Evaluation of Resin-Modified Paving Process

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The U.S. Army Engineer Waterways Experiment Station (WES) was tasked by the headquarters of the U.S. Army Corps of Engineers to evaluate the state of the art of the resin-modified pavement (RMP). This type of pavement is semirigid and semiflexible. RMP is basically an open-graded asphalt concrete mixture that contains 25 to 30 percent voids that are later filled with a resin-modified cement slurry grout. RMP is a tough and durable surfacing material that combines the flexibility characteristics of an asphalt concrete material with the fuel, abrasion, and wear resistance of portland cement concrete. A literature search and background analysis of the RMP process showed that the majority of in-service pavements constructed with this process are in Europe, particularly in France, where this process was developed. Visual observations of these sites indicate that the RMP process has potential for U.S. military applications. The final phase of the WES study involved the construction, trafficking, and evaluation of a 150- × 50-ft test section. Trafficking included both straight passes and pivot steer turns from the M-1 and M-60 tanks. FHWA's Accelerated Loading Facility was used to traffic the RMP test section by simulating heavily loaded, high tire pressure truck traffic. Sections of the test section were also subjected to controlled fuel and oil spillage. The evaluation indicated that RMP does have potential for several pavement uses. At an initial cost somewhere between asphalt concrete and portland cement concrete, RMP provides an alternative surfacing material for many Army pavement applications. These proposed applications include tracked-vehicle roads, hardstands, and aircraft parking aprons.

Asphalt concrete pavements are very susceptible to damage when subjected to fuel and oil spillage or severe abrasion from tracked vehicles. More than 80 percent of the Army's pavements are surfaced with asphalt concrete. Because of the mission of the Army and the equipment in its inventory, Army pavements are routinely subjected to fuel damage and severe abrasion. Tank trails, crossings, hardstands, wash facilities, motorpools, helicopter refueling pads, and aircraft parking aprons are examples of Army pavements susceptible to fuel or abrasion damage. Surfacing materials that are more cost-effective than conventional portland cement concrete are needed for construction and rehabilitation of Army pavements.

A resin-modified pavement (RMP) was developed in France in the 1960s as a fuel- and abrasion-resistant surfacing material. A French construction company, Jean Lefebvre, developed this pavement process as a cost-effective alternative to portland cement concrete. The RMP process has been used on various types of pavements including warehouse floors, tank hardstands, and aircraft parking aprons. RMP has been successfully constructed in numerous countries including Great Britain, South Africa, Japan, Australia, and Saudi Arabia.

RMP is a semirigid, semiflexible pavement. It is a tough and durable surfacing material that combines the flexibility characteristics of an asphalt concrete material with the fuel, abrasion, and wear resistance of portland cement concrete. RMP is basically an open-graded asphalt concrete mixture containing 25 to 30 percent voids that are filled with a resin-modified cement slurry grout. The open-graded asphalt mixture functions as a support layer and determines the RMP thickness. The slurry grout is composed of portland cement, fine aggregate, water, and a resin additive. The grout material is poured onto the open-graded asphalt mixture after the asphalt material has cooled, squeegeed over the surface, and vibrated into the voids with a small (3- to 5-ton) vibratory roller. The curing period can vary between 1 and 28 days depending on the type of portland cement used in the grout and on the loading conditions. Figure 1 is a cut cross section of an RMP field core.

During the mid-1970s, the U.S. Army Engineer Waterways Experiment Station (WES) evaluated the resin-modified pavement (*1*). A test section was constructed to evaluate the effectiveness of this special surfacing material in resisting damage caused by fuel, oil spillage, and abrasion from tracked vehicles. The results of this evaluation were not favorable. The test section did not resist damage caused by tracked vehicles and fuel spillage. The evaluation indicated that the effectiveness of RMP was very construction-sensitive and that if all phases were not performed correctly, the RMP process would not work.

In 1987 the headquarters of the U.S. Army Corps of Engineers tasked WES with reevaluating the RMP process. Good field performance in Europe and improved materials and construction procedures indicated that this process had potential as an alternative to standard paving materials. The evaluation began with a literature search and background analysis into the RMP process. The review indicated that most of the in-service pavements constructed with this process were in Europe, especially in France. Site inspections were conducted to evaluate the field performance of several private and military RMP applications in France, Great Britain, and Australia. Visual observations of these sites indicated that the RMP process had considerable potential for U.S. military applications (*2*).

OBJECTIVE AND SCOPE

The objective of this research was to determine the effectiveness of RMP in resisting damage caused by severe abrasion

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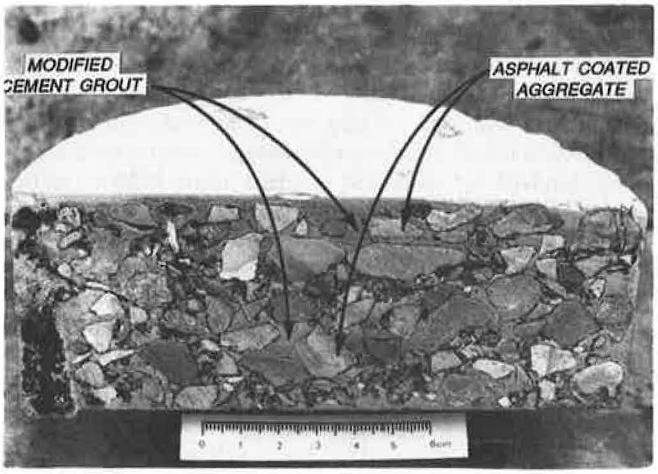

FIGURE 1 Cross section of RMP field core.

from maneuvering tracked vehicles and from fuel and oil spillage. Recommendations for the potential future uses of the RMP were based on its determined effectiveness.

In order to determine the effectiveness of the resin-modified pavement process, an RMP test strip was constructed at WES. A 50- × 150-ft test strip was constructed by a local contractor, APAC of Mississippi, with technical guidance from representatives of the company that developed the RMP process, Jean Lefebvre. The RMP test strip was constructed according to the specifications without any problems. The test strip was allowed to cure for 28 days to obtain full strength before any traffic was placed on the pavement.

The RMP test strip was trafficked with M-1 and M-60 tanks. Straight passes and 180-degree pivot steer turns were applied with the tracked vehicles to evaluate the RMP abrasion resistance. Five different fuels and oils (jet aviation fuel, gasoline, diesel fuel, synthetic oil, and hydraulic oil) were spilled on the RMP. Thirty cycles of controlled fuel and oil spillage were used to evaluate the fuel-resistant properties. FHWA's Accelerated Loading Facility (ALF) was also used to traffic the RMP test strip. ALF simulated heavily loaded, high tire pressure truck traffic. Data drawn from the traffic tests and fuel resistance analysis were the basis for the recommendations made for this new pavement process.

PRECONSTRUCTION ANALYSIS

Site Evaluation and Thickness Design

An old pavement testing area near the Geotechnical Laboratory at WES was chosen as the construction site for the proposed 150- × 50-ft RMP test strip. Various asphalt concrete test pavements had been constructed in this area by WES researchers since World War II. In 1982 approximately 1½ in. of asphalt concrete was placed over the entire area as a leveling course. Since then, the area has been used occasionally to stockpile aggregates and soil samples. This site represents an extremely strong and stiff support for the test section and prevented the possibility of base course or subgrade failure.

Because RMP is essentially a surface course, the underlying layers of the test strip had to be structurally sound. If any load-related failures were to occur during future traffic tests, a structurally sound foundation would leave no doubt that the failure was initiated in the surface course, which was, in this case, the pavement layer being evaluated. A high-quality bituminous mixture placed on top of this paved area was determined to be the most economical means of obtaining a structurally sound foundation.

A thickness design procedure was conducted to determine the required thickness of this asphalt concrete layer. The first step of the design procedure was to determine the strength properties of the existing pavement. Nondestructive tests were conducted using the falling weight deflectometer. The pavement deflection data captured during these tests were entered into a computerized layered-elastic program (BISDEF), which computes strength properties and predicts elastic moduli for each pavement layer. The moduli values were then entered into a computerized pavement thickness design program (AIRPAVE) to determine strengthening overlay requirements. A design load nearly equivalent to the M-1 and M-60 tank loads was used in this thickness design program. The results of this exercise indicated that a total thickness of 3 in. of asphalt concrete surface mixture would provide a structurally sound foundation for the 2-in.-thick RMP wearing course.

Materials Evaluation

Dense-Graded Bituminous Intermediate Course

As previously mentioned, a high-quality bituminous surface mixture was selected as the best means of providing a sound foundation beneath the RMP surface course. The aggregate gradation for this pavement layer was specified in the U.S. Army Standard Practice Manual for a ¾-in. maximum size, high tire pressure surface blend (*3*). An AC-30 grade of asphalt cement was specified for the dense-graded intermediate course. The intermediate course aggregate gradation and asphalt cement properties are shown in Tables 1 and 2.

TABLE 1 AGGREGATE GRADATIONS (PERCENT PASSING)

US Standard Sieve Size	Dense-Graded Intermediate Course Limits	Dense-Graded Intermediate Course JMF	Open-Graded Surface Course Limits	Open-Graded Surface Course JMF
3/4 in.	100	100	100	100
1/2 in.	82-96	95.3	65-75	67
3/8 in.	75-89	88.9	50-65	44
No. 4	59-73	71.3	23-33	22
No. 8	46-60	49.8	9-17	12
No. 16	34-48	38.3		
No. 30	24-38	31.6	5-10	5
No. 50	15-27	18.5		
No. 100	8-18	8.9		
No. 200	3-6	6.7	1-3	2

TABLE 2 AC-30 ASPHALT CEMENT TEST PROPERTIES

Test	Results
Viscosity, 140°F, (P)	3182
Viscosity, 275°F, (cst)	479
Penetration, 77°F, 100g, 5 sec, (0.1 mm)	58
Flash Point, Cleveland Open Cup, (°F)	590
Solubility in Trichloroethylene, (%)	99.9
Specific Gravity at 77°F	1.023
Test on Residue from Thin Film Oven Test	
Viscosity, 140°F, (P)	7523
Ductility, 77°F, 5 cm/min, (cm)	150+

Once the contract for constructing the test strip was awarded, the contractor was asked to provide samples of the aggregates and asphalt cement to WES so that the materials could be tested and a job mix formula developed. The job mix formula presented to the contractor before construction began contained the specific aggregate gradation and asphalt cement content desired. The job mix formula tests indicated that an asphalt content of 4.9 percent with the gradation shown in Table 1, labeled as the intermediate course job mix formula, would provide the optimum mixture for the given materials. These and other requirements for the dense-graded intermediate course were specified in the final construction specifications. The section of the final specifications relating to the intermediate course was designed after the standard U.S. Army Corps of Engineers Guide Specification for Bituminous Intermediate and Surface Courses for Airfields, Heliports, and Tank Roads (*4*).

Open-Graded Asphalt Mixture

A review of the available literature indicated that the mix design of the open-graded asphalt mixture would play a critical role in the proper construction of the RMP (*5*). The majority of the mix design focused on the final void content of the compacted open-graded asphalt mixture. The general requirement is 25 to 30 percent voids in the final compacted mixture. Any amount less than this would not allow the slurry grout to fully penetrate the open-graded mixture, resulting in a structurally unsound surface course that would probably have excessive cracking and deterioration. Void contents greater than this amount would increase the cost of the pavement without providing any significant structural improvements and could reduce the pavement strength by eliminating some of the aggregate-to-aggregate interlock.

A laboratory analysis of the open-graded asphalt mixture was conducted before construction of the test strip to determine the amount of asphalt cement that would produce the proper void content in the final mixture. Although checks against such aggregate properties as fractured faces and particle shapes had to be made, the final void content of the compacted mixture was the main focus of this laboratory analysis. The majority of the laboratory mix design guidance found in the literature was based on French methods, which use nontraditional specimen sizes and compaction methods (*6*). Therefore, a preliminary study was first conducted in the WES laboratories to determine the best mix design method in terms of standard U.S. military practices. This study found that a modified Marshall mix design procedure, which is both a military standard and an ASTM standard, using 25 blows of the hand hammer for the compactive effort indicates the proper asphalt content to achieve the required void criteria.

Twenty-five blows of the 6-in.-diameter Marshall hand hammer are used in the French standards for compacting laboratory samples. A comparative analysis conducted in the WES laboratories validated this compactive effort by examining the changes in void contents versus varying levels of hand hammer compaction. The results of this analysis indicated that the 25 blows would most likely produce void contents in the target range of 25 to 30 percent.

Once the proper mix design method was determined, an estimate of the optimum binder content was made using a French procedure based on material properties and design traffic (*7*). This procedure is outlined below:

$$\text{Optimum binder content} = (\alpha)(K)(\sqrt[5]{\Sigma})$$

where

- $\alpha = 2.65/\gamma_G$ (γ_G is apparent specific gravity of the combined aggregates);
- K = richness modulus, having a value of 3 to 3.5 depending on design traffic;
- Σ = conventional specific surface area $= 0.25G + 2.3S + 12s + 135f$;
- G = percentage of material retained in ¼-in. sieve;
- S = percentage of material passing ¼-in. sieve and retained on No. 50 sieve;
- s = percentage of material passing No. 50 sieve and retained on No. 200 sieve; and
- f = percentage of material passing No. 200 sieve.

Therefore, for the materials and conditions of the WES test section, the following estimate was made:

$$\alpha = \frac{2.65}{\gamma_G} = \frac{2.65}{2.648} = 1.0008$$

$$K = 3.25 \text{ (heavy-duty traffic)}$$

$$\Sigma = 0.25G + 2.3S + 12s + 135f = 0.25(0.64) + 2.3(0.32) + 12(0.02) + 135(0.02)$$

$$\Sigma = 3.836$$

$$\therefore \text{Optimum binder content} = (\alpha)(K)(\sqrt[5]{\Sigma}) = (1.0008)(3.25)(\sqrt[5]{3.836})$$

$$\text{Optimum binder content} = 4.26\%$$

The asphalt cement used in the laboratory study and actual construction was the same type as that used in the dense-graded intermediate course, an AC-30 grade. The aggregate gradation specified was taken from the literature as the standard gradation for heavy-duty pavement applications. This gradation is shown in Table 1, labeled as the limits of the open-graded surface course. The job mix formula gradation, which was recommended by the Jean Lefebvre representative, is also shown in Table 1. The coarser gradation was recommended to ensure that the final void content would be sufficient to allow full penetration of the grout.

With all of the aggregate and binder materials in hand, an established aggregate gradation, and an estimate of the optimum binder content, a laboratory job mix formula analysis was conducted. Binder contents at, above, and below the estimated optimum value were evaluated. The laboratory analysis of the open-graded mixture indicated that an asphalt cement content of 4.2 percent would result in a void content of about 30 percent in the final compacted mixture. This asphalt content, along with the surface course aggregate gradation limits shown in Table 1, was specified in the final construction specifications as the open-graded asphalt mixture job mix formula.

Resin-Modified Slurry Grout

A preconstruction laboratory study was also performed on the resin-modified slurry grout. The literature was fairly specific about the types of materials and relative proportions of these materials to produce a satisfactory slurry grout (*7*). Nonetheless, laboratory tests were necessary to ensure that these recommendations would work for the materials to be used in the WES RMP test strip.

The individual components of the slurry grout are cement, sand, filler, water, and a latex resin additive. The additive is generally composed of 5 parts water, 2 parts of a cross-polymer resin of styrene and butadiene, and 1 part water-reducing agent. The type of cement used is purely a design option, as is the case for portland cement concrete. WES used a standard Type I cement. The sand must be clean, sound, and durable, and it must range from the No. 30 to No. 200 sieve sizes. WES used a washed silica sand to meet these requirements. The filler must have a very fine gradation (minimum of 95 percent passing the No. 200 sieve) and may be fly ash, limestone dust, or rock flour. WES used a fly ash. The resin additive acts as a plasticizer to reduce the slurry grout viscosity for better penetration and as a strength-producing agent. The solid constituents of the grout are almost equal proportions of sand and filler with about twice that amount of cement. Enough water is added to produce a water-to-cement ratio of 0.60 to 0.70. The resin additive is added to the mixture last in an amount equal to 2.0 to 3.0 percent of the total batch weight. This combination of ingredients produces a slurry grout that is very fluid and only slightly more viscous than water.

The WES laboratory analysis of the slurry grout consisted of varying the mix proportions within the recommended allowances to determine the best mix formula. The single acceptance criterion for the slurry grout is a Marsh flow cone viscosity of 7.0 to 9.0 sec immediately after mixing. (Water has a Marsh flow cone viscosity of 6.0 sec.) Because this viscosity range is relatively narrow, slight variations of the water-to-cement ratio and amount of resin additive were used to obtain a slurry grout mix formula of the proper viscosity.

After 10 different slurry grout formulations were mixed and tested in the laboratory (Table 3), a final formula was derived that produced a slurry grout viscosity of just over 7 sec. It was thought that a slurry grout in the lower end of the acceptable viscosity range, combined with an open-graded support layer in the upper end of the acceptable voids range, would help to ensure full penetration of the grout during construction. The final slurry grout formulation used on the test strip is shown in Table 4.

CONSTRUCTION

Dense-Graded Bituminous Intermediate Course

Before the construction of the RMP test strip, a 10- × 40-ft trial test section of dense-graded intermediate course was constructed. This test section was tested and evaluated to ensure that the asphalt mixture and construction procedures would conform to all of the specified requirements. Quality control tests conducted on the asphalt concrete mix included asphalt extractions, aggregate gradations, and field compaction. These tests indicated that the construction of the trial test section was acceptable. The results of the quality control tests for the test section are shown in Tables 5 and 6.

The construction of the RMP test strip began with the dense-graded bituminous intermediate course. The existing surface

TABLE 3 SLURRY GROUT LABORATORY ANALYSIS

Trial	Type 1 Cement wt(g) [%]	Sand wt(g) [%]	Filler wt(g) [%]	Water wt(g) [%]	Resin Additive wt(g) [%]	Marsh vis.* (sec.)
1	1835[36.7]	920[18.4]	920[18.4]	1190[23.8]	135 [2.7]	11.0
2a	1820[36.4]	910[18.2]	910[18.2]	1225[24.5]	135 [2.7]	9.7
2b	1820[36.2]	910[18.1]	910[18.1]	1250[24.9]	135 [2.7]	9.0
2c	1820[36.3]	910[18.1]	910[18.1]	1225[24.4]	150 [3.0]	9.0
3a**	1810[36.2]	905[18.1]	905[18.1]	1240[24.8]	140 [2.8]	7.2
3b	1810[36.3]	905[18.1]	905[18.1]	1230[24.6]	140 [2.8]	7.1
3c	1810[36.2]	905[18.1]	905[18.1]	1240[24.8]	135 [2.7]	7.2
4a	1800[36.0]	900[18.0]	900[18.0]	1250[25.0]	150 [3.0]	6.7
4b	1800[36.1]	900[18.0]	900[18.0]	1240[24.8]	150 [3.0]	6.6
4c	1800[36.1]	900[18.0]	900[18.0]	1250[25.0]	140 [2.8]	7.1

* Results shown are average of three viscosity tests.

** This formula chosen as specified job mix formula.

TABLE 4 RESIN-MODIFIED SLURRY GROUT FORMULA

Component	Percent by Weight
Type I cement	36.2
Fly ash	18.1
Sand	18.1
Water	24.8
Cross polymer resin	2.8

was swept clean and a light tack coat of Type SS-1 asphalt emulsion was sprayed on the clean surface by a distributor truck. The tack coat bonded the new dense-graded asphalt mixture with the existing asphalt surface. This tack coat was applied during the afternoon before construction of the intermediate course began to allow enough curing time and to prevent construction delays the next morning.

With the construction equipment already in place, the intermediate course construction was completed in less than 1 day. The hot mix was spread with a mechanical paver and compacted with a 10-ton rubber-tired roller and a 10-ton steel-wheeled roller. Samples of the hot mix were taken at several intervals during the day for determination of mixture properties by WES laboratory personnel. These laboratory quality control tests, along with data obtained from field cores cut out of the test strip early the next day, indicated that both the mix and construction procedures were satisfactory. A final thickness of approximately 3 in. was laid across a 160- × 60-ft area. These dimensions were designed to provide the sound foundation required for the 2-in.-thick, 50- × 150-ft resin-modified surface course.

Resin-Modified Pavement

Open-Graded Asphalt Mixture

After completion of the intermediate course, a trial section for the open-graded asphalt mixture was constructed. Several batches of material were produced at the batch plant before placing the material. After visually observing slight asphalt drainage of the open-graded material, the Jean Lefebvre representative recommended decreasing the asphalt content to 4.0 percent. This change in asphalt content ensured that the mixture had enough void structure to allow full penetration of the slurry grout.

The open-graded asphalt mixture trial section was constructed on top of the dense-graded intermediate course trial section. The asphalt material was sampled and tested for conformance. The test results, shown in Table 7, indicated that the production of the open-graded material and construction procedures used to place the material were satisfactory.

The open-graded asphalt mixture for the RMP test strip was placed on top of the dense-graded bituminous intermediate course 1 week after the intermediate course was placed. A light tack coat was sprayed onto the intermediate course using the same type of asphalt emulsion and application rate as before. The tack coat was allowed to cure for a few hours before the open-graded mixture construction began.

Techniques similar to the quality control techniques used during the construction of the intermediate course were used to take samples of the hot open-graded mix from the haul trucks at several intervals during the day. Laboratory tests on these materials to determine the asphalt content, aggregate gradation, and most importantly the final void content helped to determine the properties of the in-place mix. Additionally, core samples were cut out of the hardened test strip the following morning to recheck these same properties. All loose mix samples and core samples indicated that the open-graded mix was placed with satisfactory material properties and construction techniques.

The open-graded mixture was spread with the same mechanical paver used for placing the intermediate course (Figure 2). Under normal circumstances, open-graded mixes of this nature tend to cool off relatively quickly because of their

TABLE 5 BITUMINOUS INTERMEDIATE COURSE ANALYSIS

Sieve Size	Specified Limits	JMF	Trial Test Section	Test Strip S-1	Test Strip S-2	Test Strip S-3
3/4 in.	100	100	100	100	100	100
1/2 in.	82-96	95.3	97.9	96.0	93.8	97.1
3/8 in.	75-89	88.9	90.2	90.3	86.5	89.0
No. 4	59-73	71.3	67.1	72.3	68.6	69.7
No. 8	46-60	49.8	47.8	52.3	49.8	50.9
No. 16	34-48	38.3	36.3	39.5	37.5	39.1
No. 30	24-38	31.6	29.3	32.0	30.3	32.3
No. 50	15-27	18.5	18.2	19.9	18.9	19.8
No. 100	8-18	8.9	9.2	10.5	10.1	10.0
No. 200	3-6	6.7	6.7	8.1	7.7	7.7
Asphalt Content		4.9	4.4	4.9	4.4	4.6
Marshall Stability (lb)	1800 min	2232	2853	2540	2473	2309
Flow (0.01 in.)	16 max	12	10	12	12	12
Percent Voids Total Mix	3-5	3.6	3.6	2.8	3.9	3.9
Percent Voids Filled	70-80	76.2	74.5	80.7	72.9	73.6
Density (pcf)		150.4	152.1	152.2	151.7	151.2
Theo Density (pcf)		155.9	157.8	156.6	157.8	157.3

TABLE 6 BITUMINOUS INTERMEDIATE COURSE FIELD DENSITY ANALYSIS

Location	Core No.*	Thickness (in.)	Unit Weight (pcf)	Compaction (%)
Trial Test Section	M-1	3	148.3	97.5
	M-2	2 3/4	148.3	97.5
	M-3	3	148.7	97.8
	M-4	2 3/4	146.3	96.2
	M-5	2 3/4	148.4	97.6
	AVG	2 7/8	148.0	97.6
RMP Test Strip	M-1	3 1/4	149.7	98.7
	M-2	3	150.0	98.9
	M-3	3	148.2	97.7
	M-4	3	148.2	97.7
	M-5	2 1/2	148.9	98.2
	M-6	3	149.7	98.7
	M-7	2 7/8	146.2	96.4
	AVG	3	148.7	98.0
	J-1	2 7/8	147.5	97.2
	J-2	2 1/4	148.9	98.2
	J-3	3 1/4	147.7	97.4
	AVG	2 3/4	148.0	97.6

Lab Unit Weight - Test Section - 152.2 pcf
Test Strip - 151.7 pcf

* M=Mat Core, J=Joint Core

TABLE 7 OPEN-GRADED ASPHALT MIXTURE ANALYSIS

Sieve Size	Specified Limits	JMF *	Trial Test Section	Test Strip S-1	Test Strip S-2	Test Strip S-3
3/4 in.	100	100	100	100	100	100
1/2 in.	65-75	67	68.3	74.1	79.4	72.8
3/8 in.	50-65	44	42.2	50.4	52.8	47.2
No. 4	23-33	22	17.9	19.7	21.8	20.5
No. 8	9-17	12	10.2	8.2	9.5	9.0
No. 30	5-10	5	4.7	2.9	3.6	3.0
No. 200	1-3	2	1.1	0.8	1.3	0.8
Asphalt Content		4.0	3.5	3.4	3.5	3.4
Percent Voids Total Mix	French +	30.8	31.2	32.4	31.2	32.6
	Corps #	33.8	34.5	35.9	34.6	35.9
Percent Voids Filled	French +	17.2	15.2	14.1	15.2	14.0
	Corps #	15.9	14.0	12.9	13.9	12.9
Density (pcf)		102.8	102.1	100.1	101.9	100.0
Theo Density (pcf)		154.6	154.9	156.1	155.8	156.1
Temperature (°F)		265	250	240	250	275

* Gradation recommended by Jean Lefebvre representative
+ French Method - $VTM = 1 - \frac{WTair - WTwater}{volume} \times 100$
# Corps Method - $VTM = [1 - (\frac{WTair}{volume} (\frac{1}{SG_T}))] \times 100$

VTM = Voids total mix
WTair = Dry weight of specimen
WTwater = Weight of specimen in water after soaking for 15 minutes
Volume = $\pi/4\ D^2H$ (measured)
SG_T = Theoretical specific gravity

FIGURE 2 Placing open-graded asphalt material.

high internal voids and low mixing temperatures (265°F). This tendency usually means that the required compaction must closely follow the paver that is placing the mix. Because the ambient temperatures were so unusually high during the construction of the test strip, rapid heat loss of the asphalt mix was not a problem. To the contrary, the afternoon temperatures, which reached well over 100°F, forced the construction crews to wait several hours before rolling so that the roller would not cut and shove the hot mat.

As is the case for most open-graded asphalt mixes, compaction during construction was not used to achieve any density requirements, but merely to "seat" the asphalt-coated aggregates and smooth over the rough surface. A relatively small (3-ton) steel-wheeled roller was used to accomplish this goal (Figure 3). The static, lightweight, steel-wheeled roller, rather than more traditional heavier models (8 to 10 ton), was used to minimize the loss in voids incurred during the rolling process.

Once the open-graded asphalt mixture had cooled for several hours, a single pass of the small steel-wheeled roller in the static mode was made over the entire 150- × 50-ft area. Small cut marks were left along the edge of the roller wheels after this process. Therefore, after another hour of cooling, another pass of the small roller was used to roll out these marks. After these final passes of the roller, the construction of the open-graded asphalt layer was complete.

Because of the high percentage of voids and the modest slope of the test section, a sand asphalt material was placed on the edges of the open-graded material to prevent seepage of the fluid grout material. The entire freshly paved area was covered with polyethylene sheeting for the night to prevent contaminants (dirt, sand) from blowing onto the pavement surface and falling into the open voids.

FIGURE 3 Three-ton steel-wheel roller.

Resin-Modified Slurry Grout

A trial application for the resin-modified slurry grout was conducted the day after the open-graded trial section was completed. One batch of slurry grout was produced according to the recommended mixture proportions. The slurry grout had the proper viscosity, but the sand material was settling out before placement was completed. The Jean Lefebvre representative recommended that the amount of sand be decreased to avoid any problems of settling. The final mixture proportions for the resin-modified slurry grout are shown in Table 8.

The resin-modified slurry grout was added to the open-graded asphalt pavement 2 days after the open-graded mix was placed. The slurry grout used in the construction of the test strip was made at a local concrete batch plant. The dry cement, sand, and fly ash were mixed in the plant's pugmill (in their proper proportions) for several minutes before they were dumped into the transient mixer truck. Next, the proper amount of water was dumped into the transient mixer truck and the resulting slurry grout was mixed in the rotating mixing drum for several minutes. At this point, the proper amount of the cross-polymer resin additive was poured into the mixing drum; the truck operator left the plant site and drove toward the test strip job site while the mixing truck continuously rotated.

At the test strip job site, the transient mixing trucks were positioned directly on the open-graded asphalt pavement, which had hardened overnight. A sample of the slurry grout was taken and the Marsh cone viscosity was checked on the test strip job site to ensure that the grout was of the proper viscosity. Samples were taken from each transient mixer truck

TABLE 8 REVISED RESIN-MODIFIED SLURRY GROUT FORMULA AND VISCOSITY TEST RESULTS

Material	Batch Percentage
Type I cement	38.2
Fly ash	19.1
Sand	13.3
Water	26.7
Cross polymer resin	2.7

Viscosity Test - No. 1 - 6.2 sec
No. 2 - 7.0 sec
No. 3 - 7.0 sec
No. 4 - 7.0 sec

at the test strip job site and approved before the grout was placed. Viscosity test results are shown in Table 8.

The grout was to be placed in the same 10-ft-wide longitudinal lanes that were used during construction of the open-graded asphalt pavement. This pattern gave a sense of order to the grout application and prevented overworking of the crew. This crew consisted of four people working broom-handled squeegees behind the transient mixer truck. The slurry grout was slowly poured onto the open-graded asphalt surface; when an area became saturated with grout, the squeegees were used to pull the grout along the surface to undersaturated areas. The grout was poured down a pivoting delivery chute onto the pavement surface. As the grout was slowly poured onto the pavement, one person continuously directed the chute to dry areas of the pavement. Once an area of a lane was completely saturated with grout, the truck driver slowly moved the truck forward. After a short time at the beginning of the grout application, the squeegee operators, chute operator, and truck driver were able to continue the grouting procedure in an efficient, controlled manner. Figure 4 is a typical view of the grout application procedure used on the test strip.

Immediately behind the grouting operation, the small steel-wheeled roller made several passes over the grout-filled pavement in the vibratory mode to ensure that all subsurface voids were filled. Because the void content of the open-graded asphalt pavement and the slurry grout viscosity were within the specified ranges, most of the internal voids were filled with grout as the pavement was saturated when the grout was poured over the surface. However, a small amount of internal voids seemed to be isolated from the initial grout application, as evidenced by small air bubbles that appeared behind the vibratory roller. These air bubbles usually appeared only after the first pass of the vibratory roller, indicating that all voids were being filled with grout.

After each of the five 10-ft lanes had been saturated with grout and vibrated, all excess grout remaining on the surface was removed by continually pulling the hand squeegees in one direction. This process also filled any undersaturated areas. After this step, the grout application was complete.

FIGURE 4 Resin-modified slurry grout being applied to open-graded asphalt material.

To evaluate whether full penetration of the slurry grout had occurred, 4-in. field cores were taken from the completed RMP test strip. Random cores were taken throughout the RMP test strip. All cores indicated that the slurry grout material had penetrated the total thickness of the open-graded layer. The test results of the field cores are shown in Table 9.

Curing

After the grout application was completed, a curing compound was sprayed over the surface of the wet, grout-filled pavement. The material used was a white pigmented concrete curing compound, which is commonly used in curing Type I portland cement concrete. The white pigments reduce maximum pavement temperatures during the curing period, which in turn reduce the expansion and contraction stresses resulting from extreme temperature changes. An overabundance of

TABLE 9 RMP TEST STRIP FIELD CORES

Location	Core No.	Thickness (in.)	Unit Weight (pcf)	Penetration (%)
Trial Test Section	1	1 3/8	140.6	100
	2	2 1/2	140.5	100
	3	2 3/4	139.7	100
	4	2 3/8	141.0	100
	AVG	2 1/4	140.5	100
RMP Test Strip	1	2 9/16	139.0	100
	2	2 1/4	138.3	100
	3	2 1/8	138.8	100
	4	2 1/2	140.8	100
	5	2 1/8	138.0	100
	6	2	139.0	100
	AVG	2 1/4	139.0	100

these stresses can lead to shrinkage cracking during the curing period. The curing compound was applied by a pressurized, hand-operated sprayer wand with a fan-type nozzle. A light coating of the curing compound (200 sq ft/gal) over the entire test strip completed the construction process. The pavement cured with no traffic for 28 days before traffic testing began.

EVALUATION

In order to determine the effectiveness of the resin-modified pavement, a series of tests and evaluations was conducted on the pavement surface. A layout of the testing areas is shown in Figure 5. To evaluate the abrasion-resistant characteristics of RMP, tracked-vehicle maneuvers were conducted. Controlled fuel and oil spills were conducted to evaluate the fuel-resistant properties. ALF was used to evaluate RMP under heavy rubber-tired vehicular traffic.

Tracked-Vehicle Traffic

As mentioned, the RMP test strip was allowed to cure for 28 days before any traffic was allowed on the pavement. This cure time ensured that the RMP test strip had plenty of time for adequate strength gain. The effectiveness of the RMP greatly depended on its performance during the tracked-vehicle trafficking.

Tracked-vehicle traffic on the RMP test strip consisted of M-1 (gross weight 113,000 lb) and M-60 (gross weight 100,000 lb) tanks. Six hundred 180-degree pivot steer turns at the same point and 5,000 straight passes were applied with the tracked vehicles to the test strip. Excessive wear of the rubber pads on the tank track was noticed during the initial trafficking of the RMP. During the initial stage of trafficking, the RMP withstood the abrasive action of the pivot steer turns very well; only excess grout was worn off. As the tank track turned during the pivot steer, the track pads dragged across the RMP surface (Figure 6). After 420 turns at the same location, the tracked vehicle produced enough rough abrasion and high stresses to start surface raveling. The surface raveling began without any warning. Once the raveling started, the deterioration increased rapidly because the loose debris that had been dislodged caused further damage as it was dragged and scraped across the RMP surface.

At 600 pivot steer turns, the turning traffic was stopped because the abrasive action had produced a raveled area 1 in. deep covering 35 sq ft. It was thought that a large number of concentrated pivot turns of this nature are not commonly applied to one location in the field, making this traffic test much more severe than normal applications. For example, it would require the tanks of two armored divisions performing 180-degree pivot steer turns at the same point to equate this traffic test.

The 5,000 straight passes with the tank traffic caused only slight surface wearing of the grout, which exposed the surface of the coarse aggregate. The tracked vehicle moving forward and in reverse caused no significant damage to the RMP. At the conclusion of the tracked-vehicle trafficking, it was determined that RMP had effectively demonstrated a resistance to severe traffic abrasion and could be used as a pavement surface for tracked vehicles.

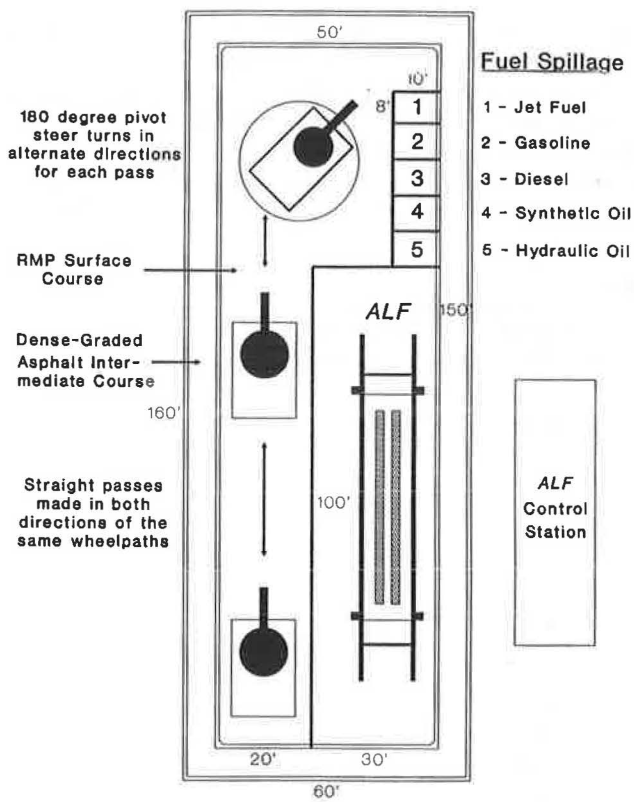

FIGURE 5 Layout of testing areas.

Fuel and Oil Spillage

Five different fuels and oils were used to evaluate the effectiveness of RMP in resisting deterioration caused by fuel and oil spillage. Jet aviation fuel, gasoline, diesel fuel, synthetic oil, and hydraulic oil were spilled on the resin-modified pavement. Thirty cycles of 1 qt of each material were spilled on the RMP surface. Each spill area was 8 ft by 10 ft. The ma-

FIGURE 6 M-1 tank performing pivot steer turns on RMP test strip.

terials were spilled from a height of 30 in. The rate of spillage was set so that each material took 20 to 30 min to drip 1 qt. The fuels and oils were allowed to sit on the RMP surface for 30 days after the spillage cycles were completed.

Visual observations indicated that RMP resisted deterioration from fuel and oil spillage. However, field cores taken from the spillage areas indicated that the fuels and oils had penetrated the resin-modified pavement, causing varying degrees of low-level deterioration. The gasoline and jet aviation fuels had a fast rate of evaporation, which prevented these materials from significantly penetrating the RMP. The diesel fuel had the fastest penetration and caused the most damage. Once again, this test is thought to be an acceleration of typical fuel spillage problems in the field because most spills are cleaned and not allowed to soak into the pavement for a month.

After the fuel and oil penetration was discovered, the stability of RMP was questioned. The maximum penetration was approximately 1 in. in the diesel area. The remaining fuels and oils penetrated less than ½ in. A 1-ton van was used to traffic the fuel spillage areas. Fifty passes and fixed-position, power-steering turns were applied to the contaminated areas by the van. Only slight scuffing was noticed after the van had trafficked the RMP with no appreciable damage.

Accelerated Loading Facility

FHWA's Accelerated Loading Facility was also used to traffic the resin-modified pavement test strip (Figure 7). ALF simulated truck traffic by applying a load of 19,000 lb to a dual wheel assembly with tire pressures of 140 psi. ALF applied 80,000 passes to a 48-in.-wide strip of the RMP. No appreciable deterioration or deformation occurred in the wheel path. Only slight wearing of the excess grout on the RMP surface was observed. The ALF evaluation indicated that vehicular traffic had little effect on the resin-modified pavement and that the RMP should have good field performance when trafficked by rubber-tired vehicles.

SUMMARY

The resin-modified pavement construction process can be used to build new pavements or rehabilitate existing pavements that are subject to heavy, abrasive loads and fuel spillage. RMP can be used to surface areas used by tracked vehicles such as tank trails and crossings, hardstands, and wash facilities. This pavement may also be used in motorpools, refueling pads, and aircraft parking aprons. RMP provides an alternative surfacing material in areas where conventional pavement materials have excessive maintenance problems. The resin-modified pavement can be used in place of asphalt concrete and portland cement concrete in these specialized areas.

RMP provides a tough and durable surfacing material for military pavements. The current data and evaluations indicate that the RMP process has potential for several uses. The variable costs of materials (aggregates, asphalt cement, and portland cement) and variable construction costs throughout the United States make cost estimates for RMP very site-specific. However, the additional cost of the resin additive can range from $4 to $6/sq yd, depending on the void content of the open-graded support layer and the dosage rate of additive in the slurry grout. Therefore, it is estimated that the initial cost of RMP in 1990 was between $10 and $15/sq yd compared with $15 to $25/sq yd for portland cement concrete. At this price, RMP is a cost-competitive method to construct or rehabilitate many of the Army's abrasion- and fuel-resistant pavements.

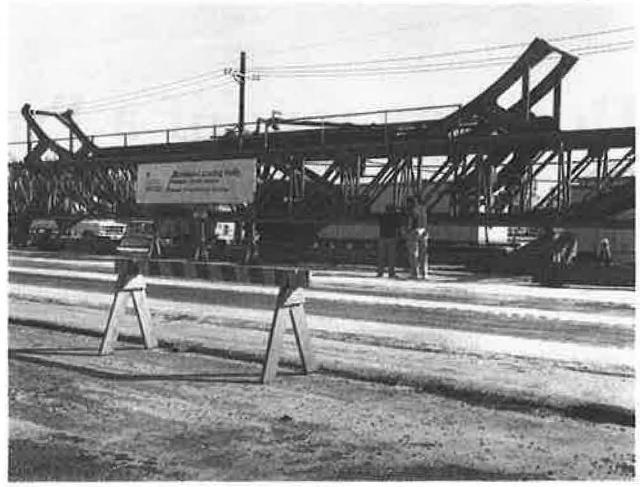

FIGURE 7 ALF trafficking RMP test strip.

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