

Dense-Graded Solvent-Free Emulsion Mixes

Introduction

Dense-graded solvent-free mixes are prepared from crushed and graded aggregates and CSS emulsions either in a central cold mix plant, mobile mix-paver, or in-place. Dense mixes prepared from uncrushed or ungraded materials are described under soil stabilization. The mixes are mainly used for road bases and bases courses, but have been used for reinstatements and for reprofiling. They normally need to be sealed. Cement or other hydraulic binders can be incorporated with the emulsion to provide early strength and water resistance. Workability in these systems is ensured by the presence of unbroken emulsion. Solvent-free mixes are not normally suitable for stockpiling for more than a few days.

Design of Roads Based on Dense-Graded Emulsion Mixes

Road base modified by small amounts (<3%) of emulsion can be treated as an unbound granular material in design calculations. The function of the emulsion is to increase internal friction and provide some improvement in water resistance.

Base and surface courses with higher asphalt levels will when fully cured approximate the behavior of similar hot mixed materials. When small amounts of cement or lime are included (<2%), there is evidence that any cementitious bonds eventually fail due to fatigue and the properties approach those of a purely asphaltic material. Layer equivalencies of 0.5-1 times the thickness of a corresponding hot-mixed layer have been found in laboratory and field studies. However, the design of the road has to take into account that strength in dense cold-mixed materials may develop over a period of weeks or months.

Some countries such as France and Ireland have well-developed road designs based on a specific type of dense cold mix called Grave emulsion mix.

Aggregate Gradation and Binder Content

Wide ranges of dense gradations have been used successfully. The table ('Typical Gradations for Dense-Graded Cold Mixes') shows gradations based on those from AEMA for processed dense-graded mixes. AEMA recommends a minimum sand equivalency of 35 for processed material and 30 for other materials. Aggregates with sand equivalency less than 25 are best treated with a combination of emulsion with either lime or cement.

Design of Dense-Graded Emulsion Mixes

The object of the design method is to first identify an emulsion recipe that gives adequate coating, workability and compactability to the mix under the conditions of its intended use (a mix made in a central plant will have different requirements than one made in a mix-paver) and also to determine the right asphalt content for the mix. The water resistance of the fully or partly-cured mixture is also particularly important with emulsion mixes.

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Typical Gradations for Dense-Graded Cold Mixes

Sieve Size mm	Base	20 mm Wearing Course	10 mm Wearing Course	Grave Emulsion Mix 14 mm
38.1	90-100			
25.4	--	100		100
19.0	60-80	90-100		92-100
12.7	--	--	100	82-97
9.5	--	60-80	90-100	75-88
4.75	20-55	35-65	60-80	60-72
2.36	10-40	20-50	35-65	45-55
1.18	--	--	0-5	35-43
0.60	--	--	--	27-35
0.30	2-16	3-20	6-25	20-25
0.15	--	--	--	10-16
0.075	0-5	2-8	2-10	4-8
Binder		3.8-4.8	3.6-4.8	3.8-4.6

Starting Point for Asphalt Content

A starting point for the asphalt content is the same as for the corresponding hot mix or it can be estimated from the aggregate grading:

$$P = 0.05A + 0.01B$$

A= percent passing 4.75 mm; B= percent retained on 4.75 mm

Coating

500 g samples of pre-wetted aggregate are vigorously mixed by hand in a steel bowl for 30 seconds with different asphalt emulsion formulas and different pre-wet water contents until a recipe giving good coating is identified. The target should be 85-100% coated.

In the final optimization tests the water content of the aggregate should be adjusted 24 hours before the mix test. Pre-wet water should be kept to a minimum because it causes problems with compaction. It is better to select a less reactive emulsion than use a high water content, which may mean the mix requires aeration before compaction. The water content of the job-site aggregate should be controlled for best results.

All emulsion mixes will tend to decoat and dry out on extended mixing, but some are more sensitive than others and this can lead to stripping during transport and paving. Sensitivity to this decoating can be estimated by extending the mix time to 2 minutes and re-checking coating.

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Compatibility Test

100 g uncompact samples of these trial mixes are cured in a forced draft oven at 60°C (140°F) overnight, then subjected to a boiling-stripping test, to eliminate emulsions with poor compatibility at an early stage. The addition of cement or lime can improve water resistance in difficult cases.

Workability

Emulsion mixes may start to stiffen immediately after mixing or remain free-flowing over a period of hours or days. The 'workability window' required for transport and paving of the mix will depend on the specific circumstances of the project. Even in a mix-paving operation, a window of 30 minutes may be prudent to allow for temperature and other field variables. Workability is estimated qualitatively by storing trial mixes in covered containers or sealed plastic bags (to avoid drying out) and examining at different periods after mixing. To simulate the pressure from a stockpile, some workers have placed weights on the mixes. Quantitative workability testers have been designed which have been validated in field tests, for instance the Nynas Workability Tester.

Depending on the results of the workability tests, it may be necessary to reformulate the emulsion or impose restrictions on the storage time of the mixtures before paving. Addition of solvent generally has a bad effect on the workability and coating of dense emulsion mixes, since it tends to accelerate breaking of the emulsion.

Compactability and Specimen Preparation

Compactability is an issue similar to workability. It is measured by the degree of compaction obtained by a standard compaction effort. For emulsion mixes the simplest way to measure the density of the compacted mix is by the dimensions of the compacted specimen. As a first approximation, the voids of the compacted specimen can be assumed to be full of water. A better approximation can be obtained by using standard methods on specimens cured by drying in the oven at 60°C(140°F) overnight.

Akzo Nobel Method

The Akzo Nobel laboratory test method uses a gyratory compactor which automatically displays the specimen height. A mechanical mixer prepares mixes. 150 mm specimens are compacted with 200 gyrations at 32 rpm, an angle of 1 ¼ degrees and pressure of 0.1 MPa to produce a limiting density (height) for a freshly-prepared mix. The molds for the gyratory compactor have slots to allow water to escape if necessary. Trial mixes, after storage for an appropriate period, are then compacted and the number of gyrations required to reach 96% of this limiting density is taken as a measure of the compactability. Specimens for use in subsequent structural testing

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are compacted to this density. 35-70 cycles are considered acceptable. Less than 35 indicates a very tender mix (not often seen with dense-graded emulsion mixes unless the aggregate grading needs adjustment); more than 70 suggests the mix will be difficult to compact in the field. Difficult-to-compact mixes may need an adjustment in the water level or type or quantity of emulsion. Generally a slower-setting emulsion will give easier compaction as will emulsions based on stiffer binders.

Too much water in a mix will inhibit compaction. Mixtures may be allowed to dry out before compaction, but workability should be re-checked. It is better if a mix can be designed without the need for so much pre-wet water that aeration is required.

There is evidence that dense-graded emulsion mixes do not reach the same densities in the field as hot mixed asphalts of the same design. The target density may need to be adjusted in the light of field experience.

AEMA method

An alternative approach is described in a draft ASTM method. Specimens are formed by gyratory or Marshall hammer compaction, allowed to partially cure for 48 hours at 60°C then recompacted at 60°C by a 178N (40,000 lbs.) static load using the double plunger method. This technique is believed to give densities close to field experience.

Optimum Asphalt Content

To determine the optimum asphalt content, specimens are prepared with different amounts of emulsion varying by 1% or 0.5%, and fully cured by storing for 48 hours at 60°C in a forced air oven. Marshall stability, Hveem stability, California Bearing ratio (CBR), compressive strength, rut-testers or resilient modulus can be used to determine the structural properties of the mix relevant to the application. At Akzo Nobel we have used the Nottingham Asphalt Tester for both stiffness modulus and unconfined permanent deformation. A level and grade of asphalt, which meets the stiffness modulus, rutting resistance and water resistance requirements of the particular application, is selected.

Cohesion Building

Cohesive strength develops during compaction and more slowly during the lifetime of the roadway. For base materials which will be covered the possible damage caused by turning traffic is not particularly significant; more important is the bearing capacity. Akzo Nobel has developed a laboratory cohesion tester for emulsion based surface courses based on the ISSA cohesiometer. Compacted samples are stored for 1–6 hours and cohesion determined. A minimum of 30Nm has been associated in limited field trials with traffic time.

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Water Resistance

It is essential that water resistance of the partly fully-cured compacted mix be evaluated. Specimens are fully cured at 60°C(140°F) for 3 days and water resistance is tested according to AASHTO T283, with a target of 55% tensile strength ratio. Soaking methods based on Marshall stability, compressive strength or CBR are alternatives. Increasing the asphalt content or adding lime or cement increases water resistance.

Emulsion recipes

Cationic slow-setting emulsions are the most suitable.

Asphalt	60	60
Redicote E-4868	1.2	
Redicote E-11		1.0
Water phase pH	2.5	5
Water	to 100	to 100

The emulsions are compatible with cement. In contrast with open-graded mixes, coating is not generally helped by the addition of solvent or by heating the emulsion. Solvent may lead to decoating in the mixer or paver. Hard binders give longer stockpile life.

Manufacturing the Mix

Simple mixers like cement mixers or pug mills are suitable. Cold mix plants equipped with two or more bins for different aggregate size fractions and a pug mill are preferred for consistent quality. Mixes can be prepared in hot mix plants but heat generally has a bad effect on coating and the water content of the cold aggregates needs to be controlled. Mobile mixers are also suitable and mix-in-place is a technique which offers cost advantages.

Very dry aggregate should be pre-wetted to 1-3% moisture before adding emulsion but excess water should be avoided because it hampers compaction. If cement is included in the mix then about 0.5% extra water for every 1% cement may be added. Water dosage can be adjusted by eye on the cold mix plant with a view to producing a coated material with a relatively dry consistency. It may not be possible to achieve full coating of the coarse size fractions. Stockpiled aggregate should be sheeted or bins used to control moisture. The mix should leave the mixer brown. For extended storage life the stockpile should be covered to avoid drying out.

Specially designed cold mix plants allow two or more aggregate size fractions to be added separately to the pug mill. In these cases it may be possible to improve coating of the larger aggregates by adding the coarse aggregate first to the pug mill and introducing the fines later when the coarse aggregate is mostly coated. More complicated arrangements with more than one emulsion spray are possible to optimize coating.

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For advice on in-place mixing see the datasheet on Soil Stabilization.

Laying the Mixtures

The mixtures can be laid with a paver or grader depending on application. The grader has the advantage of allowing some aeration but at the expense of smoothness. It is usually not necessary to tack or prime.

Compaction is preferably with a combination of steel and pneumatic rollers, although for small reinstatements a plate compactor is suitable. Dense cold mixes require more compactive effort than hot mixes. A typical regime would be several passes with a steel roller, initially with vibration, then pneumatic-tired roller and finally steel again. Thinner lifts cure faster although the thickness should be minimum 2–2½ times the top-sized aggregate. The maximum lift which can be effectively compacted is approximately 10 cm (4"), so thicker layers must be laid in several lifts. No tack coat is needed between layers.

The finished job should be sealed after a few weeks when most of the water has evaporated. Chipseals, slurry or microsurfacing are suitable. Priming or tack coating is not required.

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