

# Improved Quick-Set Slurry Seal Emulsifiers with Tall Oil Derivatives

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Improved rapid-setting cationic and anionic emulsifiers for bituminous emulsions suitable for slurry seal are described. The cationic emulsifiers are based on condensation products of polymeric ethylene amines with polyfunctional fatty acids. These are obtained by reacting tall oil fatty acids with acrylic acid, fumaric acid, or maleic anhydride. The anionic emulsifiers are obtained by reacting these cationic products with chloroacetic acid or acrylic acid. Emulsions show improved mixing stability with mineral aggregates and good adhesion of the asphalt to the aggregate when the emulsion has set. The reaction mechanisms for obtaining these desired properties are discussed.

Slurry seal is a rapid, low-cost pavement treatment that provides new or existing roads with smooth, antiskid surfaces. One of the most appealing features in addition to cost-effectiveness is swift application, which allows roads to be reopened to traffic less than an hour after treatment. The main benefits are extended life of existing roads afforded by protection from oxidative deterioration and improved skid resistance as the result of eliminating the hazard of loose stones.

Slurry seal is a mixture of fine-graded aggregate of varying coarseness, an asphalt emulsion, and inorganic fillers. In recent years, polymeric latices have been added to further improve durability. The slurry is produced and applied, usually in a thickness of  $\frac{1}{8}$  to  $\frac{3}{8}$  in., with a slurry paver. Slurry pavers are self-contained, continuous-flow mixing units capable of accurately delivering predetermined amounts of aggregate, emulsion, inorganic filler, and water to the mixing chamber. The thoroughly mixed materials are discharged into a spreader box and uniformly distributed on the road surface.

A delicate balance of the components must be achieved for satisfactory handling of the slurry seal mix in the mixing chamber and spreader box. Slurry seal must also set and cure properly after it has been laid. The most important factors influencing these properties are the chemical composition and surface charge of the aggregate, the type of asphalt, and the emulsifiers employed.

With a wide variety of surface active chemicals and emulsifiers available, it is possible to tailor the asphalt emulsion properties for individual applications by matching the surfactant system to chemical properties of the aggregate, the inorganic fillers, and the polymer latices. The chemical structure of the surfactant determines its ionic charge in solution and influences its relative solubility in the asphalt and water phase

and its degree of adsorption at the asphalt-water interface. A combination of these characteristics determines the ultimate chemical properties of the asphalt emulsions and their behavior in contact with aggregate surfaces.

The purpose of this paper is to familiarize the slurry seal contractor and the asphalt emulsion producer with improved types of cationic and anionic emulsifiers based on tall oil fatty acids, which anticipate the needs of modern slurry seal formulations.

In the early days of slurry seal, modified cement mixers were used to prepare asphalt emulsions. The emulsions had to be extremely stable in the presence of aggregate because of the time necessary for proper lay-down. Anionic emulsions containing rosin soaps and sodium lignate combined with highly oxidized stump wood extracts (complex mixtures of high molecular weight phenolic compounds and oxidized rosin acids) gave adequate mixing performance but were very slow setting. This type of slurry seal emulsion is still being applied in hot, dry regions where set times are accelerated by the rapid evaporation of water.

With the advent of sophisticated continuous mixing slurry seal machines, slurry seals were developed with shorter set times at lower temperatures and with enough stability to prevent premature break in the mixing chamber or spreader box. These new quick-setting slurry seal emulsions are usually cationic in character because better adhesion of the asphalt to negatively charged aggregate is achieved.

## CATIONIC EMULSIFIERS

Before specific structures are discussed, the role played by emulsifiers will be explained. The main action during the preparation of an oil-in-water emulsion is the stabilization of small oil droplets by adsorption of emulsifier at the interface. Thus, it is necessary for the emulsifier to be soluble in the aqueous phase and partly soluble in the oil phase. This is achieved by incorporating two distinct regions of opposing solubility in these molecules: the nonpolar hydrophobic region and the highly polar, electrically charged hydrophilic region. When dissolved in water, surfactants form micelles thereby lowering the surface tension of water and facilitating emulsification. The nature and concentration of the emulsifier in an asphalt emulsion determines the coalescence rate (stability) of the emulsion droplets; it also influences particle size distribution, storage stability, rate of setting, and adhesion of the asphalt to the aggregate when the water has evaporated. One of the major difficulties in developing a suitable slurry seal emulsion is the requirement that the emulsion be very stable while it

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is being mixed with the aggregate but unstable after the mix is placed on the road surface.

Asphalt emulsions break on the surface of mineral aggregates by neutralization of the electrical charges of the emulsion droplets by the charges of the aggregate surface. This process causes coalescence of the asphalt droplets resulting in a continuous film of asphalt on the aggregate surface when applied to the road.

Cationic emulsions with highly charged anionic aggregates are generally preferred. Cationic emulsifiers are exclusively fatty, nitrogen-containing molecules with either permanent positive charges (quaternary ammonium salts) or fatty amines that are quaternized by reacting with strong acids to form the corresponding protonated species in the emulsion mixture.

Examples of cationic emulsifiers are fatty amidoamines (1), combinations of tall oil fatty imidazolines and ethoxylated nonylphenol (2), VINSOL-tetraethylene pentamine condensates (2), ethoxylated imidazolines (3), fatty mono- and diquaternary ammonium salts (4), and combinations of cationic compounds (5).

The hydrophobic region of the commonly used asphalt emulsifiers consists of straight  $C_{12}$ - $C_{20}$  carbon chains, which can be saturated or contain double bonds. The polar segments can contain one or more nitrogens in the form of primary, secondary, or tertiary amino groups. Structures such as amidoamines, imidazolines, or diaminopropanes also may be used. The fatty amines based on oleic acid shown in Figure 1 serve as examples of these types of emulsifiers.

In general, the ionic strength of the nitrogens in fatty amines increases in the order primary, secondary, tertiary. Deprotonation occurs at a lower rate when the more sterically hindered trialkyl ammonium hydrochlorides approach a negatively charged surface or a hydroxyl anion. A similar situation exists for the amidoamines, where, depending on the amine used for the condensation, primary, secondary, or tertiary nitrogens can be introduced into the molecule. For simple cationic emulsifiers, the more hindered the amine, the more stable the emulsion but the slower the set of the slurry seal.

Emulsions prepared with conventional quaternary ammonium salts that have permanent positive charges interact

slowly with aggregates. The positively charged center of the emulsifier is sterically hindered. It is neutralized by the negative charge of the aggregate, which deactivates it as an emulsifier and thereby initiates the "break" of the emulsion.

Condensation products of fatty acids with diethylene triamine result in a mixture of amidoamines (A) and (B) (Figure 2) containing two primary groups or one primary and one secondary amino group. Further reaction results in ring closure to yield an imidazoline (C) with a primary and two tertiary nitrogens in the molecule.

Among these structures, the protonated imidazoline (D) (Figure 3) is the most stable cation because of delocalization of the positive charge over three atoms. Thus protonated imidazolines are relatively stable in the presence of negatively charged surfaces, and emulsions prepared with fatty imidazolines break more slowly when mixed with aggregates than do emulsions prepared with protonated amidoamines (A) and (B).

Cationic emulsions prepared from unmodified tall oil fatty acid-derived amines and imidazoline are still not stable enough to be used for slurry seal mixes. They break prematurely when brought into contact with the aggregate. Successful mixes can be achieved when retarders, such as cement or aluminum sulfate, or excess emulsifier solution, or both, are added.

## DIELS-ALDER MODIFIED TALL OIL CATIONIC EMULSIFIERS

Recently, amidoamines and imidazolines, which yield emulsions with improved mixing stability without a retarder in the mix, were found at the Westvaco Corporation. The key to this difference in behavior is the introduction of reactive polar groups in the center of the fatty acid molecules.

Oleic acid, a mono-unsaturated acid, and the dioenoic linoleic acid isomers are the major constituents of tall oil fatty acid. By applying a proper catalyst, linoleic acid isomers can be converted to the highly reactive conjugated linoleic acid (E) (Figure 4). This readily undergoes Diels-Alder cycloadditions with dienophiles such as acrylic acid, fumaric acid, or maleic anhydride to give  $C_{21}$ -dicarboxylic acid (F),  $C_{22}$ -tricarboxylic acid (G), and  $C_{22}$ -tricarboxylic anhydride (H) (Figure 4). In this way, additional reactive carboxyl groups can be added to the

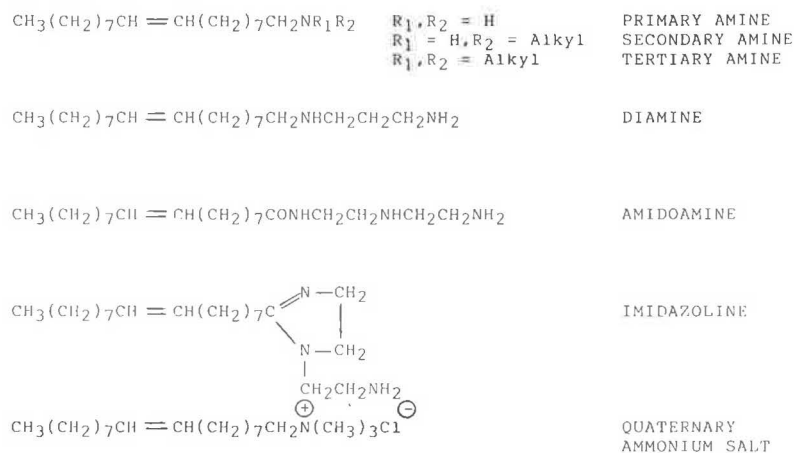


FIGURE 1 Fatty amines based on oleic acid.

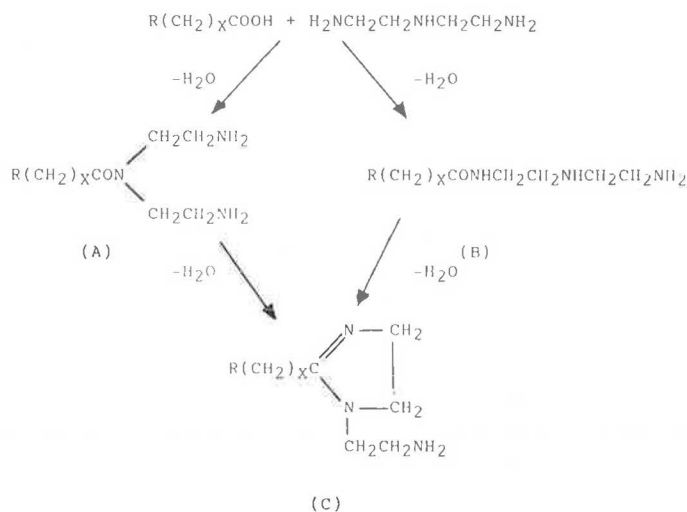


FIGURE 2 Condensation products.

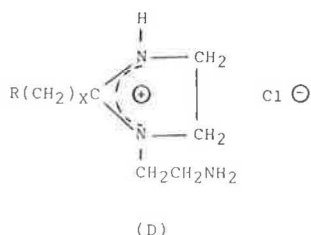


FIGURE 3 Protonated imidazoline.

middle of the fatty acid chain. The other common feature of these molecules is the cyclohexene structure to which the additional carboxyl groups are attached.

Oleic acid also can be modified with maleic anhydride to introduce carboxyl groups on its fatty acid chain. The addition is accomplished by the "ene" reaction to give succinic anhydride derivatives of oleic acid (I) (Figure 5).

Reaction products of these polyfunctional fatty acids with suitable polyamines are effective emulsifiers for cationic quick-set slurry seal. Examples of these cationic emulsifiers are the  $C_{21}$ -diamidoamines (J),  $C_{22}$ -triamidoamines (K), and  $C_{22}$ -amidoimidoamines (L, M) (Figure 6) obtained when the various modified fatty acids are reacted with diethylenetriamine.

Emulsions prepared with these polyamidoamines are stable and can be safely mixed with aggregate without breaking prematurely. The increased nitrogen functionality results in a molecule with higher overall polarity and the ability to form a di-cation in dilute hydrochloric acid. With a second positive charge in the center of the molecule, a different arrangement at the asphalt-water interface can be visualized with the emulsifier attached to the asphalt particle at two sites (Figure 7). Thus the chemical structure of this emulsifier does not allow close packing of the aliphatic oil-soluble chains as is the case with conventional emulsifiers (Figure 8).

When a cationic asphalt emulsion is mixed with an aggregate bearing a negatively charged surface, the emulsion droplets are

destabilized by proton transfer from the emulsifier to the aggregate surface, which neutralizes its charge and breaks the emulsion. In the case of the new polycarboxylic acid-derived slurry seal amidoamines, each molecule bears two positive charges. On approaching a negatively charged aggregate surface, both centers must be deprotonated for the emulsifier molecule to have zero charge. Even when the emulsifier molecule loses only one proton from the central or terminal amino group, it still remains an effective emulsifier. In this case, its ratio of molecular weight to protonated amino group is not very different from that of a common protonated fatty amidoamine emulsifier.

These new emulsifiers provide not only superior stability but also improved cohesive strength development of the cured slurry matrix. Comparison of the cohesive strength development, using a modified cohesion tester for a new dicarboxylic acid diamidoamine (6), a diquaternary ammonium salt (4), and a common tall oil fatty acid monoamidoamine, demonstrates the outstanding performance of these new products in the cured asphalt-aggregate mat (Figure 9).

Emulsions prepared with common tall oil fatty acid monoamidoamine can only be mixed with aggregate in the presence of a retarder such as aluminum sulfate, which neutralizes some of the negative charges of the aggregate. However, the aluminum sulfate also slows down the cohesive strength development of the slurry seal. This situation is avoided with the new dicarboxylic acid diamidoamine because a retarder is not needed for a stable emulsion. Even though the diquaternary ammonium salt required no retarder either, an emulsion produced with this emulsifier had poorer cohesive strength development than that of the dicarboxylic acid diamidoamine (Figure 9).

A retained stone coating of nearly 100 percent after subjecting cured slurry mixes containing di- or polyamidoamine to the hot water boiling test indicates that a strong bond between the asphalt and aggregate is formed with these new emulsifiers (see Appendix). This indicates the superiority of the polyfunctional amidoamines. Mixes prepared with emulsions containing fatty

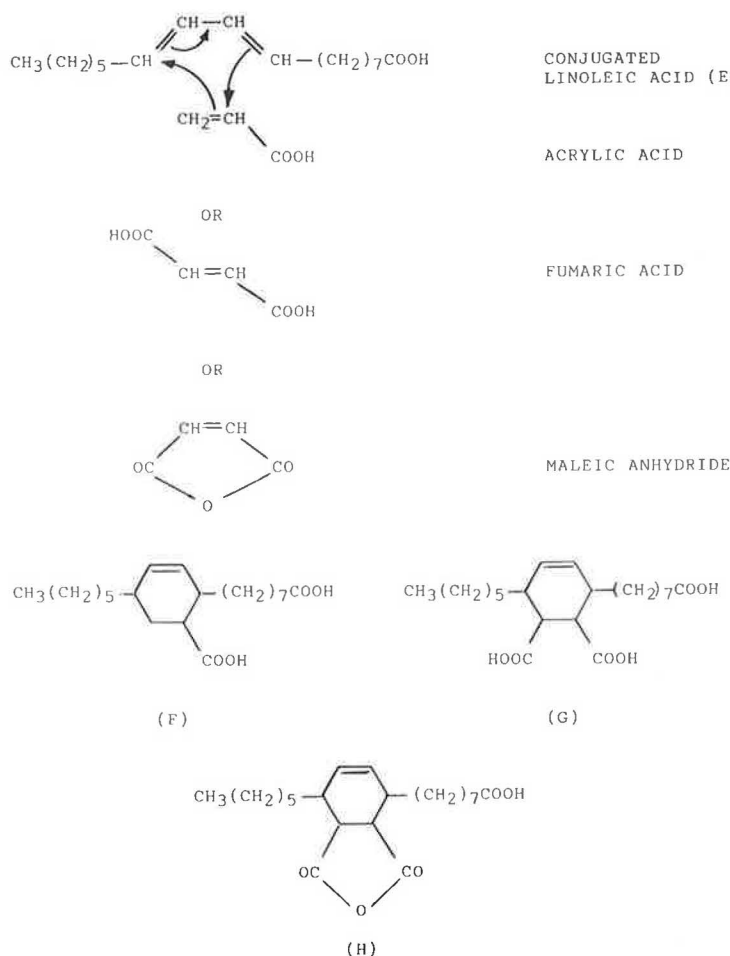


FIGURE 4 Diels-Alder cycloadditions of linoleic acid.

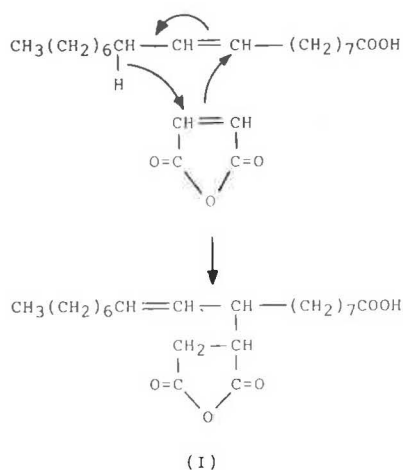


FIGURE 5 Succinic anhydride derivatives of oleic acid.

quaternary ammonium salts show a lower degree of retained coating due to weaker bonds between asphalt and aggregate.

#### ANIONIC EMULSIFIERS

The oldest and most widely used low-cost anionic asphalt emulsifiers are soaps or carboxylates. These compounds are

water soluble salts, usually the sodium salt, of long-chain fatty acids derived from animal fats, vegetable oils, and tall oil. Other anionic surfactants used are long-chain aromatic fatty sulfates and sulfonates. As in the case of cationic emulsions, the long nonpolar carbon chain is soluble in asphalt, whereas the hydrophilic head group is soluble in the water phase (Figure 10). Note that the hydrophobic entity R may be obtained from natural fatty or resin acids or from petroleum-based feedstock.

For the manufacture of fast setting anionic emulsions, two types of emulsifiers are used: fatty acid soaps and sulfonates such as -olefin sulfonates, petroleum sulfonates (7), and dodecylbenzene sulfonates (8). Fatty acid soaps, because of their rapid interaction with Ca<sup>2+</sup> or other polyvalent cations that render them water insoluble, are not suitable as slurry seal emulsifiers. Their emulsions break prematurely (within seconds) when brought into contact with aggregates. Sulfonic acid salts, on the other hand, do not interact with calcium ions and give emulsions with good mixing stability. However, in slurry seal produced with these emulsions, the asphalt shows inferior adhesion properties due to a lack of interaction with the aggregate surfaces.

Emulsions that were prepared with emulsifiers modified from fatty acids having one or two additional (F, G) carboxylic groups in the center of the molecule broke prematurely. However, with further modification, these di- and tricarboxylic

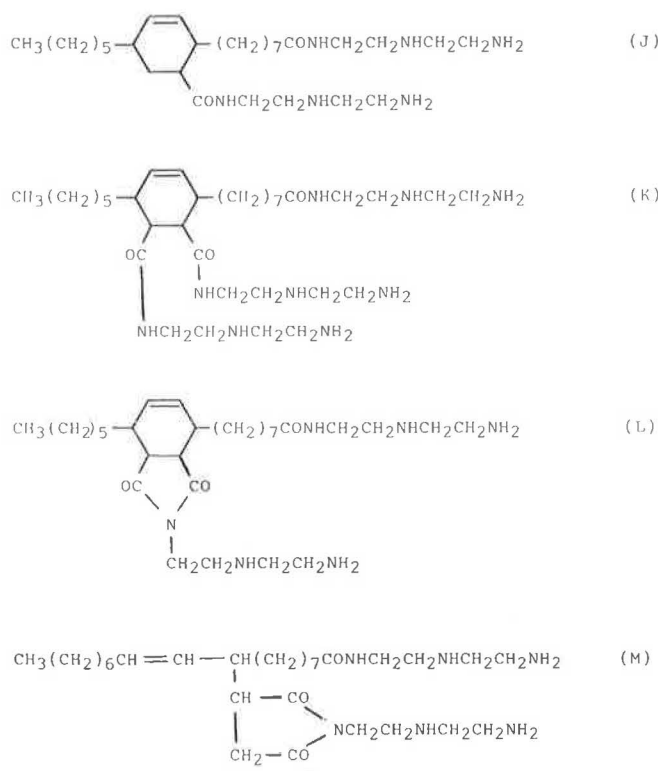


FIGURE 6 Cationic emulsifiers.

fatty acids can be converted into workable anionic emulsifiers. These emulsifiers are obtained by reacting the polycarboxylic acid-derived amidoamines or imidoamine (J) through (M) (Figure 6) with the reactive carboxylic acids, acrylic acid, or chloroacetic acid. The resulting amino acids are very effective anionic slurry seal emulsifiers and insensitive to  $\text{Ca}^{2+}$  ions.

Sulfonic acid groups may also be introduced via sulfomethylation (9-11). If a dicarboxylic acid diamidoamine (J) is used as starting material, the reaction products are very complex aminoalkylcarboxylic acids (N, O) or aminomethyl sulfonic acids (P), as shown in Figures 11 and 12.

A benefit of using these complex aminoalkyl carboxylic acids is the flexibility of the pH value at which the emulsions can be prepared. The mixing behavior of the emulsion is readily influenced by the proper choice of the alkali charge. At

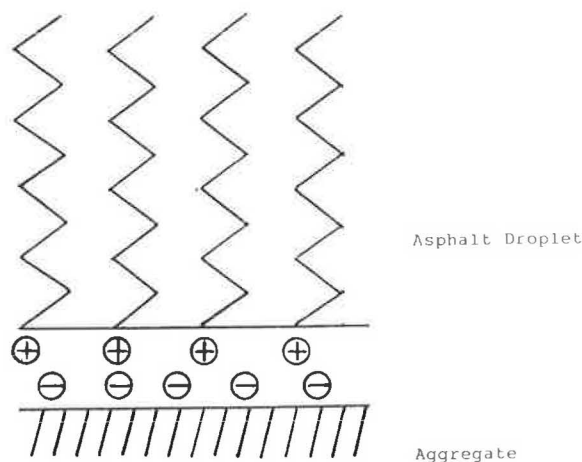


FIGURE 8 Arrangement of conventional cationic emulsifiers in an asphalt droplet.

higher pH values the number of negatively charged carboxyl groups increases, resulting in longer mixing times because of the increase in concentration of repulsive forces between aggregate surface and emulsion droplets (Figure 13).

Conversely, if the emulsions prepared with these surfactants at relatively low pH values (9.5 to 10.0) can be mixed with an aggregate, a short set time will result. Mixes prepared at these lower pH values generally show better adhesion of the asphalt to the aggregate than do mixes prepared at very high pH values. If during production an aggregate requires more mixing time, this can be achieved by the addition of more alkali at the expense of some adhesion. This adhesion loss can be counteracted by the use of small amounts of additives containing calcium ions, which results in good adhesion at high pH. Emulsions prepared with alkylbenzene sulfonates generally result in poor adhesion of the asphalt to the aggregate because at any pH value above 7 the sulfonic acid groups are fully deprotonated.

Figure 14 shows the rate of cohesive strength development of slurries prepared with emulsions containing these aminoalkyl carboxylic acids. It can be seen that these slurries are comparable to a slurry containing cationic emulsions prepared with a diamidoamine. It should be noted that a decrease in pH increases the rate of strength development.

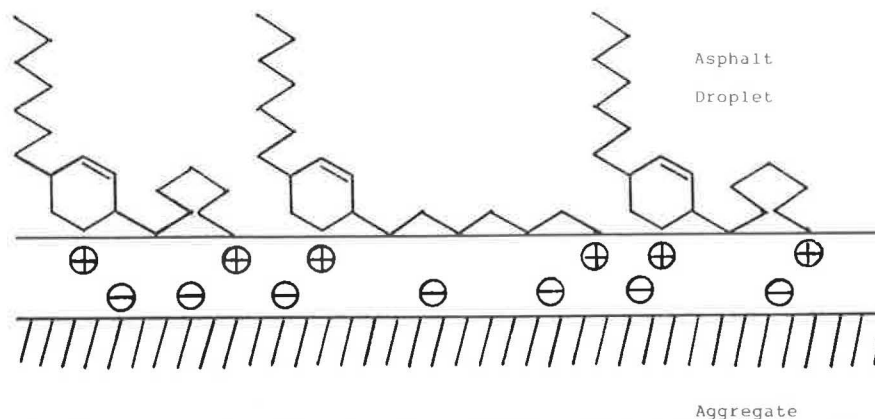


FIGURE 7 Arrangement of fatty acid diamidoamines in an asphalt droplet.

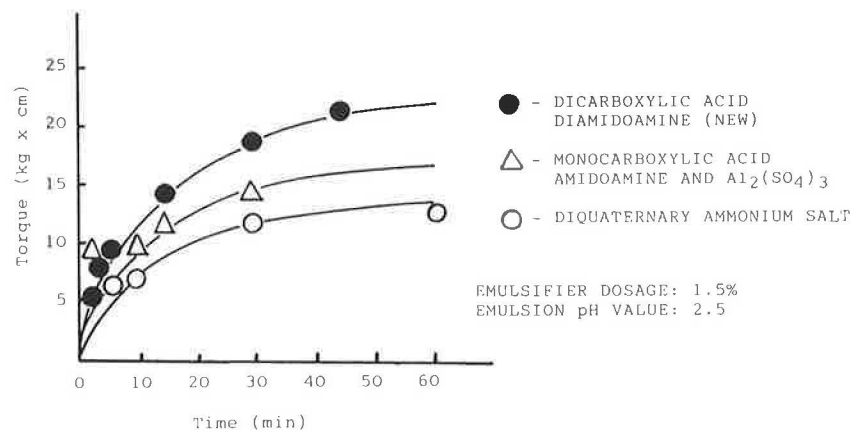


FIGURE 9 Cohesive strength development of cationic slurry seals.

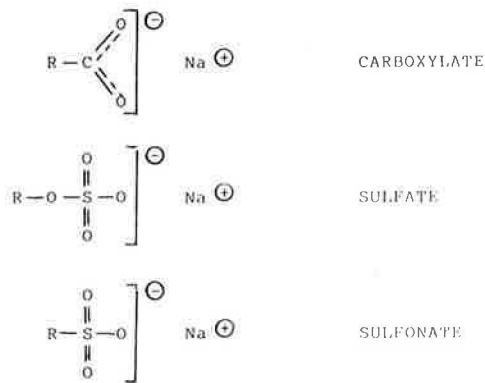


FIGURE 10 Anionic emulsifiers.

### CHOICE OF PROPER EMULSIFIER

The key to a successful slurry seal application is understanding the total system of emulsified asphalt, mineral aggregate, filler, and water. Therefore the contractor must know the properties of the emulsion and the chemistry of the aggregate. Because aggregate and asphalt sources change constantly, testing is required to identify the proper emulsion-aggregate combination. In this regard, the most flexible component in the system is the emulsifier. By finding the proper emulsifier and by optimizing dosage and pH value, asphalt emulsions can be adjusted to the aggregate so that the slurry will mix, set, and cure to the desired specification.

The factors responsible for the performance of asphalt-aggregate mixes are cohesive forces within the asphalt, adhesive forces at the asphalt-aggregate interface, and coalescence. A very high rate of coalescence and undesirably large cohesive forces result in poor mixing performance. When adhesive forces are greater than cohesive forces, premature breaking of the asphalt emulsion on the aggregate surface occurs. If the opposite is true, stripping of asphalt from the aggregate occurs.

Often slurry properties that actually oppose each other have to be achieved. For example, good mixing stability and rapid-setting characteristics are both desired. The rapid-setting characteristic is obtained by keeping the emulsifier concentration low, which makes mixing difficult. To prepare a conventional medium-setting emulsion, an increase in dosage level of

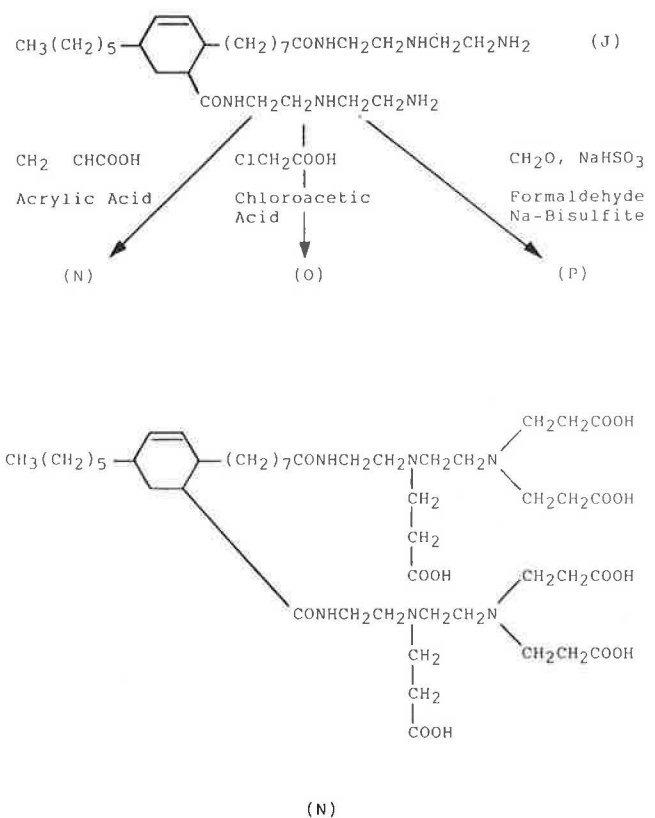


FIGURE 11 Aminoalkylcarboxylic acid.

the emulsifier yields the desired mixing stability. However, the break of the emulsion is undesirably slow.

To obtain the necessary mixing stability with aggregates containing an appreciable amount of fines, large amounts of emulsifier have to be used, but the emulsion is still expected to set in less than 30 min. The use of freshly crushed aggregates instead of weathered aggregate requires a very high emulsifier concentration. The use of emulsifiers based on tall oil derived di- and tricarboxylic acid can easily overcome many of these problems and produce stable slurries with the desired set times.

### ROLE OF MINERAL AGGREGATES

About 75 percent of the volume of a slurry seal mix is mineral aggregate. Aggregates are generally characterized by physical



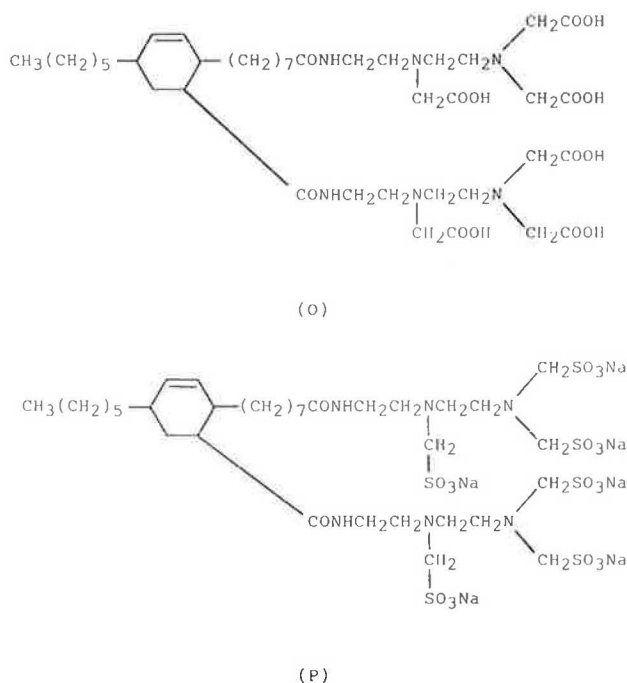


FIGURE 12 Aminoalkylcarboxylic acid and aminomethyl sulfonic acid.



FIGURE 13 Reaction between aggregate surface and emulsion droplets.

and chemical testing for hardness, abrasiveness, absorbency, porosity, surface texture, and acidity. The role of the aggregate surface as a chemically reactive site has generally been ignored. The chemical reactions between the aggregate surface and the emulsion droplets determine critical properties of a slurry mix such as adhesion, cohesion, mix stability, compatibility, set, and cure time. Historically, emphasis was placed on the aggregate surface charge, which in the case of calcareous aggregate is electropositive and in case of siliceous aggregate is electronegative.

This may be true if the aggregate is perfectly dry. However, when wetted with water, both types of aggregates become negatively charged according to the reaction scheme shown in Figure 15.

Although the electrical charge is important for adhesion, for slurry seal mixes porosity, absorption of asphalt into aggregate pores, chemical reactivity, ion exchange, and density should be of greater concern to the formulator. Many of these properties can be altered with small amounts of chemically reactive additives to improve mixing and setting characteristics of the slurry seal.

### CHEMICAL ADDITIVES—MIX AIDS

The ability of a slurry seal system to be modified by chemically reactive additives plays an integral role in fully using slurry seal technology. Such additives are generally incorporated to improve the strength of the slurry mat; improve the adhesion or cohesion; alter the electric charge of aggregate (partial charge neutralization); improve asphalt properties to achieve longer service life; and increase or decrease the mixing time, rate of setting, and curing time of the mix.

Typical aggregate additives include hydrated lime, portland cement (Types I and III), gypsum, or ammonium sulfate. A wide variety of chemical additives is used in the prewet water at concentrations of 0.01 to 0.05 percent based on the weight of the aggregate. Typical additives are aluminum sulfate, surfactants, or the same emulsifier solution used in the preparation of the emulsion. Fatty amines and latex elastomers are added to the asphalt to improve adhesion and low-temperature flexibility. Toughness and improved emulsifiability of the asphalt are other benefits given by asphalt additives such as fatty amines and tall oil fatty acids.

### INERT FILLERS

Inert fillers such as limestone dust, sand, agricultural lime, or fly ash are added to increase the amount of fines in the mix. This is done to provide better compaction of the slurry seal.

### SLURRY SEAL PERFORMANCE TESTS

There are many tests available to determine the performance of a slurry system, but most tests do not indicate the compatibility

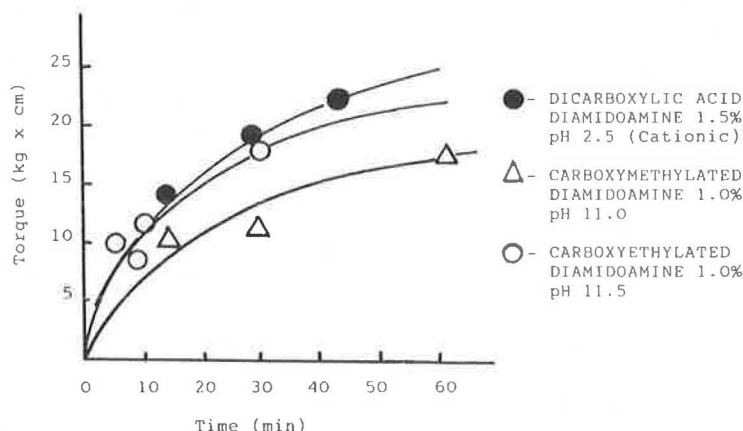
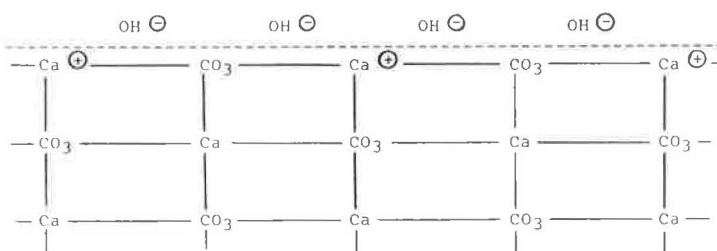


FIGURE 14 Cohesive strength development of anionic slurry seals.

## Calcareous Aggregate:



(OH<sup>-</sup> adsorbs onto Ca<sup>2+</sup>)



## Siliceous Aggregate:

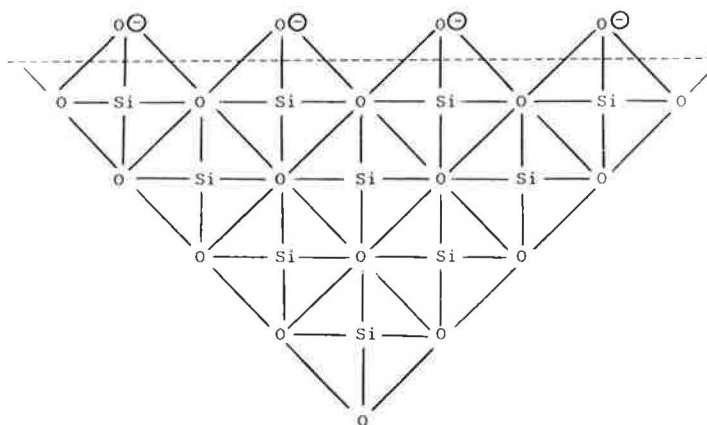
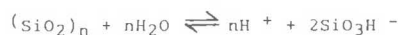


FIGURE 15 Reaction schemes for wetted aggregates.

of emulsion (asphalt) and aggregate in the slurry system. For this reason, the proposed boiling test is applied to cured slurry seal mix specimens. This test allows development of the best emulsifier formulation and simultaneously allows determination of the compatibility of all ingredients in the total system (see Appendix).

The data given in Table 1 indicate how the results of the boiling test correlate with cohesive strength development and the Wet Track Abrasion Test (WTAT) for four different slurry seals. The following conclusions can be drawn from this table:

- Emulsions prepared with a dicarboxylic acid diamidoamine can perform quite well with Camak aggregate, a highly charged aggregate.

- The addition of hydrated lime shortens the setting time (decreases the blotting time by 50 percent) while extending the mixing time.

- When the hydrated lime is replaced with cement, the adhesion is completely destroyed as determined by the boiling test. The increase in aggregate loss shown in the WTAT supports the validity of the boil test.

- The addition of aluminum sulfate extends the handling characteristics of the system while maintaining performance. Although cohesive strength development is slow, actual setting time in the field was about 15 to 20 min. No damage was done when a truck drove over the freshly laid slurry after only 30 min.

- Good overall performance is achieved with the addition of a natural latex.

- Unusual hydroplaning results in cohesion and loss in WTAT with the addition of an accelerator. Although excellent mixing results are obtained with Camak and some other aggregates, mixing time is decreased with other aggregates to less than a minute.



TABLE 1 CORRELATION OF BOILING TEST RESULTS WITH COHESIVE STRENGTH DEVELOPMENT AND WTAT

Additive (%)	Emulsion (%)	Boiling Test Retained Coat (%)	Blot Set (min)	Cohesion (cm · kgs)				WTAT (g/m <sup>2</sup> )
				15	30	60	90	
No Additive								
—	16.0	100	90	14.5	14.5	12.5	16.5	535
—	18.0	100	90	13.0	14.5	16.0	15.5	348
—	19.0	100	105	12.0	14.9	13.5	15.0	243
Lime Addition								
0.5 lime	18.0	90	45	10.0	12.0	16.5	18.2	455
1.0 lime	18.0	100	45	9.5	12.2	13.5	17.0	345
Cement Addition								
0.5 Type III	18.0	20	45	10.5	9.5	11.2	12.0	1251
1.0 Type III	18.0	20	45	8.0	9.0	14.0	17.8	852
Alum Addition								
0.03 alum	18.0	100	90+	10.0	9.2	9.2	11.2	240
0.05 alum	18.0	90	90+	9.8	10.0	11.0	12.1	296
Natural Latex Addition								
1.8	18.0	100	90	9.8	9.8	10.4	10.8	124
1.8	14.0	100	75	9.8	11.5	10.4	10.4	200
Naural Latex + Accelerator								
2.0 accelerator	18.0	100	15	Hyd.	Hyd.	Hyd.	Hyd.	0
2.0 accelerator	14.0	98	15	Hyd.	Hyd.	Hyd.	Hyd.	145

NOTE: Aggregate = Type II granite, Camak, Georgia; emulsifier = dicarboxylic acid diamidoamine (1.5 percent dosage, pH 2.8); asphalt = West Coast AC-20. The hydrated lime and portland cement (Type III) were added to the aggregate. The alum (aluminum sulfate) was added to the prewet water; the concentration was based on the weight of the aggregate. The concentration of 1.8 percent natural latex was based on the solids of the elastomer. Hyd. denotes hydroplaning of the pressure foot on the surface of the test specimen.

These results clearly indicate that the addition of an additive may improve the performance of one slurry system but be deleterious in another. This indicates the complexity of these systems.

## APPENDIX: PROPOSED BOILING COMPATIBILITY TEST

1. Sieve job aggregate according to the following specification: No. 4, No. 8, No. 16, No. 30, No. 50, No. 100, and No. 200.
2. Reconstitute a 100-g sample in the correct proportions as obtained from the sieve analysis.
3. Mix the emulsion, aggregate, and chemically active additive for 1 min (additives: 0.5 percent, 1 percent Type I or III cement; 0.5 percent, 1 percent lime; or 0.03 percent, 0.05 percent aluminum sulfate—all based on the aggregate weight). Higher concentrations of cement and lime may be used when required. (Aluminum sulfate is added to the prewet water.)
4. Place the template (Figure A-1) on aluminum foil.
5. Deposit the mix in the template and level the surface with a squeegee or spatula.
6. Allow the mix to air cure (70°F to 77°F) for 24 hr (minimum 12 to 15 hr).
7. Boil approximately 700 mL of water in a 1000-mL beaker. Use a No. 20 mesh screen in the bottom of the beaker to create a shelf. Bend the edges down so that the sample is raised 1/2 in. from the bottom of the beaker, avoiding direct contact of the aggregate and heat source. Place the sample in the boiling water. If the sample cannot be easily removed from the foil, cut the foil around the outside of the sample. Place the sample in the boiling water and remove the foil from the water (the boiling water should allow the foil to become detached).
8. Boil for 10 min.
9. Decant the water and spread the mix on a level surface.
10. Observe the coating of the mix.
11. Record the percent retained coating using 2 percent accuracy.
12. Determine mix compatibility:
  - 90 to 100 percent coated surface—good mix compatibility,
  - 75 to 89 percent coated surface—fair to good mix compatibility,
  - 50 to 74 percent coated surface—poor to fair mix compatibility, and
  - Less than 50 percent coated surface—poor mix compatibility.

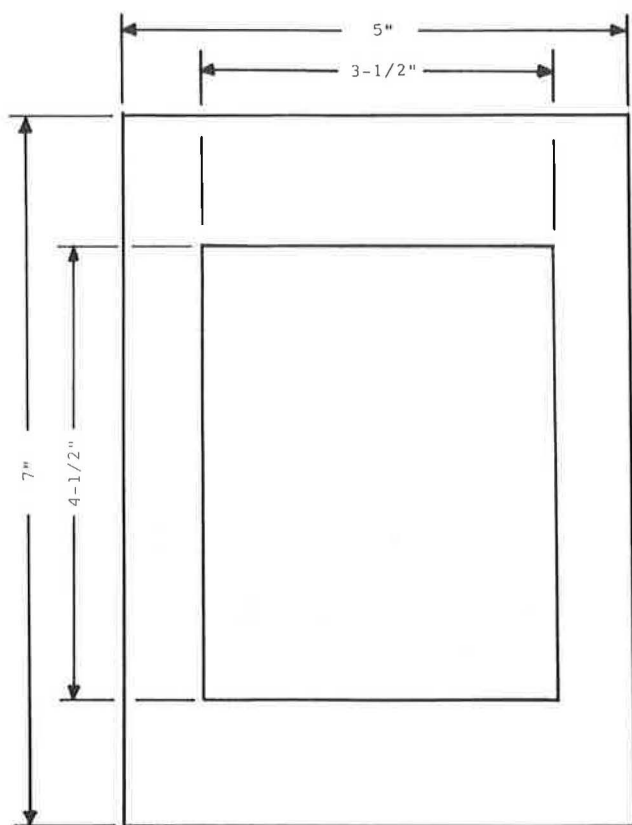


FIGURE A-1 Template ( $1/4$  in. thick).

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