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Special Report 179

NAPA

NATIONAL ASPHALT PAVEMENT ASSOCIATION

Uses of Waste Asphalt Shingles in HMA

State-of-the-Practice

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SPECIAL REPORT 179

CONTENTS

ABSTRACT

This document is a State-of-the-Practice examination of how the Hot Mix Asphalt (HMA) Industry has developed procedures for using waste asphalt shingles in HMA. Chapters address sources of waste shingles, mix design considerations, equipment modifications, laboratory and field studies of the quality of HMA containing waste shingles, and operational, environmental, and economic considerations for the use of the material. The problem waste shingles create as the third largest source of construction material landfilled each year is also discussed.

KEY WORDS

Waste Asphalt Shingles
Recycling
Hot Mix Asphalt

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Uses of Waste Asphalt Shingles in HMA

State-of-the-Practice

CHAPTER 1

INTRODUCTION

With the many waste products created annually in the United States, waste asphalt roofing shingles may not seem to be a large problem. However, once the magnitude of waste asphalt shingles is put into perspective, the problem is significant. It has been reported that asphalt shingles represent the third largest source of construction waste landfilled each year. Only wood products and wallboard are higher [ARMA, 1992].

Approximately 90 million asphalt roofing shingle squares, weighing in excess of 10 million tons, are manufactured each year. Approximately two-thirds of the shingles are used for reroofing houses and one-third are used on new houses. For each house that is reroofed, it is estimated that an equivalent amount of old shingles is removed and must be discarded. Additionally, each of the nearly 80 factories in the U.S. producing asphalt roofing shingles generate shingle scrap materials and seconds that typically range from 5 to 10% of their production [Brock, no date; Waller and May, 1993].

Unless this material is recycled, it will likely end up in landfills with disposal costs that can range from $30/ton to $55/ton [Jesitus, November, 1992]. In fact, tipping fees of $100/ton or more are not unheard of in large urban areas. Exacerbating the problem is that asphalt shingles require many years to breakdown and are not ideal materials for landfills. Thus, considering the quantities and the consequences of landfilling, it can be seen that the magnitude of the problem is very significant.

Composition of Asphalt Shingles

One of the greatest advantages of using waste asphalt shingles in HMA is that the shingles contain ingredients that some Hot Mix Asphalt (HMA) producers purchase to enhance the mixture.

The manufacturing standard for asphalt roofing shingles is published in ASTM specifications covered by ASTM D225 "Asphalt Shingles (Organic Felt) Surfaced with Mineral Granules" and ASTM D3462 "Asphalt Shingles Made from Glass Felt and Surfaced with Mineral Granules." The ASTM specifications for roofing shingles allow for a wide range of products [Newcomb, et al, June, 1993].

A profile of a residential roofing shingle is shown in Figure 1. The shingle is composed of a series of ply or base sheets. Typically, a surface of mineral granules on the weather side covers a filled asphalt coating which covers an asphalt-impregnated fiberglass or felt-reinforced substrate over another filled asphalt coating which is, in turn, covered by a fine mineral surfacing to prevent one shingle from adhering to another prior to installation.

Waste asphalt shingles typically contain the following:

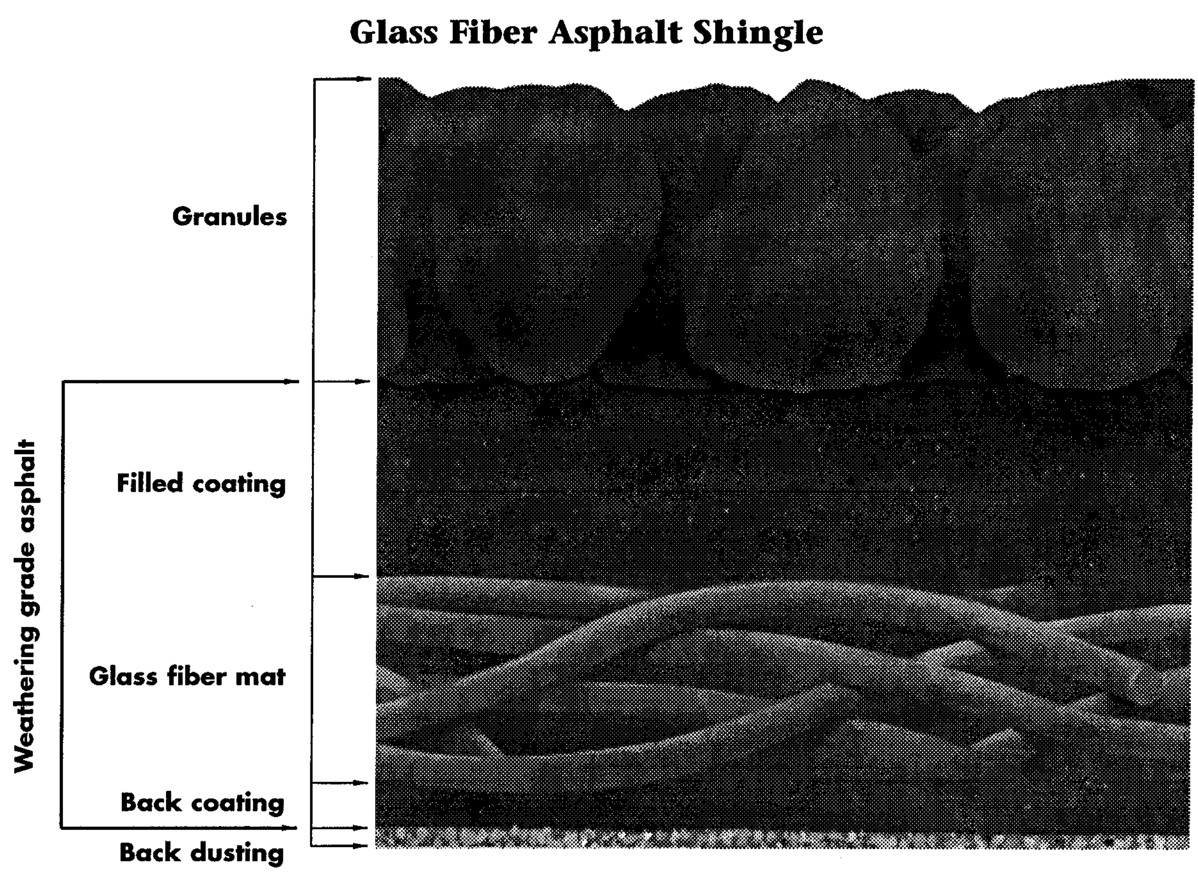
- 30% to 40% asphalt cement which is considerably harder (about 25 penetration) than paving asphalt;
- 40% to 60% hard rock granules (minus No. 10 sieve) and fillers (minus 0.15 mm); and
- 1% to 12% fiber (0.5- to 4.5-mm long fiberglass or cellulose), felt, and miscellaneous materials [Waller and May, 1993].

The Hot Mix Asphalt Industry has been very active in using Reclaimed Asphalt Pavement (RAP) [Decker, 1993]. The similarity in the generic makeup of both RAP and waste asphalt shingles is an indication that the Industry may find the use of waste asphalt shingles in HMA to be an economic advantage and an environmental benefit as well.

Objective

The objective of this State-of-the-Practice is to describe how the HMA Industry has developed procedures for using waste asphalt shingles in HMA, including modifications to laboratory mix design techniques, and to show the performance of HMA using waste asphalt shingles. Recycling this material in HMA may prove to be a better economic and environmental solution than putting it in landfills.

Figure1
Profile of a residential roofing shingle



Grzybowski, 1993 . Courtesy of Owens Corning

Scope

This State-of-the-Practice includes information available from a literature review of research and practice that has incorporated waste asphalt shingles in HMA. Information gained from on-site visits to HMA facilities using waste asphalt shingles is also included.

Background

The technical feasibility of using waste asphalt shingles in HMA has been recognized since at least 1987 [Paulsen, et al, 1987]. The Paulsen study concluded that "Acceptable paving mixtures that contain 20% by volume (see below) roofing waste can be produced." The Paulsen report raised questions concerning:

1. techniques for introducing processed roofing waste into the HMA mixing and paving process without creating adverse environmental effects,
2. the long-term performance characteristics of HMA containing roofing waste, and
3. the local economics of using this waste material in a paving mixture.

This State-of-the-Practice Report attempts to address these concerns and others in the following chapters.

> Note: percent by volume is approximately twice the percent by weight. All percentages of shingles are based on "by weight" unless otherwise noted.

CHAPTER 2

SOURCES OF WASTE ASPHALT SHINGLES

Reroofing Waste

As stated in the Introduction, approximately 65% of the 10 million tons of shingles produced annually go into reroofing houses. For each house that is reroofed, it is estimated that an equivalent amount of old shingles is removed and must be discarded [Brock]. These waste shingles are often termed "tear-offs." The total is estimated at more than 6 million tons of waste product, presenting a sizable disposal problem for the roofing contractor. Since the "tear-off" source of waste shingles is subject to the most contamination, a system to remove the nails, paper, etc., is necessary prior to incorporating the material in HMA [Brock].

Manufactured Waste

Between 5% to 10% of the 10 million tons of asphalt shingles manufactured annually, are factory scrap or seconds. The manufactured waste are often termed "tabs" or "chips." Using an average value of7.5% of the 10 million tons equates to over 750,000 tons of waste asphalt shingle "tabs" per year. This creates a sizable disposal problem for the manufacturer.

Landfills

It is estimated that 95% of all roofing waste is deposited in landfills. The Asphalt Roofing Manufacturers Association, in a 1992 presentation, estimated that the asphalt roofing waste quantity was 11 million cubic yards or a total of 9 million tons annually. (This estimate includes asphalt roofing waste in addition to asphalt shingles.) As previously noted, this quantity places asphalt shingles as the third largest source of construction waste landfilled per year.

In addition to the saved landfill space, using waste shingles in HMA also offers the opportunity to reclaim raw materials. As previously noted, the shingles are composed of asphalt cement, fine aggregate and fibers. Using an average asphalt content of 30%, the 9 million tons of waste shingles landfilled could save about 2-3/4 million tons of asphalt cement annually.

However, there are two schools of thought on the best source of waste shingles for use in Hot Mix Asphalt. Some HMA contractors that have produced HMA using waste shingles have chosen to use only manufacturing waste shingles because this source contains no foreign matter and because the history of the supply can be easily documented when necessary. Other HMA contractors use waste shingles from reroofing because this source offers a substantially greater supply and the potential problems (e.g., contaminates such as nails, paper, etc.) have not proven to be substantial.

For any HMA, the mix design must include all the ingredients that will be used in the mixture. This is particularly true for HMA using recycled materials such as asphalt shingles. The composition of the shingles and the percentage of shingles must be determined and calculated into the mix design.

CHAPTER 3

MIX DESIGN CONSIDERATIONS

Consistency of Asphalt Cement in Waste Shingles

The asphalt cement contained in the shingles can vary appreciably in its physical properties, depending on the age of the shingle. The penetration values of aged shingles have been reported to be about 15 units at 25°C (77°F) [Ali et al, 1995]. Grzybowski reported penetration values on shingle waste to be in the 15 to 60 units range with the propriety material, ReACT HMA™, having a penetration of about 37 units.* At a 5% ReACT additive rate, the consistency of the waste shingles is minimized but is still a concern to some state DOTs. This is one reason New Jersey has initially limited the use of waste shingles to factory waste.

Since each component has commercially equivalent material currently being marketed to the HMA Industry, recycled asphalt shingles seem to be a very appropriate additive for HMA [Waller and May, 1993]. For example, the fiberglass in the shingles is considered an additive that strengthens the HMA and may help prevent fatigue failures.

Percentages of Asphalt Shingles Used in HMA

Various research studies and practical experience have shown that between 5% and 10% of waste shingles can be used advantageously in HMA. Some considerations in the percentage to be used are:

- The amount of shingles available. It is preferable to have a consistent percentage of shingles in the HMA, at least within a given job. A consistent percentage of all ingredients helps keep HMA variability to an acceptable level.
- The type of HMA being produced. For example, a higher percentage of waste shingles may be used in a base mix as opposed to a surface mix, depending on the composition and quantity of the shingles.
- The uniformity of waste shingle supply. If a fairly consistent supply of a single type of shingle, e.g., felt-backed, is available, the percentage of waste shingle can be high and the uniformity of the completed HMA will be maintained. However, if the supply is made up of different types of shingles, e.g., felt-backed and fiberglass, it may be desirable to use a lower percentage of waste shingles so as not to compromise the uniformity of the completed mix.

Mix Design Procedures Using Asphalt Shingles

Modifications to a HMA mix design necessitated by using asphalt shingles are similar to those needed to include any other recycled product or additive. Some of the steps appropriate to incorporating shingles during mix design are discussed below.

Asphalt Shingles Reduced to Size

First, the shingles must be reduced in size or otherwise processed so they can be incorporated in the mix. A laboratory study at the University of Minnesota used two types of ground shingles which were added to HMA with the objective of serving as an asphalt extender and as a fiber reinforcement [Newcomb, et al, 1993]. The study investigated the addition of felt-backed and fiberglass-reinforced shingles. The asphalt shingles processed by a supplier were ground by two hammermills in tandem,

* ReACT is a commercially-available recycled asphalt roofing material. It can be used as an additive and directly incorporated in the HMA [Grzybowski, 1993]. This material is granular (minus #80 sieve) and can be provided in bags or bulk [Personal conversation, with Kenneth Grzybowski, December 26, 1995].

water cooled, and stockpiled. Water cooling after grinding was considered necessary to prevent the material from agglomerating. This required laboratory drying under a fan at ambient temperature over a 12-hour period to remove the moisture before additional testing and incorporating the material into the mix. The ground shingles had a size range of about 5 to 30 mm (1/4 to 1-1/4 in), but because some of the particles did agglomerate, determining an accurate particle size analysis wasn't possible. While an accurate particle analysis is desirable from a research standpoint, it probably is not necessary from a practical standpoint, especially when low percentages of waste shingles are used. If a particle size analysis is considered necessary, freezing the waste shingles may facilitate the process.

As a practical matter, experience with RAP has indicated that although the material is not broken down completely on crushing (or milling), when the RAP is added to the hot aggregate and mixed, the size of the agglomerated particles is reduced and uniformly distributed in the completed mixture. Information from a consultant in North Carolina who has performed HMA mix designs containing waste shingles indicates that shingles can be incorporated into the HMA mix in the same way RAP is added. [Personal conversation with Ben Ross, Consultant, December 22, 1995].

Determine the Specific Gravity of the Asphalt Shingles

The Minnesota study found that a specific gravity could be determined by modifying ASTM procedure C128, Standard Test Method for Specific Gravity and Absorption of Fine Aggregate. The modification involved applying a partial vacuum to the material in order to remove the entrapped air. Other studies have not revealed the need for any modifications to the test method in determining the specific gravity.

Determine the Asphalt Content of the Shingles

While extraction processes can be used to determine the asphalt content in the shingles, it appears that the asphalt ignition test method can also be used for this purpose. In very limited testing at the National Center for Asphalt Technology (NCAT) at Auburn University, there was no difficulty in determining the asphalt content of shingles using the ignition test. Future work is planned to examine the need for a calibration procedure using this technique [Personal conversation with E. Ray Brown, NCAT, December 22, 1995].

Adding Shingles to Mix

The Minnesota study maintained the ground waste shingles at ambient temperature until they were added to coated aggregate during the mixing process. This study found no problems in dispersing the waste shingles into the final mixture.

A recent study done in Canada found a successful way to add waste asphalt shingles to HMA was in the form of fine aggregate (Ali, et al, 1995). This study found the most successful method for shredding the waste shingles in the laboratory was to freeze the raw shingles to approximately -10°C (14°F), and then to shred the waste material with a 10-inch circular carbide-tipped blade on a saw. The study found that other methods produced heat which resulted in "gumming up" the shredded shingles and produced a poor quality waste additive. The shredded waste, also maintained at ambient temperature until added to the mixture, was mixed with aggregates which had been preheated to 150°C (300°F). The experience of contractors using waste shingles has not proven extraordinary methods of handling the waste shingles to be necessary.

With the waste shingles incorporated in the mix, the design process can follow the same general procedures used when designing a mix using RAP.

CHAPTER 4

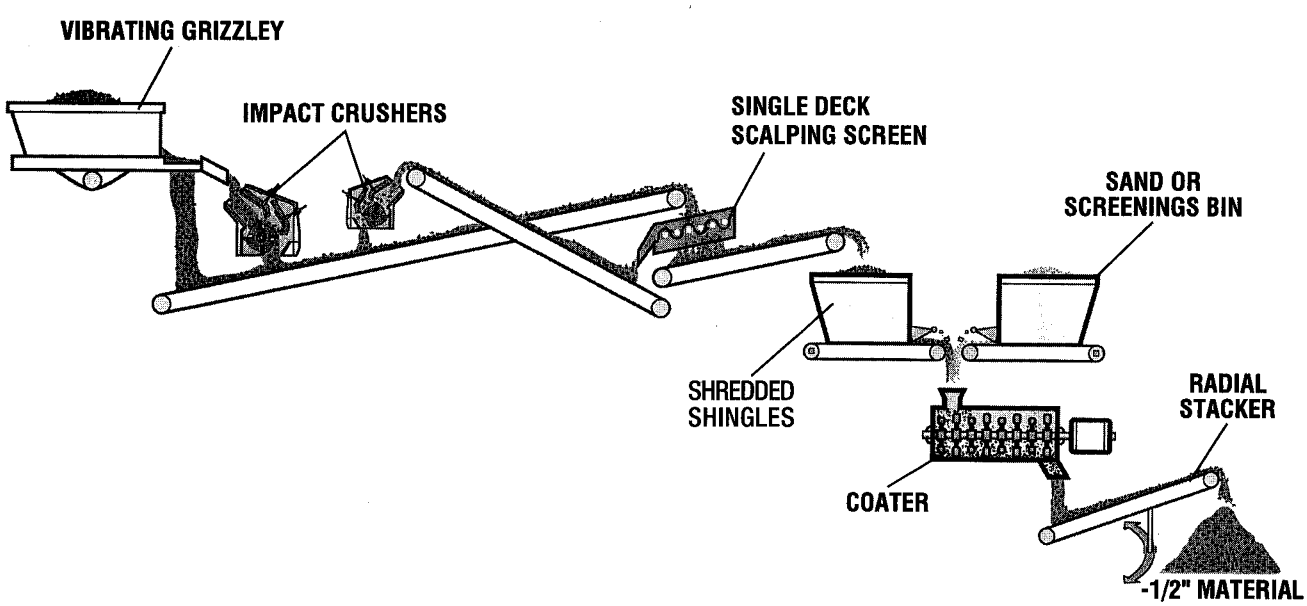
EQUIPMENT MODIFICATIONS AT HMA FACILITIES

Equipment to Handle Waste Asphalt Shingles

As previously noted, the waste shingles must be reduced in size prior to being introduced into the mix. A joint research effort by Astec Industries, Inc., and Georgia-Pacific's roofing division determined that optimum shredding reduces the shingles to at least 12.5 mm (1/2 in) or smaller particles prior to introduction into the mix. This practice ensures thorough heating of the shingles and uniform introduction into the HMA [Brock, no date].

This joint research effort has been underway for several years and significant equipment improvements have taken place over this period of time. The first process used a modified "woodhog" (a grinder used to process wood chips used in pulp digesters) to process the shingles. One of the major problems found with this equipment was in the handling and separation of the stacks of shingles. While the woodhog worked successfully, the maintenance of the machine was much higher than acceptable.

Figure 2a
The two-stage shingle shredding system



Courtesy Astec Industries, Inc.

A second system was developed using a slow speed shredder (similar to that used for shredding automobile tires) and a second stage hammer mill which reduced the shingles into a finer product. Again, this worked successfully in shredding the product, but the maintenance was excessively high.

In order to develop a more cost-effective system, a third generation shredding system was developed. A schematic diagram of the newest two-stage shingle shredding system is shown in Figure 2a. The system and the processed product are shown in Figure 2b and 2c.

The two-stage system consists of a primary feeder that delivers shingles into a large horizontal shaft impactor which is the primary crusher. The primary crusher shreds the shingles down to about 50 mm (2 in). As the shingles are conveyed up a belt conveyor, a belt magnet removes any nails from the materials. The product then passes under a suction device that removes paper and other lightweight contaminants, and catches dust and other airborne particles. The shredded 50 mm shingles are then fed onto an incline vibrating screen through which the 50 mm minus material can pass. The over-size material 50 mm (2 in plus) is fed back to the primary crusher and the 50 mm minus material is fed onto a belt conveyor that leads to a secondary horizontal shaft impactor. This machine is designed with breakers and operates at a high speed, leading to a reduction of the product to less than 12.5 mm (1/2 in). The material discharged from this secondary impactor drops onto the belt and back to the screening unit.

Figure 2b
Two-stage shingle shredding system

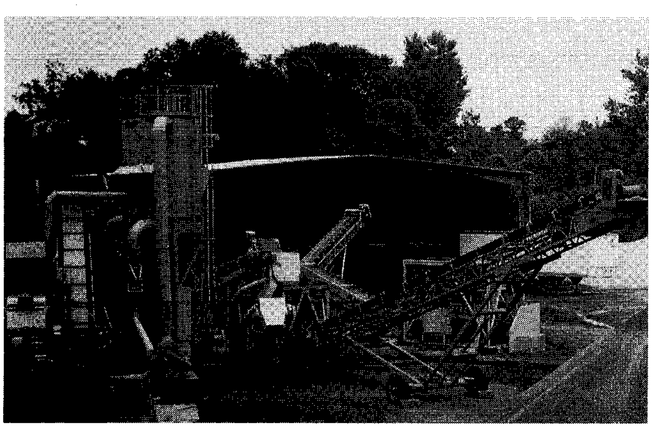
Figure 2c
The processed shingle with fine aggregate blend

Material discharged from the screening unit is then fed onto a conveyor leading to a surge hopper, which is automatically controlled by a blending system, where the shredded shingles are conveyed to a pugmill and mixed with sand or screenings, and then fed to a radial stacker for stockpiling. Approximately 20% sand or screenings is recommended to prevent new shingles from sticking together. Older shingles can often use less carrier material than new shingles [Brock].

This system, shown in Figure 3, is being used at a C.W. Matthews HMA facility in Atlanta, Georgia. It can handle several types of recycled materials including conventional RAP as well as waste shingles, and it provides a product that can be transported to a number of HMA facilities making the entire process more cost effective. Figure 4 shows the recycle bins for shingle/fine aggregate and for RAP. This set-up allows for various proportions of the two recycled ingredients to be used.

Figure 5 shows a stockpile of the shingle/fine aggregate blend which is under cover to reduce precipitation on the material. This is a precaution in anticipation that the fine-shredded shingles may hold moisture, take additional time and energy to dry, and slow production. Figure 6 shows pallets

Figure 3
Waste shingle and RAP handling system



Courtesy of Astec Industries, Inc.

Figure 4
Cold feed bins for waste shingles and RAP

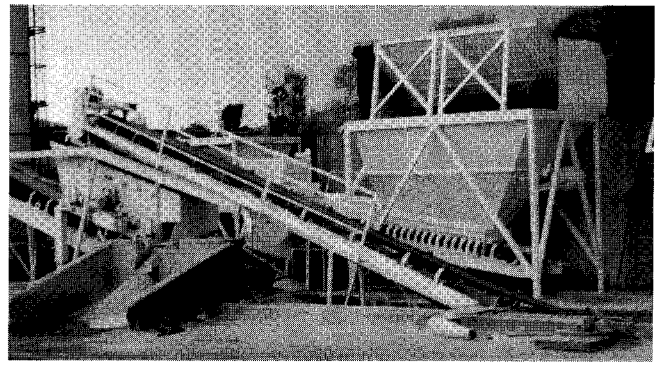


Figure 5
Covered stockpile of shingle/fine aggregate blend

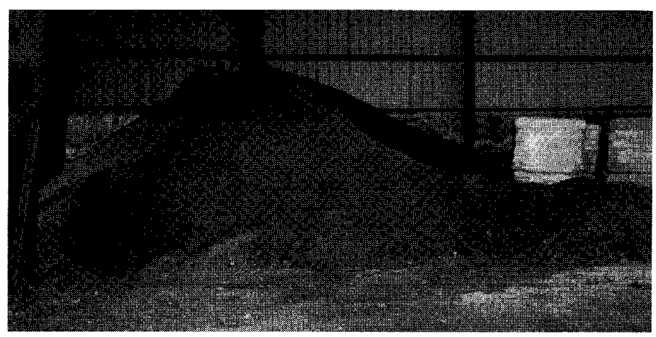
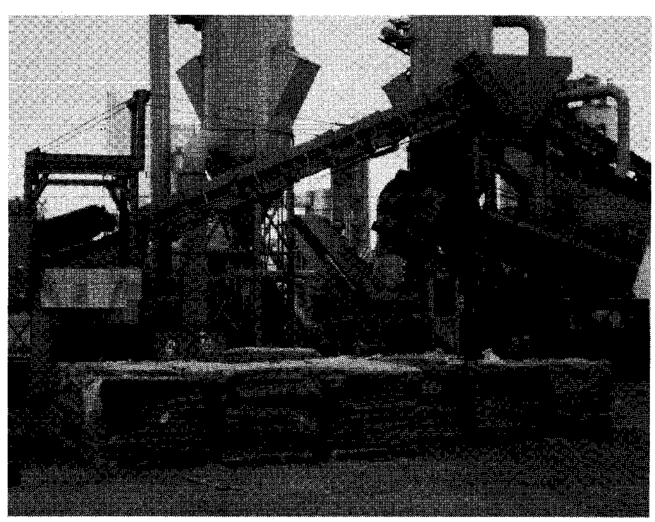


Figure 6
Pallets containing factory waste shingles



containing factory waste and Figure 7 shows reroofing waste shingles ready to be shredded.

Tarmac America in New Jersey uses a generic system for handling waste asphalt shingles and introducing them into HMA. They have a grinder/crusher that can handle many different types of waste materials including asphalt shingles and RAP (Figure 8). They use a grinder/crusher in conjunction with a bin feeder that contains a pulverizer and scalping screen (Figure 9). This equipment allows many different waste products to be uniformly added to the HMA. [Personal communication with Kenneth Zadora, Tarmac America, October, 23, 1995].

The use of waste products in HMA can be justified only if the quality of the HMA is maintained, and preferably enhanced. Even if there is an economic advantage to using a waste product, this advantage should not be gained at the expense of quality. Thus, the engineering properties of the HMA containing waste asphalt shingles are very important [Decker, November, 1993].

Figure 7
Reroofing waste shingle stockpile

Figure 8
Grinder/crusher for waste shingles and RAP

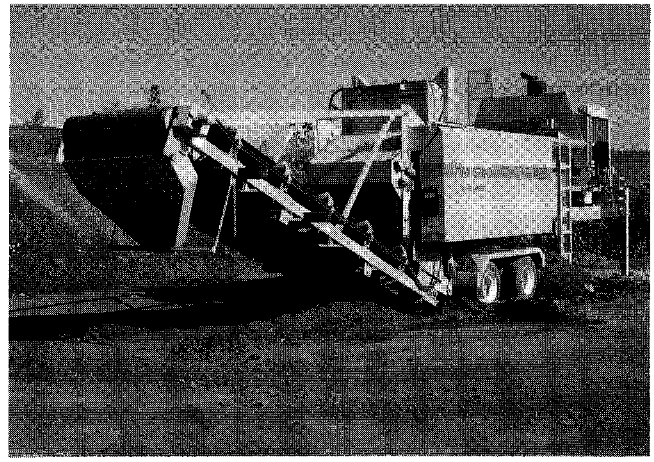
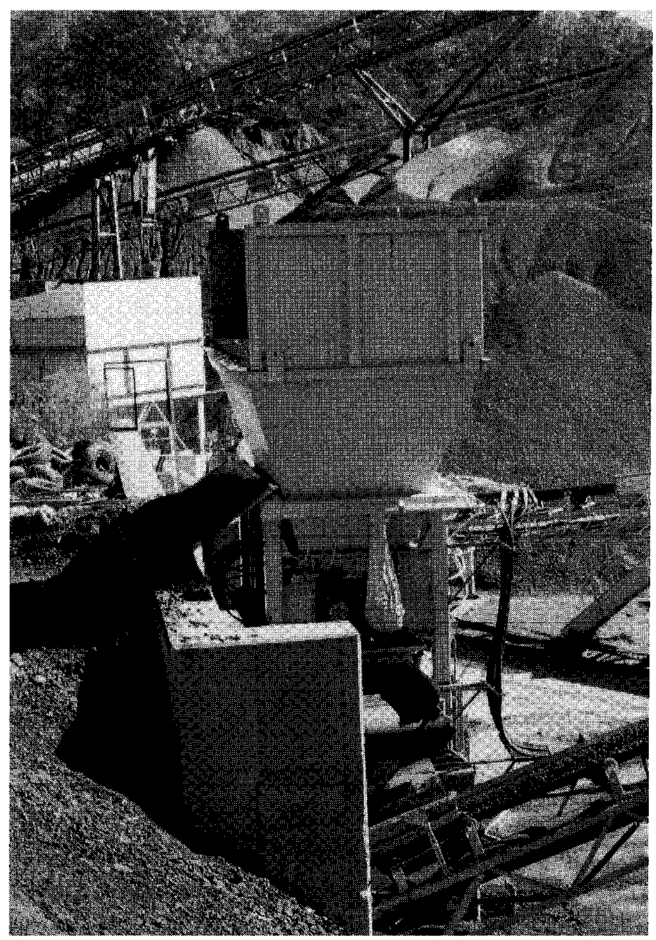


Figure 9
Screening bin with pulverizer



CHAPTER 5

QUALITY OF HMA PRODUCED USING WASTE ASPHALT SHINGLES

Laboratory Properties of HMA Using Waste Shingles

Several recent laboratory studies that have investigated the use of waste asphalt shingles in HMA are summarized below.

University of Nevada, Reno
(Paulsen et al, 1987)

This study used waste shingles from Nevada, Texas, Illinois, Georgia, and New Jersey. For the primary test program, the sources from Nevada and New Jersey were chosen to represent mixtures with a wide range of resilient modulus, tensile strength, stability, flow, and air void contents. Two maximum sizes of waste shingles were used, 25 mm (1 in) and 6 mm (1/4 in). The percentages of waste shingles used were 10, 20, and 30, by volume. An AR4000 asphalt cement was used and two recycling agents, RA-5 and RA-75, were added to help soften the harder asphalt in the shingles. The aggregate used in the study was a sub-rounded, partially crushed and washed gravel from Nevada. The aggregate had absorption values from 3% to 4%.

The specific gravity of the waste shingles ranged from 1.13 for the supply from New Jersey to 1.37 for the Nevada waste shingles. The asphalt contents from the shingles was about 37% for both sources. Different extraction methods produced different viscosities; however, the results indicated, as expected, a harder binder than typically used in HMA. The aggregate gradation of the extracted material ranged from the 4.75 mm (No.4) sieve down to the 0.075 mm (No.200) sieve, with from 9% to 23% passing the 0.075 mm (No.200).

The findings indicated:

- The quantity and type of virgin binder, to a large degree, control the properties of the mixture.
- Acceptable mixtures were prepared with virgin binder content in the range of 3% to 4% (compared to 5.9% in the control mixture) when the waste shingles are 20% by volume of mix.
- An acceptable mixture was prepared with recycling agent RA-75 and the Nevada waste. An AR4000 was required to produce an acceptable mixture with the New Jersey source because of its lower viscosity.
- The characteristics of new (virgin) binder have to be matched with the properties of the binder in the roofing waste.
- A mixture with suitable properties was produced with the Nevada waste shingles up to the 20% level (by volume). Proper selection of the type and amount of binder should allow mixtures that contain 30% (by volume) waste shingles to be produced.
- A limited economic study indicated that cost savings may be realized by using paving mixtures that contain 20% by volume of waste shingles.

University of Minnesota,
(Newcomb, et at, 1993)

This study used both felt-backed and fiberglass shingles as additives. Asphalt cements (virgin) with penetration grades of 85/100 and 120/150 were used. The gradation consisted of a blend of aggregates from two sources. The major portion (76% by weight) was a partially crushed pit river gravel, which was blended with a coarse granite aggregate. The specific gravities found in this study were 1.29 for the felt-backed material and 1.37 for the fiberglass shingles. Three levels of waste shingles were used: 0%, 5.0%, and 7.5% by weight of aggregate.

Conclusions included:

- Manufactured waste shingles were successfully incorporated into dense-graded HMA.
- The use of waste shingles in such mixtures lowered the resilient modulus at the low temperatures as well as at high temperatures. Overall, the mixtures containing waste shingles exhibited less temperature susceptability.
- Overall, the mixtures containing waste shingles exhibited less sensitivity to temperature changes.
- The tensile strength at 25°C (77°F) was maintained or increased with the addition of 5% felt shingles, and was decreased when this amount was increased to 7.5%. Fiberglass shingles tended to decrease tensile strength at either the 5% or 7.5% concentration level.
- At -18°C (0°F) the tensile strength of the waste-modified mixtures decreased as the percentage of waste increased.

ReClaim, Inc,
(Grzybowski, 1993)

This laboratory study was undertaken by a New Jersey company to evaluate the efficacy of a commercially-available waste asphalt shingle product, ReACT™. The properties of the ReACT additive are slightly different from those of waste shingles in the other studies. The asphalt content of ReACT ranged from 30% to 40% by weight, the fiber content was from 5% to 8%, the filler content was from 50% to 65%, and the specific gravity varied from 1.608 to 1.668.

The experimental designs used were selected to include mix designs used in Florida, New Jersey, and Pennsylvania. Asphalt cement grades were: Florida (AC-30), New Jersey (AC-20), Pennsylvania (AC-20), and an AC-10 for the in-house design (PRI Asphalt Technologies). The aggregate for the Florida mix was a limestone, for New Jersey it was a traprock, and for Pennsylvania it was a blend of limestone, gravel, and washed sand. Marshall designs with a 50-blow compactive effort were used. Five percent and 10% ReACT additive were used in the mixtures. The report states that to realize optimum performance properties at low levels of the additive (below 5%), pre-blending with neat asphalt cement is preferred.

The conclusions from this study are:

- A commercially-available additive was used successfully to replace a portion of the neat asphalt binder and aggregate resulting in mixes with equivalent and/or improved properties as measured by Marshall protocols.
- The use of the additive in conventional dense-graded mix designs has a wide application and yielded similar improvements for mixes using different aggregate types, aggregate gradations, asphalt binder grades, and overall designs.
- The incorporation of the additive benefitted the mix design in a synergistic manner, with all three prime components acting together to improve high temperature pavement deformation properties, such as rut resistance.
- The additive can be used in conventional equipment similar to processing RAP. The use of specialized equipment and/or processes is not required.
- Based on this laboratory study, HMA pavement designs requiring rut resistance for high-traffic or load-bearing areas can be readily achieved with the use of the additive.

Technical University of Nova Scotia,
(Ali, et al, 1995)

This laboratory study used waste residential shingles as opposed to commercial waste. Since the viscosity of the asphalt from the shingles was found to be much higher than that of typical paving grade asphalt, a 200/300 penetration grade asphalt cement was selected as the virgin asphalt for the mix. The aggregates were quarried materials from Nova Scotia. Preliminary work, in which waste shingles were added in increments of 5% from 0 percent to 50% by weight, found the optimum percentage to be in the range of 15% to 25%. The final investigation included three mixtures containing 0%, 15%, and 25% by weight, waste shingles. The mixtures were compacted using 75-blow Marshall compactive effort.

Conclusions from this study were:

- Acceptable asphalt mixes containing up to 25% waste shingles were produced at savings of approximately 3% asphalt cement as compared to conventional HMA mixes.
- Permanent deformation and rut depth prediction results strongly suggested that an increase in waste shingles (up to 25%) reduces the rutting potential in pavements.
- The use of waste shingles in asphalt mixes improved the fatigue lives of HMA pavements, especially at 25% waste shingle content.
- Preliminary analysis indicated the mix with 25% waste shingles product will outperform the mixes with lesser percentages of waste material.
- Recycling waste roofing material in HMA pavement is commercially feasible with existing technology. However, expensive start-up costs encountered in large scale production may limit its usefulness.

As a practical consideration, contractors have found a shingle additive rate of about 5% to be optimum, with some contractors considering incremental increases that may reach 10% or, conceivably, higher.

Performace of HMA Using Waste Shingles

HMA containing recycled asphalt shingles has been used on several projects. However, the performance data are sketchy.

MINNDOT Study

The Minnesota Department of Transportation (MINNDOT) placed a two mile experimental section in St. Paul on the Willard Munger Recreational Trail in 1990. Several test sections using rubber, shingles, and a combination of the two were used. One section used factory waste shingles at 9% (by weight of the aggregate). The mix design required 3.0% asphalt, and resulted in an air void content of 3.3% using a 50-blow Marshall compactive effort. The pavement was 12-ft wide, and 2.5-in thick. During paving, a few 50 to 75 mm (2 to 3 in) diameter clumps of shingles appeared. The report cautions that these should be eliminated prior to mix placement. (As a practical consideration, they should be removed prior to entering the plant cold feed). The shingle-only mixture exhibited an open texture due to the gradation used, but the early performance has been satisfactory.

Cores were used to provide information on the in-place mix and asphalt cement properties. An extraction test from pavement cores indicated an asphalt content of 5.4%. The recovered asphalt penetration was 34 units at 25°C (77°F), which was significantly lower than that of the control mix. Split tensile strengths ranged from 214 to 331 kPa (31 to 48 psi), appreciably lower than values from the control section. In-place air voids were 16.1%, an extremely high value. It is very likely that the asphalt cement in the shingles was appreciably stiffer than the virgin asphalt cement typically used. The addition of the shingles would create a much stiffer blended binder than would a mix containing no shingles. Evidently, this stiffer mix was not recognized during the compaction operations. This would explain the higher in-place air voids in the stiffer mix which, in turn, would provide the lower tensile strengths. No cost comparison was made since the shingles and shingle processing were provided to the state at no cost [Turgeon, 1991].

The MINNDOT has monitored the Munger Recreational Trail and other HMA sections using waste shingles and has found performance to be satisfactory [D. Janisch, MINNDOT, Personal communication, October 13, 1995].

The performance has been sufficiently successful for MINNDOT to add waste shingles to its list of allowable salvaged material for recycling. In the 1995 specifications, 5% scrap shingles are allowed in wearing, shoulder, non-wearing, base, and binder courses when approved by the engineer [MINNDOT Road and Bridge Specifications August, 1995]. The scrap shingles can be used by themselves or mixed with salvaged asphalt pavement as long as the scrap shingle component does not exceed 5%.

New Jersey Study

A 1-1/2 mile section of the north bound lane of Rt. 15 near Sparta, New Jersey, was paved in 1992 using 5% by weight factory-waste asphalt shingles (Figure 10). Tarmac, which produced the mix and did the paving, and New Jersey DOT have termed the product Granulated Bituminous Shingle Mix (GBSM). Approximately 50 mm (2 in) of the badly-deteriorated surface course (Figure 11) was milled and replaced with 50 mm (2 in) of conventional base and 50 mm (2 in) of surface which contained the waste asphalt shingles. After 3 years, the performance has been very good, at least comparable to a control section which did not contain waste shingles. Like MINNDOT, this project has been so successful that NJDOT is adding waste asphalt shingles to its list of materials that can be recycled in HMA. The specification will allow up to 5% waste shingles by weight, and initially, will require the shingles to be from factory waste. The NJDOT is considering broadening the specification to also allow reroofing waste.

The size of waste shingle used by Tarmac was larger than that reported in the laboratory studies. Pieces of shingle up to about 37.5 mm (1-1/2 in) were used with no problems in melting or mixing in the HMA facility (Figure 12) [Personal communication with Kenneth Zadora, Tarmac America, October 23, 1995].

Figure 10
New Jersey Rt. 15 with 5% GBSM after three years

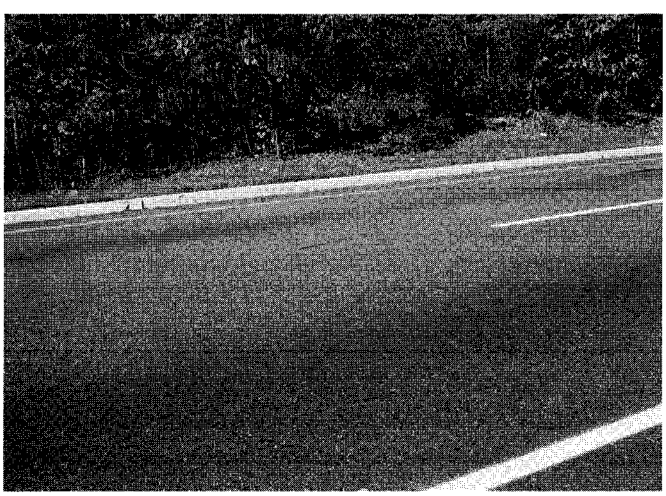
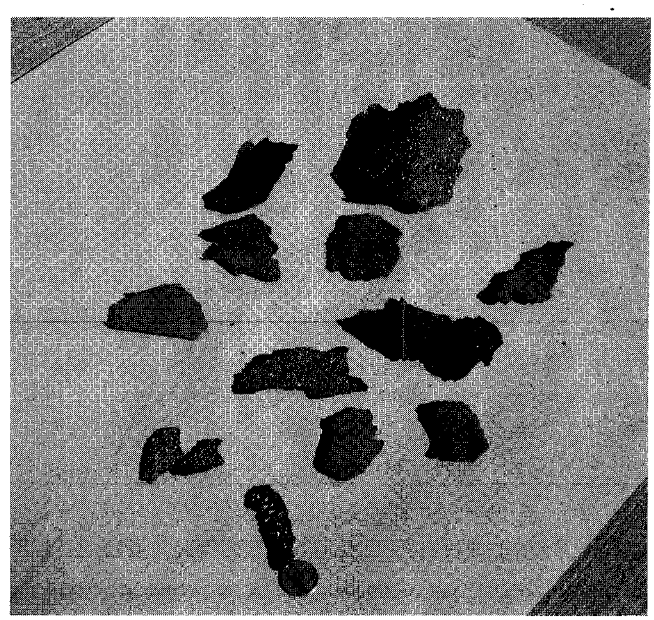


Figure 11
General condition of Rt. 15 prior to placing GBSM

Figure 12
Waste shingles used in GBSM



Courtesy Tarmac America and NJDOT

PENNDOT Study

In the summer of 1991, Pennsylvania Department of Transportation (PENNDOT) constructed test sections with and without waste shingles on State Route 2036, Lehigh County. Five percent of the waste asphalt shingles were used in the binder and in the wearing courses. An evaluation performed in August 1995, after 4 years of traffic, indicated that other than longitudinal, center-line joint cracking between the travel and passing lanes, the sections were performing equally well. The sections with shingles appeared to have the most longitudinal, center-line joint cracking. It is noted that although mix ingredients may affect joint cracking, construction activities, particularly paver operation and the lack of adequate joint compaction, are the biggest contributors to longitudinal joint cracking. Thus, it is possible that the longitudinal cracking in the mix containing shingles may be more related to the construction activities than the mix ingredients. As with the MINNDOT Study, a more aggressive compaction operation on the joint may have been warranted by the stiffer mix containing the waste shingles. Neither of the wearing courses (control without shingles, and test with shingles) showed any measurable rutting or permanent deformation [Ramirez, 1995].

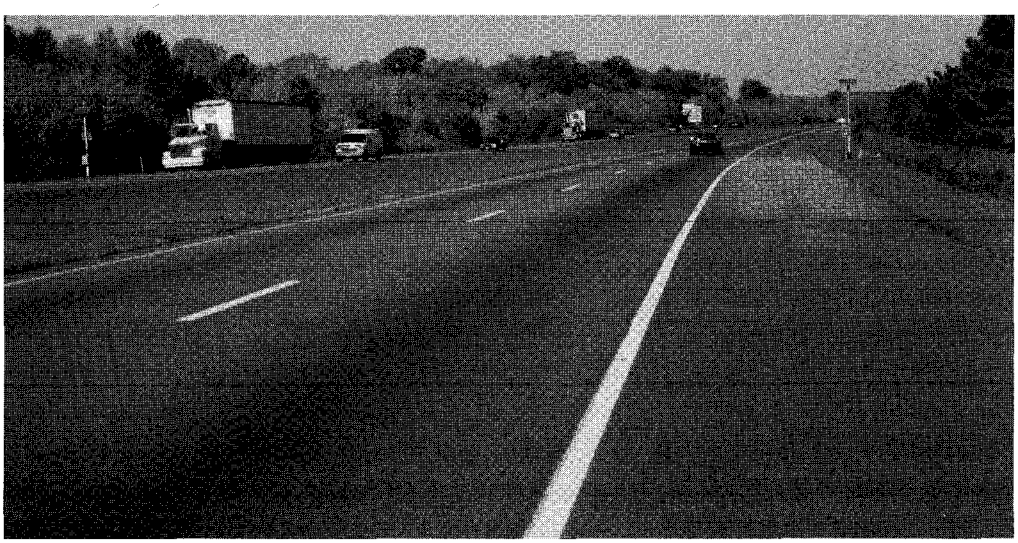
Other Projects Using Waste Asphalt Shingles

Recycled roofing materials were used successfully in the parking lots at Disney World in Florida. Testing showed that 4 to 10% added shingles can improve mix performance. Particles were shredded to a maximum of 12.5 mm (1/2 in) prior to adding to the mix to ensure meltdown and uniform dispersion. By adding 5% to the mix, the cost of the mix was reduced by about $2.30 per ton [Waller and May, 1993].

One project in the Northeast U.S. using factory-waste shingles has been down for five years under heavy traffic and is performing very well (Figure 13). This project has approximately 5% waste asphalt shingles in 50 mm (2 in) of binder and 50 mm (2 in) of surface.

North Carolina DOT has allowed waste shingles to be used in mixes on some occasions. The contractor must request that shingles be allowed, and the request is considered on a case-by-case basis. An additive rate of 5% has been typical [Personal conversation with Ben Ross, Consultant, December 22, 1995].

Figure 13
Five-year-old project with heavy traffic; mix contains 5% waste asphalt shingles



CHAPTER 6

OPERATIONAL AND ENVIRONMENTAL CONSIDERATIONS

Removing Nails and Other Contaminates from Waste Shingles

As mentioned previously, some HMA contractors who use waste shingles in their mix prefer to use factory-waste shingles because they have no metal or other contaminates that have to be removed.

However, C.W. Matthews, Inc. of Atlanta, Georgia, has decided that the supply of waste reroofing shingles is too valuable an asset not to use as a source of recycled material. In order to use this source, the shingles have to be prepared to remove any metal in the waste stream. The shingle handling system used has a magnet that removes nails and other metal. A photograph of the magnet with the bin for catching the metal is shown in Figure 14. This device has reportedly worked very well [Personal communication with Ken Woods, C.W. Matthews, Inc., October, 27, 1995].

The ratio of waste shingles from reroofing compared to factory waste is about 8 to 1. If the supply is limited to only factory waste, the amount of shingles that can be recycled is severely restricted. Such arbitrary restrictions could prevent contractors from taking full advantage of the waste asphalt shingle unless they are located near a shingle manufacturing plant. In the case where a HMA facility is located near a shingle manufacturing plant, the waste stream from that plant might produce all the waste product that a HMA plant would want to handle. Based on the number of shingle manufacturing plants and the estimate of 750,000 tons of scrap shingles produced annually, each plant averages about 10,000 tons of scrap shingles per year. At an additive rate of 5% waste shingles, 200,000 tons of plant mix could be produced with shingles from each factory's waste each year.

Recyclability and Air Emissions of HMA Containing Waste Shingles

There is sometimes a concern as to whether HMA containing some recycled materials can, in turn, be recycled, and whether the air emissions from a HMA facility will be increased. Since the generic composition of waste asphalt shingles is essentially the same as that of RAP and the HMA, the recyclability and air emissions of HMA containing waste asphalt shingles is not an appreciable concern.

Figure 14
Magnetic belt used to remove metal from waste reroofing shingles

Courtesy J. Don Brock

CHAPTER 7

ECONOMIC CONSIDERATION

The economic savings on the cost of HMA could be substantial when just 5% waste shingles are added to the HMA. Based on $120/ton for liquid asphalt, $7/ton for aggregate, $25/ton tipping fee (a very conservative figure), and $10-12/ton processing cost (equipment cost), a savings could be realized of about $2.15/ton to $2.80/ton depending on the type of waste shingles used [Brock, no date]. Based on the cost of $30/ton for HMA, a savings of $2.50/ton would be over 8%.

In a conversation with Tarmac America, the savings is thought to be in the neighborhood of $1.00/ton [Personal communication with Kenneth Zadora, Tarmac America, October 23, 1995].

Any savings calulation must consider the capital cost of equipment along with the acquisition, processing, and handling expenses as noted in the table below.

	Calculating the Costs of Using Waste Shingles	
A	Savings from Asphalt Cement: New AC $/ton ( ) x AC % in Waste Shingles ( ) x % of Waste Shingle in Mix ( )	Per ton: $
B	Savings from Fine Aggregate: New Fine Agg. $/ton ( ) x % Fine Agg. in Waste Shingles ( ) x % of Waste Shingle in Mix ( )	$
C	Savings from Tipping Fee: Tipping Fee $/ton ( ) x % Waste Shingle in Mix ( )	$
D	**Total Gross Savings per ton of Hot Mix (Add A + B + C)**	**$**
E	Less Acquisition Cost of Waste Shingles (includes Trucking Cost): Acquisition Cost $/ton ( ) x % of Waste Shingle in Hot Mix ( )	$
F	Less Additional Processing/Crushing: Process/Crushing Cost $/ton ( ) x % of Waste Shingle in Hot Mix ( )	$
G	Less any Additional Miscellaneous Cost (capital costs for equipment, etc.): Miscellaneous Cost $/ton ( ) x % of Waste Shingle in Hot Mix ( )	$
H	**Net Savings per ton of Hot Mix Asphalt (D less E, F & G)**	**$**

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. Based on laboratory and field tests, it is apparent that waste asphalt shingles can be added to HMA in an effective and economical manner.
2. The addition of waste asphalt shingles to HMA should be successful because of the compatibility of the products.
3. The mix design process using waste shingles can follow the general procedures developed for a mix design when using RAP in a mix.
4. The percentage of waste asphalt shingles that can be added depends on such local conditions as availability of waste shingles, the form of the shingles, and the equipment available to process and add the waste asphalt shingles at the HMA facility. It has been documented that the addition of 5% waste shingles to HMA is easily accomplished. Although laboratory tests indicate that technically the percentage could be increased to 10% or higher, to date, contractors have not done so.
5. From the limited performance data available, it appears compaction operations using waste shingles in HMA should be viewed critically to assure that the air void level of the compacted pavement is acceptable and that the resultant mixes perform well in both high and low temperature environments.
6. The use of waste shingles has progressed to the point that some state DOTs have added shingles to the list of products that can be added to HMA by specification.
7. Cost savings using 5 percent waste asphalt shingles have been estimated to be between $1.00/ton and $2.80/ton.

Recommendations

1. Information on performance of HMA using waste asphalt shingles should be documented to a greater extent than now exists in the literature.
2. If and when percentages of waste shingles exceeding 5 percent are used on paving projects, the facility operations and field performance should be documented.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

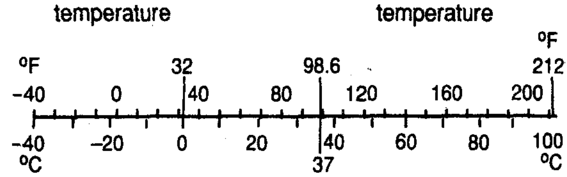
Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
inches	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
AREA				
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
VOLUME				
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
AREA				
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
VOLUME				
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
TEMPERATURE (exact)				
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement.

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