

Virginia's Experimentation With Asphalt Rubber Concrete

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The installation of test sections containing asphalt rubber concrete using the wet process and the testing of samples of the materials in the laboratory are described. Also, some preliminary test data from a laboratory study using both coarse and fine crumb tire rubber with the wet process are included. The installation of the test sections went smoothly with only minor problems. The following laboratory tests were used to evaluate the mixtures: Marshall, gyratory shear, creep, resilient modulus, indirect tensile strength, and stripping. The test results indicated that the asphalt rubber mixtures were more susceptible to permanent deformation than the same mixtures without asphalt rubber; however, the temperature at which the mixtures were compacted and tested may have affected the results, which may not therefore reflect how the asphalt rubber will perform in the field. After being subjected to the indirect tensile stripping test, the mixtures with asphalt rubber displayed less stripping than the mixtures without asphalt rubber. The laboratory study indicated that asphalt rubber binder containing either coarse or fine rubber can be stored for a reasonable period (at least 24 hr) with no breakdown of the rubber. The coarse and fine rubber reacted with the asphalt in a similar way, but the mixture containing coarse rubber required slightly more asphalt cement than the mixture with no rubber. The fine rubber mixtures displayed an optimum rubber content in those cases in which the maximum resilient modulus and indirect tensile strength were achieved.

Attempts to use old tire rubber in asphalt for highways date back to the 1920s (1). Rubber may be used in asphalt concrete as an aggregate, or it may be reacted with the asphalt cement to yield asphalt rubber. Most of the rubber that has been used has been asphalt rubber. The success of this product has been somewhat mixed: some agencies have expressed overwhelming satisfaction with it, and others have expressed doubt about the economic advantage of adding rubber to asphalt. Logically, the rubber should impart desirable characteristics that improve the life of the pavement. The use of rubber has changed since its inception; therefore, there is still a need to experiment using the recent changes to determine how it performs. Recently there has been much emphasis on recycling tires to prevent filling landfills with them, and many state legislatures have mandated that the use of tires in highway construction be studied. In 1990, Virginia Senate Bill No. 287, which encouraged demonstration projects using ground rubber from used tires in road surfacing, was passed, and an experimental field project using asphalt rubber concrete was installed in Fairfax County.

The purposes of this paper are to summarize the results of the field project, which are primarily laboratory results, and to report on the initial data from a follow-up laboratory study

dealing with the comparison of the properties of asphalt concretes using coarse rubber or fine rubber.

FIELD TESTS

Installation

In August 1990, two sections of control mixture and two sections of experimental asphalt rubber mixture were placed as an overlay on Rte. 1 in Fairfax County in an urban area in which slow-moving traffic often causes excessive permanent deformation. These four-lane sections carry 30,000 to 40,000 vehicles/day (5 to 15 percent trucks).

The asphalt contractor hired a subcontractor to supply the crumb rubber and to blend it with asphalt cement and an extender oil at the hot-mix plant concurrently with the hot-mix operation. The AC-30 asphalt cement containing extender oil was heated to approximately 420°F before being mixed with the crumb rubber, and the resultant binder was stored at 360°F before being mixed with the aggregate in the hot-mix drum plant. The construction operation went smoothly except for a minor problem with pickup on the leading roller drum of the breakdown roller.

Materials

The 1/2-in. surface mixtures (Table 1) were devised with a 75-blow Marshall design. The control mixture contained 4.5 percent of AC-30 asphalt cement, and the experimental mixture contained 6.75 percent of asphalt rubber composed of AC-30 with 6 percent extender oil and 17 percent crumb rubber (14 percent car tire rubber and 3 percent tennis-ball rubber by weight of asphalt cement). The crumb rubber (Table 2) was required to produce an asphalt rubber binder with the characteristics shown in Table 3. Crafco, Inc., which has had considerable experience with asphalt rubber, designed the asphalt rubber mixture.

Testing

Marshall, gyratory testing machine (GTM), creep, resilient modulus, indirect tensile, and stripping tests were conducted on mixtures sampled during construction.

Marshall tests were conducted according to ASTM D1559 (2) using the 75-blow compactive effort. Properties that were evaluated were voids in the total mixture (VTM), voids filled

TABLE 1 GRADATIONS OF MIXTURES

Sieve	% Passing	
	Test Sections	Lab Study
3/4	100	
1/2	99	100
3/8	91	95
4	55	58
8	40	42
30	22	25
60	13	17
100		11
200	5.4	6.2

TABLE 2 SPECIFIED GRADATION OF CRUMB RUBBER

Sieve	% Passing
#10	100
#16	95-100
#30	70-100
#60	0-20
#200	0-5

Note: No gradation tests were performed.

with asphalt (VFA), voids in the mineral aggregate (VMA), and stability.

Under the oil-filled mode of operation, specimens were tested with a GTM using initial gyratory angles of 1 and 0.75 degrees with a vertical pressure of 120 psi. The specimens were compacted until the rate of compaction decreased to 1 pcf/100 revolutions, which simulates the level of compaction after traffic. The angles of gyration are thought to produce compaction that duplicates the compaction of moderate to heavy traffic. Properties used to characterize the mixtures were final voids, shear strength, and gyratory stability index (GSI).

Compression creep tests were performed at 104°F on 2.5-in. by 4-in.-diam specimens that were compacted on the GTM to the predicted void content of pavement after traffic. The specimens were preloaded for 2 min at 30 psi, unloaded and allowed to rest for 5 min, and then loaded for 60 min at 30 psi. Axial deformation was recorded at set intervals when the load was being applied and again for 60 min after the load was released. The stiffness modulus at 60 min and the unrecovered strain after the load had been released for 60 min were analyzed.

The indirect resilient modulus and indirect tensile strength at 104°F were measured according to ASTM D4123 (2) with the Retsina device using the same specimens that were used in the creep tests. Because vertical deformation could not be measured, Poisson's ratio was assumed to be 0.35.

TABLE 3 PHYSICAL PROPERTIES OF ASPHALT RUBBER BINDER

Minimum viscosity, 350°F	1500 cp
Minimum cone penetration, 77°F (ASTM D1191)	20
Minimum softening point (ASTM D36)	125°F
Minimum resilience, 77°F (ASTM D3407)	15%

Stripping tests performed were the indirect tensile strength test (ASTM D4867)(2) and the Virginia boiling test for field mixtures (3). The tensile strength test determined susceptibility to moisture damage by testing two sets of specimens: one set was conditioned to simulate potential moisture damage and tested, and one set was tested in an unconditioned dry state. The tensile strength ratio, which is the ratio of the conditioned strength to the dry strength, was used to predict moisture damage. The boiling test was performed by boiling a sample of mixture in water for 10 min. The sample had to be as well coated as an unboiled dry sample in order to pass the test.

Results

The design criteria and Marshall properties for the mixtures are listed in Table 4. The VTM was lower than desirable, and the VFA was higher than desirable for the southern section of asphalt rubber mixture. The VTM was at the upper limit for the northern control mixture and slightly greater than the upper limit for the southern control mixture. If the Marshall void properties are indicative of pavement performance, then it is to be expected that the southern asphalt rubber section may tend to bleed or become overly dense, and the control sections may tend to be open and age prematurely.

The GTM results—predicted voids after traffic, shear strength, and gyratory stability index—are displayed in Figures 1, 2, and 3, respectively. Both asphalt rubber mixtures failed all of the tests, and the southern control mixture failed shear strength at both pressure levels and GSI at 120 psi. These test results indicate that the asphalt rubber mixtures and southern control mixture may deform if the traffic is severe enough. Because the properties of the binders may be similar at high temperatures (as used in this test) but very different at lower summer pavement temperatures, performance of the asphalt rubber mixtures may have been predicted better by performing the traffic compaction simulation at lower temperatures.

A summary of the results of the creep test are listed in Table 5. It was expected that the addition of rubber would increase the modulus and decrease the unrecovered strain; however, the asphalt rubber mixtures had a lower modulus and a higher unrecovered strain compared with the same

TABLE 4 MARSHALL DESIGN CRITERIA AND TEST RESULTS

Property	Southern		Northern		Design Criteria	
	Rubber	Control	Rubber	Control	Rubber	Control
VTM (%)	2.4	6.1	3.8	6.0	3-4	4-6
VFA (%)	87	65	80	67	—	60-75
VMA (%)	17.7	17.5	18.9	18.3	≥15	≥15
Stability (lbs)	2580	2960	2660	3120	—	—

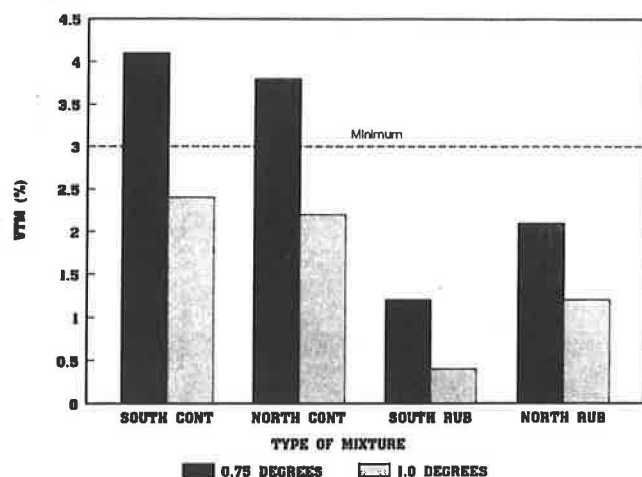


FIGURE 1 Pavement voids predicted by GTM.

properties of the control mixtures. The average differences were significant at a 95 percent confidence level. Although some research has shown that asphalt rubber increased stiffness and strength (4,5), other research has shown that asphalt rubber decreased the stiffness of mixtures that were already performing well with a normal binder (6).

The resilient modulus of the southern control mixture was significantly higher than the resilient modulus of the northern control mixture at a 95 percent confidence level (see Figure 4). It was anticipated that rubber mixtures would follow the trend observed with the creep test, in which the modulus of the rubber mixtures was lower than that for the control mixtures; however, the reason for the difference between the control mixtures could not be explained.

The indirect tensile strengths of the rubber mixtures (see Figure 5) were significantly lower than the control mixtures at a 95 percent confidence level, which was the same trend previously observed.

In those cases in which the GTM was used for testing or compacting the specimens, the results are probably biased favorably toward mixtures without rubber. The GTM test was performed at high temperatures at which the deformation

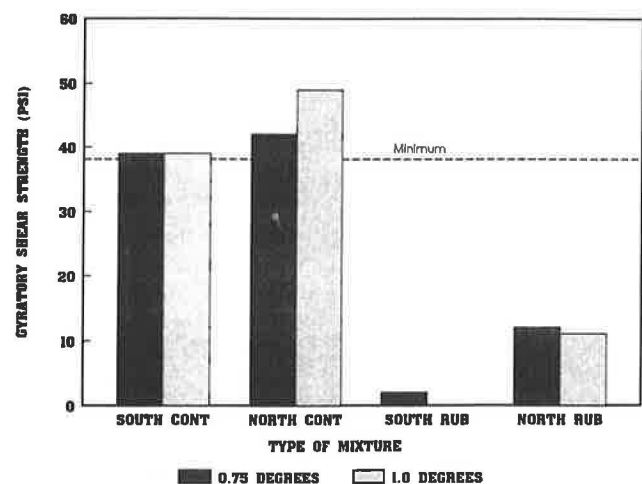


FIGURE 2 Gyrotory shear strength.

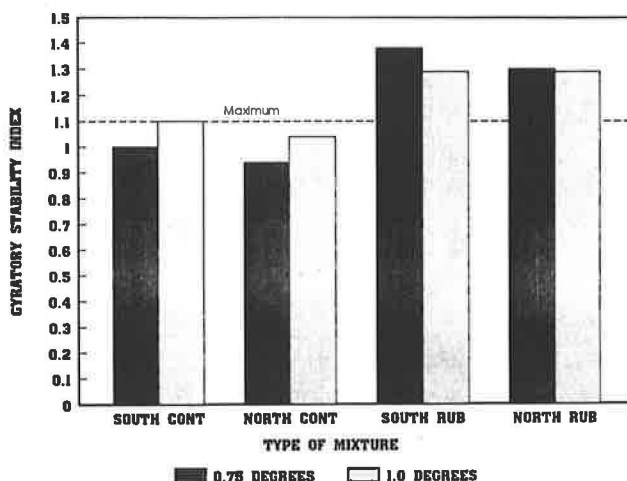


FIGURE 3 Gyrotory stability index.

resistance of the asphalt rubber is minimal. Also, the high temperature during the GTM traffic-compaction simulation allowed the specimens containing asphalt rubber to densify more than is normally observed in pavement, thereby resulting in low air voids and low values for strength and modulus, which may be misleading.

The tensile strength stripping test indicated that the control mixtures may be susceptible to stripping. The southern control mixture had a TSR less than the acceptable 0.75, and both control mixtures had considerable visual stripping. None of the mixtures failed the boiling test.

LABORATORY STUDY

Several gradations of crumb rubber that are used in other applications are available for use in asphalt rubber. A follow-up laboratory study was conducted to determine how the properties of asphalt rubber concrete containing coarse crumb rubber compared with the properties of asphalt rubber concrete containing fine crumb rubber. When rubber is mixed with asphalt cement, the rubber particles swell (react) causing the viscosity to increase, and if heat is maintained for a prolonged time, the rubber may melt and break down, resulting in an undesirable decrease in viscosity. Reaction curves were developed for asphalt rubber binders containing various percentages of fine and coarse rubber to determine whether the fine rubber should be used differently in the field. It is desirable to use the asphalt rubber binder after it has reached its maximum viscosity but before the rubber breaks down; however, rubber breakdown is not the only concern. If a short time is required to achieve maximum viscosity, the fine rubber will require less elaborate blending equipment than the coarse rubber. Perhaps the fine rubber could be added during the

TABLE 5 CREEP TEST RESULTS

Sections	Modulus, (psi)		Unrecovered Strain (%)	
	Average	Std. Dev.	Average	Std. Dev.
Control	7,900	900	0.080	0.027
Asphalt Rubber	5,500	550	0.200	0.074

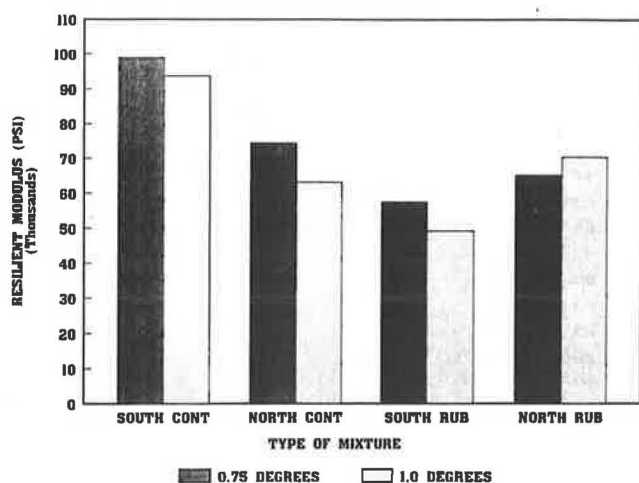


FIGURE 4 Resilient modulus at 104°F.

mixing of the binder and aggregate without blending equipment.

Materials

A 1/2-in. surface mixture using an AC-20 asphalt cement and a 75-blow Marshall design was used (Table 1). The gradation of the coarse rubber was the same as that used in the field experiment, and the fine rubber had 100 percent passing the No. 80 sieve and a mean particle size of No. 200 (0.074 mm).

Testing

Reaction (viscosity-time) curves for the asphalt rubber binders were developed using rubber contents of 5, 10, and 15 percent for both the coarse and fine crumb rubber. A portable Haake viscometer was used to measure viscosity. The rubber was mixed with the asphalt cement and maintained at 350°F, and viscosity measurements were taken at regular intervals for approximately 24 hr.

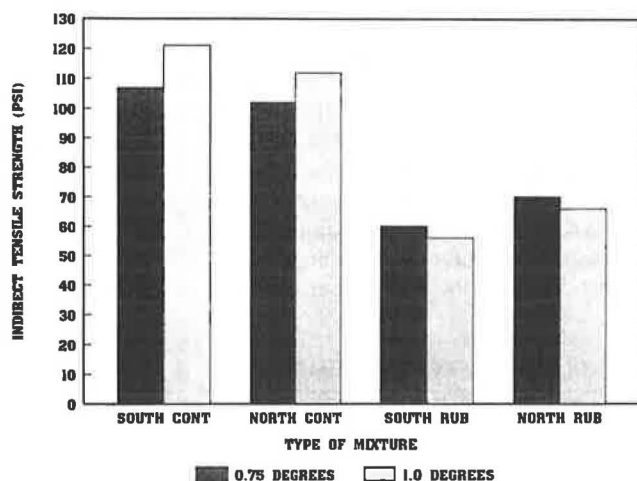


FIGURE 5 Indirect tensile strength at 104°F.

Marshall designs were performed on each binder at each rubber content to determine the optimum asphalt content at 4.5 percent VTM. The remaining tests—gyratory shear, resilient modulus, and indirect tensile—were performed at the optimum asphalt content.

Although the GTM was used, the procedure was changed from the procedure used in the study of the field mixtures. Only one initial gyratory angle of 1.0 degree and a vertical pressure of 120 psi were used. Also, the specimen was compacted to the expected density of pavement after rolling, removed from the machine, cooled to 140°F, and compacted until the rate of compaction decreased to 1 pcf/100 revolutions. Compacting at 140°F to simulate the effect of traffic was done in an attempt to show the potential advantage of rubber in resisting permanent deformation at normal pavement temperatures.

Resilient modulus and indirect tensile tests were performed on the specimens made on the GTM by the same procedures that were used in the study of field mixtures.

Results

The reaction curves for coarse and fine rubber are shown in Figures 6 and 7, respectively. It is obvious that there is considerable variation in the test results because the curves were not as smooth as expected. The variation is caused by difficulty in maintaining a constant temperature when removing a binder from the oven for viscosity testing, and the accuracy of the Haake viscometer is limited. It appears that the viscosity reached a maximum after approximately 1 hr with all of the binders except the one containing 15 percent coarse rubber, which appeared to still be gaining viscosity after 20 hr. For a rubber content of 10 percent or less, the reaction appears to be almost instantaneous. The rubber did not appear to break down after 20 hr, which would have resulted in a decrease in viscosity; therefore, these binders could be safely stored at 350°F for this time period without deleterious effects. It is evident from both sets of curves that viscosity increases significantly between 10 percent and 15 percent rubber content. The engineering properties would also change

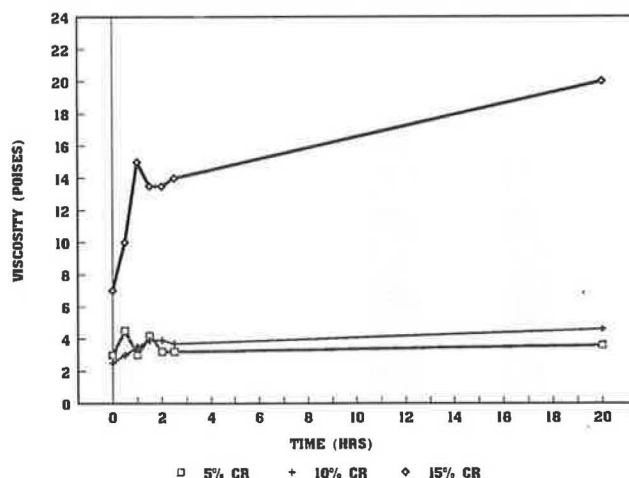


FIGURE 6 Reaction curve: coarse crumb rubber.

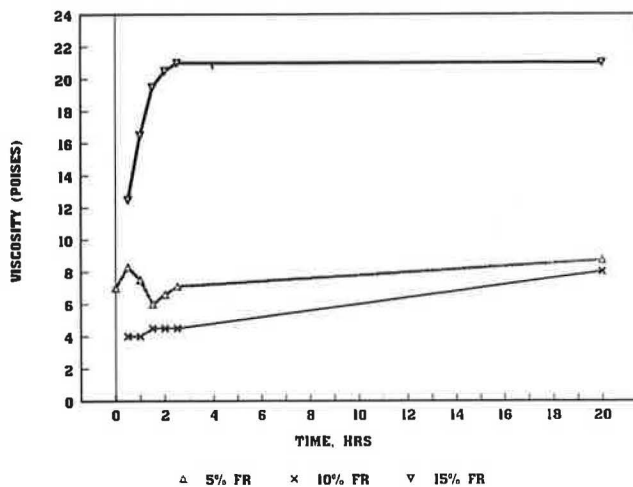


FIGURE 7 Reaction curve: fine crumb rubber.

dramatically in this range. There does not appear to be a significant difference in the viscosity of the coarse and fine rubber at a similar rubber content, and both would be expected to behave in a similar way in blending operations in the field.

The "optimum" asphalt content, which was selected at 4.5 percent VTM, and the associated VMA from the Marshall designs are shown in Figures 8 and 9, respectively. The change in asphalt content with change in rubber content (i.e., slope of the curve) was consistent between the coarse and fine rubber mixtures. The mixtures with coarse crumb rubber required approximately 0.6 percent more binder than similar mixtures with fine crumb rubber. Because the rubber particles do not melt completely, they tend to push the aggregate particles apart, as indicated by an increase in VMA in all mixtures that have a higher rubber content. As expected, the coarse rubber particles created higher VMA than the fine rubber particles because the larger particles forced the aggregate particles further apart. If they are stable, it would be anticipated that the coarse rubber mixtures with higher asphalt content would be

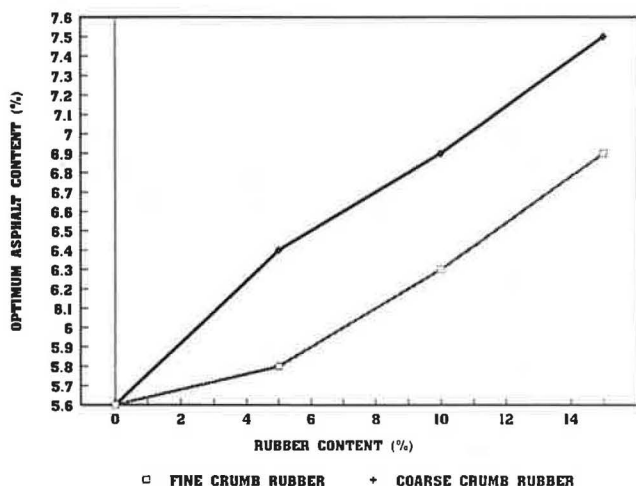


FIGURE 8 Optimum asphalt content versus rubber content.

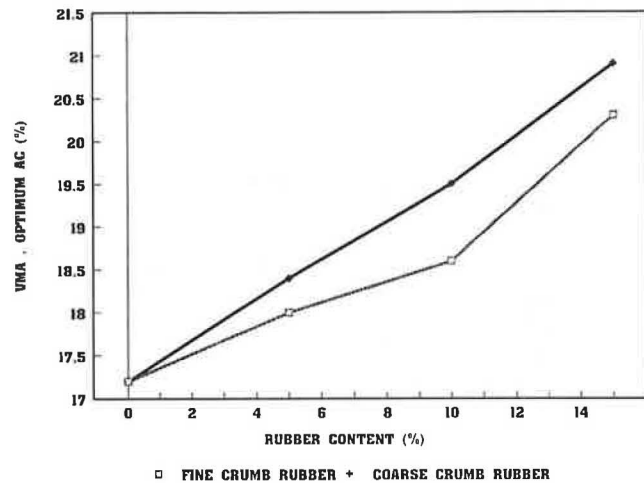


FIGURE 9 Voids in mineral aggregate at optimum asphalt content versus rubber content.

more flexible than the fine rubber mixtures with lower asphalt content.

The predicted voids after traffic, shear strength, and stability index are shown in Figures 10, 11, and 12, respectively. The mixture with 15 percent coarse rubber had a significantly higher percentage of voids (i.e., less densification) than the other mixtures, which indicates a possible greater resistance to permanent deformation. The GSI of the mixtures with 10 percent and 15 percent rubber was greater than 1.1, which indicates that they may have contained too much binder and would be prone to instability. These results are contradictory; therefore, the method of testing and analyzing asphalt rubber mixtures with the GTM needs further study. The shear strengths showed no trends for mixtures with different rubber content; however, all of the strength values were very low.

The bar graphs of resilient moduli and indirect tensile strengths (Figures 13 and 14) of the specimens made on the GTM revealed some trends. There appeared to be an optimum rubber content at which the maximum value of resilient modulus and indirect tensile strength was achieved for the

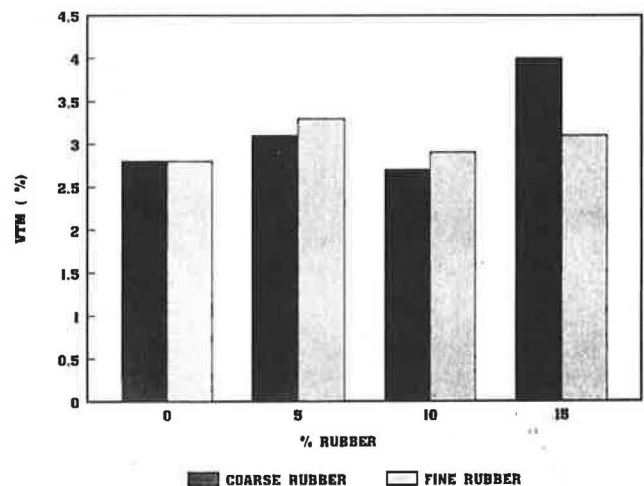


FIGURE 10 Pavement voids predicted by GTM.

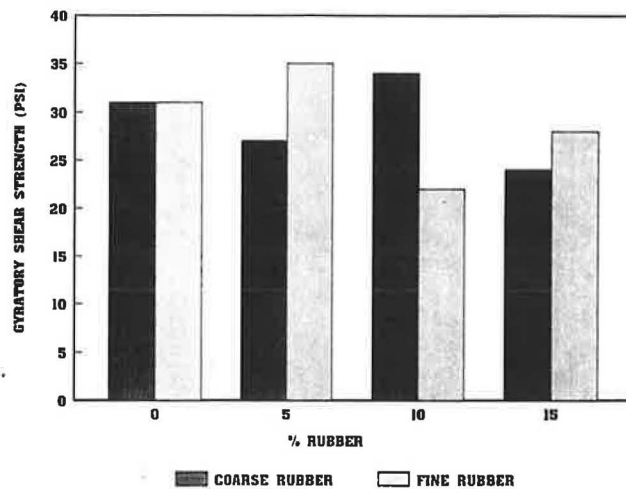


FIGURE 11 Gyratory shear strength.

fine rubber mixtures for both resilient modulus and indirect tensile strength. There was a significant difference at a 95 percent confidence level between average values at 0 and 5 percent, 5 and 15 percent, and 10 and 15 percent, but not between 5 and 10 percent, which confirms the optimum value observation. This optimum condition was not apparent for the coarse rubber mixture. The magnitude of the resilient modulus for the coarse rubber appeared to increase as the rubber content was increased. When the average values were tested, there was no significant difference between any of the average values; therefore, this apparent trend could not be confirmed.

CONCLUSIONS

Field Study

1. Laboratory test results on the mixtures sampled during construction indicate that mixtures containing asphalt rubber

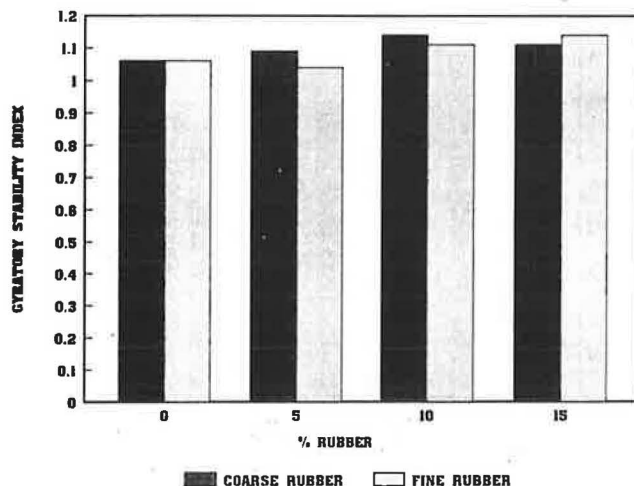


FIGURE 12 Gyratory stability index.

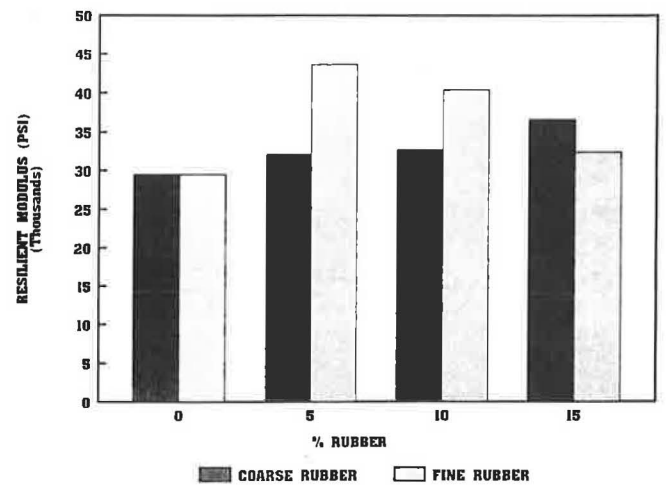


FIGURE 13 Resilient modulus at 104°F: laboratory study.

using the wet process may be less resistant to permanent deformation than mixtures without rubber; however, laboratory tests may not be able to simulate pavement behavior for these types of mixtures.

2. The mixtures with asphalt rubber displayed less stripping than the mixtures without asphalt rubber when tested with the indirect tensile stripping test.

Laboratory Study

1. Coarse and fine rubber reacted with the asphalt cement similarly.

2. The rubber did not break down over a 24-hr time period.

3. Approximately 0.6 percent more asphalt cement was required for the coarse rubber mixtures than for the fine rubber mixtures.

4. An optimum rubber content of 5 to 10 percent yielded the maximum resilient modulus and indirect tensile strength for mixtures containing fine rubber.

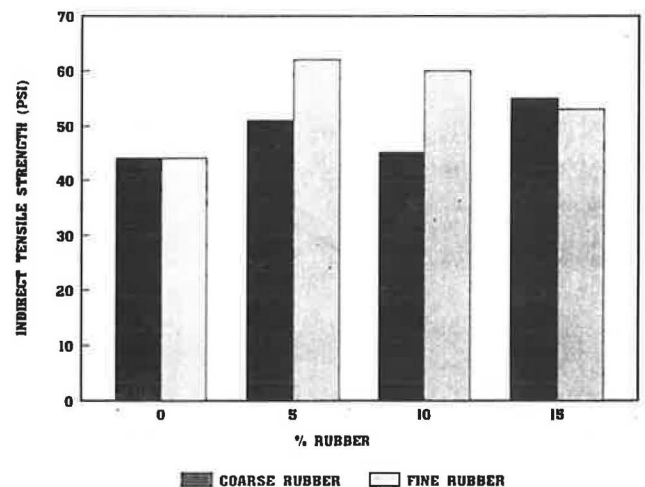


FIGURE 14 Indirect tensile strength at 104°F: laboratory study.

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