binder 1, Aggregate A has a net adsorption value of 71.3 percent and Aggregate B a value of 80.8 percent. This suggests that both of these values are acceptable (Table 1). However, if these results are reevaluated, as suggested by Woodside et al. (*6*), to express the initial and net adsorption as a percentage of the total bitumen in the solution, a more discriminating assessment of affinity and resistance to stripping is possible. On reevaluation, it is apparent that Aggregate B actually has a lower initial adsorption (42.7 percent) than A (48.2 percent) and it has only a marginally better net percentage adsorption value than A (35.7 to 35.3).

The performance criteria in Table 1 are not applicable to the reevaluated data, and ranges of values associated with acceptable, marginal, and poor adhesion performance and resistance to stripping are unavailable at this stage. These need to be developed in the light of the known performance of aggregates and binders.

EXPERIMENTAL WORK

Effect of Aggregate Size

Stepwise regression of the SHRP results (*2*) indicated that the chemical and physical properties of the aggregate have a major influence on the net adsorption of the test results. These factors are given in decreasing order of impact in Table 4.

Therefore, it was decided that analysis of the chemical composition of the bulk fine aggregate fraction and the surface of 14-mm chippings could provide a means of determining whether NAT

TABLE 3 Recalculation of NAT Results (*6*)

Calculated Net Adsorption according to SHRP		Re-evaluated adsorption according to Woodside et al(6)	
	Percent	Initial percent	Net percent
Aggregate A	71.3	48.2	35.3
Aggregate B	80.8	42.7	35.7
Performance Criteria -			
Acceptable	>70		
Marginal	55-70		
Poor	<55		

TABLE 4 Influence of Aggregate Properties on Net Adsorption (2)

Aggregate Variables	Correlation Coefficient
Potassium Oxide	0.48
Surface Area	0.71
Calcium Oxide	0.75
Zeta potential	0.87
Sodium Oxide	0.90

results (carried out on the fine aggregate fraction) are acceptable for assessing the performance of larger aggregate sizes. Accordingly, measurements of the chemical composition of the surface (two faces) of the 14-mm-sized aggregate were performed by an energy dispersion technique, after which the aggregate particle was crushed to passing 100 μm and analyzed by x-ray fluorescence spectroscopy. The elemental composition of the surface of the 14-mm chippings and the bulk composition of the fine aggregate fraction, obtained on crushing the chippings, are compared for all seven aggregates in Figure 2.

With the exception of silica (SiO_2), the composition of the surfacing of the chippings and the bulk composition of the fine aggregate fraction were similar and varied only by the order of 2 to 4 percent. Though the silica contents varied by the order of 5 to 10 percent, a *t*-test comparison for correlated samples indicated that

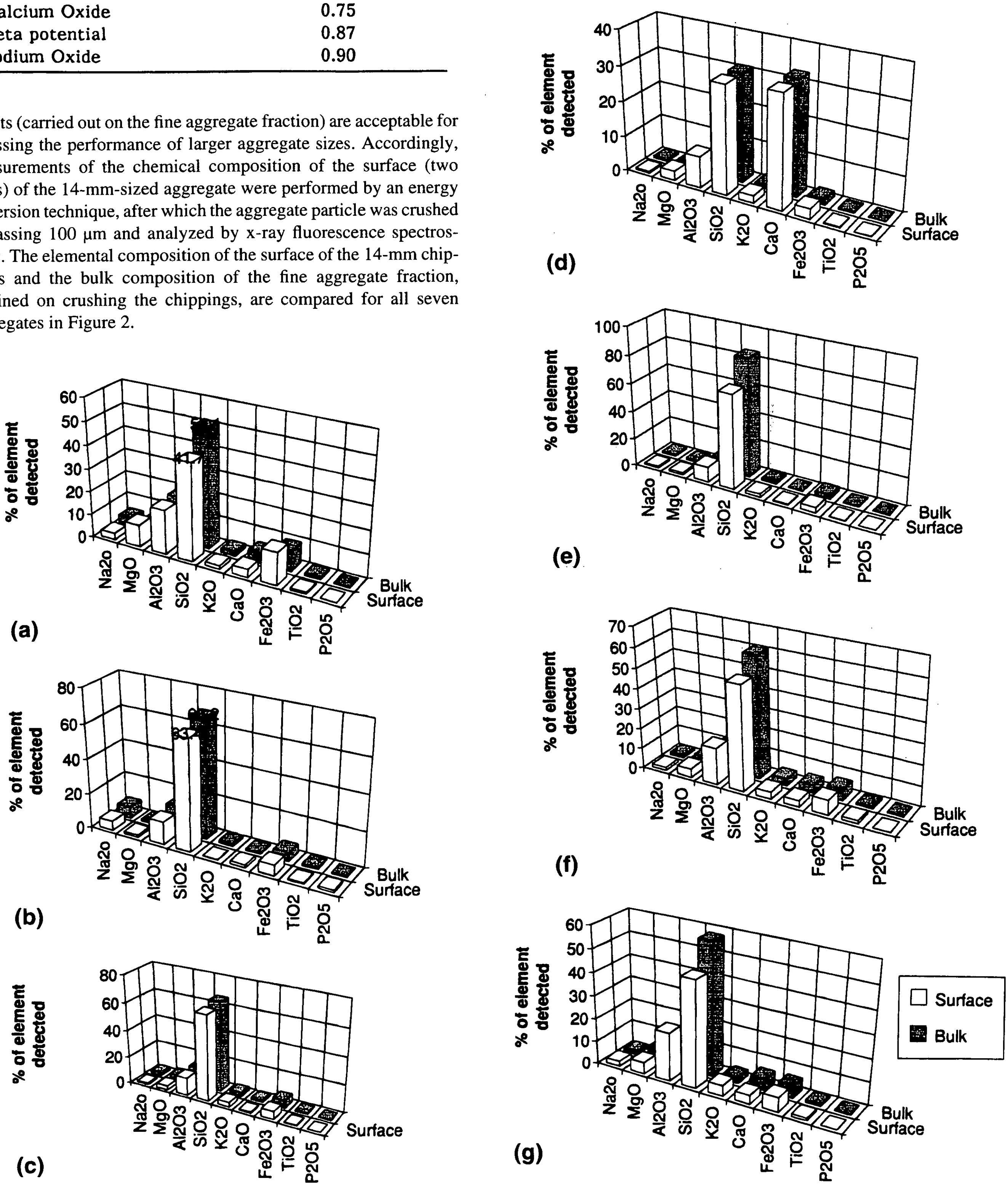

FIGURE 2 Composition: chipping surfaces and crushed fine aggregate fraction: (*a*) basalt, (*b*) granite, (*c*) gritstone, (*d*) limestone, (*e*) sandstone, (*f*) Schist A, (*g*) Schist B.

these differences are insignificant at a level of $p < 0.01$. Based on the hypothesis that the means of the sample results, that is, 14-mm size and crushed fine aggregate fraction, are the same, $\mu_1 = \mu_2$ or $\mu_1 - \mu_2 = 0$, the significance of these differences was determined by comparing the calculated *t* value (from the results) with a critical *t* value at a particular significance level. These calculations are illustrated in Table 5. In view of this finding and the strong influence of chemical composition of the aggregate on NAT results, it was accepted that results performed on the fine aggregate fraction can be used as an adhesion performance indicator of the larger, 10- to 14-mm size chippings with the binder used in the test.

Testing Using Bitumen Emulsions

In testing bitumen emulsions, it is first necessary to remove the water from the solid residue (bitumen containing emulsifying agent). The water was recovered by controlled evaporation in a stream of air under constant pressure and constant temperature for 18 hr (*7*).

It must be recognized that the real situation may be that the presence of moisture in the emulsion is likely to aid in the spreading of the bitumen over the aggregate and as such it may promote better initial adhesion than bitumen. For this reason it may be incorrect to compare test results obtained with bitumen emulsions with results obtained with paving-grade bitumens. However, there is no reason why the test should not be used to rank various bitumen emulsions with aggregates.

VALUES OBTAINED ON IRISH CHIP-SEALING AGGREGATES AND BINDERS

Seven Irish aggregates were selected for the test program. These are typically used for chip sealing in Ireland and they comprised igneous, metamorphic, and sedimentary categories of rock as indicated in Table 6.

The strength of the aggregate was determined by crushing tests yielding results such as the aggregate crushing value and the aggregate abrasion value, and the aggregate's suitability as a road-surfacing material was assessed by the polished stone value test.

Binders were chosen from five different Irish suppliers: two paving-grade bitumens (100 penetration) and three cationic bitumen emulsions.

Paving-Grade Bitumens

Table 7 and Figure 3 illustrate the results obtained for four of the aggregates with Bitumens 1 and 2.

The percentage net adsorption values range from 75.5 percent (Schist A) to 86.8 percent (gritstone) with Bitumen 1, and from 77.3 percent (Schist A) to 83.5 percent (Schist B) with Bitumen 2. Of the four aggregates, Schist A appears to have the lowest stripping resistance with both binders. The differences in net adsorption for these aggregates with Bitumen 1 are quite large; there is an 11 percent difference between the result obtained with Schist A and gritstone and a 6 percent difference between Schist B and gritstone.

An interaction diagram (Figure 4) indicates that the influence of binder type varies according to the type of aggregate. In the case of granite and gritstone, Bitumen 2 has an adverse effect on the net adsorption value, indicating a greater suspectibility to stripping. With Schists A and B, however, Bitumen 2 has a positive effect on the net adsorption value, indicating a superior stripping resistance. Thus although the aggregate properties play a very significant role in determining the strength and durability of the bond, the type of binder can also have an important effect.

The results given by Bitumen 2, with granite and gritstone in particular, are quite similar. However, reevaluation of the results, as described previously, to express the initial and net adsorption as a percentage of the total bitumen in the solution indicates (Table 8) that the adsorption varies quite considerably. It is clear that Bitumen 2 has a greater affinity for granite with an initial adsorption of 45.7 percent compared with 37.1 percent for gritstone. The net adsorption values, of 37.1 and 30.5 percent, respectively, indicate that the gritstone has a marginally higher stripping resistance than the granite.

Bitumen Emulsions

Table 9 presents the results obtained for the seven aggregates with the three cationic bitumen emulsions. The results are calculated according to the methods of SHRP and of Woodside (*6*). Figure 5 illustrates the NAT results in bar chart form.

The source of emulsions appears to play a more significant role in the effectiveness of the adhesion bond than do the variations in the source of paving-grade bitumens. For example, in the case of Emulsion 1, basalt has a net adsorption value of 66.5 percent, limestone has a value of 90.1 percent, and Schist A has a value of 75.9 percent. Comparing Table 9 with Table 7 indicates that some values are lower than those obtained with paving-grade bitumens and some aggregate-emulsion combinations are actually below the acceptable limits of 70 percent recommended by SHRP. Granite, with Bitumens 1 and 2, has high net adsorption values of 83 and 79.4 percent, respectively, but with Emulsions 1 and 2 substantially lower values, 63.8 and 64.3 percent, were obtained. Similar effects were observed with the gritstone in particular, with a 15 percent difference between Bitumen 1 and Emulsion 2. In some cases, therefore, the emulsion type can have an adverse effect on the moisture sensitivity of the bond. The affinity of an aggregate and bitumen with surfactant appears to be unique for the type of surfactant and aggregate. SHRP investigations on bitumens modified with anti-stripping agents provided similar results, as indicated in Figure 6.

The reevaluated initial and net values, in Table 9 and Figure 7, indicate that granite-emulsion combinations have the lowest affinity of all combinations of aggregate type and emulsion source. Initial and net adsorption values are 38.9 and 25.7 percent, respectively, with Emulsion 1; 40.5 and 26.8 percent with Emulsion 2; and 37.1 and 30.9 percent with Emulsion 3.

CONCLUSIONS

The NAT (M-001) developed for the SUPERPAVE procedure was used to rank the affinity of Irish aggregate-binder combinations manufacture and for chip seals (surface dressings). These rankings, however, are based on laboratory experiments. No in-field performance has been recorded to date.

The chemical composition of the surface of 14-mm chippings from seven different sources was not statistically different from the chemical content of the fine aggregate fraction obtained on crush-

TABLE 5 Statistical *t*-Test Analysis of Silica, Alumina, and Iron Content of Fine Aggregate Fraction and 14-mm Sizes of Selected Aggregates

Silica

	Dust	14mm
Basalt	51.1	41.7
Granite	68.2	63.4
Gritstone	65.7	63
Limestone	30.8	30.9
Sandstone	84.8	67.7
Schist A	60.2	51.9
Schist B	57.5	46.1

t-Test: Paired Two-Sample for Means

	Dust	*14 mm*
Mean	59.7571	52.1
Variance	275.4162	180.5833
Observations	7	7
Pearson Correlation	0.9478	
Pooled Variance	211.3717	
Hypo. Mean Difference	0	
df	6	
t	3.5130	
P(T<=t) one-tail	0.0063	
t Critical one-tail	3.1427	
P(T<=t) two-tail	0.0126	
t Critical two-tail	3.7074	

Alumina

	Dust	14mm
Basalt	19.2	18.85
Granite	14.4	12.82
Gritstone	13.5	13.2
Limestone	4.16	9.05
Sandstone	6.98	11.11
Schist A	13.5	17.95
Schist B	12.4	21

t-Test: Paired Two-Sample for Means

	Dust	*14 mm*
Mean	12.02	14.8543
Variance	24.8205	19.6506
Observations	7	7
Pearson Correlation	0.7004	
Pooled Variance	15.4682	
Hypo. Mean Difference	0	
df	6	
t	-2.0383	
P(T<=t) one-tail	0.0438	
t Critical one-tail	3.1427	
P(T<=t) two-tail	0.0877	
t Critical two-tail	3.7074	

Iron

	Dust	14mm
Basalt	8.93	14
Granite	5.09	6.12
Gritstone	5.62	5.65
Limestone	1.65	2.93
Sandstone	2.72	3.9
Schist A	5.56	7.2
Schist B	5.37	6.28

t-Test: Paired Two-Sample for Means

	Dust	*14 mm*
Mean	4.9914	6.5829
Variance	5.4514	12.8520
Observations	7	7
Pearson Correlation	0.9382	
Pooled Variance	7.8528	
Hypo. Mean Difference	0	
df	6	
t	-2.6124	
P(T<=t) one-tail	0.0200	
t Critical one-tail	3.1427	
P(T<=t) two-tail	0.0400	
t Critical two-tail	3.7074	

TABLE 6 Mechanical and Physical Properties of Aggregates Selected for the Test Program

Aggregate	Class	PSV	AAV	ACV	% Water Absorption	Specific Gravity
Basalt	Igneous	55	3.0	15	1.0	2.73
Granite	Igneous	52	3.3	26	0.5	2.69
Gritstone	Sedimentary	65	7.0	17	0.7	2.69
Limestone	Sedimentary	62	8.4	18	0.7	2.70
Sandstone	Sedimentary	63	5.3	20	1.64	2.54
Schist A	Metamorphic	63	7.8	16	1.09	2.70
Schist B	Metamorphic	62	8.1	16	0.7	2.69

PSV = Polished Stone Value.
AAV = Aggregate Abrasion Value: Percentage loss in weight of 10-14 mm aggregate chippings obtained by the continued abrasion by sand.
ACV = Aggregate Crushing Value: Percentage by weight of fine material passing a 2.36mm sieve.

TABLE 7 Percentage NAT Results Obtained with Irish Aggregate and Bitumens

	Bitumen 1			**Bitumen 2**		
Aggregate	**A_i Initial Adsorption mg/g**	**A_n Net Adsorption mg/g**	**% NA**	**A_i Initial Adsorption mg/g**	**A_n Net Adsorption mg/g**	**% NA**
Granite	**1.16±0.02**	**0.96±0.02**	**83.0**	**1.28±0.05**	**1.01±0.01**	**79.4**
Gritstone	**1.14±0.02**	**0.99±0.01**	**86.8**	**1.04±0.02**	**0.83±0.02**	**79.8**
Schist A	**1.36±0.05**	**1.03±0.02**	**75.5**	**1.45±0.02**	**1.12±0.02**	**77.3**
Schist B	**1.49±0.02**	**1.20±0.03**	**80.9**	**1.23±0.02**	**1.02±0.02**	**83.5**

Performance Criteria -

Acceptable	**>70**
Marginal	**55-70**
Poor	**<55**

ing the chippings. On this basis, it was accepted that NAT results were indicative of the adhesion performance of surface-dressing chippings when applied with the binder used in the test.

The procedure used for performing the test with bitumen emulsion binders is first to remove the water phase by evaporation so that the binder in the solvent comprises the bitumen with the surfactant.

The results obtained with aggregate-bitumen combinations confirm the SHRP findings that the aggregate type has a dominating influence on aggregate-binder adhesion. However, in testing aggregate-emulsion combinations, the test indicated that the emulsion source had a major effect on these combinations, and the presence of the surfactant may be responsible for the specific affinity of these binders for particular aggregate types as indicated in Table 10. This finding is consistent with results of SHRP studies in which the effects of antistripping agents on bonding energies were investigated.

The procedure in method M-001 of expressing the net adsorption as a percentage of the initial adsorption fails to take into account differences in the initial adsorption. To rectify this omission, consideration should be given to reporting the percentage net adsorption of the total bitumen in the solution, as proposed by Woodside et al. (*6*). Performance criteria for the reevaluated data need to be developed.

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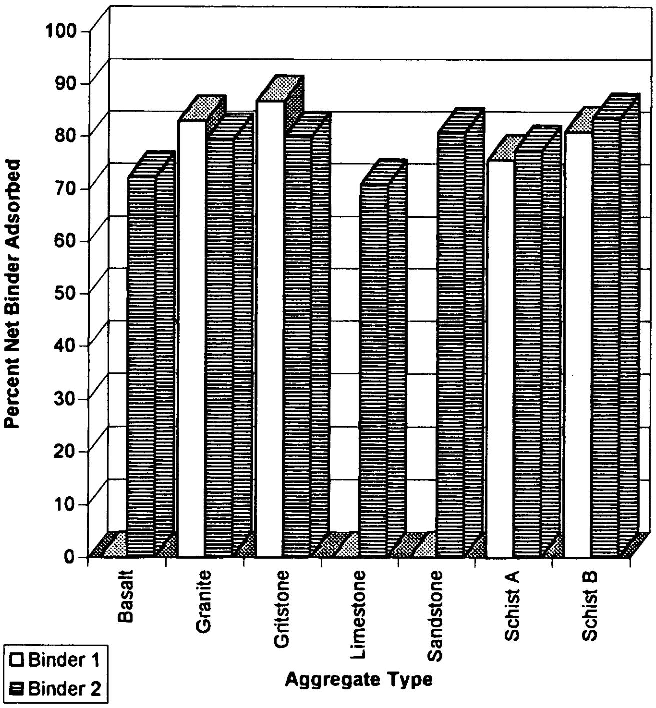

FIGURE 3 NAT results: Irish aggregates and bitumens.

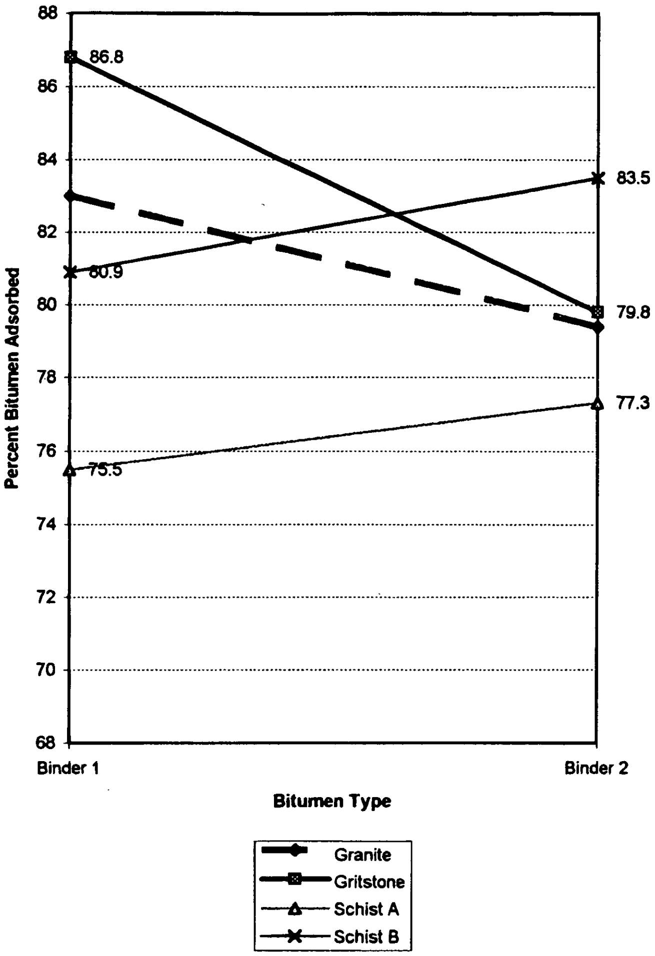

FIGURE 4 Bitumen-aggregate interaction diagram.

TABLE 8 Reevaluation of Initial and Net Adsorption Data for Bitumen 2

Net Adsorption according to SHRP		Re-evaluated adsorption according to Woodside et al(6)	
Aggregate	Percent	Initial Percent	Net (Percent)
Granite	79.4	45.7	37.1
Gritstone	79.8	37.1	30.5
Schist A	77.3	51.7	41.2
Schist B	83.5	43.9	37.9

Performance Criteria -

Acceptable	>70
Marginal	55-70
Poor	<55

TABLE 9 Reevaluation and SHRP Results for Irish Aggregates and Emulsions

AGGREGATE	Adsorption				
	Calculated according to SHRP			Calculated according to Woodside et al(6)	
	A_i Initial Adsorption (mg/g)	A_n Net Adsorption (mg/g)	% NA	Initial (percent)	Net (percent)
	EMULSION 1				
Basalt	1.54±0.06	1.02±0.04	66.5	55.0	37.9
Granite	1.09±0.08	0.70±0.03	63.8	38.9	25.7
Gritstone	1.28±0.03	1.05±0.04	82.0	45.7	38.6
Limestone	1.45±0.05	1.30±0.07	90.1	51.8	47.8
Sandstone	1.35±0.07	1.18±0.03	87.9	48.2	43.4
Schist A	1.35±0.04	1.03±0.03	75.9	48.2	37.9
Schist B	1.27±0.03	1.09±0.07	85.8	45.5	40.1
	EMULSION 2				
Basalt	1.42±0.05	1.06±0.03	74.4	50.7	39.0
Granite	1.13±0.05	0.72±0.04	64.3	40.5	26.8
Gritstone	1.35±0.07	0.96±0.06	71.3	48.2	35.3
Limestone	1.28±0.06	1.16±0.05	90.6	45.7	42.7
Sandstone	1.46±0.02	1.18±0.03	81.0	52.1	43.4
Schist A	1.46±0.07	1.04±0.05	71.3	52.1	38.2
Schist B	1.20±0.02	0.97±0.03	80.8	42.9	35.7
	EMULSION 3				
Basalt	1.37±0.03	1.06±0.04	77.4	48.9	39.0
Granite	1.04±0.02	0.84±0.03	80.5	37.1	30.9
Gritstone	1.17±0.03	0.93±0.03	79.5	41.8	34.2
Limestone	1.49±0.05	1.15±0.05	77.2	53.2	42.3
Sandstone	1.27±0.02	0.89±0.03	70.4	45.4	33.1
Schist A	1.22±0.03	1.04±0.01	85.2	43.6	38.2
Schist B	1.39±0.03	1.04±0.02	75.1	49.6	38.2

Performance Criteria -

Acceptable	>70
Marginal	55-70
Poor	<55

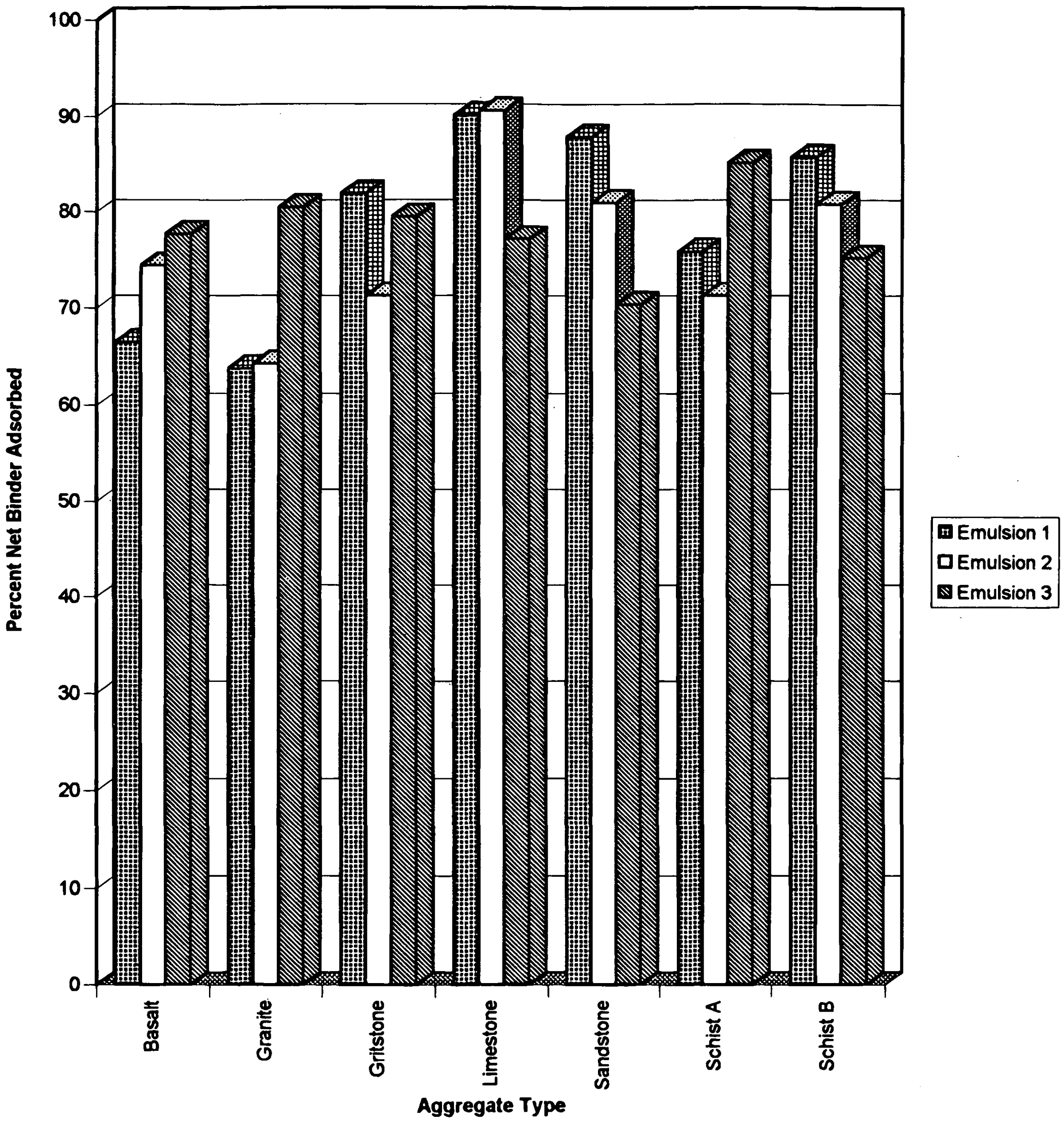

FIGURE 5 NAT results: Irish aggregates and bitumen emulsions.

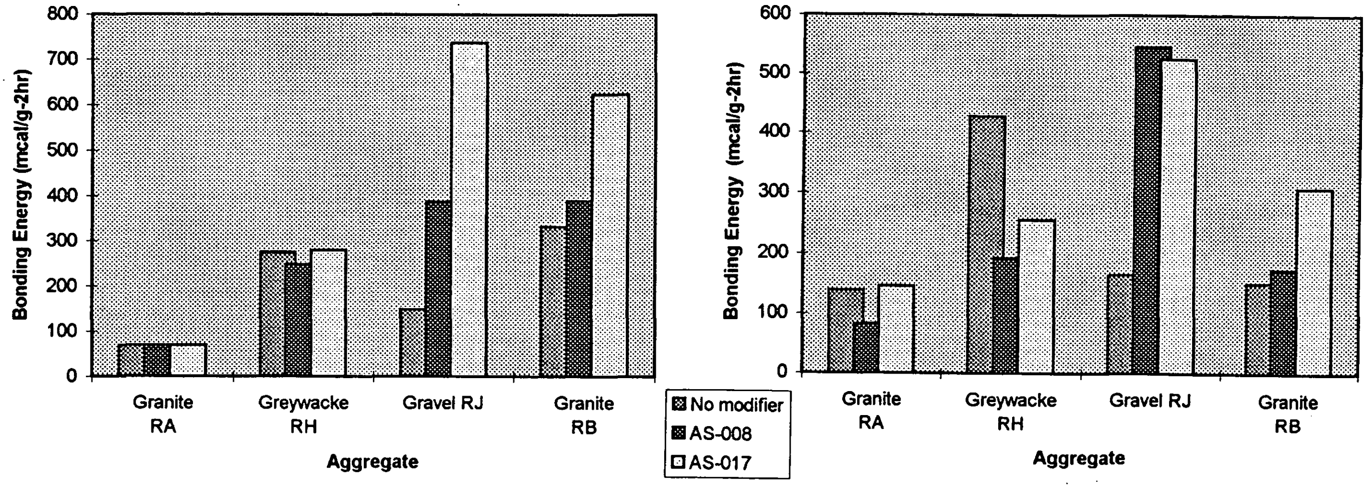

FIGURE 6 Influence of antistripping agents on bonding energies: *left,* Bitumen AAD plus 0.05% modifier; *right,* Bitumen AAM plus 0.05% modifier.

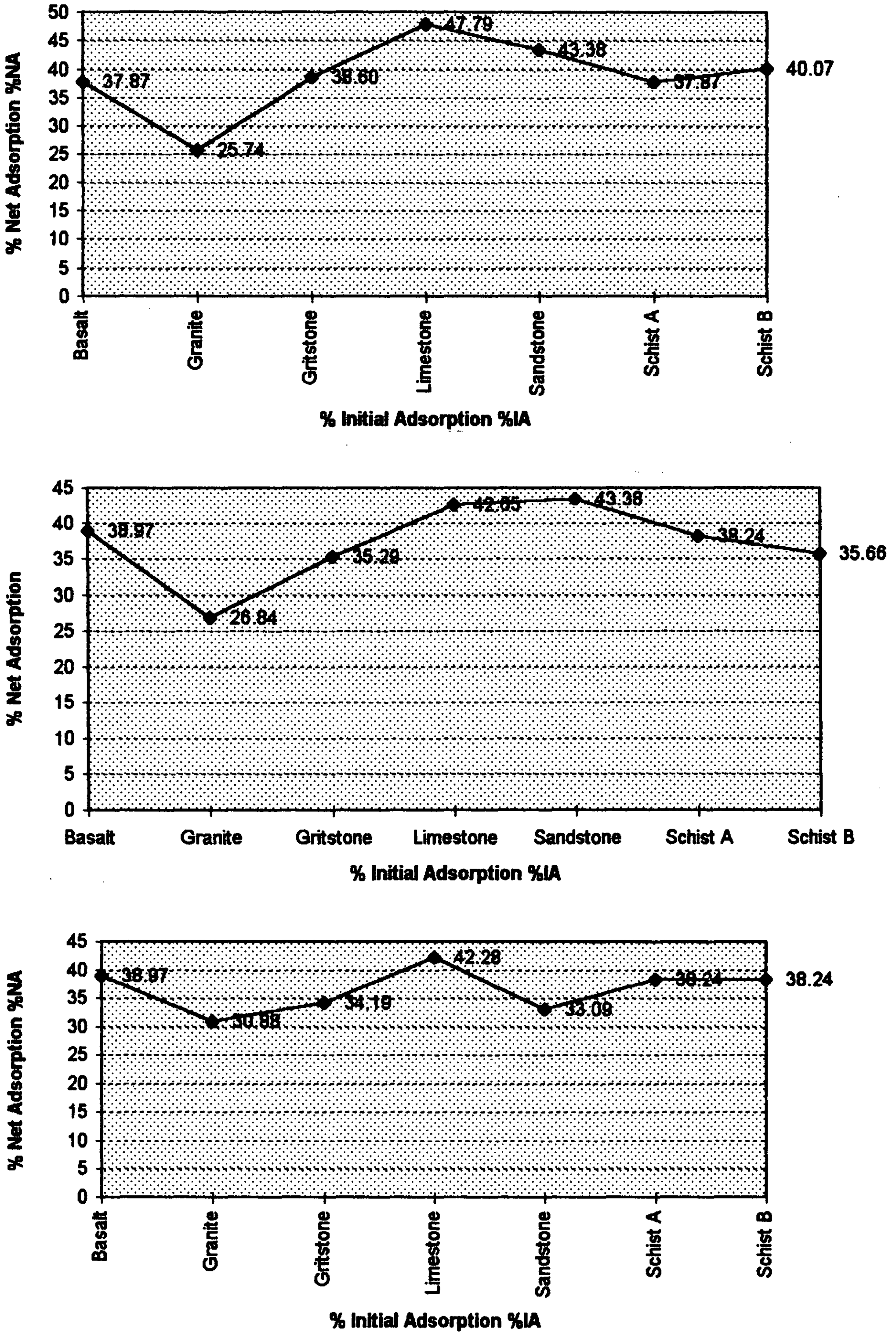

FIGURE 7 NAT results: initial versus net adsorption (*6*): *top*, Emulsion 1; *middle*, Emulsion 2; *bottom*, Emulsion 3.

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TABLE 10 Effect of Emulsion on Affinity of Binder to Aggregate Type

Aggregate	Emulsion	Net Adsorption (Percent)
Limestone	Emulsion 1	90.1
	Emulsion 2	90.6
	Emulsion 3	77.2
Granite	Emulsion 1	63.8
	Emulsion 2	64.3
	Emulsion 3	80.5
Sandstone	Emulsion 1	87.9
	Emulsion 2	81.0
	Emulsion 3	70.4

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