Slurry seal and microsurfacing

Nouryon

Slurry surfacing overview

Slurry surfacing systems (Slurry seal and Microsurfacing) are thin emulsion cold mixed overlays which are recognized as cost-effective restorative and preventive maintenance techniques for roadways of most traffic levels, airport runways and taxiways, highways, shoulders, sidewalks, foot and cycle paths, and parking lots. They may also be used as wearing courses on emulsion stabilized bases or recycled roadways, bond courses, crack fill or combined with other techniques like chipseal ("capeseal").

The systems combine finely-graded aggregates, bitumen emulsion, water and mineral fillers like cement or lime. Polymers, pigments, fibers, chemical additives and recycled materials may be included to enhance performance or processibility, or to improve the environmental profile. Bitumen emulsions used in slurry surfacing fall into the category of anionic or cationic slow-set grades, but need not pass the cement mix test. The bitumen content of the cured seals ranges from 5 to 16% by weight of aggregate.

Slurry surfacing is normally applied on highways using a purpose-designed self-propelled mix-paver but may be prepared in more basic mixing equipment and applied manually for smaller scale applications. The slurry ingredients are dosed and mixed in the paver then discharged into a spreader box which distributes the material over the roadway and maintains the profile and thickness of the seal. Application rates range from 3-14 kg/m2 for a single pass. Some specially formulated materials may be applied in multiple layers or in deeper deformations or potholes. Bond coat is sometimes applied before sealing to ensure that the new layer adheres to the existing surface.

Two slurry products can be distinguished - Slurry seal and microsurfacing. Slurry seal is normally laid no thicker than 1½ times the top size of the aggregate, which can range from 3-10 mm. Mineral fillers like cement or hydrated lime are commonly used, but are not always required. Slurry seals waterproof and seal the surface from water ingress and deterioration and provide a skid resistant, smooth running surface. Typically, slurry seal can be trafficked in 1-4 hours. "Quick-set" slurry seal can be opened to traffic within an hour and usually has a shorter mix time. Microsurfacing can be laid in multiple layers to correct significant deformations including rutting and is suitable for higher traffic or higher stress situations. Higher quality aggregate is required, and usually has a top size of 5-10 mm. The emulsion must contain minimum 3 wt% polymer by weight of bitumen and meet more demanding durability specifications than slurry seal. It is applied with a mix-paver. The mix sets within 15 to 30 minutes, and may be trafficked within 1 hour. Mineral filler is almost always included in the mixture. The appearance of cured slurry is similar to that of a thin hot applied overlay but with higher texture depth.

What can be achieved with slurry surfacing:

- Prevent water penetration
- Improve skid resistance
- Improve surface texture/surface drainage
- Rut-filling (microsurfacing mixes only)
- Correct effects of raveling
- Fill small cracks including alligator cracks
- Fill small potholes
- Correct flushed surfaces or stripped surface dressings
- Seal base courses
- Wearing surface on stabilized bases
- Bond coat
- Delineate bus lanes, cycleways, shoulders (optionally with color)
- Provide good background for road marking
- Fill open graded mixes

Slurry seal and microsurfacing cannot be used to address structural problems or major cracking associated with the existing pavement.

Microsurfacing in Czech Republic with Redipave phosphoric acid system.

Microsurfacing provides more texture than a hot mix overlay resulting in improved wet skid resistance.

Slurry surfacing mix design components.

Table 1: Slurry surfacing types

Application	Slurry	Quick-set slurry	Microsurfacing
Emulsion type*	CSS-1, SS-1	CQS-1H, QS-1	CQS-1HP, CSS-1HP
Aggregates	Wide range Type I, II or III	Wide range Type I, II or III	Selected, high quality Type II or III
Polymer	Sometimes	Sometimes	Always
Cement or lime	Not required	Cement, lime, and/or aluminum sulfate	Uses cement or lime
Lift thickness	Thin lift only (<1.5x top size)	Thin lift only (<1.5x top size)	Thick lifts and multiple applications possible
Traffic time	1-4 hours	<1 hour	<1 hour
Uses	Sealing, texture improvement, color improvement	Sealing, texture improvement, minor re-profiling	Sealing, texture improvement, rut-fill
Other notes	Formulated for ease of-application and hand work		Strict durability requirements, lower AC content

* Other emulsion grades and different naming may be encountered

The history of slurry surfacing

While cold mixes with a slurry like consistency based on clay stabilized emulsions may have been used 100 years ago, and were further developed during the 1930s in Germany as "Schlämme", the first slurry as we recognize it today is believed to have been based on chemically stabilized anionic emulsions and was in use by the late 1950s in both USA and Europe

The beginning of the 1960s saw the development of continuous mix slurry machines and systems based on cationic emulsions, including what we would now describe as quick-set slurry or microsurfacing. Today the vast majority of slurry surfacing uses cationic bitumen emulsion.

Nouryon (then AkzNobel) has played an important role in the development of slurry surfacing systems. The Redicote Slurry System, developed around 1962, was one of the very first cationic slurry systems and is still in widespread use today. Around the same time Thomas Swan & Co. Ltd. in the UK and Lancaster Chemical AZS division in the USA developed a range of slurry and microsurfacing emulsifiers, later acquired by Nobel Industries (now Nouryon) and marketed under the Catimuls tradename. The cohesion tester now used for slurry testing was developed in Nouryon's Chicago laboratory. In 1985, Scanroad International (part of Kenobel Industries) bought Slurry Seal Inc. in Waco, Texas, which since 1961 had been producing Young's slurry pavers. Raymond Young was one of the pioneers in the manufacture of slurry surfacing pavers and emulsion plants and was the first president of the ISSA (International Slurry Surfacing Association), established in the 1960s. In the 1990s Scanroad continued to manufacture and develop slurry pavers (HD-10 and SR-10), emulsion plants, as well as other construction equipment in Waco, and also operated slurry seal and micro paving contracting companies in Europe and USA. This involvement in equipment manufacturing, emulsion production and slurry seal and microsurfacing application enabled Nouryon to optimize the chemical systems and to develop expertise in emulsion production and application. In 1994 Scanroad was renamed Akzo Nobel Asphalt Applications Inc. (now Nouryon).

Slurry Seal Inc. of Waco, Texas, producers of the Young slurry seal machines, were purchased in 1985 by Kenobel which later became part of Nouryon.

In 2001 Nouryon decided to concentrate on the supply of chemicals to the road industry, and the equipment manufacturing and contracting activities were divested. Technical service laboratories were established worldwide with full capabilities to produce emulsion on pilot scale and do slurry mix design to support customers in the slurry surfacing market. The product range for slurry chemicals was expanded with patented emulsions based on phosphoric acid, and new emulsion recipes were developed capable of providing quick-traffic performance with neutral or near neutral pH emulsions. Today Nouryon offers the widest range of slurry seal and microsurfacing emulsifier chemistries with products suitable for all asphalt and aggregate qualities, including low acid value binders and varying aggregates, and climate conditions, including hot weather conditions and cooler application temperatures even below 10°C.

Redicote® Slurry System and Rex SlurryMatic paver circa 1965.

The International Slurry Seal Association (ISSA), established in 1963 and later renamed the International Slurry Surfacing Association, was instrumental in the development and standardization of slurry surfacings. The first World Congress on Slurry Seal, organized by ISSA, was held in 1977. The guidelines and test methods of ISSA form the basis of many national standards.

Pavement preservation

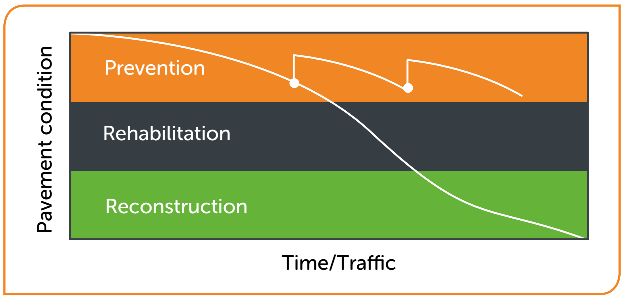
Asphalt and cement concrete roads deteriorate over time through the action of traffic, the elements and slow chemical changes in the binders themselves. Early deterioration as manifested by minor cracking, ravelling, and polishing may be quickly and economically restored by maintenance treatments.

Even earlier treatment can prevent the significant deterioration by providing a barrier between the asphalt structural layers and the elements. The concept of Pavement Preservation or Preventive Maintenance is now widely accepted by highway engineers. The road should be treated while still in good or fair condition when a small investment of time and money will pay back the most in extended life. If left too long roads become severely damaged and are expensive and disruptive to repair or reconstruct. The Michigan Department of Transportation reports that for every dollar spent on Preventive Maintenance they save six to ten dollars in future reconstruction or rehabilitation cost. In addition existing pavements lose their skid resistance characteristics over a period of time, and slurry seal or microsurfacing are highly effective ways to provide an anti-skid surface.

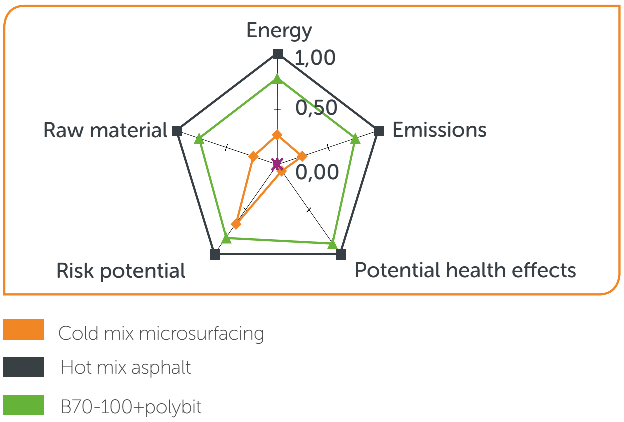
Slurry surfacings provide a good combination of restorative and preventive maintenance for relatively low cost, in a quick process which minimizes traffic delays, well adapted to urban areas or night work with minimum or no adjustment to curbs (kerbs) and drains. The seals protect asphalt or cement structural layers from water intrusion, improve friction and ride quality, and seal minor cracks. Small deformations and ruts can be corrected with slurry seals, more extensive ruts can be filled with microsurfacing. Slurry surfacing provides a quieter surface than chipseal (surface dressing), with a lower texture more receptive to road marking and less liable to snow plough damage, and without loose rock that can lead to wind-shield damage. Compared to thin or ultrathin hot mix overlays, they generally avoid the need for extensive milling and removal of old surfacing, do not usually require tack coat or compaction, and provide a surface with better wet skid resistance. The whole paving job is done with relatively small footprint in equipment and manpower in a single operation ideal for urban and residential locations.

Calculations have shown that polymer modified microsurfacing is more eco-efficient than thin hot mix overlay - it consumes less resources and emits less carbon dioxide greenhouse gas, even excluding the benefits of reduced traffic delays.

Bitumen emulsion is a key component of the slurry surfacing. The finely divided bitumen particles just a few thousandths of a millimeter in diameter can distribute themselves between and around fine aggregate particles without the need for heat, and the nature of the emulsifiers and fillers used means that the slurry mixes cure chemically on the roadway. Polymer, in the form of latex, can be easily incorporated either into the emulsion during production, as is most common, or soon afterwards The result is an environmentally friendly cold-applied product, without the fumes of hot mix asphalt, that can quickly be opened to traffic, often within one hour, with minimum disruption to road users and local residents.



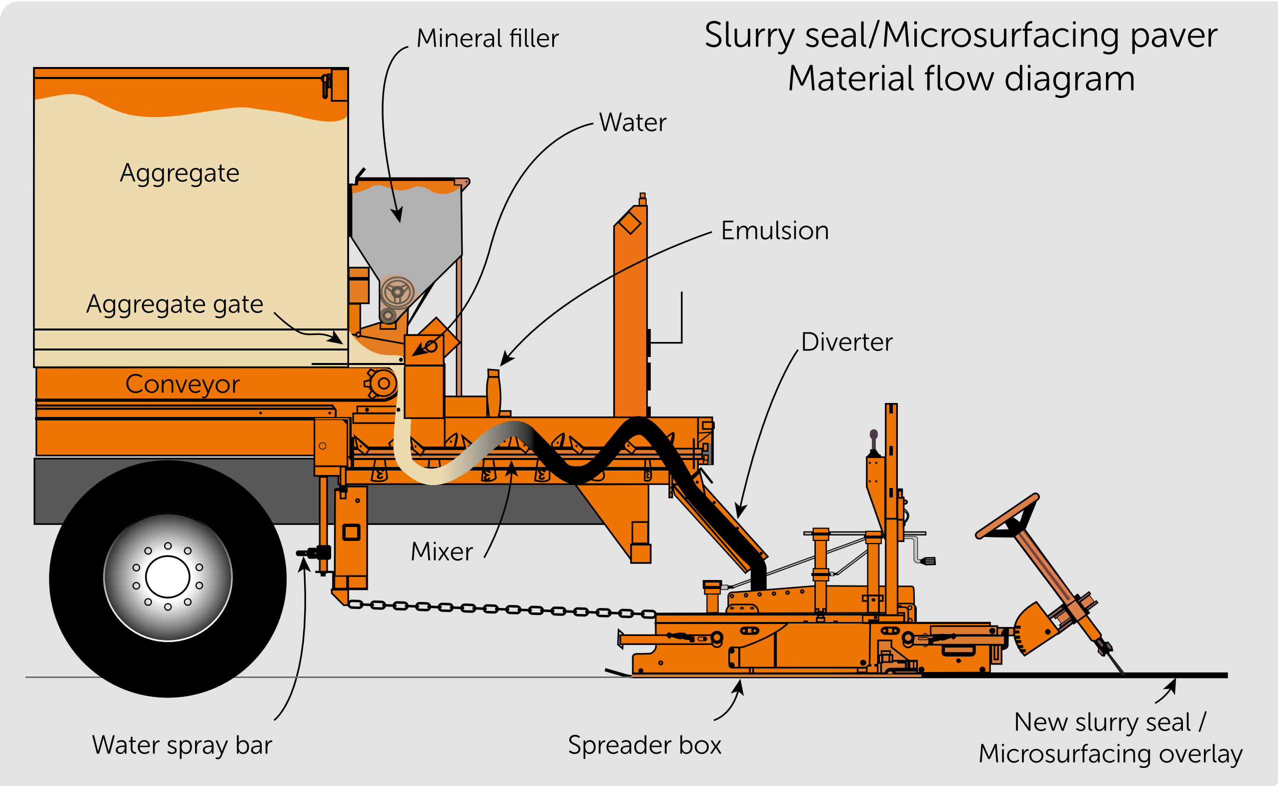
Early treatment of the road extends its life without expensive rehabilitation or reconstruction.



Microsurfacing has a lower impact on the environment than a thin hot mix overlay. Source: BASF

The paving process

The road surface is first cleaned with brushing or high pressure wash. Thermoplastic road markings may be removed or masked, and drains, utility covers and other areas may be masked to prevent adherence of the slurry.



Source Ergon

The slurry or microsurfacing mixture is prepared in a mobile mix paver "Slurry Paver" which holds all the ingredients (aggregate, emulsion, water, fillers, additives and optionally fiber and pigment). These ingredients are delivered in the correct proportions into a helical or paddle mixer, for example a pug mill, to produce the slurry which is discharged into a spreader box. Generally aggregate and cement enter the mixer first, followed by water then emulsion. Chemical additives are injected into the water line. The proportions of the ingredients are maintained constant independent of the forward speed or discharge rate of the machine, either by a common clutchshaft driving volumetric pumps for water, emulsion, additive and the filler feeder and aggregate conveyor or by electronic controls. Aggregate delivery may be volumetric via an aggregate gate, or by load cells on the conveyor. Proper calibration is vital for successful application.

The spreader box

The function of the box is to receive and contain the mix, evenly distribute the material, agitate the mix to prevent segregation, meter the material onto the road surface, control the transverse and longitudinal profile, and apply the final texture. The box is not rigidly attached to the paver, rather it travels along the road surface on skids, pulled by the paving machine. These adjustable skids on the sides and under the box support it and keep it level to control the longitudinal profile. Augers may be used in the box to spread the slurry across the road surface. With some fine slurries no augers are needed, but with coarser slurries quite intense agitation may be required to prevent segregation and to distribute the material across the road surface, and the box may contain paddle type agitators as well as the augers.

Rubber strips on the front and rear of the box, and sometimes also on the sides, help contain the mix. Adjustable flexible or rigid strips "strike offs" across the rear of the spreader box control the thickness and transverse profile. They can be raised or lowered at different points across the road. The box may be split to better follow the camber of the road. A rigid (metal) strike off is used produce a horizontal profile for a first "leveling course" or "scratch course". A flexible strike off made from polymer or rubber is used for the final course. Some pavers have a secondary strike off of softer material or burlap which can remove small drag marks and provide a consistent texture to the final seal. The width of the spreader box maybe fixed or variable. Special V-shaped spreader boxes and strike offs are used for deep rut-fill which are designed to produce a profile higher in the center, to allow for compaction under traffic.

Quality assurance and quality control

The paver has to be calibrated before use. The aggregate may be damp which affects its bulk density and the delivery using volumetric gate type feeders. In many cases a test strip will be laid. During construction the consumption of materials is carefully monitored as a double check on the metering systems. Modern pavers have integrated data-loggers which provide a record of material consumption. The quality of ingredients may be tested during construction. The slurry may be sampled for bitumen determination and performance tests may be performed with site materials or using the slurry discharged from the paver.

The fresh seal should have an even color and texture with little or no run off of emulsion from the sides. Workers may correct small imperfections and drag marks in the seal before it cures using squeegees or brooms.

Slurry spreader box.

Water

Water addition rate controls the consistency of the slurry and may be adjusted on the paver as required.

Filler and pigments

A screw feeder is used to supply filler to the mixer. Bags of cement or lime are usually added by hand to the filler hopper. Some slurries can be formulated without filler, or lime slurry has been used to avoid handling the powders. Pigments in powder form may be added via the filler feeder or a dedicated feeder. In some systems the pigment is incorporated in the emulsion. Hydrated lime filler rarely exceeds 0.5%; cement may be used up to 2.5% (expressed on aggregate).

Fibers

Fibers are used in some high performance products to improve wet consistency and sometimes the final strength. They can be pre-chopped and added via a hopper or the machine may incorporate a chopper and fiber feeder. Cellulose might be used to increase viscosity or glass or polymer for extra durability.

Chemical additives

Chemical additives may be added to retard or (less often) to accelerate the curing process. They are stored in a small tank on the paver and dosed into the water line. They may be added undiluted or as a water solution.

Handwork

It may be necessary to apply slurry by hand in order to completely cover irregularly shaped road areas such as intersections and cul-de-sacs. Slurry may also be

Handwork.

applied from small mixing equipment and spread by hand on small areas like cycleways and footpaths. Squeegees are most often used to distribute the slurry over the surface. In the case of quick-set slurry and microsurfacing, the mixture may need to be stabilized to allow enough time for handwork - which is done by the addition of break retarders.

Continuous paving

Sanding

Sand may be used to avoid damage of the seal and pick up on tires if traffic is allowed onto the surface before full cure, and especially to protect against turning or cross traffic.

Pretreatment of the road with water or tack.

A spray bar on the paver can spray water onto the road surface before the spreader box to help wet out dust on dry road surfaces and cool the surface. Some advanced equipment may have an integrated emulsion distributor to apply a tack coat before the slurry, or tack may be applied separately. Stabilized bases should be preferably treated with a primer seal before application of slurry.

Pretreatment with tack.

Batch and continuous pavers

Batch pavers are used on smaller jobs and in urban areas because they are more maneuverable. Typically they hold about 4-8 cubic meters of aggregate and are truck mounted. Larger batch equipment up to 10 cubic meters may be trailer mounted. Once the material in the truck is exhausted it must return to the stockpile and refill. Generally the contractor will utilize two or more pavers to provide more or less continuous paving at the job site. Continuous run pavers can be refilled by nurse trucks without stopping and are used on larger jobs. Compact continuous machines suitable for urban work are available and batch pavers can be retro-fitted with special nurse feeders for continuous operation.

Compaction

Rolling is not usually required but may be specified for low trafficked areas like parking lots and airports, or for deep rut-fill projects. Pneumatic tired rollers are used once the seal is stable enough to take the weight. One or two passes are sufficient. In some cases slow moving traffic is allowed initially to accelerate the curing process.

Compaction is often specified for airport jobs.

Sweeping

All of the aggregate is incorporated into the surfacing and sweeping of the finished seal is not normally required, but may be specified for airport jobs or in response to early raveling of the seal.

Multiple layers

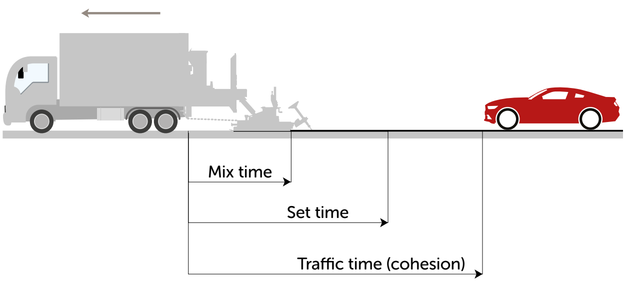
In microsurfacing a "scratch course" (correction or levelling layer) may be applied and allowed to cure under traffic before placement of the wearing course. Usually 12 hours or more is used between applications. The scratch course should be swept before covering to avoid drag marks.

Fog seal

A fog seal may be applied to prevent early raveling in cold weather paving.

The curing process

Mixing the slurry components initiates a chemical process which leads to the curing of the seal. The process can be considered in four stages:



Mix time:

During this period the slurry is brown, fluid and homogeneous and can be mixed. The slurry must remain workable and flowable during mixing and in the spreader box so it distributes easily over the road surface and the profile can be controlled with the strikeoffs.

Set time:

As the chemical reaction proceeds, the slurry builds viscosity, sometimes very rapidly and can no longer be mixed. Clean water separates from the bitumen and aggregate fractions. The process is irreversible but the seal is not strong enough to support traffic.

Traffic time:

The slurry builds sufficient cohesion that controlled speed traffic can be allowed on. The color is dark brown or black.

Full cure:

Trafficking and time complete the curing process and the seal has the character of a hot mix overlay.

Mix time and temperature

The mix time must be sufficient to allow the slurry to pass through the mixer and spreader box without problem. The residence time in the mixer is short only 10-15 seconds and 45 seconds or less in the spreader box would be typical. Different machines and boxes may require different minimum mix times. Too short mix time leads to "breaking in the box" which can completely stop production or lead to a build up of hard mix in the corners of the box causing drag marks on the seal when it leaves. Hand work requires longer mix time.

The chemical reaction in the slurry is accelerated by heat. Hot weather or hot emulsion can lead to premature breaking and insufficient mix time. This can be corrected by the addition of chemical additives "dopes" or "break-retarders" which are added to the water and act to deactivate the aggregate. On the other hand the reaction in the slurry is slower in cold weather. The reaction in cold weather can be helped by the use of hot emulsion. With some materials, mix time and set time respond to filler content. Otherwise the emulsion recipe needs to be modified for cold weather paving.

One should be careful about the amount of break-retarder used in the mix; it is not good to use an excessive amount. It is best to test the slurry mixes with the expected amount of break-retarders used in the field to ensure that they are not significantly altering the performance properties of the binder and the slurry seal or microsurfacing mix.

Additive tank on the paver. Additive is used to extend the mix time in hot weather.

Fresh slurry is brown but cures to a black surface with an appearance similar to hot mix asphalt. Source: Duncor

The chemistry of the curing process

The reaction of bitumen emulsion with aggregate in cold mix processes has been extensively studied. The mechanism of the setting and curing process depends on the interaction of the emulsion and the other components of the seal.

The droplets in bitumen emulsions are charged - positive in cationic emulsions or negative in anionic - and this charge is responsible for the stability of the emulsion. The charge is sensitive to pH - for example some cationic emulsifiers lose their charge at high pH. Moreover bitumen contains natural acid components which may develop negative charge at high pH. In quick-set slurry systems and microsurfacing the ingredients are designed to react. Most often alkaline fillers like cement or lime are included to produce a large rise in pH, and to generate soluble calcium ions.

Slow-setting systems

Even without a chemical reaction between the emulsion and the aggregate and filler components, the seal will still cure slowly simply due to the evaporation of water in a similar manner to the drying of latex paint. As water leaves the system the droplets of bitumen and aggregate are forced closer and closer together and the concentration of soluble ions in the system also rises. The consequence is destabilization and coalescence of the emulsion, and sticking of the aggregate particles together. In practice it is hardly possible to have a system where there is no chemical interaction between the bitumen droplets and the aggregate or filler fraction.

Anionic quick-set systems

In anionic quick-set systems containing resin or sulphonate emulsifiers, cement is used to produce a high concentration of calcium ions which destabilizes the emulsion by neutralizing the negative charge on the emulsion droplets. The insoluble calcium soaps formed in the process are not effective emulsifiers and the system breaks rapidly.

The Redicote slurry system

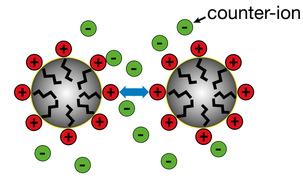
The Redicote slurry system is based on cationic slow set emulsion stabilized with quaternary ammonium emulsifiers (Redicote E-11). The emulsion droplets have a positive charge and are relatively insensitive to pH changes. When mixed with fine aggregate these droplets bind closely with negatively charged mineral particles forming tightly bound assemblies which provide structure to the seal. The attraction between the bitumen and the aggregate is strong enough to squeeze water out of the system creating a high viscosity, cohesive mat of cold mix. Eventually water is displaced from between the particles and evaporates leading to full curing. The emulsions typically pass the cement mix test, and in these systems cement and lime typically extend the mix time because the soluble ions they produce can reduce the interaction between the bitumen droplets and mineral particles.

Cationic quick-set and microsurfacing systems

Developed in the 1960s, these systems use lime or cement filler in the mix and emulsifiers which require acid formulations to be cationic. The emulsifiers used are characterized by large head groups with multiple charged centers. When the slurry components are mixed the cement reacts with the acid. The acid is neutralized, the pH rises rapidly, and at the same time large quantities of soluble calcium ions are produced, and the charge on the emulsifiers is largely destroyed. The acid components in the bitumen can play an important role in the breaking process. At the high pH and calcium ion concentrations in the slurry the droplets of bitumen rapidly coalesce.

Phosphoric acid system

Phosphoric acid slurry systems were developed in Germany during the 1970s. The emulsions are formulated with phosphoric acid rather than hydrochloric. Phosphoric acid forms insoluble salts with calcium which limits or buffers the pH changes which occur in the slurry and the limits the concentration of calcium ions. The pH of the slurry never exceeds 9 and the charge on the emulsion droplets is maintained. Destabilization and setting are thought to occur though interaction of the bitumen droplets and oppositely charged mineral and filler particles. Because the filler particles are negatively charged at the slurry pH, they directly contribute to the breaking process.



Bitumen droplets in emulsion have charge, which is destroyed in the breaking process.

Mix design

A wide variety of materials can be slurried successfully, suitable for a range of applications from footpaths and parking lots to interstate highways.

To ensure the function and durability of the surfacings, the materials and the combination of materials need to be carefully evaluated with a view to the intended application. The design process involves preparing slurry on a small scale in the laboratory and testing its properties. It focuses on the quality of the materials used, their proportions in the slurry, their compatibility, and the durability of the final seal. The output of the mix design process is a target mix recipe comprising quality raw materials, which can be processed through the mix and lay down equipment under the expected environmental conditions, and in proportions designed to provide a durable surfacing, suitable for the intended application.

The most widely adopted design process is that developed by the ISSA and also described in the standards of many national and local authorities. Separate guidelines are described for slurry surfacing and microsurfacing. The Performance Guidelines and Technical bulletins of ISSA describe recommended specifications for the raw materials, test methods to determine the compatibility and processibility of the components, and performance tests which evaluate the final properties of the cured seal and the speed at which the seal can be opened to traffic. The guidelines and test methods are under continual development and review. The main outputs of the mix design process is the minimum and maximum asphalt content of the mixture, the filler content, the range of water content and whether the mixture meets the requirements of a quick-traffic system. The design may also include an evaluation of suitable chemical dopes, and the sensitivity of the design mix to temperature.

Laboratory mix-design with representative materials from the field that takes into account the reactivity of the aggregates and field application conditions, especially temperature, is a key step preceding the slurry/microsurfacing project. The emulsion reactivity is adjusted by the type of emulsifier/emulsifiers, dosage and pH of the emulsion to match the reactivity of the aggregates and field conditions. In addition consistent quality of the raw materials, especially the aggregate, calibrated paving equipment and a thoroughly trained crew are important factors to complete a successful slurry/microsurfacing project. These factors become more important for a quick traffic slurry/micro project.

Table 2: Aggregate gradations

Sieve size		Type I Percent passing	Type II Percent passing	Type III Percent passing
3/8	(9.5 mm)	100	100	100
#4	(4.75 mm)	100	90-100	70-90
#8	(2.36 mm)	90-100	65-90	45-70
#16	(1.18 mm)	65-90	45-70	28-50
#30	(600 um)	40-60	30-50	19-34
#50	(330 um)	25-42	18-30	21-25
#100	(150 um)	15-30	10-21	7-18
#200	(75 um)	10-20	5-15	5-15

Aggregate gradations recommended by ISSA. Mixes often contain filler (cement or lime) which should be considered part of the gradation. Gap graded materials have been used successfully.

Aggregate

While a wide range of aggregate gradations can be successfully adapted for use in slurry surfacing, many local and national authorities have adopted the gradations developed by the ISSA and designated by the descriptors Type I, Type II and Type III (Table 2) which are continuously graded with top sizes in the range 3-12.5mm. Additional requirements for abrasion resistance, freeze thaw resistance may be required. Fully crushed aggregate is usually specified. It is possible to use blends of different aggregates to achieve gradation and durability requirements. The reactivity of the aggregate towards emulsion is largely determined by the very finest components which have the highest surface area. Clays are reactive in the slurry system and moreover have a negative effect on durability. Sand Equivalence (SE) is used to control the clay content - the higher the SE the "cleaner" the aggregate. Typically a minimum 45 is required for slurry and 65 for microsurfacing but lower numbers might be accepted based on experience and availability of local materials. Titration of the aggregate fines with a solution of the cationic dye methylene blue can provide a useful indication of reactivity towards cationic emulsions.

Mix design

Emulsion

The emulsions typically meet the local specifications for cationic or anionic slowsetting grades, but do not need to meet the cement mix test requirements. Some regions specify a "quick-set" grade of emulsion for quick-traffic slurry systems. Polymer is often included - in the form of latex or polymer modified binder. The properties of the residue depend on the application and region. Minimum softening point, elastic recovery or Multiple Stress Creep Recovery (MSCR) results may be specified in some regions to minimize flushing and rutting in hot weather.

Fillers

The source and type of filler can influence the slurry properties and the mix design should be done with the job materials whenever possible.

Water

Clean water is required. Potable water is suitable.

Other ingredients

Other intended ingredients such as fibers, pigments, and chemical additives need to be included during the mix design process.

Mix time

Simple hand mixes with small quantities of materials are used to check the mix time of the materials, the consistency (fluidity) of the mixture and how these are affected by filler content and dope. Mixes with a range of compositions will be tested. Mix design specialists are able to predict how a slurry will behave in the field on the basis of these small scale tests. If necessary the emulsion can be reformulated in order to provide the required mix time. The mix tests may be repeated at higher temperatures to ensure that the mix time can be achieved in hot weather.

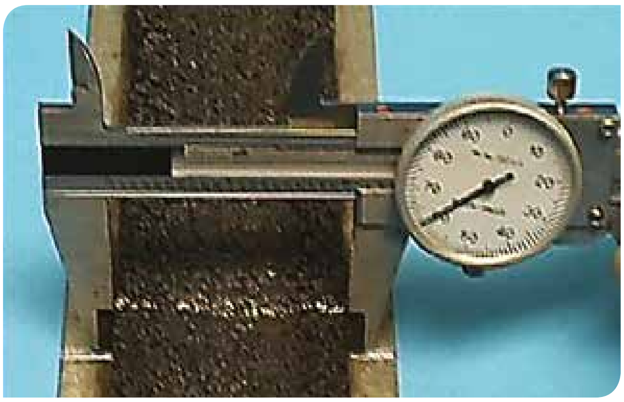
Cohesion development by cohesiometer

The hand mixtures are poured out and the rate of cohesion developement measured using a cohesiometer. Standards have been set to identify quick-set and quick-traffic systems. To ensure good hot or cold weather performance the test can be done in a temperature controlled room or the materials can be conditioned in an oven or refrigerator.

Durability by wet track abrasion tester (WTAT)

Seals, fully cured at 60C, are immersed in water for 1 hour or 6 days and then subjected to 5 minute abrasion with a weighted rubber hose under water to simulate the effect of traffic in wet conditions. In most regions the tests are done using just the minus 4 mesh portion of the aggregate. The weight loss is compared to specification limits. Increasing the bitumen content usually reduces the weight loss and the WTAT sets a minimum value for the bitumen content.

In the Schlulze Breuer Ruck test small "pills" prepared from the slurry ingredients in fixed proportions are subjected to water soak and abrasion, eventually in boiling water, and the damage assessed on a points scale..



Too much binder leads to deformation in asphalt mixes. Cured samples of microsurfacing are prepared 1.25x thicker than normal and subjected to 1000 cycles in the LWT. The increase in width is measured. The test sets an upper limit on the bitumen content of micro-surfacing when it is to be used in thick or multiple lifts.

Compatibility by the Shultze Breuer Ruck (S-B-R) test

Long term moisture damage in microsurfacing may be related to the compatibility of the mastic components. In the S-B-R test a fixed gradation of the finest portion of the aggregate and filler is mixed with emulsion, cured and compacted into "pills" which are subjected to soaking in water, abrasion and a boiling stripping test. The performance is scored on a points system. Because the amount of bitumen in the test sample is fixed, the results are sensitive to the filler content and typically set an upper limit on the filler content of the slurry. The test identifies emulsion chemistry incompatible with the finest mineral fraction.

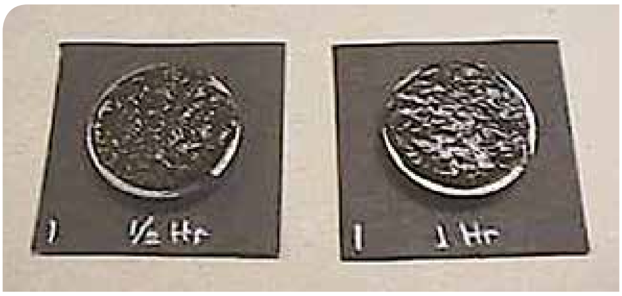
Determining maximum bitumen content by loaded wheel test (LWT)

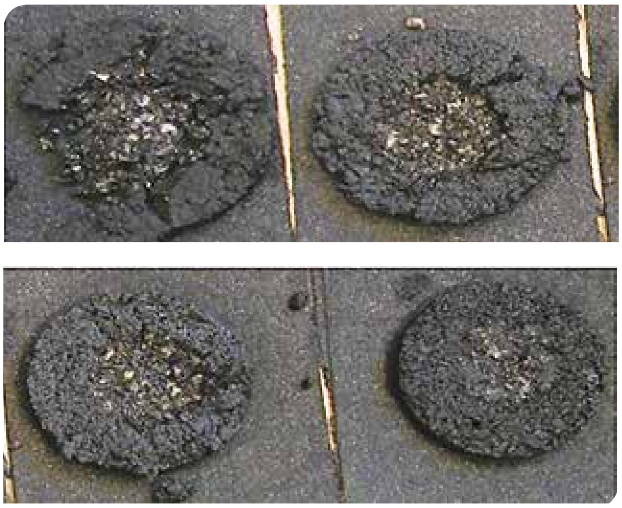
High levels of bitumen may result in flushing and deformation which are addressed in the LWT. The LWT results set a maximum limit on the bitumen content. The combination of the LWT and WTAT test results leads to an acceptable range of bitumen contents.

Other tests and design approaches

Not all the standard tests and specifications described by ISSA are demanded in all regions, and some of the tests may be modified according to the requirements of the local markets and applications.

Mix design specialists often use simple tests like blot test (which shows the initial set time when clean water is expressed) to determine the progress of the reaction.





In the cohesion test small samples are mixed and are cast into molds, which are then removed. The cohesion tester measures the torque required to tear apart a specimen with a rubber foot loaded to 29 psi, designed to represent the effect of power steering on the surface.. Measurements are taken over a period to determine the set and traffic time.

In some countries the WTAT test has been modified (Surface Cohesion Test) to study early cohesion development. Seals are cured at room temperature (or expected job site temperature) and subjected to abrasion with a wheeled attachment to the WTAT. The weight loss is used to determine the traffic time.

Instead of the LWT, optimum or maximum bitumen content can be calculated from the surface area of the aggregate, or determined by Marshall or modified Marshall design methods.

Tips for meeting mix design specifications

Too little mix time

- Increase emulsifier dosage
- Formulate at higher soap pH (cationic systems)
- Use chemical break retarder (dope) or aluminum sulphate
- Use lime filler instead of cement
- Use different emulsifier chemistry
- Increase filler content (some systems)

Too slow cohesion development

- Reduce emulsifier content if there is sufficient mix time
- Increase filler content (some systems)
- Formulate at lower soap pH
- Reduce or eliminate break retarder if sufficient mix time

Mix design

- Include solvent in recipe, if allowed, to improve low temperature cohesion development
- Include an acid dope for the bitumen or soap phase
- Use different emulsifier chemistry
- Use phosphoric acid system and appropriate emulsifier chemistry

Fail loaded wheel test (rutting)

- Reduce emulsion content
- Increase polymer content
- Increase filler content

Fail wet track abrasion test

- Increase emulsion content
- Increase cement or lime content (most systems)
- Increase polymer content
- Change polymer type
- Formulate to higher soap pH (cationic grades)
- Use different emulsifier chemistry
- Include an acid dope for the bitumen or soap phase

Fail sand adhesion test

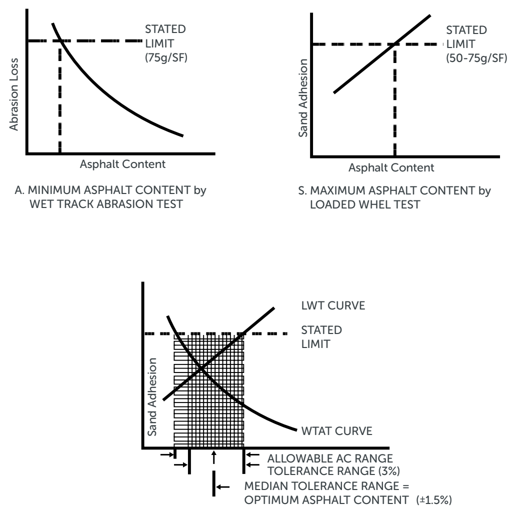
- Reduce emulsion content
- Raise filler content

Fail Schulze Breuer Ruck

- Reduce filler content
- Increase polymer content or change polymer type
- Raise or lower emulsifier content (depends on system)
- Change emulsifier chemistry

Fail consistency

- Adjust water content
- Adjust filler content
- Select alternative break retarder

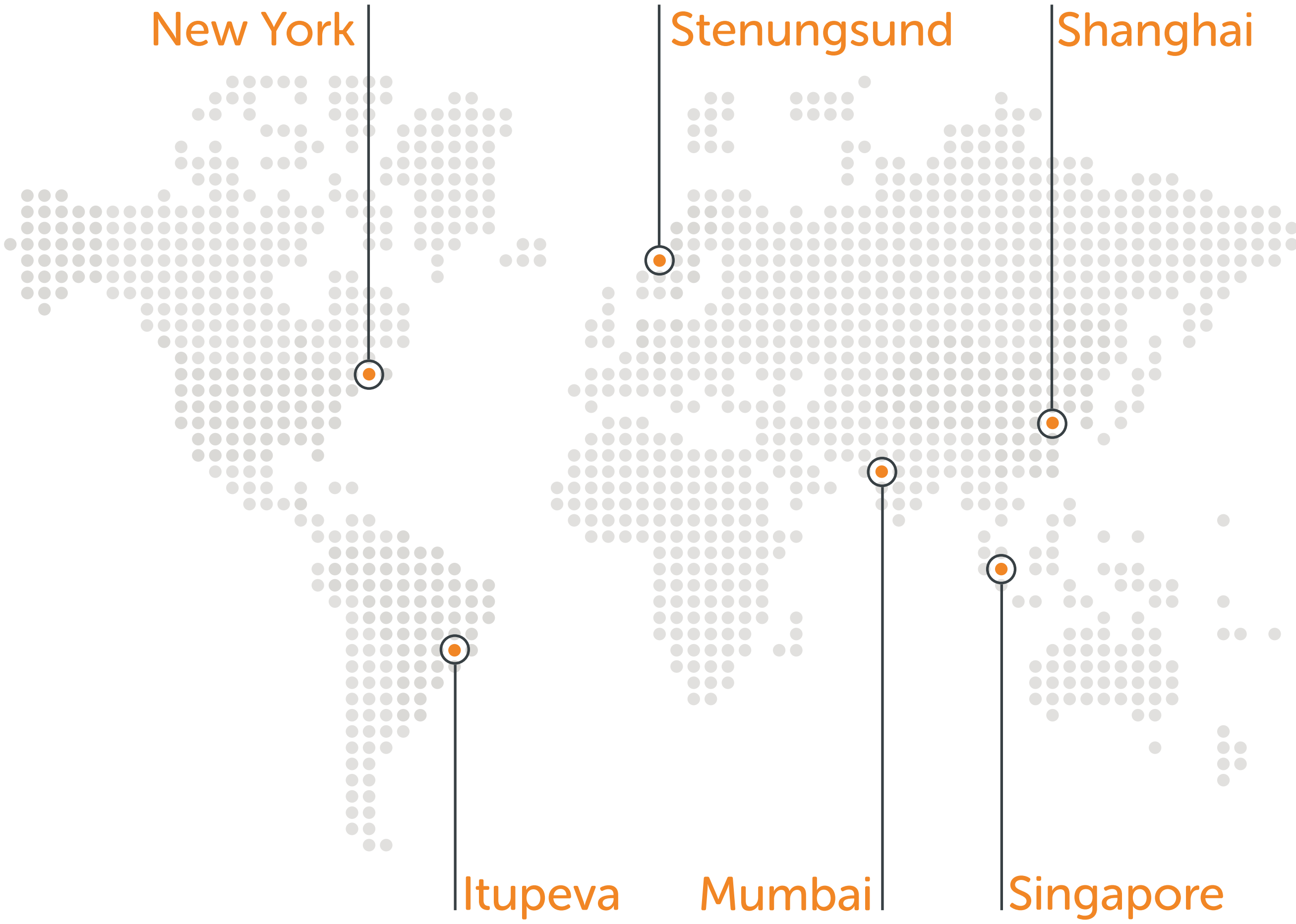


The minimum bitumen content is determined by the WTAT and the maximum by the LWT (either sand adhesion for flushing or deformation for rut-fill). Together they set a range for the bitumen content of the seal.

Table 3: ISSA specifications

Tests	Method	Slurry seal	Micro-surfacing
Mix time, sec. (25°C)	TB113	80 Min.	120 Min.
Cone consistency	TB106	2-3 cm	
Wet cohesion	TB100	For quick traffic only	
30-min		12 kg-cm, min.	
1 hour		20 kg-cm, min	20 kg-cm, min
Wet stripping	TB114	90% min	90% min
WTAT, g/m2 loss	TB100		
- 1 hr. soak		807.0 Max.	538 g/m², max
- 6 days soak		None	807 g/m², max
LWT	TB147		
Lateral displacement			5%, max
Specific Gravity after 1000 cycles			2.1, max*
LWT	TB109	High traffic areas only	
Excess asphalt sand adhesion		538 g/m2, max.	538 g/m², max.
Classification compatibility (Schultze Breuer Ruck)	TB144		11 points, min

Mix design laboratories in Nouryon



Nouryon provides slurry mix designs to its customers all over the world in fully equipped laboratories. Conveniently located for shipment of samples and with good knowledge of local requirements, the laboratories are able to develop emulsion recipes to match the needs of local materials.

Overview of Nouryon products

Table 4: Product overview

Product	Region	Comments	Conventional slurry	Quick-traffic slurry	Microsurfacing
Redicote E-4868 Redicote E-4875	A E,S,C	Produce "super-stable" cationic slow set emulsions for the most reactive aggregates and hot conditions.	Yes	No	No
Redicote E-11 Redicote E-11E Redicote E-11HF Redicote E-11HF-1 Redicote 611	E,S,C A E A E,S	Produce cationic slow setting emulsions with excellent latex compatibility. Cement or lime filler not always required. Emulsions can be formulated with neutral or near neutral pH. The products can also be used as dope in these systems.	Yes	Sometimes	Yes
Redicote 404 Redicote C-450 Redicote C-471 Redicote C-500	E, S, C A A E, S, C	Produce cationic emulsions for quick-traffic systems and microsurfacing. Choice of product determines mix time. Products can be combined to achieve reactivity suited to most aggregate types and climate conditions. Latex modified or polymer modified asphalt can be used. The products canalso be used as dopes in these systems.	Yes	Yes	Yes
Redicote C-320 Redicote C-320E Redicote EM-44 Redicote EM-44A	A E E A	Products for phosphoric acid systems. Reliable cohesion development with wide range o bitumens and in cool weather f	Yes	Yes	Yes
Redicote E-7000	A, E, S	Can be used for both anionic and cationic quick-set recipes. Excellent latex compatibility. Can be formulated together with Redicote E-11 , Redicote C-450 or Redicote C-471 to produce cationic quick-set emulsions with a wide range of reactivity	Yes	Yes	Yes
Redicote 540	E	Accelerates cohesion development and improves durability in all systems	Yes	Yes	Yes

A= North and South America; E= Europe, Middle East, India, Africa; S = South East Asia, excl China; C= China
Products may not be available in every country within a region.

Options for conventional slurry

The Redicote slurry system

Developed more than 60 years ago and still going strong, the Redicote Slurry System has passed the test of time with honors.

Today products in the Redicote E-11 family are produced worldwide in Singapore, Brazil Sweden and USA. Why is the system still so popular? It is a simple, reliable and value for money process which performs well in a wide range of climates.

Neutral pH emulsions with strong cationic character

The Redicote E-11 family of quaternary ammonium emulsifiers are low viscosity, completely water soluble and emulsions can be formulated without the need for acid, although hydrochloric acid and/or calcium chloride may be incorporated if desired. The built-in cationic charge on the emulsifier molecules produces emulsion with exceptional adhesion to siliceous aggregates, while typically passing the cement mix test and particle charge tests.

Hand work

The creamy nature of the slurries make them ideal for handwork with low risk of segregation. Products prepared using Redicote Slurry System can be applied by hand for the maintenance of footpaths and cycleways.

Blacker seals

Because the emulsions are neutral, with little or no acid used, less cement, lime or limestone aggregates are dissolved which avoids unsightly white surface staining caused by soluble calcium salts.

Latex

The emulsions are particularly compatible with latex. With the right order of addition natural rubber and some anionic SBR latex grades can be incorporated into the soap solution, or can be stabilized in a separate production step.

Break control additive

The Redicote E-11 is its own control additive. Emulsions can be prepared with the minimum of chemical and the mix time adapted on the paver by addition of Redicote E-11. High flash point grades of the product are available for safe use in the field.

Super-stable emulsions for hot climates

The hot climates and highly reactive aggregates experienced in some geographical regions can challenge conventional cationic slurry emulsions. Specially formulated "super-stable" emulsions have been developed to provide mix time in these demanding conditions. Nouryon offers Redicote E-4868 and Redicote E-4875 which are concentrated liquid emulsifiers able to produce superstable cationic slow-setting emulsions at dosages of 0.8-2.0%. The emulsions pass the cement mix test and show excellent storage stability. The system provides a slurry with traffic times in the 2-4 hour range under laboratory conditions, but often faster in the field because of the hot climates where it is used. The slurry seals do not meet quick traffic requirements.

Cement and lime

Some aggregates with very high natural filler content may provide good slurry consistency without cement but normally a high level of cement (0.5-2%) is recommended to provide the right slurry consistency and to ensure durability of the seal. Hydrated lime may substitute for cement to provide additional mix time with some aggregates. Mix time and cohesion development are not very sensitive to filler content but generally increasing filler content increases the mix time while reducing the time before the road can be opened to traffic.

Mix time

Increasing the emulsifier dosage increases the mix time. Break retarders are not used.

Emulsion pH

The products are completely soluble in water without the need for acid.The performance is relatively insensitive to pH. A soap pH of 2-3 is typical. Phosphoric acid or sulphuric acid can be used instead of hydrochloric, depending on local availability, but the compatibility of these acids with the particular emulsifier needs to be verified.

Polymer

The systems are not normally modified. Polymer modified binders can be used. The Redicote E-4868 and E-4875 products are compatible with natural rubber latex but can show reduced mix time with SBR latex.

Quick-Set slurry and microsurfacing with traditional hydrochloric acid system

Redicote emulsifiers for the traditional slurry systems based on hydrochloric acid are fatty alkylimidazolines manufactured in Europe and the USA, derived from our own polyethylene amine raw materials. .

Products provide a range of emulsion reactivity

The key to successful quick-set slurry and microsurfacing is to closely match the emulsion reactivity with the reactivity of the aggregate, under the local environmental conditions. The more reactive the aggregate and the hotter the local conditions, then the less reactive should be the emulsion in order to provide sufficient mix time.

The products Redicote 404, Redicote C-471, Redicote C-450, and Redicote C-500 are evolved from the original Catimuls emulsifiers introduced in the 1960s. While all the Redicote products used in the traditional microsurfacing systems share similar chemistry and are used in the same way, differences in the details of their chemical structure provide emulsions with different reactivity. By the choice of emulsifier, or by combining more than one emulsifier, the emulsion formulator can match the emulsion reactivity with the available aggregates and climate conditions without the need for extreme high or low chemical loadings which might impact emulsion quality or performance. All the Redicote products mentioned below meet the requirements of both microsurfacing and the lower technical demands of quick-set systems.

Redicote C-471 produces the most reactive emulsions, suitable for the least reactive aggregates. Redicote C-500 and C-450 product the least reactive emulsions suitable for the most reactive aggregates. Used alone or in combination the products allow the full range of microsurfacing aggregates to be used.

Redicote 404 provides a medium reactivity emulsion and is often the best choice where only a single emulsifier system is desired.

Typical use levels for the products range from 0.6-1.8%, basis emulsion.Some contractors favor a process using very reactive emulsion recipes with low dosages of emulsifier, and use additional chemical on the paver "break retarder" to adapt the breaking characteristics. Others prefer not to use any chemical in the field, and the emulsion recipe will reflect these approaches.

Emulsion pH

With all the products in this class, cohesion development in the slurry is generally helped by low emulsion pH, although at the expense of some mix time. For the very fastest cohesion development a soap pH as low as 1 may be required, but for many systems a soap pH of 2 is sufficient to meet all the requirements for quick-traffic systems.

Bitumen quality

The system demands bitumens with some acid value, preferably 0.4 mg KOH/g or higher, to function correctly. As natural bitumens with this acid value become less available, dopes such as naphthenic or fatty acids can be added to the bitumen before emulsification to help cohesion development and durability of the seal. Nouryon offers a unique additive Redicote 540 which can be conveniently added to the soap solution together with the emulsifier, and avoids the need for pre-treatment of the bitumen.

Polymer

Natural or synthetic rubber latex is the most common modifier. Cationic grades of latex are compatible with the finished emulsion or can be injected into the soap. Anionic grades of latex can sometimes be incorporated into the soap in a batch process before acid addition but some stabilization (e.g. with Redicote E-11) may be required.

Break control additive

Redicote C-450 is water-soluble and is the preferred break control additive for the systems. Redicote C-471, 404 and C-500 can all be used as dope, but are less easily soluble in water. They form stable dispersions, or can be partially neutralized with acid to provide full solubility. Redicote 611 is a low viscosity fully water soluble product widely used to control mix time in Europe.

Cement, lime and aluminum sulphate

Cement is the most common filler for microsurfacing systems based on hydrochloric acid. Hydrated lime may be used with some highly reactive aggregates to provide more mix time. The filler is an essential part of the system and may vary between 0.25 and 1%, or even higher. The effect of filler on mix time is highly variable. In most cases the filler extends mix time.

Aluminum sulphate is used in western areas of the United States in so- called quick-set, quick-traffic systems, which provide many of the features of microsurfacing but to less demanding specifications. Occasionally aluminum sulphate is used in microsurfacing but always in conjunction with cement. The emulsifiers mentioned in this section are fully compatible with aluminum sulphate. Aluminum sulphate has the effect of extending mix time.

The Redipave slurry system

Conventional slurry systems use hydrochloric acid to formulate the emulsions. The Redipave system uses phosphoric acid together with patented emulsifiers in emulsions for quick-set, quick-traffic slurry and microsurfacing systems which perform well with a wide range of bitumens, including low acid bitumen. Polymer modified binders as well as latex modified emulsions can be used.

Bitumen quality

High acid value binders traditionally derived from Venezuelan crude oil have been the basis of the most effective slurry and microsurfacing systems. As crude sources and refining processes change, it can be difficult to maintain performance with today's bitumens, even with the use of acid dopes and other additives. A major advantage of the Redipave system is that it can use a wide range of binders including low acid value bitumens and synthetic bitumens derived from petroleum resins.

Blacker seals

After curing the seals prepared using the Redipave system are clearly blacker than those made with the conventional systems, an effect resulting from the way the emulsion interacts with cement in the slurry.

Cool weather paving and night work

The phosphoric acid systems show exceptionally rapid cohesion development, good even at low temperatures, making them especially suitable for cool weather and night work.

Emulsion formulation

Easy to use, liquid emulsifiers Redicote EM44 and Redicote C-320 are recommended.

Technical grades of phosphoric acid are suitable. The target soap pH is in the range 2.5-3.5 and 0.6-1.5% emulsifier is sufficient for most aggregates.

Polymer modified binders may be used. Alternatively, cationic polymer latex can be incorporated into the soap solution or into the finished emulsion. Some anionic latex grades can be incorporated into the soap solutions, but additional stabilization may be required.

The slurry

The slurry comprises emulsion, fine grained aggregate, filler and water. Portland cement filler is an essential component of the Redipave system—hydrated lime is not suitable. Water is used to adjust the consistency of the mixture—typically a little less water is used in the system than in conventional hydrochloric acid systems.

The chemistry of the system is different and some aggregates which react poorly in the hydrochloric system can give good performance with phosphoric acid.

Mix design

Mix design with the Redipave system is undertaken in the normal way. The emulsion recipe and slurry composition is adapted for the reactivity of aggregate and the climate conditions and the desired cohesion development using hand mixes and the ISSA cohesiometer. The proportion of bitumen in the slurry is determined by durability tests like the Wet Track Abrasion test.

Increasing emulsifier content in the emulsion provides more mix time. The mix time is less temperature sensitive than in the hydrochloric acid system. The mix time is typically reduced by increasing cement content and cement dosage can be used in the field to adjust mix reactivity. Mixtures with good consistency are produced with cement levels as low as 0.25%. Aluminum sulphate can be used together with cement to provide extended mix times without any negative effect on slurry consistency or cohesion development.

Chemical break retarders like Redicote E-11 HF-1 or Redicote C-450 can be used on the paver to extend mix time if necessary. If chemical break retarders are to be used, we always advise that they are evaluated during the mix design process.

When to use Redipave

1. When conventional systems will not build cohesion
2. For night work and cool conditions
3. With difficult binders including polymer modified bitumens and synthetic binders
4. To avoid corrosion issues during manufacture, storage and paving
5. When hydrochloric acid is not readily available or use is restricted

Systems using Redicote E-7000

Nouryon patented Redicote E-7000 betaine emulsifier allows the emulsion formulator to meet the requirements of quick-traffic slurry systems but using emulsions of neutral or near neutral pH and providing excellent value for money.

Easy to use

Redicote E-7000 is a completely water-soluble low viscosity liquid emulsifier which can be used to prepare both cationic and anionic emulsions for slurry surfacing, and is compatible with all emulsifier types. Used alone or in combination with emulsifiers such as Redicote E-11 or Redicote C-450, it can produce cationic emulsions which produce slurry meeting quick-set, quick-traffic requirements. Emulsions typically pass the cement mix test, yet the slurries build cohesion faster than recipes based on super-stable emulsions.

Latex compatibility

Alone, or combined with Redicote E-11, Redicote E-7000 provides excellent latex compatibility as well as plenty of mix time in hot conditions or with reactive aggregate.

Bitumen quality

High acid value bitumens provide better cohesion development. Additives can be used to help cohesion development in cases where high acid value bitumens are not available.

Emulsion pH

The emulsions can be produced over a wide range of pH from 2 to neutral, avoiding the corrosion problems seen with traditional microsurfacing systems. As labeling and placarding requirements of emulsions become more restrictive, the ability to formulate effective emulsions at pH close to neutral is an advantage.

Compared to conventional recipes the emulsions with co-emulsifiers are neutral or near neutral with soap pH in the range 4-7. A typical recipe might use 1-2% Redicote E-7000 and 0.4-0.8% of the co-emulsifier. When used alone we recommend a soap pH of around 2.

Overall the formulations provide significant cost savings compared to other quick-set slurry recipes, and because of the lower acid content of the emulsions, white staining due to soluble calcium ions is reduced.

Anionic slurries

For anionic quick-set emulsions, typical recipes use 1.5%-2.5% emulsifier with a soap pH of 11.5. These emulsions can optionally be latex-modified. Cement should be included in the mix design as it is necessary to attain quick-set, quick-traffic properties with this system. With highly reactive aggregates, Redicote E-7000 can be combined with Redicote E-6945.

Break control additive

Redicote E-7000 is water-soluble and is the preferred break control additive for both anionic and cationic systems. Redicote E-11 or Redicote C-450 are effective at extending mix time in cationic systems.

Additives

Generally the emulsifier can also be used as a break retarder on the slurry paver.

Water soluble

Redicote E-11HF-1, Redicote E-11HF, Redicote 611, Redicote E-7000 and Redicote C-450 are particularly suitable because they are water soluble and do not contain flammable solvents.

Cohesion development

Redicote 540 has been especially developed to enhance cohesion development when using low acid value bitumens, but can be used with all binder types. It is conveniently added into the soap solution as coemulsifier and avoids the need to treat the bitumen with acidic additives. Durability as measured by weight loss in the Wet Track Abrasion tests is also improved.

Redicote E-62 can be added into the bitumen or post-added into emulsions to improve cohesion development and durability.

Troubleshooting slurry paving

Table 5: Troubleshooting slurry paving

Problem	Possible cause	Possible solution
Premature break in mixer or spreader box	Hot emulsion High clay or fines in aggregate Insufficient emulsion or water Hot road surface Aggregate segregation in stockpile Too long residence time Too reactive emulsion	Check temperature, use additive, allow to cool. Check grading and methylene blue value, use additive Check calibration on paver Spray water. Pave in early morning Remix stockpile Reduce residence time by increasing road speed Re-formulate emulsion e.g. increase emulsifier
Extended set and traffic time (slow cure)	Cold conditions Overdosage of additive Overdosage of emulsion Low aggregate reactivity False slurry/false break Change in bitumen source Emulsion not reactive enough	Reformulate emulsion, use warm emulsion Reduce or eliminate additive Calibrate flows on paver Check gradation, methylene blue value. Increase filler Treat as premature break - "slow down" the mix Repeat mix design Reformulate e.g. lower emulsifier content or lower pH
Emulsion or slurry running off the mix	Too little fines, incorrect grading Too much emulsion or water	Increase filler (cement) content. Check gradation Calibrate flows. Use drier mix. Check aggregate moisture
Varying color or texture	Filler feeder problem Aggregate dry and segregating Underlying surface variable in composition Mix too dry or too "fast" to self-leve Varying emulsion or water content l Poor start and stop procedures on paver	Check filler dosing system Check moisture content, gradation of stockpile and calibration Use leveling or scratch course Use wetter or slower mix Check calibration Improve process
Tire marks in freshly paved seal	Opened to traffic too early Very hot road temperatures Power steering damage in parking areas	Sand the seal where traffic vehicles turns or crosses Sand the seal where traffic turns or crosses Consider compaction to accelerate final cure
Early raveling (loss of coarse aggregate)	Cold or freezing conditions Opened to traffic too early Segregation Poor embedment of coarser particles Seal applied too thinly Aggregate gradation too coarse Poor aggregate interlock Secondary strike off dislodging coarse stone	Avoid paving in cold conditions, reformulate emulsion Control traffic speed for extended period Increase filler content. Check aggregate gradation Consider compaction or fog seal Should be 1.25x largest aggregate Check gradation Check crushed faces on coarser particles Adjust strike off to prevent damage
White or grey staining on seal surface or pronounced brown or grey color to seal	Slow cure, low paving temperature Too high water content High filler content Poor emulsion quality	Adjust system reactivity. Use warm emulsion Use drier mix Formulate with lower filler content Check particle size
Delamination of seal	Road surface not clean Road surface not wetted Road surface polished	Better preparation Spray water or tack. Increase fluids content of slurry Use leveling or scratch course
Early fatting up of binder in wheel paths	Too high emulsion content Underlying road surface soft or rich Too low filler or fines in mix Raveling of coarse aggregate Too high application rate Too much water in mix Extremely hot road temperatures	Check mix design Consider capeseal Check gradation and mix design See early raveling above Should be <1.5x top size for slurry Use drier mix Consider sanding problem areas
Drag marks	Oversize in aggregate Spreader box or strike offs not clean Inattentive corrective actions Slurry applied too thinly (less than topsize) Variable height underlying surface Incomplete sweeping	Screen aggregate Keep box clean. Avoid broken material in box Increase application rate Use leveling or scratch course Improve sweeping Slow down
Washboarding or ripple effect	Too fast road speed for paver Too dry or too "fast" mix for self-levelling	Slow down Use wetter or slower mix (e.g. add additive)

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