Recycling Waste Roofing Material in Asphalt Paving Mixtures

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The technical feasibility of using waste roofing products in asphalt concrete paving mixtures is addressed. Approximately 9 million tons of roofing waste are generated annually in the United States. Disposal costs are significant. Recycling represents an economical and, perhaps, environmentally attractive alternative to placing these wastes in landfills. The relatively large quantities of asphalt cement and "aggregate-type" materials present in roofing waste suggest that these materials have potential as a partial substitute for asphalt cement or aggregate, or both, in a paving mixture. A study that arrived at the following conclusion was conducted. (a) Acceptable paving mixtures, which contain up to 20 percent by volume of roofing waste, can be produced; (b) proper selection of binder type and quantity is critical to the performance of the mixture and depends on the type and quantity of the roofing waste in the mixture; (c) improved asphalt cement extraction and recovery processes need to be developed to effectively determine the properties of the asphalt cement in the roofing waste; (d) the total "active binder" content, depending on the effectiveness of the recycling agents, should be considered when designing asphalt concrete mixtures; (e) the gradations of conventional aggregates and roofing wastes should be considered when designing paving mixtures; and (f) the long-term field performance of paving mixtures containing roofing waste needs to be established.

Approximately 9 million tons of roofing waste are generated annually in the United States (*1*, p. 2). As is the case with large amounts of any type of waste, disposal costs are significant. Recycling represents an economical alternative to placing these wastes in landfills. Recycling of roofing waste into paving materials is an alternative.

Typical roofing waste products, such as old shingles or built-up roofing, contain about 36 percent asphalt cement; 22 percent hard rock granules (minus No. 10 to plus No. 60 sieve size); 8 percent filler (minus No. 100 sieve size material); and smaller amounts of coarse aggregate (approximately 1 in. in size), cellulose fiber felt, glass fiber felt, asbestos felt, and polyester films. The relatively large quantities of asphalt cement and "aggregate-type" materials present in roofing waste suggest that it has potential as a partial substitute for asphalt cement or aggregate, or both, in a paving mixture. This paper contains the results of a preliminary investigation to establish the feasibility of using roofing waste products in asphalt concrete paving mixtures.

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BACKGROUND

Technically, a wide variety of waste products and by-products, including old pavement materials, waste glass, battery cases, polypropylene containers, old tires, fly ash, bottom ash, and slag, can be successfully incorporated into paving materials (*2–7*). From a national perspective and based on both a technical and an economic viewpoint, the reuse of old pavement materials, old tires, fly ash, and slag has been successful. Literature that addresses the technical and economic feasibility of using roofing wastes in asphalt paving materials is not available.

Several technical items will have to be addressed before widespread use is made of roofing waste in asphalt concrete mixtures. These items include

1. The nature and quantities of the material in roofing waste including the properties of the asphalt cement and the grain size distribution of the solid material;
2. The quantity of roofing waste that can be introduced into a paving mixture without adversely altering the engineering properties of the mixture;
3. The quantity and type of asphalt cement or aromatic-type oils, or both, needed to soften the aged roofing asphalt to an appropriate paving grade asphalt cement;
4. The techniques for introducing the processed roofing waste into the asphalt concrete mixing and paving process without creating adverse environmental effects;
5. Establishing the long-term performance characteristics of asphalt concrete containing roofing waste by an extensive laboratory and field testing program; and
6. Determining the local economics of using this waste material in a paving mixture.

A test program that addresses Items 1 through 3 has been conducted. A more extensive research effort, including additional and more sophisticated laboratory testing and field studies, will be required to define Items 1 through 6 in sufficient detail to gain acceptance by the contracting and engineering communities.

TEST PROGRAM

Roofing wastes from five sources have been obtained and subjected to the test program shown in Figure 1.

Figures 2 and 3 show and Table 1 gives a further description of the asphalt concrete mixture test program. The first three parts of the mixture-testing program shown in Figure 2 were performed to establish the source of roofing waste, the range of

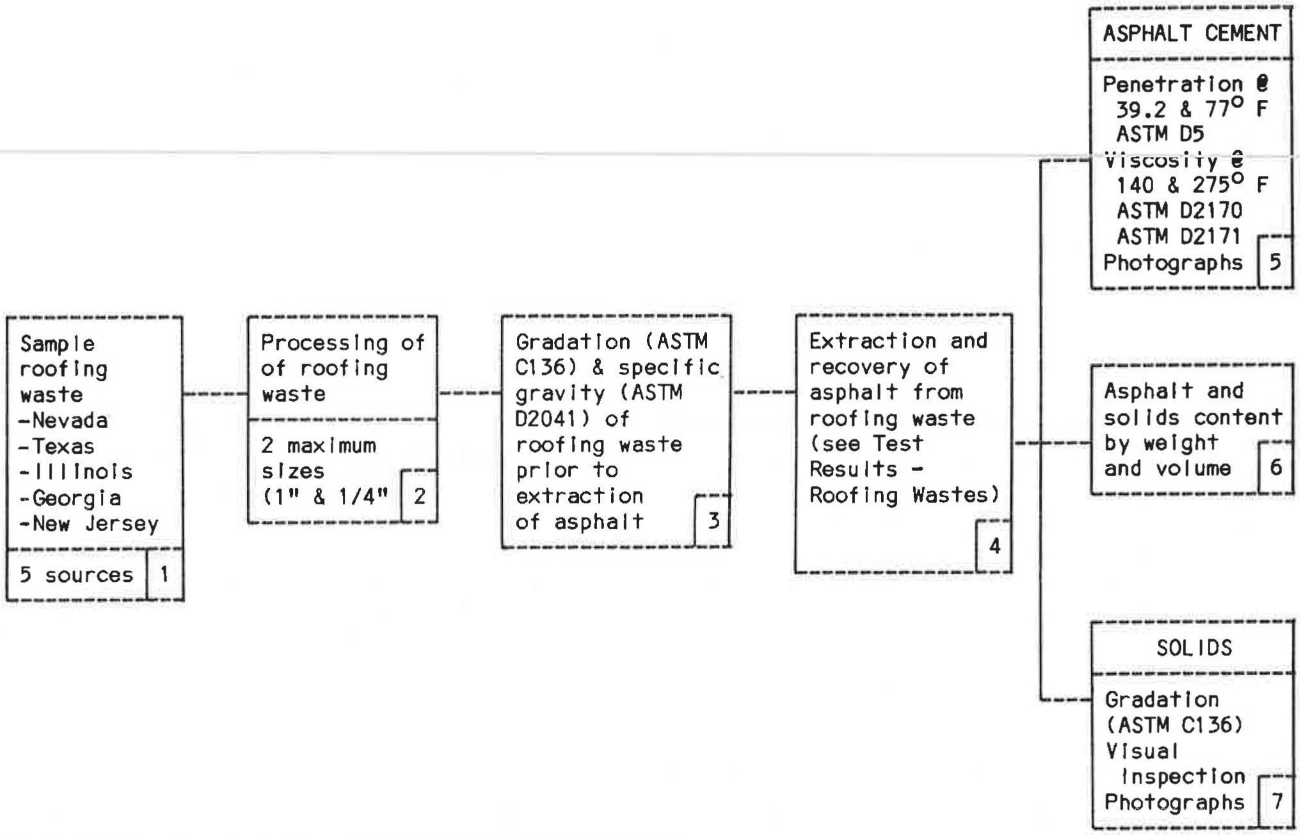


FIGURE 1 Test sequence for defining properties of roofing wastes.

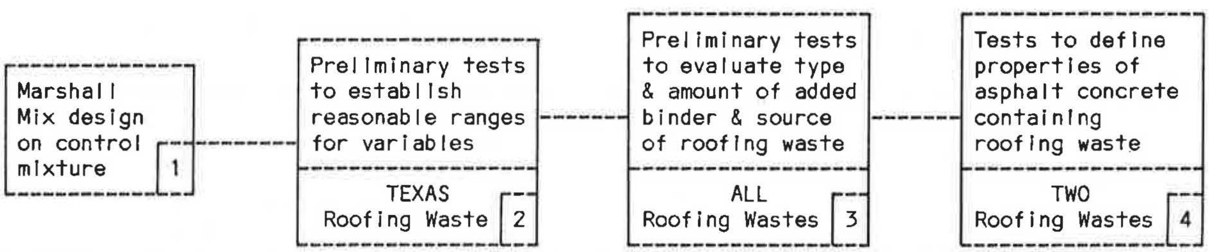
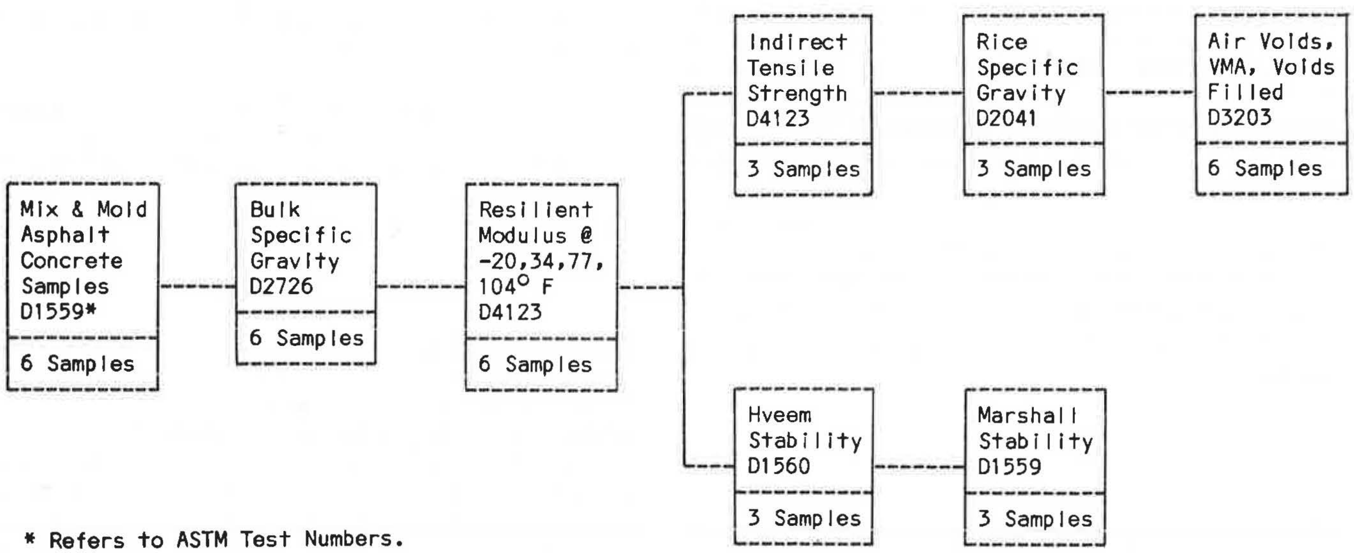


FIGURE 2 Test sequence for defining properties of asphalt concrete that contains roofing waste.



* Refers to ASTM Test Numbers.

FIGURE 3 Test program identified in Table 1.

TABLE 1 TEST MATRIX FOR MIXTURE-TESTING PROGRAM

Type and Source of Roofing Waste	Quantity of Roofing Waste (% by volume)	Type of Binder: RA-5[a], Quantity of Added Binder (% by weight)			RA-75, Quantity of Added Binder (% by weight)			AR4000, Quantity of Added Binder (% by weight)		
		3	4	5	3	4	5	4	5	6
1 in. minus, New Jersey	10									
	20		x			x			x	
	30									
1/4 in. minus, New Jersey	10				x	x	x			
	20	x	x	x	x	x	x	x	x	x
	30				x	x	x			
1/4 in. minus, Nevada	10					x				
	20		x		x	x	x		x	
	30					x				
1 in. minus, Nevada	10									
	20		x			x			x	
	30									

[a]RA = recycling agent.

quantities of roofing waste, the type of added binder, and the quantity of added binder to be used in the fourth and major part of the study. The major portion of the mixture-testing program was performed on two roofing wastes as indicated in Table 1.

All asphalt concrete mixtures were subjected to the test methods shown in Figure 3. Each mixture was placed in an oven at the specified 275°F compaction temperature for 1 1/2 hr after the completion of mixing. This was done to simulate mixing at the hot plant, transportation to the job site, and laydown elapse time. In addition, this extra time would allow the recycling agent to digest the aged waste asphalt cement. Each mixture was then remixed before compaction.

Air voids were calculated by ASTM D 3203 using Rice specific gravities corrected for absorption. The presence of roofing waste material did not affect the air void analysis. The magnitude of the correction for absorption was consistent with that for mixtures containing the same absorptive aggregate and no roofing waste.

MATERIALS

Asphalt Cement

An AR4000 asphalt cement was used in the control mixture and in mixtures containing roofing wastes. The physical properties of this asphalt cement are given in Table 2. This California Valley asphalt cement is used in Arizona, California, Nevada, and Oregon and has been used in several research projects in the western states.

Recycling Agents

Two recycling agents were used in mixtures containing roofing wastes. These products meet Pacific Coast specifications for RA-5 and RA-75 recycling agents and have been used on recycled asphalt mixture projects in the western states. The physical properties of these materials are given in Table 2. These lower viscosity materials have the capability of softening harder asphalts. The chemical composition of these materials has been established to ensure compatibility with a wide range of paving-grade asphalt cement types.

Aggregates

Aggregate was obtained from a pit located in Sparks, Nevada. The aggregate is a subrounded gravel, partly crushed and washed, from an alluvial deposit. The aggregate is considered an absorptive aggregate with absorption capacities in the range

TABLE 2 PHYSICAL PROPERTIES OF BINDERS

Physical Property	AR4000	RA-5[a]	RA-75
Penetration at 39.2°F, 100 g/5 sec (0.1 mm)	14	–	–
Penetration at 77°F, 100 g/5 sec (0.1 mm)	54	–	–
Viscosity at 140°F	2180 P	260 cSt	8000 cSt
Viscosity at 275°F	270 cSt	13 cSt	60 cSt
Ductility at 77°F, 5 cm/min	100 +	–	–
Ring-and-ball softening point (°F)	123	–	–
Flash point, Cleveland open cup (°F)	–	400 min	450 min
Specific gravity	0.98–1.02	0.98–1.02	0.98–1.02

[a]RA = recycling agent.

TABLE 3 PROPERTIES OF ROOFING WASTES

Property	Reno, Nevada	Dallas/Fort Worth, Texas	Oakbrook, Illinois	Savannah, Georgia	New Jersey
Apparent specific gravity[a]	1.37	1.26	1.36	1.28	1.13
Asphalt content[b] (Method 1)	37.2	39.1	33.2	35.4	37.6

[a]Before extraction.
[b]Percentage by total weight of waste.

of from 3 to 4 percent. The gradation of the aggregate meets the Nevada Department of Transportation's specification for Type-2 dense-graded plant mix and road mix. The maximum aggregate size is ³/₄ in.

TEST RESULTS—ROOFING WASTES

Specific Gravity

The specific gravities of the wastes are given in Table 3. The specific gravities of these materials are considerably below those of conventional aggregates, which typically have values between 2.55 and 2.70. Thus the percentages of roofing wastes in mixtures expressed as a percentage by total volume or a percentage by total weight will be considerably different. Asphalt concrete mixture design concepts are based on volume concepts but are commonly expressed on a weight basis for construction convenience.

Extraction and Recovery

Two methods were used to extract and recover the asphalt cement from the roofing waste. Method 1 used ASTM D 2172 (Method B) to extract and a Buchi Rotavapor distillation apparatus to recover the asphalt cement from the roofing waste. Method 2 was performed by the Manville Service Corporation. This method used a centrifuge process and a cyclohexane solvent for extraction and a hot-plate evaporation system for recovery. A more detailed description of Method 2 is found in Appendix A of Paulsen et al. *(8)*.

Asphalt Cement Content

The asphalt content expressed by the total weight of the roofing wastes is given in Table 3. Data in Table 3 were determined from extraction and recovery Method 1. However, when Method 2 was used, asphalt contents for the Nevada and New Jersey roofing wastes were 20 and 26 percent. Method 2 uses a cyclohexane solvent, which may have dissolved only a portion of the asphalt and therefore resulted in low asphalt contents. The black color of the mineral residue after extraction tended to confirm this suspicion.

Penetration (ASTM D 5)

Penetrations at 39.2°F and 77°F, 100 g, and 5 sec were obtained for the asphalt cement extracted and recovered by Method 2. These test results are given in Table 4. Roofing waste asphalt cements extracted and recovered by Method 1 were not suitable for penetration testing. Air bubbles could not be eliminated in the recovered asphalt; thus penetration results were erratic.

Viscosity (ASTM D 2170 and D 2171)

Viscosity tests were performed at 140°F and 275°F. Test results from the asphalt cement extracted and recovered by Method 2 are given in Table 4. Blank data entries are the result of the recovered asphalt cements having viscosities greater than available viscosity tube ranges. All asphalt cements recovered by Method 1 had viscosities that exceeded available viscosity tube ranges.

The data contained in Table 4 suggest that the asphalt recovered from the Nevada roofing waste, by Method 2, is considerably softer than are asphalts recovered from other wastes. All data in Table 4 relate to Method 2. However, this same recovered asphalt appeared to have the highest viscosity when extracted and recovered by Method 1. This observation was completely subjective because actual viscosity data from Method 1 were unattainable. The nature of this highly weathered asphalt, possibly produced with a ferric chloride

TABLE 4 RECOVERED ROOFING WASTE ASPHALT CEMENT PROPERTIES (Method 2)

Source of Roofing Waste	Penetration at 39.2°F, 100 g/5 sec (0.1 mm)	Penetration at 77°F, 100 g/5 sec (0.1 mm)	Viscosity at 140°F (poise)	Viscosity at 275°F (cSt)	Pen-Vis No.
Reno, Nevada	104	189	27	52	–2.97
Dallas/Fort Worth, Texas	11	24	149 000	2 630	0.73
Oakbrook, Illinois	5	12	–[a]	3 880	5.53
Savannah, Georgia	3	7	–[a]	53 100	2.68
New Jersey	4	11	–[a]	31 500	2.67

[a]Recovered asphalt cement viscosity exceeded available tube ranges.

catalyst, may have imparted different solubility characteristics in various solvents. All recovered asphalts from Method 1, which uses a hot extraction process and a trichloroethylene solvent, were very hard. This supports experimental evidence that recovered asphalt may have higher viscosity values when recovered from solutions obtained by hot extraction methods. The recovered asphalt from the Nevada roofing waste was very soft when Method 2 was used. This may be because only a portion of the asphalt was dissolved when extraction Method 2 was used. It is the authors' opinion that Method 1 more accurately represented the asphalt contents and relative stiffnesses of the asphalts in the roofing wastes. In any case, improved extraction and recovery procedures for roofing wastes need to be developed.

Gradation

A typical comparison of roofing waste gradations before and after extraction of the asphalt cement is shown in Figure 4. A comparison of materials before and after extraction is shown in Appendix B of Paulsen et al. *(8)*. The ¼-in.-minus roofing waste from Nevada has a finer gradation except at the No. 200 sieve than do the wastes from other sources. The percentage passing the No. 200 sieve for the roofing wastes processed ranged from 9 to 23 percent. It should be noted that the aggregate gradation for each asphalt concrete mixture was adjusted for the quantity and type of roofing waste in the mixture so that the final mix gradation was equivalent to the gradation in the control mixture, which did not contain roofing waste.

TEST RESULTS—ASPHALT CONCRETE MIXTURES

The reader is urged to note that all roofing waste quantity percentages are by volume of the mixture and that added binder contents are by weight of the mixture.

Control Mixture

The Marshall mixture design method as defined by the Asphalt Institute was used to select an asphalt content for the control mixture. The control mixture contained aggregate from a Sparks, Nevada, pit and an AR4000 California Valley asphalt cement. The design asphalt cement content was 5.9 percent by total weight of mixture.

Preliminary Tests—Range of Variables

Preliminary tests were performed on mixtures to establish reasonable ranges for the study variables. The processed roofing waste from Texas was used in all mixtures because it alone was available during the early stages of the study. Quantities of roofing wastes ranged from 10 to 50 percent by total volume of the mixture. The RA-5 and RA-75 recycling agents were used in percentages that ranged from 3.0 to 5.5 percent by total weight of mixture. The test sequence shown in Figure 3 was followed.

The desirable ranges of the various test parameters are given in the following table (*9* and researchers' unpublished data).

Parameter	*Range*
Resilient modulus	200,000 to 800,000 psi at 77°F
Indirect tension	75 to 250 psi
Hveem stability	Minimum of 30 for light traffic
	Minimum of 35 for heavy traffic
Marshall stability	Minimum of 750 for light traffic
	Minimum of 1,500 for heavy traffic
Marshall flow	8 to 20 for light traffic
	8 to 16 for heavy traffic
Air voids	3 to 5 percent

Mixtures that contain the higher percentages of recycling agents at 10, 30, and 50 percent roofing wastes have values that are slightly below or at limiting values. These same mixtures have low tensile strength, Hveem stability, and air voids. Mix-

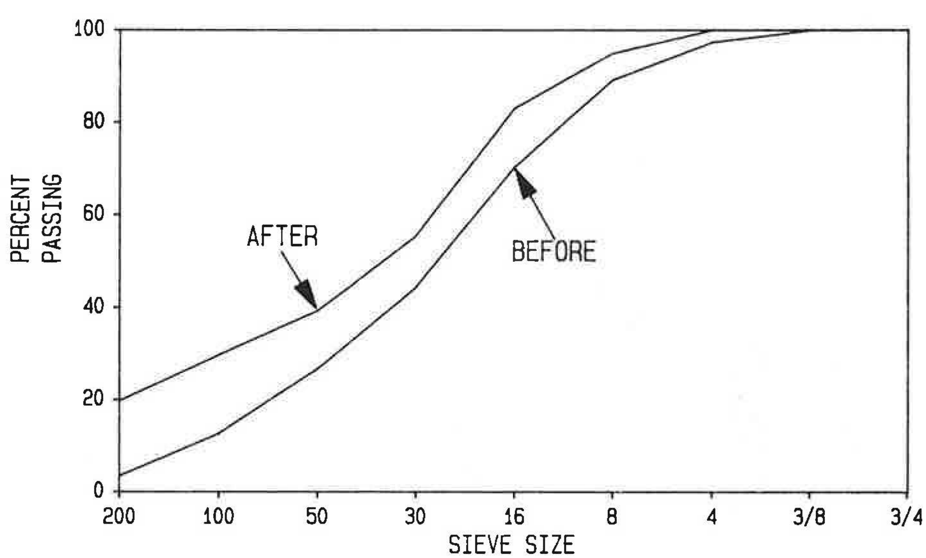


FIGURE 4 Typical grading curves of roofing waste before and after extraction.

tures that contain 30 and 50 percent roofing wastes have low air voids, which suggests that excessive additional binder was used or that the viscosity of the binder was too low, or both.

Mixtures that contain these high percentages of roofing wastes might also contain higher than generally accepted percentages of minus No. 200 material depending on how much roofing waste asphalt is digested by the recycling agent. On the basis of experience with recycling asphalt concrete mixes, hot-mix plant air quality problems, associated with smoke generation, can be expected at approximately 50 percent wastes during field mixing operations. Large waste percentages cause a decrease in new aggregate contact and an increase in mixing temperatures. Both of these factors will result in smoking of the asphalt in both drum and batch mixing plants.

This preliminary testing program indicated that mixtures with acceptable properties can be made with roofing wastes. However, in general, the content of additional binder needs to be decreased or its viscosity needs to be increased, or both, to increase the resilient modulus, tensile strength, Hveem stability, and air voids. Marshall flow values need to be decreased for some mixtures.

Preliminary Tests—Type of Roofing Waste

Preliminary tests were performed on mixtures prepared from the five roofing wastes. Ten and 30 percent roofing waste by total volume of mixtures with recycling agents RA-5 and RA-75 were evaluated. The test sequence shown in Figure 3 was used.

Mixtures that contained 10 percent roofing waste and 4.75 percent recycling agent RA-75 were, in general, low in resilient modulus, tensile strength, Hveem stability, and air voids. The binder content should be reduced or the viscosity of the binder increased, or both.

Mixtures that contain 30 percent roofing wastes and 2 percent recycling agent RA-5 have properties that are within acceptable ranges with the exception of some Hveem stabilities.

Previous research conducted on conventional mixtures indicates that values of resilient modulus reflect the stiffness of the binder contained in the mixture. The resilient modulus results shown in Figure 5 and the asphalt stiffness parameters given in Table 4 do not exhibit the expected relationship. Mixtures produced from the roofing wastes from Nevada and Texas have the highest resilient moduli, and mixtures made with the roofing wastes from Illinois and New Jersey have low values of resilient modulus. This conflicting behavior is partly due to the inability of extraction and recovery Method 2 to properly characterize the binder properties of waste roofing asphalt. Differences in the relative digestion of the waste roofing asphalt by the recycling agent or "active" binder content may also contribute to this inconsistency.

The results from the preliminary tests were used to select the source and amount of roofing waste as well as the type and amount of binder to be used in the test matrix of Table 1.

Properties of Mixtures

The test sequence shown in Figure 3 was used for mixtures identified in the test matrix of Table 1. The Nevada and New Jersey roofing wastes were selected to represent mixtures with a wide range of resilient modulus, tensile strenth, stability, flow, and air void contents.

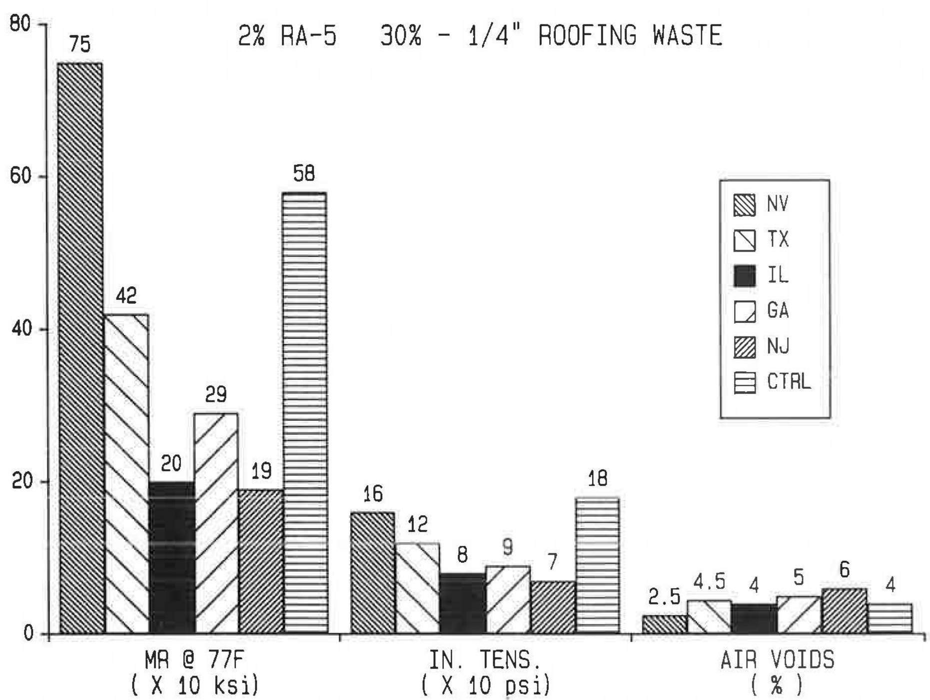


FIGURE 5 Effect of type of roofing waste—preliminary testing.

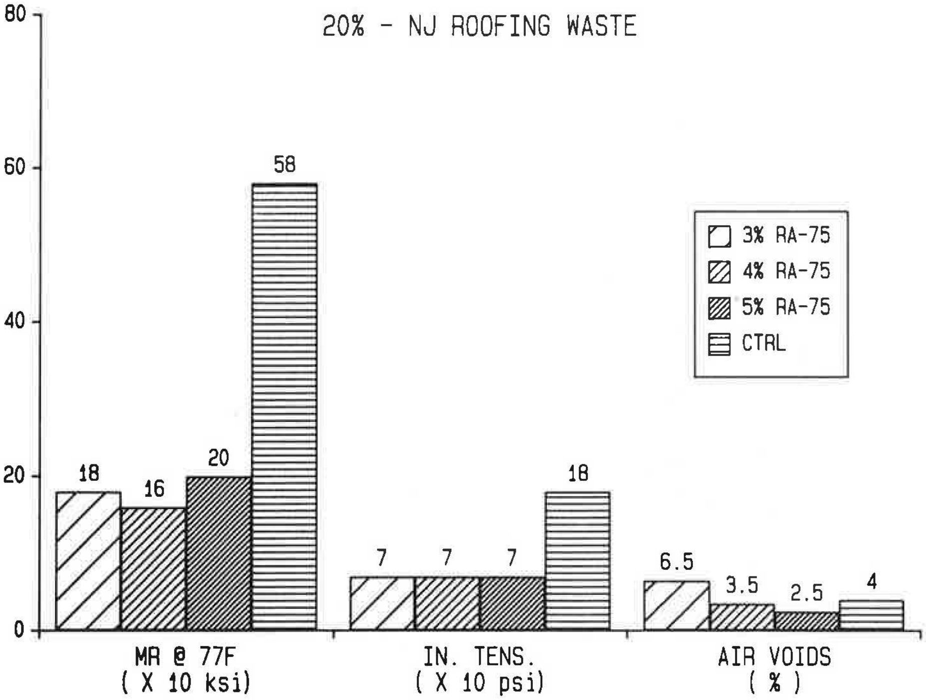


FIGURE 6 Effect of added binder content—New Jersey roofing waste and RA-75—on resilient modulus and tensile strength.

Quantity of Binder

Figures 6–11 show some of the effects of the quantity of added binder on the properties of mixtures. The quantity and type of binder, to a large degree, control the properties of a mixture. Mixtures prepared with the New Jersey roofing waste and recycling agent RA-75 (Figures 6 and 7) had low resilient modulus, tensile strength, and Hveem stabilities and high flows. At higher binder contents, air voids were also low.

Figures 8–11 suggest that acceptable mixtures can be prepared at binder contents in the range of 3 to 4 percent when the roofing waste contents are 20 percent by volume. The mixture containing 20 percent New Jersey waste and 4 percent AR4000 binder has good resilient modulus and tensile strength, but

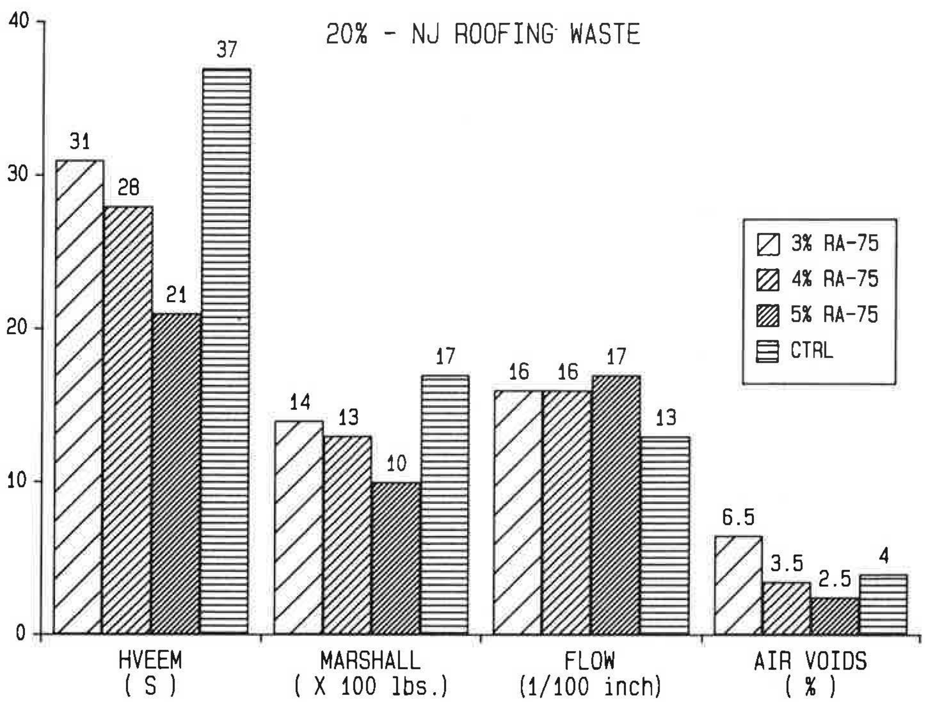


FIGURE 7 Effect of added binder content—New Jersey roofing waste and RA-75—on stability and flow.

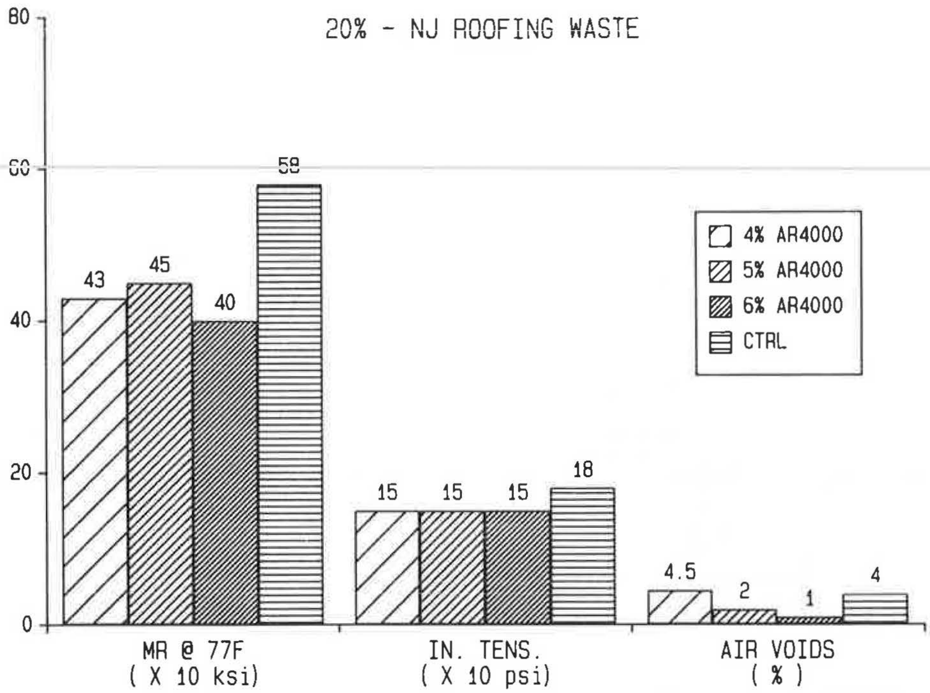


FIGURE 8 Effect of added binder content—New Jersey roofing waste and AR4000—on resilient modulus and tensile strength.

stability values are slightly outside acceptable ranges. A reduction to 3.5 percent binder would probably produce an acceptable mixture.

An acceptable mixture is possible at the 3 percent binder level when the Nevada roofing waste is used at the 20 percent level with recycling agent RA-75.

Type of Binder

Figures 6–11 also show some of the effects of the type of binder on the properties of the mixtures. Because the asphalt in the Nevada roofing waste appeared to be more viscous than the asphalt in the New Jersey roofing waste (observations from

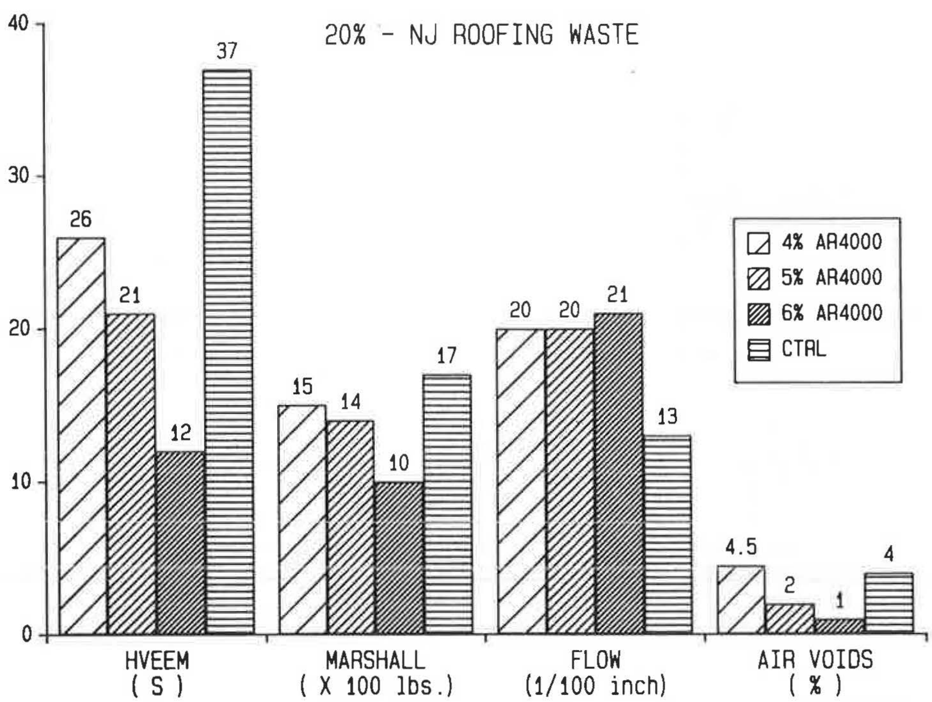


FIGURE 9 Effect of added binder content—New Jersey roofing waste and AR4000—on stability and flow.

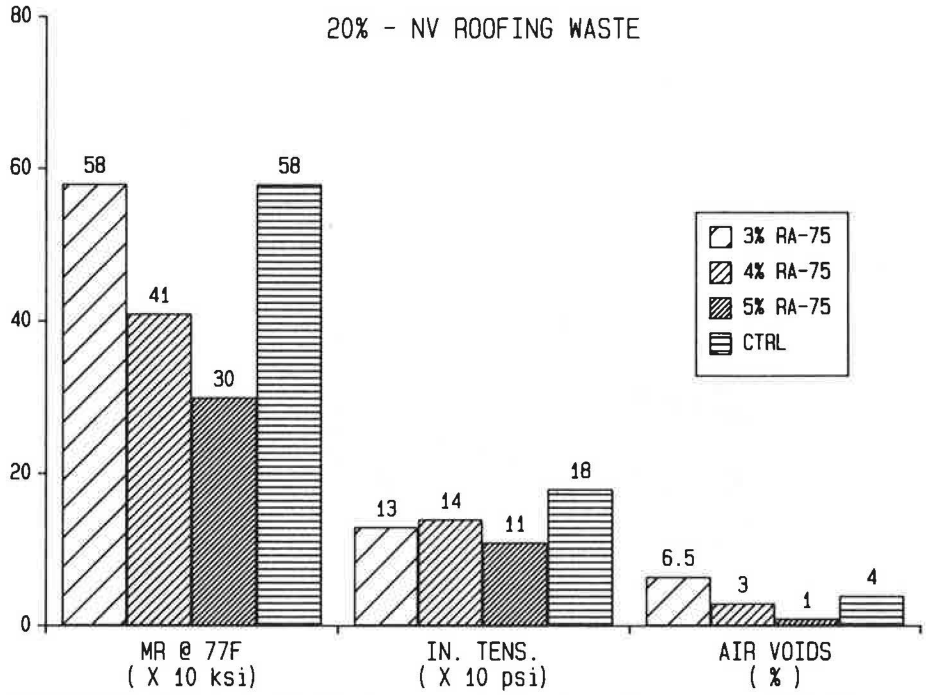


FIGURE 10 Effect of added binder content—Nevada roofing waste and RA-75—on resilient modulus and tensile strength.

extraction and recovery Method 1), an acceptable mixture can be prepared with recycling agent RA-75 and the Nevada waste. A harder binder (AR4000) is required to produce an acceptable mixture with the New Jersey roofing waste. The characteristics of the new binder have to be matched with the properties of the binder in the roofing waste and, perhaps, with the physical characteristics of the roofing waste solids.

Quantity of Roofing Waste

Figures 12–15 show some of the effects of the quantity of roofing waste. Unfortunately, the selected binder (RA-75) was too soft to produce mixtures with desirable properties from the New Jersey roofing waste. With the exception of Hveem stability, a mixture of suitable properties was produced with the

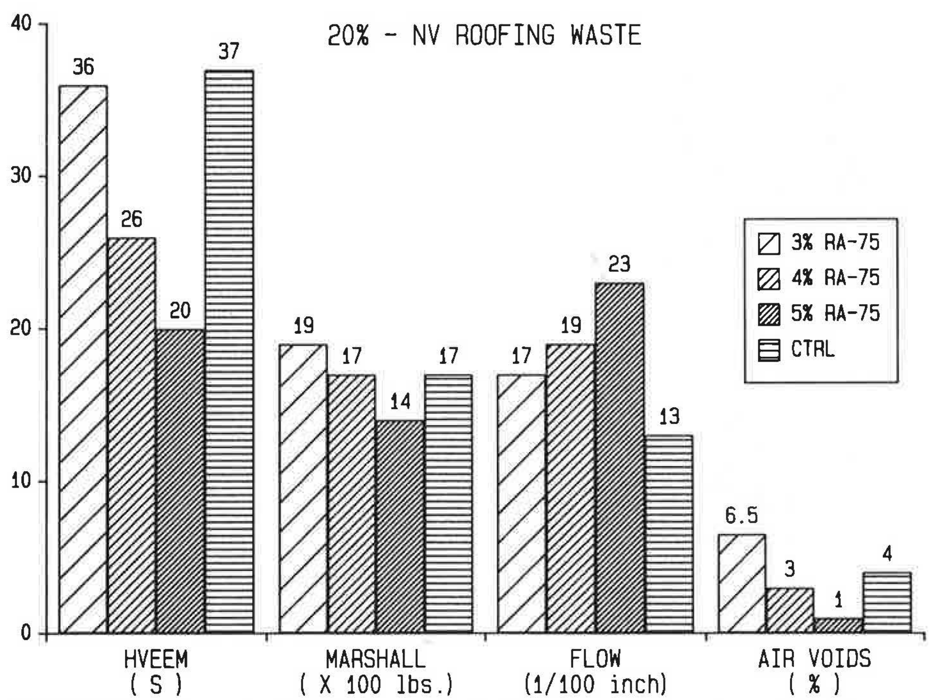


FIGURE 11 Effect of added binder content—Nevada roofing waste and RA-75—on stability and flow.

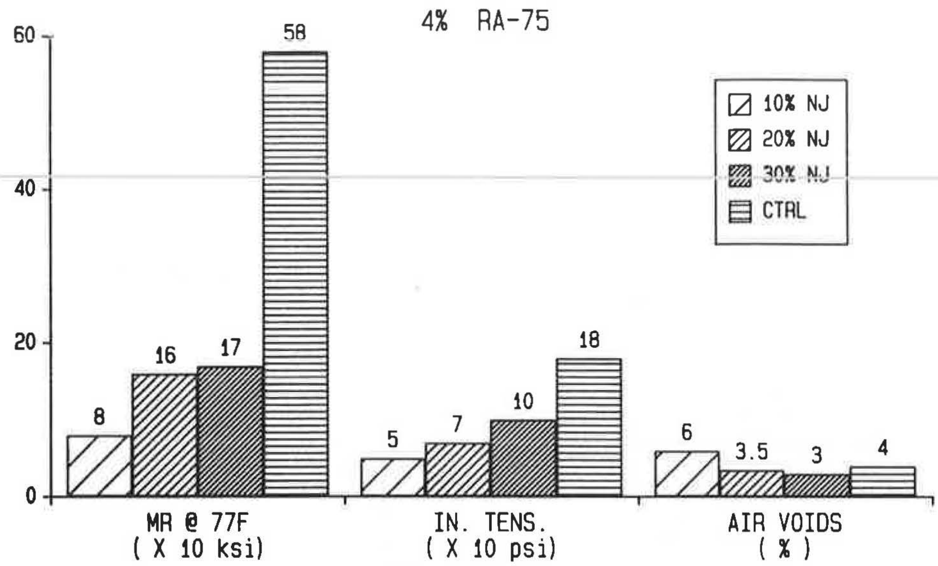


FIGURE 12 Effect of roofing waste quantity—New Jersey roofing waste and RA-75—on resilient modulus and tensile strength.

Nevada roofing waste up to the 20 percent level. Proper selection of the type and amount of binder should allow mixtures that contain 30 percent roofing waste to be produced.

Size of Roofing Waste

Test results reported by Paulsen et al. *(8)* indicate that the effect of the size of the roofing waste cannot be determined by the limited data collected in this study. In general, higher quantities of the finer sieve size materials are produced when hammer mill processing produces 1/4-in. material.

ECONOMIC CONSIDERATION

A limited economic study, which indicates that cost savings of 20 percent may be realized by using paving mixtures that contain roofing wastes, has been conducted. Adequate coverage of this study cannot be given here. Interested readers

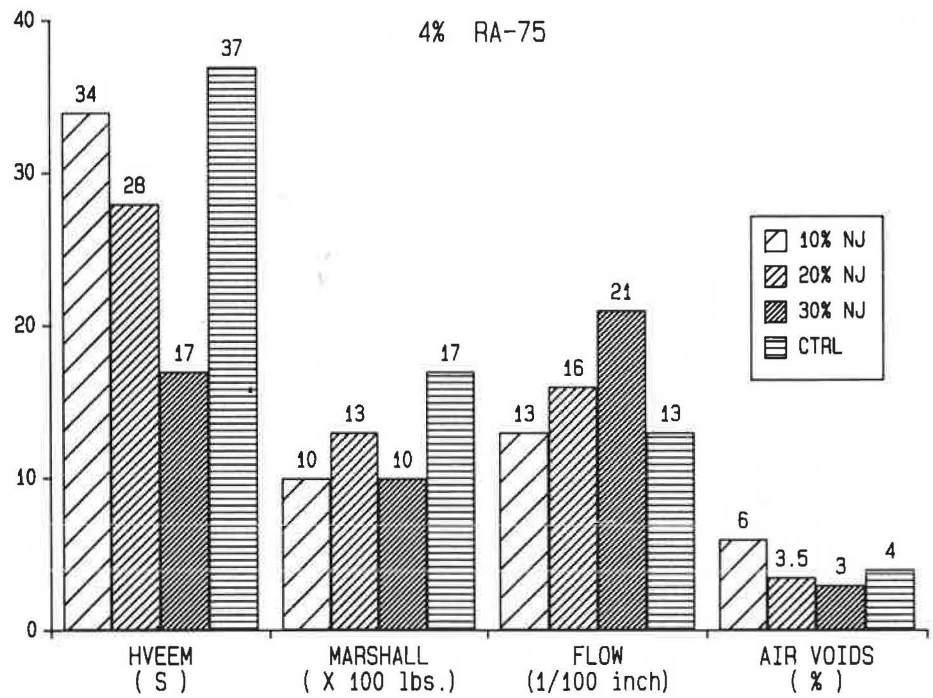


FIGURE 13 Effect of roofing waste quantity—New Jersey roofing waste and RA-75—on stability and flow.

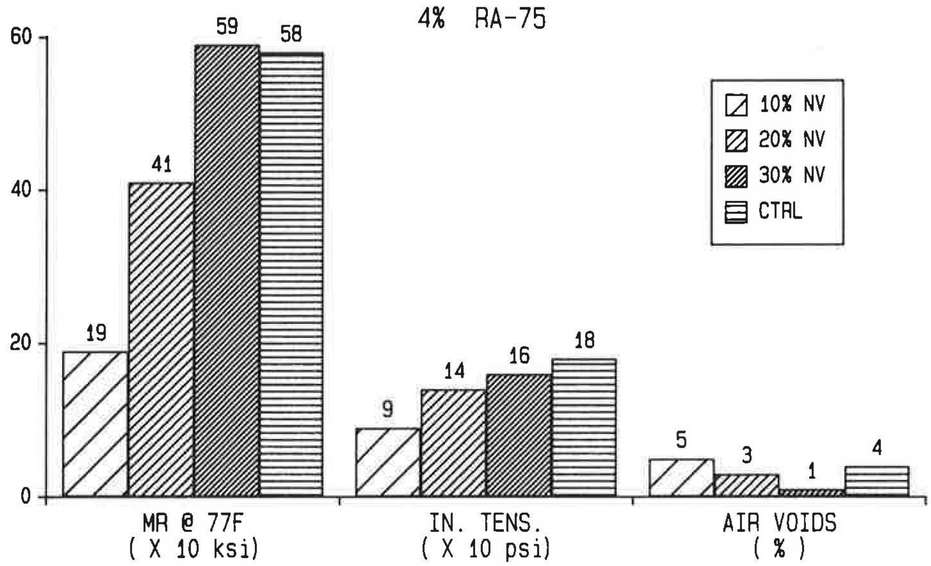


FIGURE 14 Effect of roofing waste quantity—Nevada roofing waste and RA-75—on resilient modulus and tensile strength.

are encouraged to contact the authors for a copy of the report on that study *(10)*.

CONCLUSIONS

Results from this study indicate that acceptable paving mixtures that include roofing waste can be made. However, because roofing asphalts are generally air-blown asphalts and are highly weathered, asphalt concrete mixtures that contain roofing waste may experience durability problems. Thus the application of these mixes may be limited to surface courses of lightly trafficked roads or to the lower layers of pavement sections. Long-term field performance needs to be established.

It was seen that different extraction and recovery methods can produce quite different asphalt contents and binder properties for the same roofing waste. This is an important factor to consider when designing asphalt concrete mixtures that contain roofing wastes. In addition, the relative digestion of the roofing waste asphalt by the recycling agent must be considered. Al-

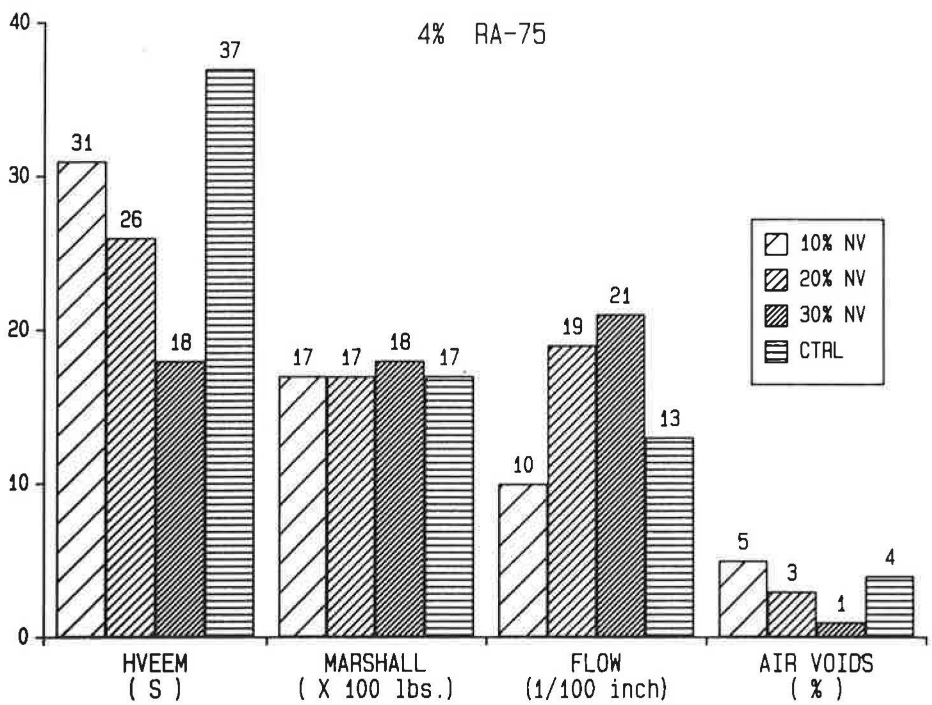


FIGURE 15 Effect of roofing waste quantity—Nevada roofing waste and RA-75—on stability and flow.

though difficult to quantify, the amount of roofing waste asphalt that becomes an "active" binder in the mix will also affect the properties of the asphalt concrete mixture.

Laboratory test results obtained in this preliminary study indicate that

1. Acceptable paving mixtures that contain 20 percent by volume roofing waste can be produced. With proper selection of binder type, binder quantities, and aggregate gradations, acceptable mixtures containing roofing waste quantities to, and perhaps beyond, the 30 percent level can probably be prepared.
2. The type of binder selected for use in a mixture containing roofing waste should be based on the stiffness (penetration and viscosity) of the asphalt cement in the roofing waste.
3. Improved asphalt cement extraction and recovery processes need to be developed for roofing wastes in order to effectively determine the properties of the asphalt cement in the roofing waste.
4. Gradations of conventional aggregates and roofing wastes should be considered when designing paving mixtures.

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