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16. Abstract

Existing information on the use of roofing waste in hot mix asphalt (HMA) was obtained from reviews of published and unpublished literature and interviews of cognizant individuals. Ground waste roofing is available from at least 3 locations in Texas. Laboratory testing was performed on HMA containing roofing manufacturing waste (new roofing) and consumer (tear off) roofing waste. Two types of HMA were modified with ground roofing and tested in the laboratory: dense-graded and coarse matrix-high binder (CMHB) surface mixtures. Roofing waste was added to HMA at 5% and 10% and the engineering properties of the resulting HMAs mixtures were compared to untreated mixtures. Laboratory tests consisted of Hveem stability, indirect tension, resilient modulus at several temperatures, moisture susceptibility, TxDOT static creep, air void content, and voids in the mineral aggregate.

The findings indicate that roofing waste is a viable waste stream that has utility in HMA. It should be possible to incorporate 5% or less roofing waste into typical HMA paving mixtures and have a product that will meet the standard quality control specifications. Because of the relatively higher VMA and asphalt film thickness, a CMHB mixture may be more capable of accommodating roofing waste than a dense graded mixture. Standard procedures for mixture design and quality control appear satisfactory for HMA containing roofing waste. Materials specifications and construction guidelines for using roofing waste in HMA paving mixtures were developed.

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ROOFING SHINGLES AND TONER IN ASPHALT PAVEMENTS

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IMPLEMENTATION STATEMENT

All known information regarding the use of waste roofing in hot mix asphalt was obtained from reviews of the literature and from interviews with knowledgeable individuals with paving and roofing agencies around the U.S. Limited laboratory work was performed to measure the effects of the addition of various quantities of waste roofing on strength, stability, creep characteristics, water susceptibility, air void content, and voids in the mineral aggregate (VMA) of asphalt paving mixtures. Two types of shredded roofing materials were included in the study: manufacturing waste and consumer waste. Manufacturing waste shingles are defined as new material that is obtained from a roofing shingle production plant. Consumer waste shingles are those obtained during the removal of existing roofs (tear offs).

A considerable amount of information is available on recycling of waste roofing in hot mix asphalt pavements. Several agencies have conducted small laboratory and field studies. Research results generally appear positive.

Manufacturing waste is the most promising source for rapid implementation of these study findings. Manufacturing waste is a very uniform, predictable product. Consumer waste, on the contrary, is inherently quite variable in quality and may be contaminated with various other building materials. However, consumer waste has been successfully used in HMA as much or more than manufacturing waste. Equipment is readily available for shredding and handling waste roofing. To enhance implementation of this research, materials specifications and construction guidelines have been prepared and are contained in Appendices B and C.

Standard TxDOT hot mix asphalt design procedures and materials quality control protocols appear satisfactory for designing HMA mixtures containing roofing waste and maintaining an acceptable finished product.

Roofing waste can be incorporated into asphalt mixtures much in the same way as reclaimed asphalt pavement (RAP). Sometimes properties of the modified mixture are degraded, but there is evidence that roofing waste can also improve mixture properties in some cases.

Generally, the incorporation of 5% to 10% roofing waste into the dense-graded and CMHB mixtures studied herein was detrimental to the engineering properties of the mixtures. Based on the data obtained, it appears that quantities of roofing just under 5% would be satisfactory in these mixtures. Other state DOTs and researchers have reported improved resistance to plastic deformation upon the addition of waste roofing to HMA.

CMHB mixtures with their relatively higher VMA and thicker asphalt films can probably accommodate roofing wastes better than a dense-graded mixture. In fact, the stiffer asphalt and fibers in shredded shingles may retard asphalt draindown in hot uncompacted CMHB mixtures.

Field trials using roofing waste or roofing waste with RAP in HMA pavements are encouraged. It is not likely that shredded shingles can be economically hauled for very long distances. Since the largest roofing manufacturers in Texas are in the Dallas/Ft. Worth area, these and possibly surrounding districts will need to be involved in implementation of the findings of this study.

Other researchers have demonstrated that waste toner retrieved from copiers can be successfully incorporated into asphalt cement and asphalt concrete. Specifications and guidelines for using toner in HMA are not available. Large-scale techniques for collection, handling, and stockpiling of toner have not been developed. Therefore, large-scale implementation of this process in not recommended until more experience is gained through experimental applications.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Texas Department of Transportation (TxDOT) or the Federal Highway Administration (FHWA). This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes.

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SUMMARY

Researchers examined published and unpublished information on the use of waste roofing in hot mix asphalt (HMA) and interviewed personnel associated with various state highway agencies, paving contractors, materials suppliers, scrap shingle shredders, equipment manufacturers, and roofing manufacturers. They found that several small laboratory efforts and several field tests using waste shingles in HMA have been conducted. Shredded waste roofing is available from at least 3 locations in Texas.

Laboratory experiments were conducted on asphalt concrete mixtures containing two types of waste roofing. Roofing manufacturing waste (new roofing) and consumer waste (tear off shingles) were included in the study. Two types of HMA were modified with shredded roofing and tested in the laboratory. These included a dense-graded, Type D mixture and a coarse matrix-high binder (CMHB) Type C mixture. The roofing waste materials were added to the HMAs at 5% and 10% and the engineering properties of the resulting HMAs mixtures were compared to untreated mixtures. AC-20 was used in all mixtures except one in which AC-10 was used. Laboratory tests measured the effects of the roofing wastes on Hveem stability, indirect tension, resilient modulus at several temperatures, moisture susceptibility, TxDOT static creep, air void content, and voids in the mineral aggregate.

The findings indicate that roofing waste is a viable waste stream that has utility in HMA. It should be possible to incorporate up to 5% roofing waste into typical HMA surface mixtures and up to 10% roofing waste in base mixtures and produce materials that will meet the standard quality control specifications.

Standard HMA mixture design and quality control procedures are suitable for designing and evaluating mixtures containing waste roofing. Mixing and compaction temperatures of HMA may need to be increased in the laboratory and in the field to accommodate the relatively stiffer roofing-modified mixtures. For mixture design and construction purposes, waste roofing can be handled using the techniques established for RAP. Because of the relatively higher VMA and asphalt film thickness, a CMHB mixture may be more capable of accommodating roofing waste than a dense graded mixture. Standard procedures for mixture design and quality control appear satisfactory for HMA containing roofing waste. Materials specifications and construction guidelines for using roofing waste in HMA paving mixtures were developed and are presented in the appendices.

INTRODUCTION

"You can't argue against motherhood, apple pie, and recycling," said one asphalt industry engineer. It is not only politically correct but also smart to be on the side of the environment. There is increasing emphasis by governments as well as taxpayers to recycle waste materials in roadway construction and maintenance projects. Without question, this is the direction our society must move. Utilization of our waste materials and by-products is logical, sensible, and many times, cost effective. Two consumer products which create millions of kilograms of waste each year are roofing shingles and spent toner from copiers, printers, and fax machines. A prudent action for the asphalt industry would be to utilize to the fullest extent the vast quantity of waste roofing that the U.S. generates each year.

Two sources of waste roofing are manufacturing waste and consumer waste. Manufacturing waste emanates from trimmings and "out-of-spec" shingles from the roofing manufacturing process. Consumer waste is defined herein as old shingles torn off roofs when replacement is necessary. The most logical place to utilize significant portions of these waste streams is clearly in hot asphalt paving mixtures and cold patching mixtures.

Each year, roofing manufacturers in the U.S. produce approximately 9.1×10^8 kg of new waste roofing shingles and shingle trimmings (1). In addition, residential and commercial roofing replacement activities generate 7.3×10^9 to 9.1×10^9 kg of old roofing waste (2, 3, 4). Historically, about 95% of this 22 million cubic yards of valuable, non-biodegradable solid waste has been placed in landfills (5). These by-products and waste materials are composed of hard, crushed aggregate, high viscosity asphalt, and fibers, products that may be desirable in certain asphalt paving applications.

More than 4.5×10^{11} kg of asphalt mixtures are produced annually in the U.S., about 90% of which is hot mix asphalt (HMA) (6). Therefore, an average of only about 2% roofing waste in all asphalt mixtures placed would be required to use all manufacturing and consumer waste roofing. Of course, it is not possible to use roofing in all mixes, and all roofing waste is probably not suitable for such use. In Texas, about 1.8×10^{10} kg of HMA is placed annually by TxDOT, counties, and municipalities, which provides a significant opportunity for use of roofing and toner wastes.

The primary goal of this rather limited study is to provide TxDOT with information needed to specify materials, to design, to produce, to place, and to evaluate paving mixtures containing roofing waste. Review of published and unpublished information (1 - 26) has determined that considerable information is available. Evaluations of paving mixtures with and without roofing wastes in controlled laboratory experiments were conducted. Specific objectives of this study were to:

- Review published information;
- Interview cognizant individuals representing state DOTs, roofing manufacturers, shingle recyclers, and paving contractors;
- Develop materials specifications for paving mixtures containing roofing waste;
- Develop or identify suitable mixture design and mixture analysis procedures for paving mixtures containing roofing waste;
- Develop construction guidelines for applying asphalt mixtures containing roofing waste; and
- Measure engineering properties of asphalt mixtures containing roofing waste in a limited laboratory experiment.

A secondary goal of this study is to examine the feasibility of using spent copier toner in asphalt paving mixtures. This element of work consisted only of a review of available information.

Review of published and unpublished information and a limited laboratory study were used to prepare specifications and construction guidelines for using waste roofing in HMA. The scope of the study includes measuring the effects of both manufacturing (new) and consumer (old) roofing waste on both dense-graded HMA and coarse matrix-high binder (CMHB) mixtures. Potential uses of waste roofing in cold-applied asphalt patching mixtures were studied at Texas A&M Kingsville as a part of this project and have been reported separately to be published as *Research Report 1344-1*.

STATE OF THE ART

The findings summarized below were derived from reviews of published and unpublished literature and phone conversations or personal interviews with individuals who have particular knowledge pertinent to this study.

Roofing Waste

Factory waste consists of shingle tab cutouts (trimmings from the manufacturing process) and finished shingles or shingle sheets that do not meet specified aesthetic requirements. New shingles today typically contain about 20% to 30% asphalt. The asphalts are usually air blown such that the viscosity is significantly higher than that of paving grade asphalts. They also contain about 10% to 20% "extender" (mineral filler). The asphalts may contain proprietary antistripping agents and antioxidants. Shingles have a fabric (usually fiberglass or cellulose) backing to provide strength and integrity. This backing is typically 5% to 15% by weight of the shingle. From a given manufacturing plant, factory waste is a highly uniform material ready for use by enterprising paving engineers.

Field waste shingles may contain more than 30% asphalt; this is because new shingle compositions require less asphalt and some of the aggregate has been lost due to weathering during service. The asphalt may be so age hardened that the mastic will not flow at typical asphalt plant operating temperatures. Addition of filler also stiffens the asphalt. Field waste may contain shingles and built-up or "hot mop" asphalt roofing along with nails, wood, paper, polyester films, asbestos felt and other debris and, therefore, may be quite variable in quality and composition. It is estimated that only about 1 in 200 roofs have asbestos in the shingles, and the Federal EPA does not classify as hazardous asphalt roofing containing less than 1% asbestos.

Old roofing waste has a higher asphalt content than new roofing waste. The main reason is that many of the cover stones are eroded away during service on a roof. In addition, the manufacturing processes have been altered over the years to reduce the proportion of asphalt, one of the more expensive components.

Recovering and reprocessing of roofing waste began in the early 1980s in response to federal legislation and regulations (5). Roofing recycling processes studied have included:

- Separation of solids from liquids and recovery of No. 6 fuel oil,
- Incineration and use as an energy source,
- Reuse of factory waste in new roofing, and
- Incorporation into asphalt paving mixtures.

The last three processes have shown significant promise for implementation.

The concept of replacing natural round, smooth aggregate particles (certain sands) with the comparatively rough-textured manufactured roofing aggregate suggests improved resistance to plastic deformation in asphalt mixtures. The incorporation of fibrous materials into asphalt paving mixtures should help provide a tenacious and cohesive paving mixture resistant to rutting and cracking (27). The hard asphalts in roofing which may contribute to thermal or fatigue cracking can be offset by using softer virgin asphalts or adding rejuvenating agents to the roofing waste. Problems in maintaining a workable stockpile of shredded roofing waste throughout the year are expected; however, blending the shredded roofing with crusher screenings, sand, or reclaimed asphalt pavement (RAP) may counter this problem.

Processing Roofing Waste

Roofing waste must be shredded in order to use it successfully in asphalt mixtures. The degree of shredding depends on the type of roofing waste and the end use of the reclaimed product. Most engineers agree that the finer the roofing is shredded, the better it is for incorporation into asphalt mixes. Because the aged binder is hard and sometimes even embrittled, field waste is normally easier to shred than factory waste. Heat generated during grinding softens the asphalt and thus interferes with the process. Commercial equipment is available to shred roofing waste into chips (7) that are 12 mm (maximum dimension) and less; however, some shredders will only shred the material down to a maximum size of 38 mm. Contractors are currently set up to grind roofing waste in several states, including Texas. After start up, the cost of shredding the material is about 0.88¢ to 1.1¢ per kilogram (2).

Because of the high asphalt content, stockpiles of roofing waste will consolidate and form clumps that impede handling and preclude effective incorporation into an asphalt mixture. This material must be "delumped" for practical applications. Equipment designed to feed an asphalt plant with delumped shingles is commercially available for about $35,000. Ideally, the roofing waste should be shredded and used within a short time (at most, a few days) after shredding.

To alleviate stockpile conglomeration it may be possible to incorporate fine aggregate with the shredded roofing. Ideally, a preplanned, controlled quantity of crusher fines would be added. This blend would need to be included during mixture design work to determine the optimum quantity to meet grading specifications and produce a quality mix.

Roofing waste has been successfully ground, screened, stockpiled, and recycled in hot and cold applied asphalt paving mixtures. Eagle Recycling in Houston, Texas, grinds consumer waste roofing and screens it over a 4.75 mm and 1 mm sieve. This produces three grades of ground roofing material: coarse (25 mm to +4.75 mm), intermediate (-4.75 mm to +1 mm), and fine (-1 mm). The capability of producing roofing chips passing a 4.75 mm sieve is very encouraging. The appearance of these finely ground materials eliminated much of the concern about uniformly blending consumer roofing waste into virgin asphalt mixes. It appears that the intermediate and finer materials could easily be blended into asphalt paving mixtures much like reclaimed asphalt pavement (RAP).

Gant Recycling, Inc. has recently set up roofing grinding operations near Wichita Falls, Texas. Holland Companies of Flower Mound, Texas, is currently setting up to grind roofing in the Dallas area.

The researchers contacted four organizations who have developed equipment for size reduction of waste roofing shingles: Eagle Recycling, Houston, Texas; Reclaim Inc., Tampa, Florida; City-Wide Recycling, Atlanta, Georgia; and Omann Brothers, Hanover, Minnesota.

Most waste roofing processors grind consumer waste. Although some have ground manufacturing waste, they find it more difficult to grind because the "new" asphalt becomes sticky when it heats up due to friction produced in the grinding process. As a result, it was more difficult in this study to obtain ground manufacturing waste.

Hot Mix Asphalt

Laboratory and/or field tests have been conducted on asphalt paving mixtures containing waste roofing in Florida, Georgia, Minnesota, Nevada, Massachusetts, Missouri, New Jersey, New York, Pennsylvania, Maryland, Indiana, Tennessee, and Ontario (1 through 21). Draft specifications for hot mixed asphalt containing waste roofing were obtained from Florida DOT and Minnesota DOT. Mixture information was obtained from Florida DOT, Minnesota DOT, and Georgia DOT.

Most highway agencies agree that acceptable paving mixtures containing up to 10% by weight roofing waste can be produced and that a softer than usual binder should be used to offset the hard binder in the roofing shingles. Most report that virgin asphalt content can be reduced slightly when shingles are added, but the roofing asphalt is so comparatively hard (and/or required to coat the fibers and solids in the shingles) that it does not contribute greatly to the asphalt required to coat the virgin stone. This is particularly true for consumer roofing waste. Gradation of the aggregates in the roofing waste should be considered during mixture design. Aggregates in the virgin mix should be reduced by the amount of the aggregates of the same sizes added in the recycled roofing material. Most DOTs feel comfortable using factory (new) waste because of its uniform quality, but they do not feel so comfortable using consumer waste because of its inherent variability and proportion of deleterious materials.

One contractor in Florida has been producing ground factory waste and using it in HMA for about eight years. Most of his product is applied to county roads and city streets; this practice is not uncommon in other states. Florida DOT is in the process of updating its draft specifications to permit the use of recycled roofing material in asphalt mixtures on state roads. Florida DOT allows up to 10% of 25 mm (maximum) waste shingles by mass of HMA. They permit the use of shingles, provided that the combined products do not exceed 20% of the total weight of aggregate. Because of the harder asphalt in the shingles, Florida DOT requires the use of AC-20 in place of the usual AC-30 when shingles are used. Florida DOT found increased Marshall stability, tensile strength, and resistance to rutting (from wheel tracking test) when factory waste was included in asphalt concrete.

Early work in Nevada and Minnesota (12, 13, 14) noted decreased indirect tensile strength (25°C) but increased strain to failure of asphalt mixtures when shredded shingles with chips up to 25 mm in diameter were included. They also reported decreased Hveem and Marshall stability and resilient modulus along with increased Marshall flow when 10 to 30% consumer waste shingles with recycling agent was included in mixtures. Minnesota DOT's draft specification allows only 5% of 19 mm (maximum chip dimension) shingles by mass of mix. They also permit combining shingles and RAP provided the blend does not exceed 50% of the mixture for base courses and 30% for wearing courses.

Test sections containing 3% to 5% shingles in Pennsylvania, Minnesota, Florida, and Ontario are only a few years old. No comparative field performance for HMA with shingles is available, but a positive sign is that no short-term performance problems have been reported.

Tennessee DOT conducted a brief study on the effects of recycled consumer roofing waste in hot mix asphalt. They deleted 5% sand and 5% screenings from a dense-graded mixture in common use and replaced it with 10% recycled roofing. Since the roofing contained 28% asphalt, the virgin asphalt content was reduced slightly. Because the asphalt in the roofing was quite hard, the asphalt plant mixing temperature was raised by 6°C. Laboratory data suggested the mix was "very satisfactory."

In August 1994, Georgia DOT placed a test pavement near Savannah along with an untreated control section to evaluate performance of a factory waste modified asphalt mixture. They used a supplemental agreement with the contractor to allow the test rather than prepare a specification for waste shingles. Five percent shredded shingles were added through the center drum inlet (RAP belt). DOT representatives interviewed stated that the operation was successful.

Finoll Recycling Ltd. of Brampton, Ontario, Canada, has developed a patented process whereby the asphalt mastic and fiber are separated from the stone component of consumer waste roofing shingles. The separated asphalt mastic/fiber flakes, called recycled roofing shingle material (RRSM), is designed to be utilized in hot mix asphalt paving mixtures. The aggregate may also be used in asphalt paving mixtures. Only about 2% of the incoming roofing waste (nails and other metals) ends up in a landfill site. A research program is underway to design paving mixtures containing RRSM. They typically use an asphalt one grade softer than that in a conventional mixture. RRSM is used at a rate of about 2% by weight of total mixture, depending on the viscosity of the virgin asphalt and the specific application. The project, which is partially funded by the Industrial Research Assistance Program (IRAP) of the National Research Council of Canada, will use Superpave Level 1 mixture design methodology to formulate 9.5-mm top size mixtures containing RRSM. These mixtures will be subjected to dynamic creep and resilient modulus measurement using the materials testing apparatus (MATTA) according to Australian testing protocols. A pavement construction project containing RRSM is planned in the city of Brampton in the spring of 1996. This project is under the direction of W. K. MacInnis & Associates of Markham, Ontario.

No comparative field performance for HMA with shingles is available, but a positive sign is that no catastrophes have been reported. Some believe that, because of the fibers and angular aggregate content of shingles, they may be an ideal admixture for stone mastic asphalt (SMA) mixtures and, thereby, reduce the expense of neat fibers or polymer additives. Coarse matrix-high binder (CMHB) mixtures are becoming widely used across Texas. CMHB mixtures have relatively high VMA and gradations similar to SMA mixtures along with thick asphalt films. These types of mixtures should provide the best use of ground roofing shingles. They have "more room" to accommodate shredded roofing. Furthermore, the fibers and/or filler may reduce asphalt drain down when the mixture is hot and not compacted.

Cold-Applied Asphalt Mixtures

A few organizations are shredding roofing shingles to make cold patching materials or paving materials (for bike paths and park trails) containing up to 100% shingles (4, 5, 11). Typically, they grind consumer waste to less than 9.5 mm and blend it with aggregate to produce patching mixes. Formulations for these high roofing content mixtures almost always include asphalt rejuvenators to activate the aged asphalt in the roofing waste. They can furnish unique specifications to potential buyers of their products. These products are used mostly by city and county paving authorities. Controlled, unbiased laboratory and field evaluations of these patching materials may be obtained from customers. Heating during mixing and/or addition of solvents such as diesel, kerosene, or asphalt rejuvenating (or recycling) agents may be required to activate the air-blown and possibly aged asphalt in the roofing.

A wide variety of asphalt-aggregate mixtures are used as cold-applied maintenance materials. They range from dense graded to open graded. These products appear to provide an excellent opportunity to recycle waste shingles. Because of the uniform, fine sizes of ground roofing that are available, it should be possible to produce high quality maintenance mixtures using these materials.

It is not probable that a high percentage of the roofing waste generated in Texas can be used in cold-applied paving materials because of its relatively low volume when compared to hot mix asphalt. Nevertheless, the hard asphalt, fibers, and angular fine aggregate in ground roofing waste appear to have potential for not only use in cold-applied asphalt maintenance mixtures but also in actually improving their quality.

Factors Affecting Recycling of Roofing

Those states that have had the earliest success with recycling shingles are those that have stringent regulations with regard to landfills. They have legislated high tipping fees and even disallowed opening of new landfills. About 50% of all states have now adopted legislation aimed at recycling selected components of the solid waste stream (15). If Texas should mandate no landfilling of waste roofing, it may be possible to stockpile roofing waste and then later "mine" the material as processes are developed for its use and/or as the price of asphalt or fuels increase. A large stockpile of scrap roofing should produce less undesirable runoff than those same shingles on many rooftops.

The most promising source for rapid implementation of shingle recycling is factory waste. It is not likely that shredded shingles can be hauled economically for very long distances. Since the largest roofing manufacturers in Texas are in the Dallas/Ft. Worth area, these and possibly surrounding districts will need to be involved in implementation of the findings of this study.

Recycling and reuse of natural resources is acceptable to the general public and demonstrates responsible administration by public agencies. However, economics, more than any other factor, have been the impetus for recovery and recycling wastes, including scrap shingles. Use of roofing waste in HMA can lower the virgin asphalt requirements and increase the total HMA tonnage at lower cost. It has some potential to improve the performance and thus extend the life of HMA pavements at no additional cost; a lower life-cycle cost would certainly provide additional incentive for their use (15). However, small percentages of roofing waste (less than 5%) will probably not change the properties of most HMA mixtures substantially.

In order to utilize roofing waste to the fullest extent in highway pavements, field waste will need to be included. Even though field waste is not uniform in quality, it may be possible to incorporate very small percentages in HMA without significant adverse effects. Testing must be performed in each case to answer this question. Specifications need to be prepared that will allow contractors and, in turn, the taxpaying public to "profit" from using this cheap material. In certain areas of the state where maximum quantities of natural, rounded sands are routinely used for economic reasons, small percentages of roofing waste used to replace part of the sand might significantly improve the properties of certain mixtures.

Before widespread use is made of roofing waste in asphalt paving mixtures, several technical items must be addressed. These items include (13, 17):

- 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;
- The maximum quantity of roofing waste that can be introduced into a paving mixture without adversely altering the engineering properties of the mixture;
- The quantity and grade of asphalt cement and/or rejuvenating oils (if any) needed to soften the relatively hard roofing asphalt to an appropriate paving grade asphalt cement;

- Techniques for introducing the shredded roofing waste into the asphalt concrete mixing and paving process without creating adverse environmental effects;
- Establishing the long-term performance characteristics of asphalt concrete containing roofing waste by an extensive laboratory and field testing program; and
- Determining the local economics of using this waste material in a paving mixture.

Only a few of these were confronted in the limited study described herein.

Copier Toner

Toner is essentially the dry "ink" used in copiers, printers, and fax machines. In certain types of machines, excess or spent toner is collected in cartridges that must be emptied before remanufacturing. Spent toner may contain paper fibers and dust. According to cartridge remanufacturing firms, the spent toner is currently disposed of along with other trash, which is eventually deposited in landfills. The most commonly used Xerox, Minolta, Konica, Cannon, and Mita copiers use toners composed primarily of styrene acrylate copolymer, carbon black, polypropylene, and pigment. Some toners contain traces of amorphous silica and ferrites (iron oxides or salts). These are fairly benign materials, and, although they are considered to be nuisance dust, they are treated as low hazards for usual occupational settings (22, 23, and 24).

Based on available data, human exposure to toner has been shown to cause minimal respiratory tract irritation as may occur with large amounts of any non-toxic dust. The results of one animal study where rats inhaled toner that was ten times more respirable than commercially available toner were observed to have no lung changes at low exposures. At higher levels, a slight degree of lung fibrosis was observed due to excessive amounts of dust retained in the lungs for a prolonged interval (23).

The melting temperature of these types of toners is typically between 100°C and 130°C (23, 24). Toner becomes sticky when melted. These are positive signs with regard to use in hot mixed asphalt pavements. Carbon black and certain polymers have shown benefits when used in hot mixed asphalt concrete (25). Therefore, asphalt pavements may be a suitable disposal site for spent toner.

Although interest has been expressed in recycling of toner (24), only one study (26) regarding reusing toner in asphalt paving mixtures has been conducted. Ayers and Tripathi (26) demonstrated that waste toner retrieved from Xerox duplicators can be successfully incorporated into asphalt cement and asphalt concrete. When they blended 2% to 10% toner by weight with asphalt cement, the temperature susceptibility of the resulting asphalt binders was reduced. When blended with asphalt paving mixtures, they found increasing toner content successively increased Hveem stability. They examined several mediums for dispersing toner into asphalt cement or asphalt mixtures: dry toner or suspensions of toner in motor oil, mineral oil, and water with anionic or cationic emulsifying agents. The addition of dry toner appeared to be the most successful from a field operations standpoint. The researchers successfully constructed an asphalt concrete test strip and are monitoring performance. They concluded that Xerox toner can be a beneficial additive to asphalt paving mixtures.

These successes are very encouraging. Although toner may be a suitable additive for asphalt paving mixtures, some type of large-scale collection process as well as packaging and/or shipping procedures will need to be devised before sufficient quantities of toner can be made available to the paving industry. Trucks and materials handling paraphernalia similar to those used in hauling and handling hydrated lime or Portland cement may suffice for handling toner.

Due to the limited time and funds, no testing of reclaimed copier toner or asphalt mixtures containing copier toner was planned or conducted as a part of the study reported herein.

DESCRIPTION OF EXPERIMENTAL PROGRAM

Hot mix asphalt concrete specimens were prepared and tested in the laboratory in a limited program to aid in determining how waste roofing shingles can best be used in asphalt pavements. Two asphalt paving mixtures commonly used by TxDOT were selected for the study: a dense-graded mixture and a coarse matrix-high binder (CMHB) mixture. The concept was to determine which type of mixture may be most suitable for incorporation of waste shingles. It was believed that the CMHB mixture with the relatively higher voids in the mineral aggregate (VMA) and asphalt film thickness might be more capable of accepting this "foreign material" with the least effects on engineering properties.

Two types of shredded roofing, manufacturing waste (MW) and consumer waste, were employed. Only one size of manufacturing waste was available. Two sizes, coarse (CC) and fine (CF), of the consumer waste shingles were used. Two grades of asphalt cement were used to prepare asphalt concrete specimens. These materials were used in a partial factorial experiment. Test procedures routinely used by TxDOT to design and evaluate asphalt mixtures were used in this study to evaluate the roofing mixtures and the utility of the test procedures.

Experimental Design

A laboratory experimental design (Table 1) was developed to guide the hot mix asphalt testing program. The experiment was designed to determine the effect of roofing waste on dense-graded and CMHB mixtures.

Materials Selection and Acquisition

Dense-Graded Mixture. A dense-graded TxDOT Item 340, Type D (9.5 mm nominal maximum size) mixture design was obtained from the Bryan District. It was composed of limestone aggregates and field sand (Table 2). Aggregate for the mixture was sampled at Young Brothers Contractors in Bryan, Texas. Sieve analyses were performed on the stockpile samples to ensure conformity with specifications listed in the mixture design. Optimum asphalt content for the mixture was 6.2% by mass of total mixture.

Table 1. Experimental Design for Testing Hot Mix Asphalt Concrete Containing Roofing Waste.[1]

Test Method	City Wide Unsized Manufacturing Waste						Consumer Waste												
	CMHB + AC-20			Dense +AC-20			CMHB + AC-20						Dense + AC-20						CMHB +AC-10
							Eagle Coarse			Eagle Fine			Eagle Coarse			Eagle Fine			Eagle Fine
	L[2]	M	H	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H	H
IDT @ 25°C	X	X	X	X	X	X	X	X		X	X	X	X			X	X	X	X
Tex-321-F	X	X	X	X	X	X	X	X		X	X	X	X			X	X	X	X
M_R @ 0°C	X	X	X	X	X	X	X	X		X	X	X	X			X	X	X	X
M_R @ 25°C	X	X	X	X	X	X	X	X		X	X	X	X			X	X	X	X
M_R @ 40°C	X	X	X	X	X	X	X	X		X	X	X	X			X	X	X	X
Air Voids	X	X	X	X	X	X	X	X		X	X	X	X			X	X	X	X
VMA	X	X	X	X	X	X	X	X		X	X	X	X			X	X	X	X
Tex-531-C	X		X	X		X	X			X		X	X			X		X	X
Hveem Stability	X	X	X	X	X	X	X	X		X	X	X	X			X	X	X	X

[1] An "X" in the chart indicates that three replicate tests will be performed.

[2] L, M, and H indicate low, medium, and high roofing waste contents, respectively. Low = 0% by wt., medium = 5%, and high = 10% roofing waste.

Table 2. Gradations of Aggregates Used in the Dense-Graded Mixture Design.

Sieve Size	Limestone D/F Blend, % passing	Washed Limestone Screenings, % passing	Field Sand, % passing
12.5 mm	100	100	100
9.5 mm	99.9	100	98.5
4.75 mm	49.5	99.7	97.6
2.00 mm	4.0	80.2	95.7
425 μm	2.0	25.3	91.1
180 μm	1.7	8.4	8.2
75 μm	0.7	1.7	2.7
Job Mix Formula	63.3%	22.2%	14.5%

CMHB Mixture. A Type C (16 mm nominal maximum size) CMHB mixture design was obtained from the Materials & Tests Division of TxDOT. Limestone aggregates were obtained from Colorado Materials Company in San Marcos, Texas. Table 3 describes the aggregates comprising the CMHB mixture. Sieve analyses were performed to ensure conformation to specifications. The optimum asphalt content was 5.2% by weight of total mix.

Waste Roofing Products. Seven different ground roofing shingle products were obtained from three of these organizations for potential use in the laboratory testing program. The products and sources and a brief description of the materials are as follows.

Table 3. Gradations of Aggregates Used in the CMHB Mixture Design.

Sieve Size	C-Rock % Passing	D-Rock % Passing	F-Rock % Passing	Screenings % Passing
19 mm	100	100	100	100
12.5 mm	81.1	100	100	100
9.5 mm	3.6	62.9	100	100
4.75 mm	1.6	2.7	70.4	99.9
2.00 mm	1.5	2.1	8.1	92.2
425 μm	1.3	1.8	1.4	50.2
180 μm	1.2	1.6	1.0	33.4
75 μm	0.9	1.3	0.4	15.4
Job Mix Formula	35%	17%	30%	18%

1. City-Wide: Unsized, approximately - 6.3 mm max. dimension consumer waste;
2. City-Wide: Unsized, approximately -12.5 mm max. dimension consumer waste;
3. City-Wide: Unsized, approx. 9.5 mm to -180 μm manufacturing waste;
4. Eagle Fine: Approx. -4.75 mm to +180 μm consumer waste;
5. Eagle Coarse: Approx. -12.5 mm to +4.75 mm consumer waste;
6. Reclaim: Reacts HMA, -425 μm to +180 μm consumer waste (designed for HMA); and
7. Reclaim: Reacts CP, -4.75 mm to +425 μm consumer waste (designed for use as cold patching material).

Most of the materials were generally similar in appearance and texture with the following exceptions:

- The City-Wide manufacturing waste was notably stiffer and stickier than any of the consumer tear-off waste specimens. This material tended to clump together when stored at room temperature in a small quantity (less than 9.1 kg), signifying potential stockpiling difficulties during stockpile storage,
- The finer graded consumer waste products had a dry appearance much like black sand; it did not clump together when stored for long periods at room temperature, and
- The coarse Eagle Recycling consumer waste contained mostly flakes (since the finer sizes were removed) and contained some particles of nail and wood scrap.

Two shredded shingle products were selected for use in the HMA study. The manufacturing waste was obtained from City-Wide Recycling of Atlanta, Georgia. The City-Wide material was selected because it was the only available source of new ground roofing waste; only one size grade of this material was available. The supplier indicated this product originated from an Owens-Corning fiberglass reinforced shingle plant and contained about 18% asphalt and 55% stone, the remainder being fiberglass and filler.

Consumer waste was obtained from Eagle Recycling of Houston, Texas. Two grades were used in the study: coarse and fine. The coarse material is not normally considered suitable for use in HMA. It was selected to determine if it could be incorporated into HMA and what effects it would have on the engineering properties of the mixture. Eagle consumer waste was selected for this study merely because the company is located in Texas.

Asphalt Concrete Sample Preparation

Dry aggregate, blended to the appropriate grading, was heated in an oven to the specified temperature. A predetermined quantity of shredded shingles was thoroughly mixed with the hot aggregate and the mixture was replaced in the oven for a short period. Sequentially, hot asphalt binder was added, and the mixture was thoroughly blended. The blended material was replaced in an oven and held at 121°C for 2 hours. Control (untreated) specimens were prepared in accordance with standard TxDOT procedures.

All mixture specimens were compacted using the Texas gyratory compactor and the procedures specified in Tex-206-F. Compacted cylindrical specimens were 102 mm in diameter and approximately 50 mm in height. Specimens for measuring resistance to moisture damage were compacted to approximately 7% air voids, as required in the standard.

Laboratory Tests

Tests were conducted to estimate the relative performance of asphalt paving mixtures with and without shredded waste roofing shingles. Laboratory testing was conducted in accordance with Table 1. The program included resilient modulus, indirect tensile strength, moisture susceptibility, and static creep tests. The following paragraphs give a brief description of each test method. Height and bulk specific gravity of all specimens were measured. Specimens for testing were selected randomly. Three replicates of each test were conducted.

Resilient Modulus (MR). Resilient modulus testing (ASTM D 4123) was performed at three temperatures (4°C, 25°C, and 40°C) using the Retsina pneumatic apparatus. A diametral load (magnitude depends on test temperature - typically 138 kPa to 517 kPa) was applied for a duration of 0.1 seconds while monitoring the diametral deformation perpendicular to the loaded plane. A set of specimens of each composition type and roofing content were tested at each temperature in succession.

Indirect Tension (IDT). Indirect tension (ASTM D 4867) tests were performed at a temperature of 25°C and a crosshead speed of 50.8 mm per minute using an Instron machine. An adjustable frame held the specimen with its cylindrical axis transverse to the crosshead. Two LVDTs mounted within the frame (also transverse to the crosshead and along the diameter of the specimen) were used to measure the horizontal (diametral) deformation under load.

Moisture Susceptibility. For this test, hot mixed asphalt specimens were specially prepared to contain 7%±1% air voids as required by the standard, (i.e., Tex-531-C, which is very similar to AASHTO T283). Tensile strengths were measured before and after moisture conditioning, and tensile strength ratios (TSRs) were calculated.

Texas DOT Static Creep. Static creep testing was performed in accordance with protocol Tex-231-F. Compacted cylindrical specimens 102 mm in diameter and approximately 50 mm in height were prepared. Specimens were first capped with a plaster compound and then brought to the test temperature of 40°C. Axial loading of specimens was accomplished using a MTS closed-loop, servo-hydraulic system with an integral environmental chamber. The closed loop system was regulated using a Gardner GS-2000 controller, which contains the pre-programmed test sequence and automatic data acquisition.

The test sequence is as follows: Apply 3 cycles of a 556 N square wave preload for one minute intervals followed by a 1 minute rest period for each cycle. This will allow the loading platens to achieve more uniform contact with the specimen. Apply a 556 N load to the specimen for 1 hour. At the end of one hour, remove the load and allow the specimen to rebound for 10 minutes. During the entire loading and unloading time, monitor and record the load which is being applied and the resulting vertical deformations for each LVDT. Pertinent data includes total axial strain, permanent strain, slope of the steady-state portion of the creep curve, and creep stiffness.

RESULTS OF LABORATORY TESTS AND DISCUSSION

Preliminary Testing

Technicians heated small samples of roofing waste to temperatures typical of asphalt plants and observed their behavior. Manufacturing and consumer waste samples were heated in an oven to temperatures of 121°C, 135°C, and 143°C. The heated materials were rodded into 25 mm square (approximate) makeshift molds at each of these temperatures, and it was found that the materials were malleable and compactible under light hand pressure at 135°C and above and appeared quite soft at 143°C. Since shear energies in the compaction machine are substantially greater than those generated by hand, researchers decided to perform the mixture designs and prepare test specimens using the standard procedures at the standard temperatures listed in Tex-205-F.

Extraction and Recovery of Binder from Roofing Shingles. Technicians extracted and recovered the asphalt from selected ground roofing products and measured the asphalt content, asphalt penetration, and aggregate gradation. Asphalt was extracted using Tex-210-F and recovered using Tex-211-F. This was done in an attempt to better understand the roofing materials and estimate their potential effects on resulting asphalt mixtures. The results of these tests appear in Tables 4 and 5.

All asphalts extracted from the consumer waste shingles, which had been exposed to several years of aging, gave penetration values of 5 dm or less. Asphalt from the new manufacturing waste proved to be a significantly softer material (Table 4).

Table 4 . Results from Extraction of Asphalts from Waste Shingles.

Sample Identification	Asphalt Content, % by weight	Penetration, (100g, 5 sec) dmm
City-Wide Waste Consumer	31.0	0
City-Wide Waste Manufacturing	22.4	15
ReClaim React CP	19.8	0
ReClaim React HMA	27.5	0
Eagle Recycling - Coarse	31.3	5
Eagle Recycling - Fine	25.5	3

Table 5. Particle Size Distribution of Solids (aggregate and fibers) Extracted from Selected Ground Waste Roofing Materials.

Sieve Size	Percent Passing, City Wide Manufacturers Waste	Percent Passing Eagle Recycling Coarse-Ground Consumer Waste	Percent Passing Eagle Recycling Fine-Ground Consumer Waste
31.5 mm	100	99.4	100
25 mm	100	95.3	100
19 mm	100	90.5	100
12.5 mm	100	87.9	100
9.5 mm	97.7	83.4	96.7
4.75 mm	97.4	79.6	92.3
2 mm	74.5	32.0	36.5
425 μm	60.4	25.5	28.6
80 μm	36.6	16.9	16.1
200 μm	0.5	0.3	0.2

Mixture Designs. The researchers measured gradation and asphalt contents of the roofing materials to estimate their potential impacts on the dense-graded and CMHB mixes. For each mixture type, researchers decided that a logical way to conform to specified gradation limits was to substitute the prescribed amount of roofing for an equal amount of the finest aggregate in the mix. This was equivalent to a one-for-one weight substitution of roofing waste material for the field sand in the dense-graded mix and for the crusher screenings in the CMHB mix. Table 6 illustrates an example of the effects of these substitutions compared to the TxDOT specifications for a dense-graded Type D mixture.

Table 6. Effects of Incorporating Roofing Manufacturing Waste in Dense-Graded Mixtures.

Sieve Size	Percent Passing by Mass		
	Type D Asphalt Mix without Shingles	Type D Mix with 10% Shingles	TxDOT Specification Limit
12.5 mm	100	100	100
9.5 mm	99.8	99.9	85-100
4.75 mm	67.6	67.6	50-70
2.00 mm	34.2	34.4	32-42
425 μm	20.1	18.4	11-26
180 μm	4.1	9.4	4-14
75 μm	1.2	4.6	1-6

Technicians fabricated specimens of the TxDOT Type D (9.5 mm nominal maximum size) dense-graded mixture and the Type C (16 mm nominal maximum size) CMHB mixture to ensure the optimal mixture design values for the Control (untreated) mixtures. Once the procedure was confirmed as per the mixture design received, the introduction of shingles into the mixtures was allowed.

Initial attempts to incorporate roofing waste into the dense-graded mixture and maintain the design requirements were unsuccessful. That is, air void contents achieved using the standard compaction procedure were greater than 5%. It was assumed this was due to the relatively stiffer asphalts in the shredded shingles. Therefore, the temperatures for both mixing and compaction were increased by 14°C, and much better compliance with the air void requirement was achieved, particularly with the manufacturing waste specimens. Control specimens were prepared at standard temperatures. Appendix A provides results of air void measurements on individual test specimens.

Table 7 lists optimum asphalt contents used for the different mixtures included in the experimental design (Table 1). The results indicate that, when using the TxDOT design procedure, the consumer waste roofing contributed little to the optimum binder content of any of the mixtures. That is, the optimum virgin asphalt content did not need to be reduced when consumer waste was added. When the manufacturing waste was added, the optimum virgin asphalt content was reduced significantly for the dense-graded mixture but not appreciably for the CMHB mixture.

Table 7. Optimum Virgin Asphalt Content of the Different Mixtures Studied.

Mixture ID	Dense-Graded Mixture	CMHB Mixture
Control (AC-20)	6.2	5.2
5% Manufacturing Waste (AC-20)	5.7	5.0
10% Manufacturing Waste (AC-20)	5.0	5.0
5% Consumer Fine (AC-20)	6.0	5.2
10% Consumer Fine (AC-20)	5.8	5.1
5 % Consumer Coarse (AC-20)	--	5.2
10% Consumer Fine (AC-10)	--	5.0

Resilient Modulus Tests

Figures 1 and 2 depict resilient modulus as a function of temperature for the dense-graded mixtures and the CMHB mixtures, respectively. The addition of the roofing wastes generally had little effect on the resilient modulus of the dense-graded mixture. However, the addition of either roofing waste to the CMHB mixture at either quantity exhibited higher resilient moduli at 40°C and lower resilient moduli at 0°C than the Control mixture. Thus, incorporation of roofing waste lowered the temperature susceptibility of the CMHB mixture. Use of AC-10 instead of AC-20 with the consumer waste demonstrates an advantage with regard to lowering mixture temperature susceptibility; this is indicative of improved performance of this CMHB mixture.

Resilient moduli at lower temperatures are often a reflection of rheological properties of the binder. Therefore, one might normally expect the roofing modified mixtures with the harder asphalts to exhibit higher resilient moduli if asphalt alone was contributed by the roofing. A possible explanation for this more compliant mixture at low temperature and the increase in stiffness at high temperature could be due to the dispersion of fibrous materials from the roofing into the relatively thick asphalt films of the CMHB mixture.

Indirect Tension

For the dense-graded mixtures, the addition of either manufacturing waste or consumer fines reduced the tensile strength (Figure 3). The MW exhibited a larger drop in tensile strength than the CF.

For the CMHB mixtures, the indirect tension (IDT) tests show an increase in tensile strength of the mixtures when fine consumer waste is added and a decline in tensile strength when manufacturing waste is added at either 5% or 10% (Figure 4). Coarse consumer waste was added to the CMHB mixture at the 5% level; it yielded only a slight increase in tensile strength. The incorporation of manufacturing waste in the CMHB mixture increased the amount of strain required to produce failure, whereas the addition of consumer waste made no appreciable change in strain at failure. These results obtained upon addition of fibrous

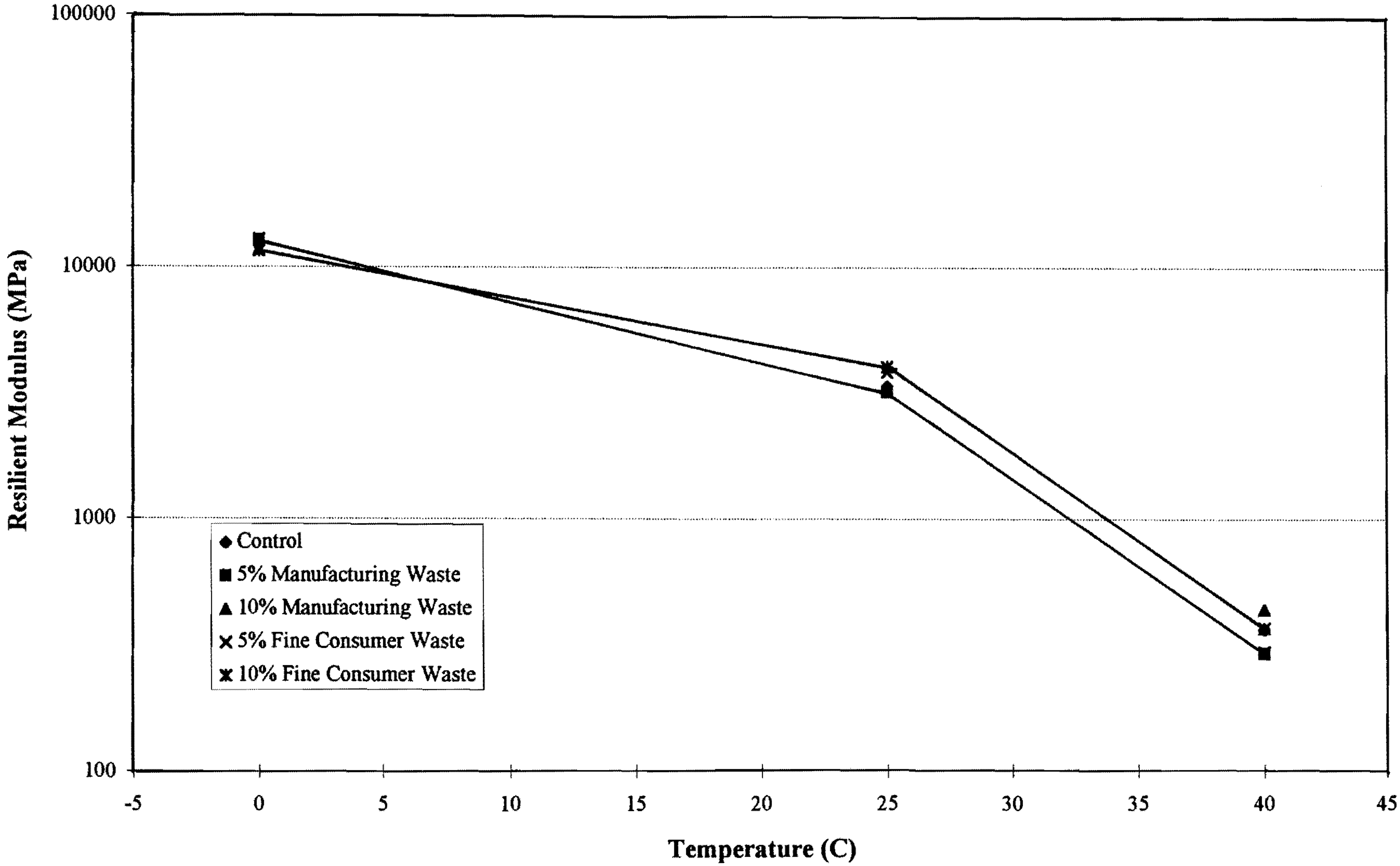

Figure 1. Resilient Modulus versus Temperature for Dense-Graded Specimens Containing Different Amounts of Shingles.

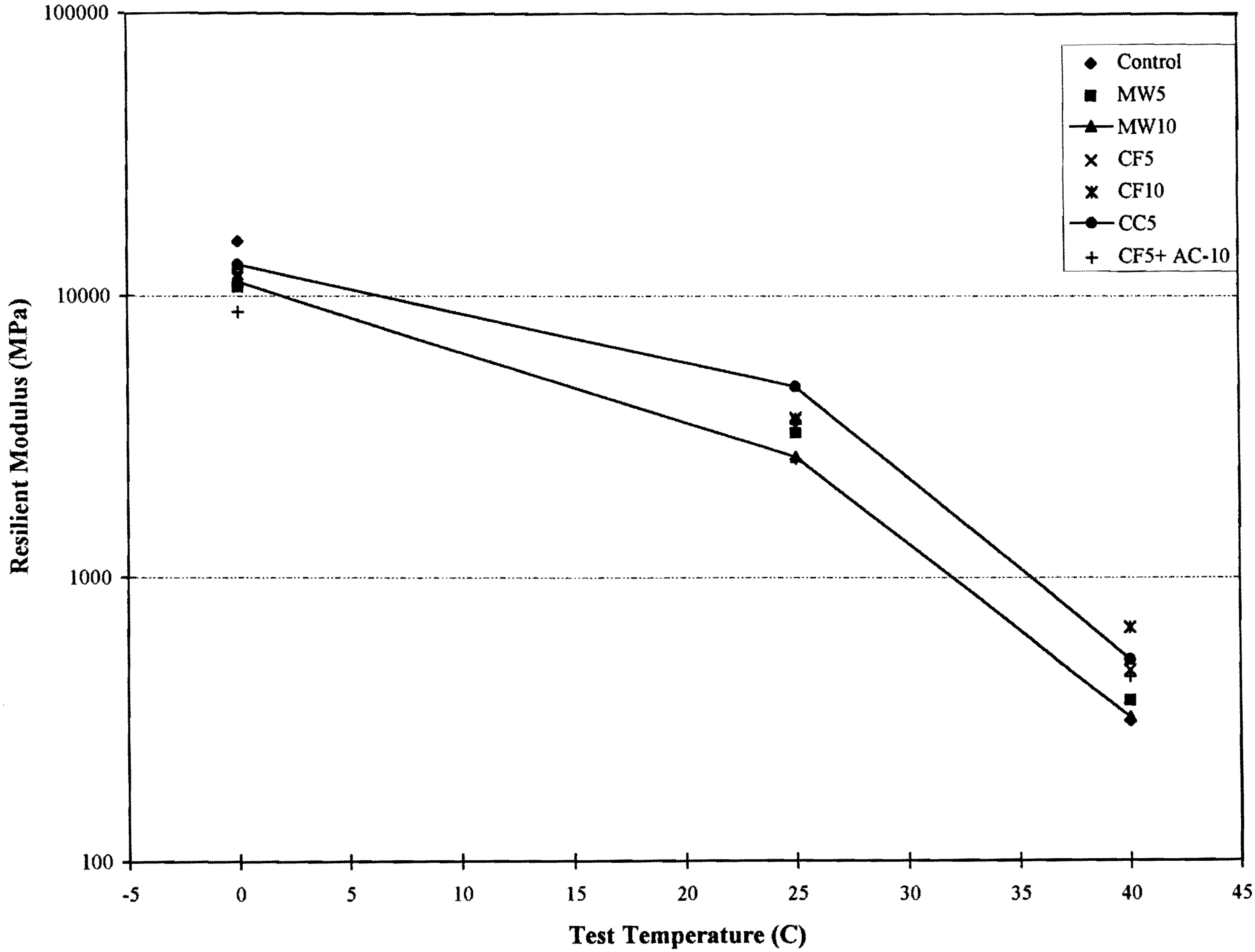

Figure 2. Resilient Modulus versus Temperature for CMHB Specimens Containing Different Amounts of Shingles.

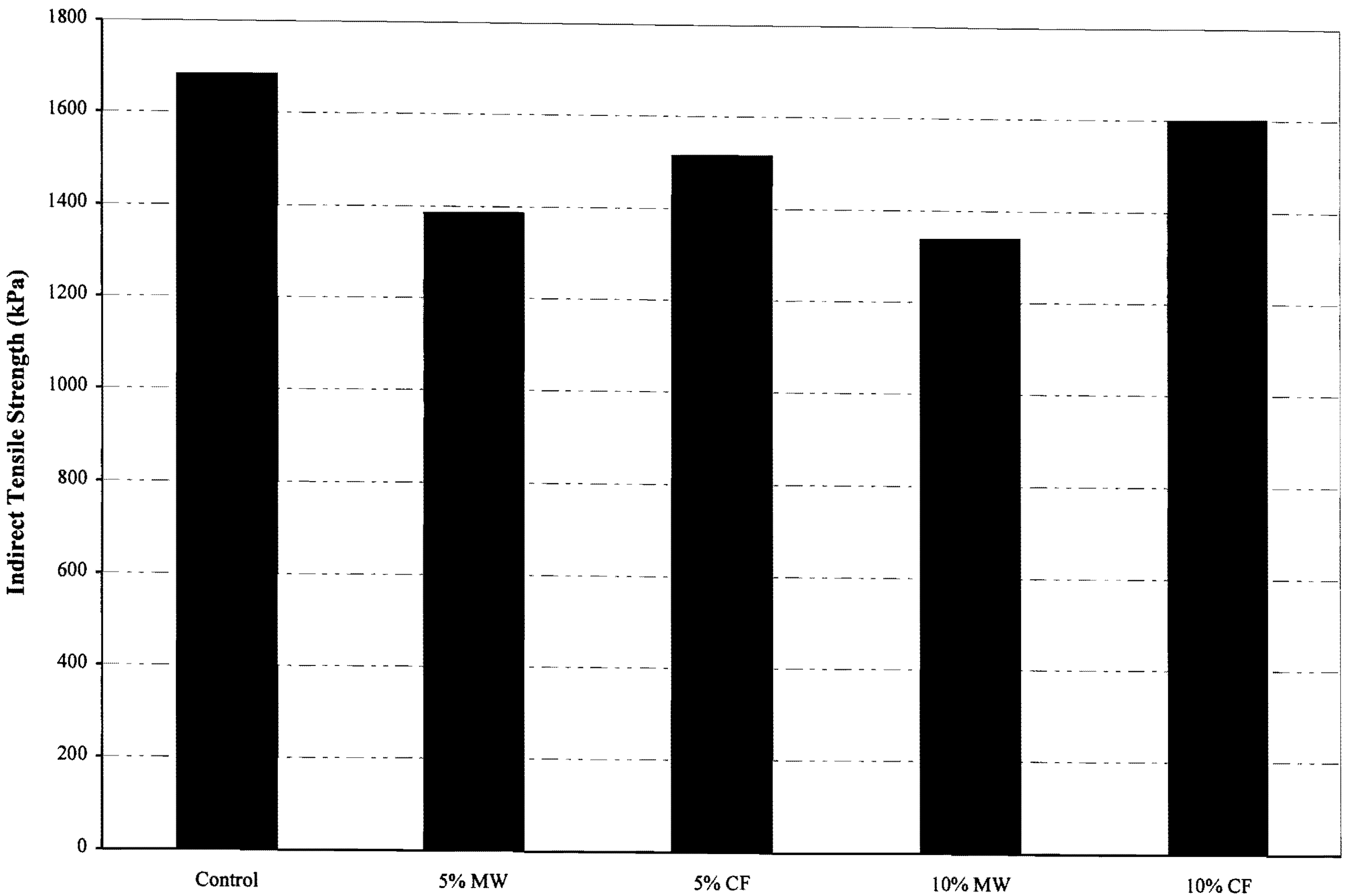

Figure 3. Indirect Tensile Strength at 25°C for Dense-Graded Specimens Containing Different Amounts of Shingles.

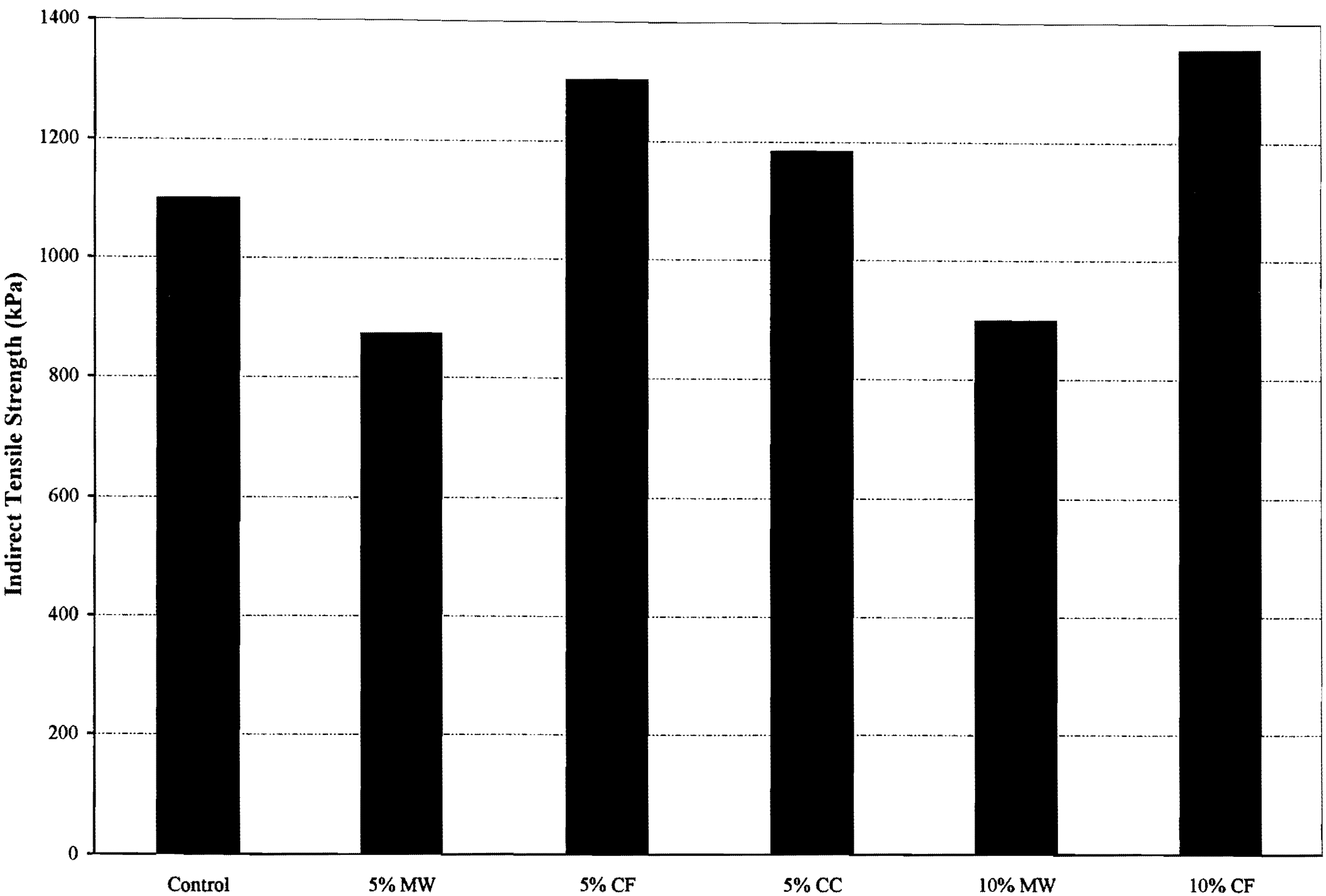

Figure 4. Indirect Tensile Strength at 25°C of CMHB Specimens Containing Different Amounts of Shingles.

manufacturing waste to CMHB are similar to those obtained by Button et al. (27) when synthetic fibers were added to hot mix asphalt.

Results from the "dry" dense-graded specimens prepared for Tex-531-C testing (Figure 5) show that the addition of CF yields no significant change in tensile strength; whereas, the addition of MW gives a decrease of about 15% in tensile strength.

Results from the "dry" CMHB specimens prepared for Tex-531-C testing (Figure 6) show that the addition of CF yields a marked increase in tensile strength and addition of CC yields only a slight increase in tensile strength. The addition of 5% MW to CMHB yields no change in tensile strength and only a slight increase at the 10% level. Based on mixture design work, the asphalt in the consumer waste contributed little to the binder content in the asphalt concrete mixtures. The asphalt in the consumer waste was exceedingly stiff (virtually impenetrable in penetration tests). However, these higher tensile strengths indicate there is some mixing or interaction of the virgin asphalt and the asphalt in the roofing waste (even the consumer waste) at the mixing temperatures used.

Moisture Susceptibility

Results of the moisture susceptibility tests (Figures 5 and 6) were used to compute tensile strength ratios (TSRs) for each type of the mixture (Table 8). The TSRs represent the average IDT strength for three specimens subjected to wet freeze-thaw cycling divided by the average tensile strength of three similar specimens subjected to the same temperatures but without water impregnation.

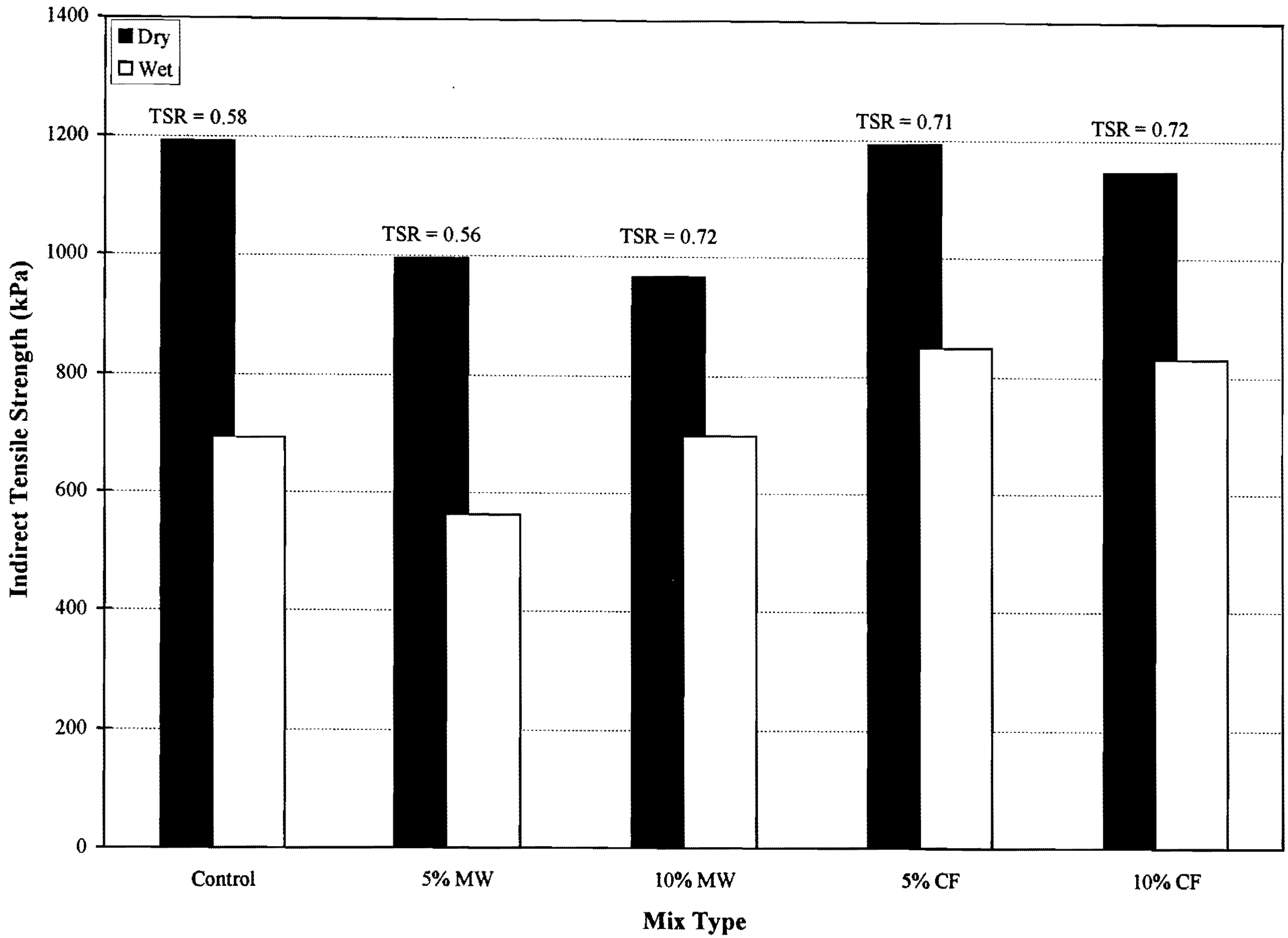

Figure 5. Results of Tex-531-C Tests on Dense-Graded Mixture Specimens (25°C).

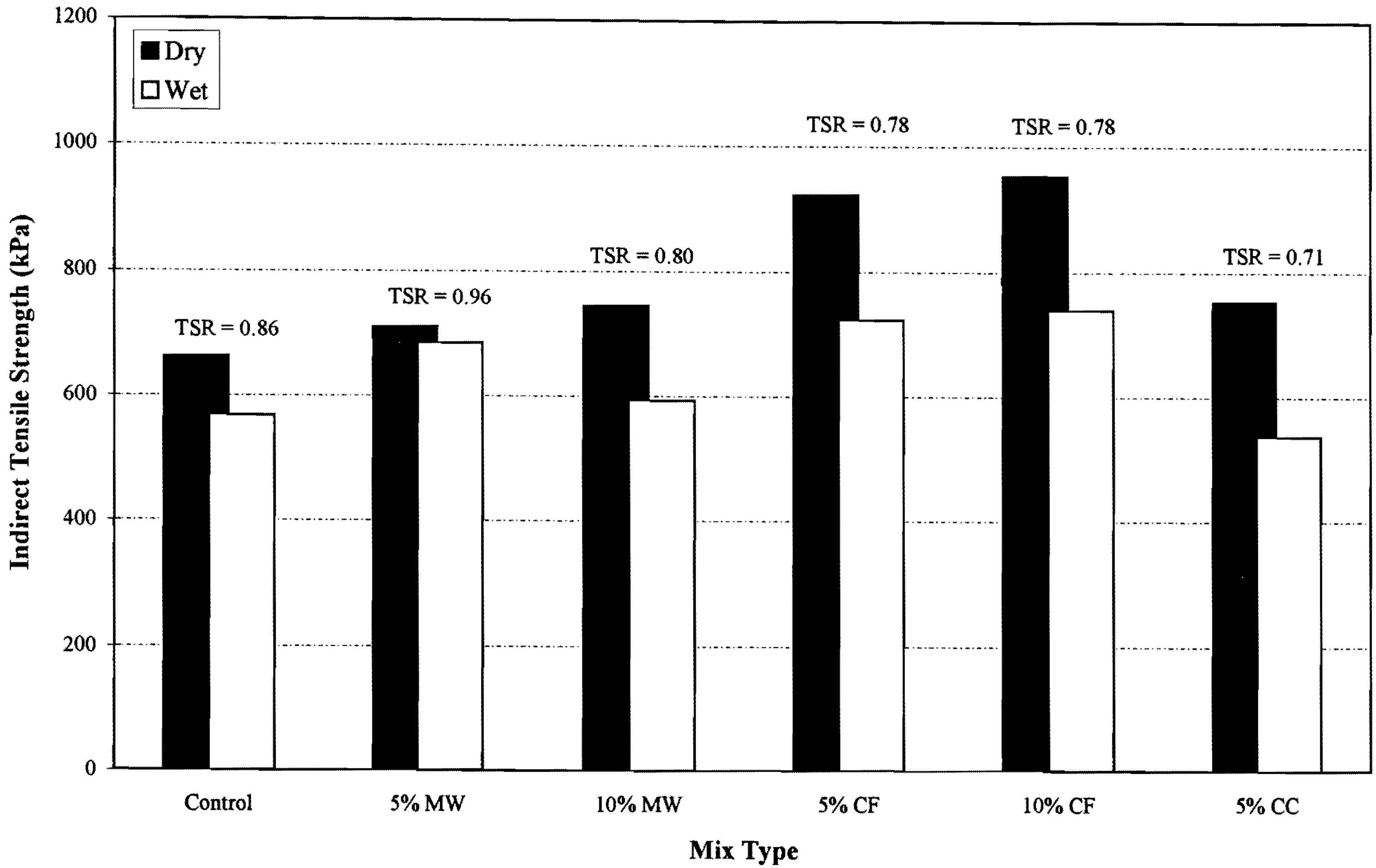

Figure 6. Results of Tex-531-C Tests on CMHB Mixtures Specimens (25°C).

Table 8. Tensile Strength Ratio Values for Dense-Graded and CMHB Specimens.

Mixture Composition	Tensile Strength Ratio (TSR)
Dense Graded	
Control	0.58
5% Consumer Waste (fine)	0.71
10% Consumer Waste (fine)	0.72
5% Manufacturing Waste	0.56
10% Manufacturing Waste	0.72
CMHB	
Control	0.86
5% Consumer Waste (fine)	0.78
10% Consumer Waste (fine)	0.78
5% Manufacturing Waste	0.96
10% Manufacturing Waste	0.80
5% Consumer Waste (coarse)	0.71

For the dense-graded mixtures, the TSRs suggest that the roofing wastes (except for 5% MW) impart improved resistance to freeze-thaw or moisture damage. However, for the CMHB specimens, the presence of roofing waste (except for 5% MW) reduces resistance to the freeze-thaw or moisture damage. It should be pointed out that the specimens containing roofing waste were mixed and compacted at a temperature about 14°C higher than the Control specimen and that this higher mixing temperature alone will improve adhesion of asphalt to aggregate and thus improve resistance to moisture.

The CMHB Control mixture was composed of 100% crushed limestone with relatively thick asphalt films, which exhibited good resistance to moisture damage. The dense-graded Control mixture contained field sand to which poor moisture resistance is often traced. The addition of the roofing materials enhanced the poor moisture susceptibility and degraded the good moisture susceptibility. These results probably have more to do with void structure and asphalt film thicknesses than with the presence or absence of roofing waste. Based upon examination of the mixture designs, it is postulated that the addition of roofing wastes reduced the effective film thicknesses in the CMHB mixtures and increased the effective film thicknesses in the dense-graded mixtures, which probably contributed to the results obtained.

Hveem Stability

The Hveem stability test results (Figures 7 and 8) show a consistent decrease upon the addition of either roofing waste product at either concentration level. The reduction of Hveem stability was not dependent on the type or quantity of the roofing waste. Average Hveem stability was not reduced below the acceptable level (35) for any of these mixtures.

The implications of Hveem stability results for CMHB mixtures may be questionable as these mixtures have different aggregate and mixture dynamics than dense-graded mixtures for which this test was developed and for which the pavement performance database has been established. Overall, little can be drawn from these results other than no mix appeared to be particularly bad, even though the CMHB specimens (particularly those containing with manufacturing waste) appeared to be overasphalted.

These test results demonstrate very important findings, which the researchers expected. The fibrous flakes of roofing are not completely disintegrated during mixing. The presence of these flakes and individual fibers (27) acts to reduce stone-to-stone contact and thus reduces the angle of internal friction of the mixture, which is manifested by the reduced Hveem stability. However, the CMHB mixture is negatively affected less than the dense-graded mixture. That is, because of the relatively thicker asphalt films and the higher VMA, a CMHB mixture appears to be more capable of accommodating the roofing waste than a dense-graded mixture.

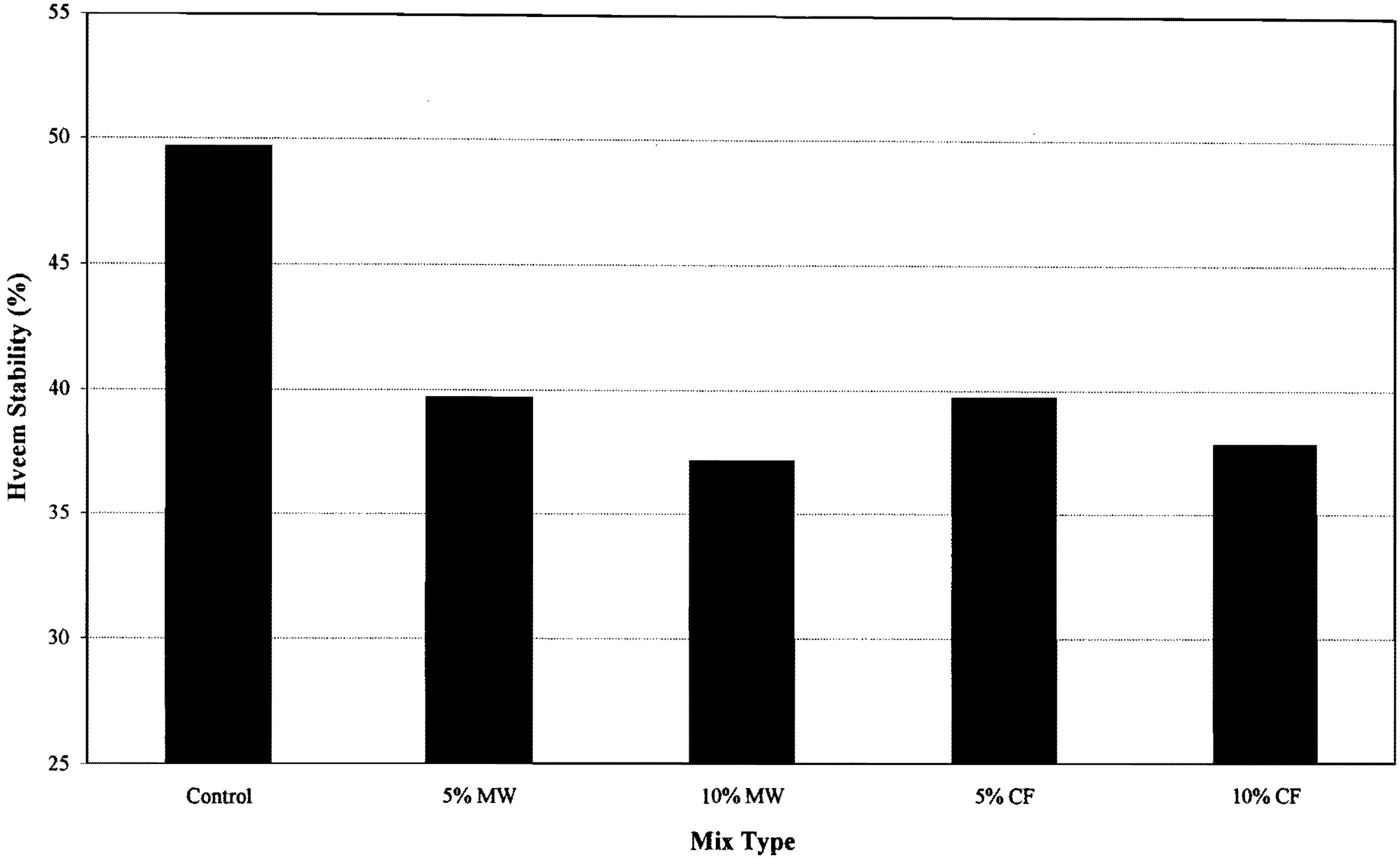

Figure 7. Hveem Stability of Dense-Graded Specimens Containing Different Amounts of Different Types of Shingles.

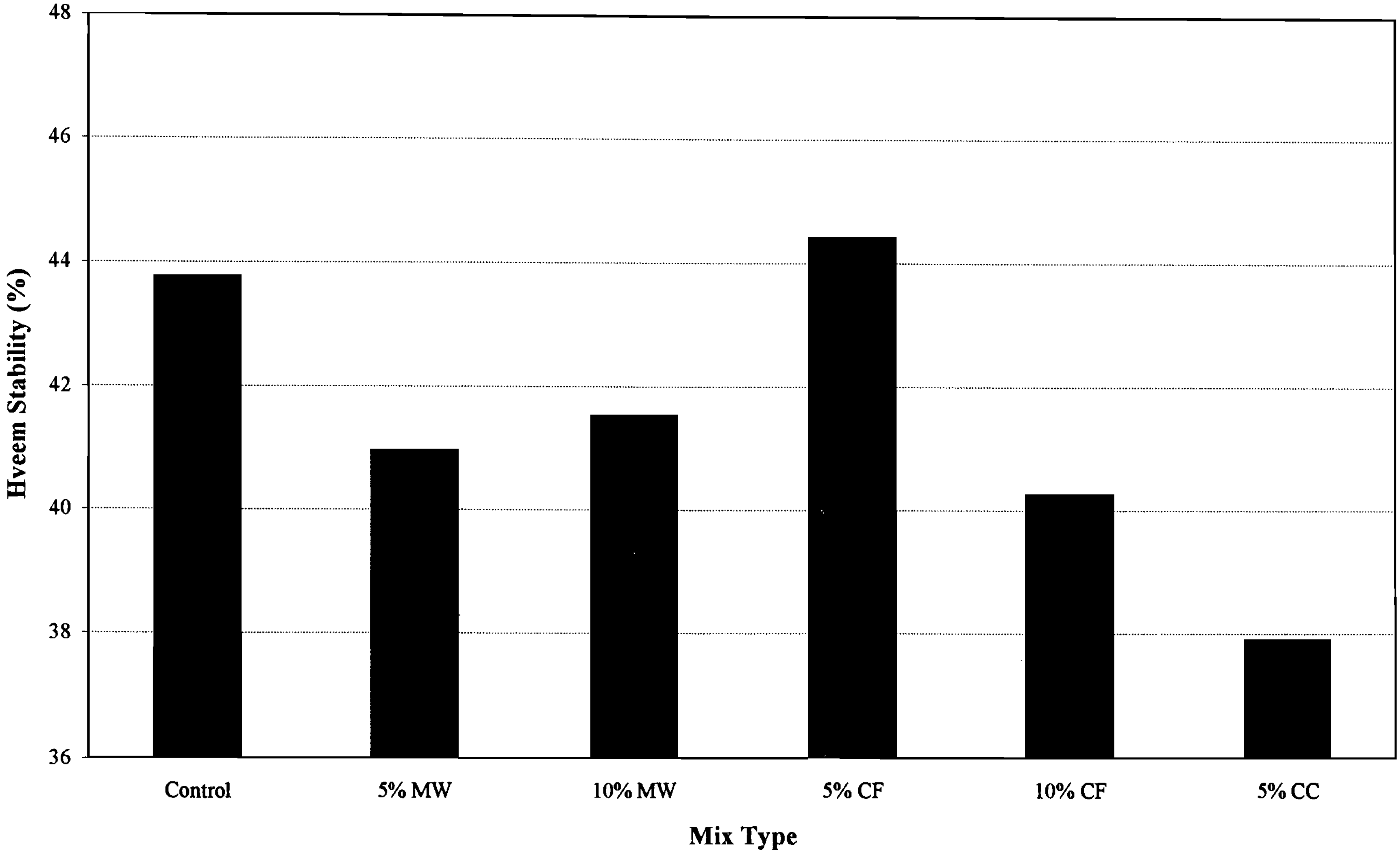

Figure 8. Hveem Stability of CMHB Specimens Containing Different Amounts of Different Types of Shingles.

Texas DOT Static Creep Test

The TxDOT creep test and associated criteria were developed primarily to evaluate CMHB mixtures. Nevertheless, the procedure should be valid for comparative evaluations of modified and unmodified dense-graded asphalt mixtures; however, the criteria may not be valid. Test results for the dense-graded mixtures (Table 9) show that the Control mixture meets the specified permanent strain and creep stiffness criteria but fails the slope criterion. Generally, the incorporation of roofing has negative effects on static creep results, and more roofing is worse. All the modified mixtures pass TxDOT's permanent strain criterion; however, none of them pass the criterion for slope of the steady state portion of the creep curve. Creep stiffness for the dense-graded mixtures drops significantly upon the addition of roofing waste. In fact, only the mixture containing 5% MW satisfies the stiffness criterion.

The CMHB Control conforms to all three requirements in the specification (Table 10). Again, the incorporation of increasing amounts of roofing waste has negative effects on static creep results. All the roofing modified CMHB mixtures meet the permanent strain and creep stiffness criteria, and none of them meet the slope criterion.

Based on these findings, the CMHB mixture cannot handle 5% roofing and meet the TxDOT quality control requirements. It appears that just under 5% MW would be satisfactory in either mixture and that just under 5% CF would be acceptable in the CMHB mixture.

Examination of Shingle Particle Breakdown

It was desirable to determine if the larger shingle particles would be melted and disintegrated during heating, mixing, and compacting a HMA specimen. Three compacted specimens containing 10% shredded shingles were heated to soften them and the aggregates were manually separated in search of shingle particles that were still intact. A diligent examination of these three specimens revealed only one small roofing particle still intact (Figure 9). This exercise indicates that the heating and mixing during routine laboratory specimen preparation using TxDOT procedures is sufficient to melt and disintegrate most of the roofing particles, even the larger ones.

Table 9. Summary of TxDOT Creep Test Results for Dense-Graded Mixtures.

Test I.D.	Air Voids,%	Permanent Strain, mm/mm	Slope, mm/sec.	Creep Stiffness, kPa
Specification	*4.0*	*< 5.00 x* 10^{-4}	*< 8.89 x* 10^{-7}	*> 41370*
Control	3.5	3.31 x 10^{-6}	1.03 x 10^{-6}	67513
5% Manufacturing Waste	3.6	3.82 x 10^{-6}	9.91 x 10^{-7}	57507
10% Manufacturing Waste	4.0	1.47 x 10^{-6}	5.37 x 10^{-6}	29790
5% Consumer Waste - Fine	5.3	1.03 x 10^{-6}	3.85 x 10^{-6}	34044
10% Consumer Waste - Fine	5.7	1.93 x 10^{-6}	7.70 x 10^{-6}	23194

Table 10. Summary of TxDOT Creep Test Results for CMHB Mixtures.

Test I.D.	Air Voids,%	Permanent Strain, mm/mm	Slope, mm/sec.	Creep Stiffness, kPa
Specification	*3.0*	*< 5.00 x* 10^{-4}	*< 8.89 x* 10^{-7}	*> 41370*
Control	2.9	1.11 x 10^{-6}	6.69 x 10^{-7}	77040
5% Manufacturing Waste	2.4	2.52 x 10^{-6}	1.02 x 10^{-6}	75500
10% Manufacturing Waste	2.7	4.18 x 10^{-6}	1.35 x 10^{-6}	62800
5% Consumer Waste - Fine	2.4	3.47 x 10^{-6}	1.10 x 10^{-6}	76760
10% Consumer Waste - Fine	2.4	5.59 x 10^{-6}	2.19 x 10^{-6}	66070
5% Consumer Waste - Coarse	3.0	6.99 x 10^{-6}	2.27 x 10^{-6}	54010
10% Fine Consumer Waste with AC-10	3.3	2.35 x 10^{-6}	9.74 x 10^{-7}	78350

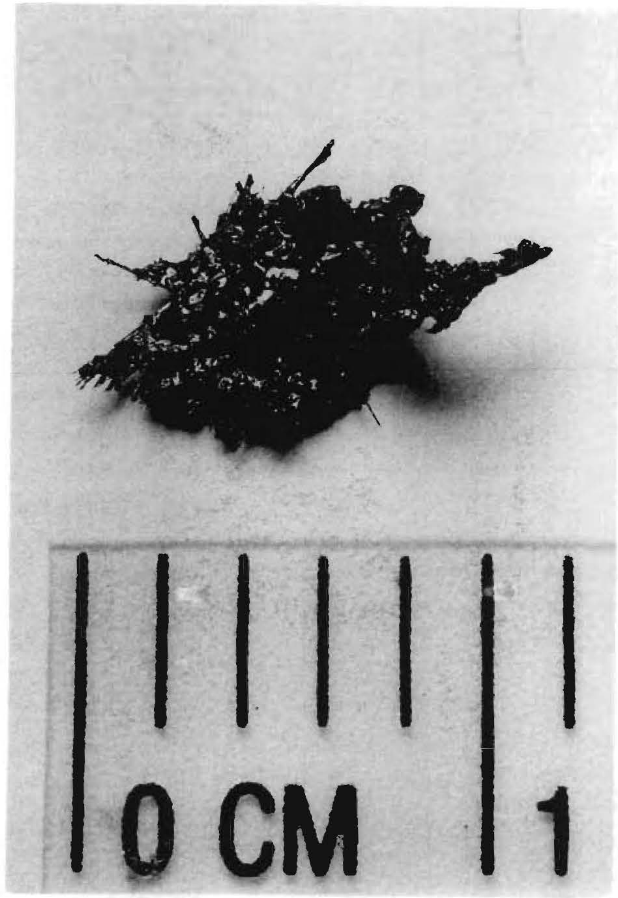

Figure 9. Roofing Particle Recovered from a Laboratory Test Specimen.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Existing information on the incorporation of waste roofing into hot mix asphalt was obtained from the literature and from interviews with cognizant persons in various agencies around the U.S. A brief laboratory study was performed to measure the strength, stability, creep characteristics, and water susceptibility of modified and unmodified asphalt mixtures. Roofing materials included both manufacturing waste and consumer (tear off) waste. Two different types of hot mix asphalt, dense-graded and coarse matrix-high binder (CMHB) mixtures, were studied. Based on the findings of this study, the following was concluded.

1. Considerable information is available regarding recycling of waste roofing in hot mix asphalt pavements. Small laboratory and field studies have been conducted by several agencies. Research results generally appear positive. Not only can roofing waste be incorporated into asphalt mixtures, but there is evidence that it can actually improve mixture properties in some cases.
2. Standard TxDOT hot mix asphalt design procedures appear satisfactory for designing mixtures containing roofing waste.
3. Standard TxDOT quality control procedures appear satisfactory for evaluating mixtures containing roofing waste.
4. Generally, the addition of 5% to 10% roofing waste into the dense-graded and CMHB mixtures, as studied herein, was detrimental to the engineering properties of the mixtures. Based on the data obtained, however, it appears that quantities of roofing just under 5% would be satisfactory in these mixtures.
5. Mixing and compaction temperatures of HMA may need to be increased by about 10 to 20°C in the laboratory and in the field to accommodate the relatively stiffer roofing-modified mixtures. Standard compaction temperatures may yield higher air voids than desirable.
6. For purposes of mixture design and construction, waste roofing can be handled using the techniques already established for reclaimed asphalt pavement (RAP).

7. A CMHB mixture with the higher voids in the mineral aggregate and asphalt film thickness can accommodate roofing wastes better than a dense-graded mixture.

Recommendations

1. This small study was the first study of roofing waste in hot mix asphalt in Texas. The findings were sufficient to warrant a more intensified effort to establish long-term performance characteristics of asphalt concrete containing roofing wastes through laboratory and field testing programs.
2. The specifications and guidelines for using roofing waste in HMA in Appendix A should be tested in field applications and revised as needed.
3. Most of the future work on surface mixtures should be devoted to CMHB mixtures. The maximum quantity of roofing waste should be limited to about 5% by weight of mixture. It may be possible to successfully incorporate higher concentrations of roofing waste into hot mix asphalt, but it is felt that more time is needed to properly develop these types of mixtures and measure the resulting engineering properties.
4. Studies should be conducted to determine the utility of roofing waste in asphalt stabilized base mixtures.
5. Field trials combining roofing waste and RAP in HMA pavements should be attempted.
6. It has been demonstrated in other research (26) that waste toner retrieved from copiers can be successfully incorporated into asphalt cement and asphalt concrete. The Texas Natural Resources Conservation Commission and/or TxDOT should consider funding research to further this promising concept to recycle polymers.

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APPENDIX A

SUMMARY OF DATA FOR INDIVIDUAL TEST SPECIMENS

Table A1. Summary of Resilient Modulus and Hveem Stability Results for Individual Dense-Graded Specimens.

Specimen ID	Air Voids, %	Resilient Modulus, MPa 0°C	25°C	40°C	Hveem Stability, Percent	VMA
Control						
DC1A20	3.6	12963	3500	390	53	13.5
DC2A20	3.8	11696	3131	365	44	13.6
DC3A20	3.5	11864	3558	334	52	13.5
DC4A20	3.2					13.2
DC5A20	3.2					13.2
DC6a20	3.5					13.5
Average	**3.4**	**12174**	**3396**	**363**	**50**	**13.4**
5% Manufacturing Waste						
5M11	3.9					13.3
5M12	3.2	13462	3197	325	40	12.7
5M13	3.6					13.1
5M14	3.5	12422	3208	298	37	12.9
5M15	3.4					12.8
5M16	3.9	12335	3213	249	42	13.3
Average	**3.6**	**12740**	**3206**	**290**	**40**	**13.0**
10% Manufacturing Waste						
10M11	4.4					14.6
10M12	3.5					13.8
10M13	4.2					14.4
10M14	4.0	12999	4087	637	45	14.3
10M15	4.7	10236	2530	321	32	14.8
10M16	3.3	12022	3349	338	34	13.6
Average	**4.0**	**11752**	**3322**	**432**	**37**	**14.3**
5% Consumer Fine Waste						
5cf11	5.5					15.7
5cf12	5.0	12405	3734	230	39	15.3
5cf13	5.4					15.6
5cf14	5.8	12876	4375	319	43	16.0
5cf15	5.0					15.3
5cf16	5.5	13355	3476	334	36	15.7
Average	**5.4**	**12878**	**3862**	**294**	**40**	**15.6**

Table A1. Continued

Specimen ID	Air Voids, %	Resilient Modulus, MPa 0°C	25°C	40°C	Hveem Stability, Percent	VMA
10% Consumer Fine Waste						
10cf11	4.7	12296	4310	388	40	16.1
10cf12	5.4					16.7
10cf13	4.9	12285	4290	423	39	16.3
10cf14	5.6					16.9
10cf15	5.2	10138	3579	286	35	16.5
10cf16	6.4					17.6
Average	**5.4**	**11573**	**4060**	**366**	**38**	**16.7**

Table A2. Summary of Resilient Modulus and Hveem Stability Results for Individual CMHB Mixture Specimens

Specimen ID	Air Voids, %	Resilient Modulus, MPa 0°C	25°C	40°C	Hveem Stability, Percent	VMA
Control						
CMC1	3.1					14.3
CMC2	3.3	16002	4051	357	46	14.5
CMC3	2.1	16150	3640	300	46	13.5
CMC4	2.6					13.9
CMC5	1.8	14550	3168	283	40	13.2
CMC6	3.0					14.3
Average	**2.6**	**15567**	**3620**	**313**	**44**	**13.9**
5% Manufacturing Waste						
CM5m1	2.9	8882	3346	325	40	13.8
CM5m2	3.0	13054	3305	427	45	13.9
CM5m3	2.7	10308	3172	352	38	13.6
CM5m4	2.3					13.2
CM5m5	2.6					13.5
CM5m6	2.2					13.1
Average	**2.6**	**10748**	**3275**	**368**	**41**	**13.5**
10% Manufacturing Waste						
CM10m1	3.1	12177	3119	369	41	14.5
CM10m2	2.3	6324*	2006*	202*	44	13.8
CM10m3	2.2	15148	2950	395	41	13.7
CM10m4	2.6					14.1
CM10m5	2.8					14.2
CM10m6	2.6					14.1
Average	**2.6**	**13663**	**3035**	**382**	**42**	**14.1**
5% Fine Consumer Waste						
CM5cf1	2.2	11430	3438	468	45	13.7
CM5cf2	2.4	11567	3982	487	47	13.9
CM5cf3	2.1	12817	3732	468	41	13.7
CM5cf4	2.2					13.7
CM5cf5	2.3					13.8
CM5cf6	2.5					14.0
Average	**2.3**	**11938**	**3717**	**474**	**44**	**13.8**

Table A2. Continued

Specimen ID	Air Voids, %	Resilient Modulus, MPa 0°C	25°C	40°C	Hveem Stability, Percent	VMA
10% Fine Consumer Waste						
CM10cf1	2.3	11655	3759	708	45	14.7
CM10cf2	2.8	10763	3324	577	26*	15.1
CM10cf3	2.7	12413	3985	718	36	15.0
CM10cf4	2.0					14.4
CM10cf5	2.7					15.0
CM10cf6	2.4					14.7
Average	**2.5**	**11610**	**3689**	**668**	**40**	**14.8**
5% Coarse Consumer Waste						
CM5cc1	2.4	12375	4600	586	39	14.9
CM5cc2	2.4	12617	4711	496	35	14.9
CM5cc3	2.9	13577	4919	465	40	15.4
CM5cc4	2.5					15.0
CM5cc5	2.9					15.3
CM5cc6	3.4					15.8
Average	**2.8**	**12857**	**4743**	**516**	**38**	**15.2**
5% Fine Consumer Waste + AC-10 Binder						
CM10cf1a10	2.9	8083	2630	465	42	15.2
CM10cf2a10	2.0	9853	2967	481	39	14.4
CM10cf3a10	2.9	8407	2350	400	40	15.2
CM10cf4a10	3.3				39	15.6
CM10cf5a10	3.1				42	15.3
CM10cf6a10	3.6				37	15.8
Average	**3.0**	**8781**	**2649**	**449**	**40**	**15.3**

*Outliers

Table A3. Summary of Indirect Tension and TxDOT Creep Data for Individual Dense-Graded Specimens.

		Tensile Properties			TxDOT Creep Properties		
Specimen ID	Air Voids, %	Tensile Strength, kPa	Strain @ Failure, mm/mm	Secant Modulus, MPa	Permanent Strain	Slope, mm/sec	Stiffness, kPa
Control							
DC1A20	3.6	1664	---	---			
DC2A20	3.8	1581	---	---			
DC3A20	3.5	1803	---	---			
DC4A20	3.2				2.92E-04	9.91E-07	69437
DC5A20	3.2				3.69E-04	1.07E-06	65590
DC6a20	3.5						
Average	**3.5**	**1683**	**---**	**---**	**3.31E-04**	**1.03E-06**	**67513**
5% Manufacturing Waste							
5M11	3.9				4.73E-04	2.57E-07	47746
5M12	3.3	1344	0.0074	366			
5M13	3.6				3.89E-04	1.47E-06	57075
5M14	3.5	1449	0.0067	439			
5M15	3.4				2.82E-04	1.24E-06	67700
5M16	3.9	1367	0.0063	440			
Average	**3.6**	**1387**	**0.0068**	**415**	**3.82E-04**	**9.91E-07**	**57507**
10% Manufacturing Waste							
10M11	4.4				1.93E-03	6.48E-06	24332
10M12	3.5				1.19E-03	4.75E-06	33839
10M13	4.2				1.29E-03	4.88E-06	31199
10M14	4.0	1523	0.0056	546			
10M15	4.7	1219	0.0070	351			
10M16	3.4	1275	0.0073	353			
Average	**4.0**	**1339**	**0.0066**	**417**	**1.47E-03**	**5.37E-06**	**29790**

Table A3. Continued

Specimen ID	Air Voids, %	Tensile Properties: Tensile Strength, kPa	Tensile Properties: Strain @ Failure, mm/mm	Tensile Properties: Secant Modulus, MPa	TxDOT Creep Properties: Permanent Strain	TxDOT Creep Properties: Slope, mm/sec	TxDOT Creep Properties: Stiffness, kPa
5% Fine Consumer Waste							
5cf11	5.50				1.48E-03	4.98E-06	24745
5cf12	5.04	1460	0.0060	491			
5cf13	5.37				1.13E-03	4.01E-06	29641
5cf14	5.79	1702	0.0048	711			
5cf15	5.04				4.73E-04	2.57E-06	47746
5cf16	5.46	1523	0.0071	430			
Average	**5.37**	**1562**	**0.0060**	**544**	**1.03E-03**	**3.85E-06**	**34044**
10% Fine Consumer Waste							
10cf11	4.69	1691	0.0054	638			
10cf12	5.37				1.87E-03	7.49E-06	23794
10cf13	4.95	1663	0.0048	704			
10cf14	5.59				1.62E-03	7.24E-06	26062
10cf15	5.20	1449	0.0061	480			
10cf16	6.35				2.30E-03	8.38E-06	19726
Average	**5.36**	**1601**	**0.0054**	**607**	**1.93E-03**	**7.70E-06**	**23194**

Table A4. Summary of Indirect Tension and TxDOT Creep Data for Individual CMHB Mixture Specimens.

		Tensile Properties			TxDOT Creep Properties		
Specimen ID	Air Voids, %	Tensile Strength kPa	Failure Strain, mm/mm	Secant Modulus, MPa	Permanent Strain	Slope, mm/sec	Stiffness, kPa
Control							
CMC1	3.1				1.19E-04	6.35E-07	69327
CMC2	3.3	1012	0.0056	367			
CMC3	2.1	1151	0.0062	374			
CMC4	2.6				7.38E-05	6.86E-07	80600
CMC5	1.8	1135	0.0063	365			
CMC6	3.0				1.40E-04	6.86E-07	81193
Average	**2.6**	**1100**	**0.0060**	**369**	**1.11E-04**	**6.69E-07**	**77040**
5% Manufacturing Waste							
CM5m1	2.9	802	0.0103	158			
CM5m2	3.0	862	0.0068	255			
CM5m3	2.7	957	0.0058	335			
CM5m4	2.3				2.94E-04	1.09E-06	71554
CM5m5	2.6				2.72E-04	1.19E-06	76539
CM5m6	2.2				1.91E-04	7.62E-07	78407
Average	**2.6**	**874**	**0.0076**	**249**	**2.52E-04**	**1.02E-06**	**75500**
10% Manufacturing Waste							
CM10m1	3.1	909	0.0070	262			
CM10m2	2.3	921	0.0074	253			
CM10m3	2.2	868	0.0073	239			
CM10m4	2.6				3.44E-04	1.22E-06	69334
CM10m5	2.8				4.93E-04	1.47E-06	56289
CM10m6	2.6						
Average	**2.6**	**899**	**0.0072**	**251**	**4.18E-04**	**1.35E-06**	**62811**

Table A4. Continued

Specimen ID	Air Voids, %	Tensile Properties: Tensile Strength, kPa	Tensile Properties: Failure Strain, mm/mm	Tensile Properties: Secant Modulus, MPa	TxDOT Creep Properties: Permanent Strain	TxDOT Creep Properties: Slope, mm/sec	TxDOT Creep Properties: Stiffness, kPa
5% Fine Consumer Waste							
CM5cf1	2.2	1335	0.0056	481			
CM5cf2	2.4	1186	0.0058	415			
CM5cf3	2.1	1387	0.0058	486			
CM5cf4	2.2						
CM5cf5	2.3				3.49E-04	1.02E-06	81620
CM5cf6	2.5				3.44E-04	1.19E-06	71705
Average	**2.3**	**1303**	**0.0057**	**461**	**3.47E-04**	**1.10E-06**	**76663**
10% Fine Consumer Waste							
CM10cf1	2.3	1304	0.0051	519			
CM10cf2	2.8	1286	0.0073	355			
CM10cf3	2.7	1479	0.0051	585			
CM10cf4	2.0				5.77E-04	2.08E-06	62232
CM10cf5	2.7				5.35E-04	2.41E-06	69141
CM10cf6	2.4				5.65E-04	2.08E-06	66838
Average	**2.5**	**1356**	**0.0058**	**486**	**5.59E-04**	**2.19E-06**	**66070**
5% Coarse Consumer Waste							
CM5cc1	2.4	1212	0.0054	457			
CM5cc2	2.4	1196	0.0053	454			
CM5cc3	2.9	1145	0.0060	387			
CM5cc4	2.5				6.47E-04	2.06E-06	54524
CM5cc5	2.9				8.21E-04	2.64E-06	49084
CM5cc6	3.4				6.28E-04	2.11E-06	58433
Average	**2.8**	**1184**	**0.0055**	**433**	**6.99E-04**	**2.27E-06**	**54014**

Table A4. Continued

Specimen ID	Air Voids, %	Tensile Properties: Tensile Strength, kPa	Tensile Properties: Failure Strain, mm/mm	Tensile Properties: Secant Modulus, MPa	TxDOT Creep Properties: Permanent Strain	TxDOT Creep Properties: Slope, mm/sec	TxDOT Creep Properties: Stiffness, kPa
10% Fine Consumer Waste, AC-10 Binder							
CM10cf1a10	2.9						
CM10cf2a10	2.0						
CM10cf3a10	2.9						
CM10cf4a10	3.3				3.16E-04	1.04E-06	74905
CM10cf5a10	3.1				2.02E-04	9.65E-07	85171
CM10cf6a10	3.6				1.89E-04	9.14E-07	74967
Average	**3.0**				**2.35E-04**	**9.74E-07**	**78347**

Table A5. Summary of Moisture Sensitivity Data for Individual Dense-Graded Specimens.

		Tensile Properties, Not Moisture Treated			Tensile Properties, Moisture Treated		
Specimen ID	Air Voids, %	Tensile Strength, kPa	Failure Strain, mm/mm	Secant Modulus, MPa	Tensile Strength, kPa	Failure Strain, mm/mm	Secant Modulus, MPa
Control							
CONL6W	6.8				730	0.0055	267
CONL2W	6.1				566	0.0098	159
CONL5W	6.4				782	0.0051	308
CONL4D	5.6	1322	0.0052	518			
CONL1D	6.3	1266	0.0051	501			
CONL3D	7.5	989	0.0067	298			
Average	**6.5**	**1192**	**0.0057**	**439**	**693**	**0.0068**	**245**
5% Manufacturing Waste							
DG5MWL3W	6.6				502	0.0143	71
DG5MWL2W	6.4				665	0.0116	115
DG5MWL4W	6.6				518	0.0123	85
DG5MWL1D	6.3	1010	0.0107	190			
DG5MWL5D	6.3	1022	0.0092	225			
DG5MWL6D	6.3	956	0.0084	229			
Average	**6.4**	**996**	**0.0094**	**215**	**562**	**0.0127**	**91**
10% Manufacturing Waste							
DG10MWL4W	7.2				653	0.0112	118
DG10MWL5W	6.9				628	0.0112	113
DG10MWL6W	7.1				814	0.0094	175
DG10MWL1D	7.2	985	0.0056	357			
DG10MWL2D	7.7	981	0.0077	257			
DG10MWL3D	8.0	933	0.0087	217			
Average	**7.4**	**966**	**0.0073**	**277**	**698**	**0.0106**	**135**

Table A5. Continued

Specimen ID	Air Voids, %	Tensile Properties, Not Moisture Treated: Tensile Strength, kPa	Failure Strain, mm/mm	Secant Modulus, MPa	Tensile Properties, Moisture Treated: Tensile Strength, kPa	Failure Strain, mm/mm	Secant Modulus, MPa
5% Fine Consumer Waste							
DG5CFL1W	6.9				809	0.0094	174
DG5CFL2W	6.5				871	0.0109	161
DG5CFL6W	6.5				866	0.0094	185
DG5CFL3D	6.3	1172	0.0091	259			
DG5CFL4D	6.1	1195	0.0088	274			
DG5CFL5D	6.4	1214	0.0068	359			
Average	**6.5**	**1194**	**0.0083**	**297**	**849**	**0.0099**	**173**
10% Fine Consumer Waste							
DG10CFL1W	6.4				854	0.0104	166
DG10CFL2W	6.7				826	0.0093	180
DG10CFL3W	6.7				813	0.0105	156
DG10CFL6D	7.5	1199	0.0070	344			
DG10CFL4D	7.6	1152	0.0074	314			
DG10CFL5D	8.1	1091	0.0072	307			
Average	**7.2**	**1147**	**0.0072**	**322**	**831**	**0.0101**	**167**

Table A6. Summary of Moisture Sensitivity Data for Individual CMHB Specimens.

		Tensile Properties, Not Moisture Treated			Tensile Properties, Moisture Treated		
Specimen ID	Air Voids, %	Tensile Strength, kPa	Failure Strain, mm/mm	Secant Modulus, MPa	Tensile Strength, kPa	Failure Strain, mm/mm	Secant Modulus, MPa
Control							
CMCONL1W	6.1				546	0.0106	103
CMCONL3W	6.0				573	0.0085	137
CMCONL5W	6.8				583	0.0132	87
CMCONL8D	8.7	541	0.0073	151			
CMCONL6D	6.4	745	0.0075	201			
CMCONL7D	7.1	702	0.0083	170			
Average	**6.9**	**663**	**0.0077**	**174**	**567**	**0.0108**	**109**
5% Manufacturing Waste							
CM5MWL1W	6.9				684	0.0109	126
CM5MWL2W	6.7				--	--	--
CM5MWL3W	6.2				--	--	--
CM5MWL6D	6.1	737	0.0065	230			
CM5MWL5D	6.0	691	0.0061	228			
CM5MWL7D	6.0	704	0.0097	147			
Average	**6.3**	**711**	**0.0074**	**202**	**684**	**0.0109**	**126**
10% Manufacturing Waste							
CM10MWL4W	7.2				555	0.0135	83
CM10MWL5W	6.7				620	0.0107	117
CM10MWL6W	6.8				604	0.0138	88
CM10MWL1D	6.0	761	0.0085	181			
CM10MWL2D	6.3	696	0.0080	175			
CM10MWL3D	6.5	780	0.0107	147			
Average	**6.6**	**746**	**0.0091**	**168**	**593**	**0.0127**	**96**

Table A6. Continued

Specimen ID	Air Voids, %	Tensile Properties, Not Moisture Treated: Tensile Strength, kPa	Failure Strain, mm/mm	Secant Modulus, MPa	Tensile Properties, Moisture Treated: Tensile Strength, kPa	Failure Strain, mm/mm	Secant Modulus, MPa
5% Fine Consumer Waste							
CM5CFL1W	7.1				631	0.0141	90
CM5CFL2W	7.2				--	--	--
CM5CFL5W	7.2				815	0.0082	199
CM5CFL3D	7.0	904	0.0071	257			
CM5CFL4D	6.8	927	0.0044	425			
CM5CFL7D	6.6	941	0.0061	310			
Average	**7.0**	**924**	**0.0059**	**331**	**723**	**0.0112**	**145**
10% Fine Consumer Waste							
CM10CFL1W	6.7				729	0.0128	115
CM10CFL2W	7.0				685	0.0102	136
CM10CFL5W	7.8				805	0.0069	237
CM10CFL3D	6.3	1027	0.0065	319			
CM10CFL4D	6.4	944	0.0061	314			
CM10CFL7D	6.6	889	0.0076	236			
Average	**6.8**	**953**	**0.0067**	**290**	**739**	**0.0099**	**162**
5% Coarse Consumer Waste							
CM5CCL4W	6.9				587	0.0104	114
CM5CCL6W	6.9				474	0.0169	57
CM5CCL9W	6.7				546	0.0142	78
CM5CCL3D	6.6	739	0.0107	140			
CM5CCL5D	6.4	775	0.0090	174			
CM5CCL10D	6.3	750	0.0100	152			
Average	**6.6**	**754**	**0.0099**	**155**	**536**	**0.0138**	**83**

APPENDIX B

GUIDELINES FOR CONSTRUCTING ASPHALT PAVEMENTS CONTAINING ROOFING WASTE

GUIDELINES FOR CONSTRUCTION OF ASPHALT CONCRETE PAVEMENTS CONTAINING SCRAP SHINGLES

INTRODUCTION

These guidelines address the design, manufacture, placement, and compaction of hot mix asphalt (HMA) concrete paving mixtures containing a small amount of scrap asphalt shingles. Scrap shingles may be obtained directly from a roofing production plant (manufacturing waste) or from those torn off old roofs (consumer waste). Manufacturing waste is preferred over consumer waste because

- it is much more uniform in content;
- the asphalt is softer and more functional in a paving mixture;
- it is not contaminated with nails, wood, paper, plastic films, "hot mop" roofing, and other deleterious materials;
- it contains no organic roofing felt; and
- it contains no asbestos.

Straight-run consumer waste containing large pieces should not be incorporated into HMA; however, when screened over a 12.5 mm sieve or smaller, most of the deleterious materials are removed, and the product is suitable for use in HMA. Most modern shingles have a fiberglass backing rather than an organic felt backing.

Consumer waste typically contains about 20% to 30% asphalt; it may contain more than 30% asphalt. This is because some of the aggregate on used shingles has been lost due to weathering during service and the shredded product may contain roofing felt. The asphalt in new shingles is stiffened by air blowing and by adding filler. With age hardening, the mastic may not flow readily at typical plant operating temperatures. Penetration of asphalt extracted from consumer waste may have a penetration less than 5 dmm; whereas, that extracted from manufacturing waste may be 15 dmm or more.

The pieces of shredded roofing may not completely disintegrate during the plant or laboratory mixing process; therefore, the asphalt and filler in the roofing may not be utilized to the fullest extent in HMA.

Most waste roofing processors prefer to grind consumer waste. They find grinding manufacturing waste more difficult because the new asphalt becomes sticky when heating occurs due to the energy produced during the grinding process. Because of this, along with the fact that much more consumer waste is produced than manufacturing waste, highway agencies will have more opportunities to use consumer waste than manufacturing waste.

Scrap shingles are produced during the shingle manufacturing process for a variety of reasons. In some cases, the application of the colored granules to the surface of the shingle might not be completely uniform. In other cases, the color of the granules may differ and create differences in appearance when the shingles are placed on a roof. Occasionally, some shingles might get torn during the manufacturing process. Because of the speed at which the shingle manufacturing line typically moves, it is generally cheaper to pull suspect shingles from the line and scrap them than to slow down production to assure that each shingle is perfectly made. In addition to whole and partial piece shingles, shingle scrap also consists of the tabs that are cut out of each shingle. Typically, a shingle sheet is trimmed to produce a three-tab shingle. These cutouts are not reprocessed but are normally hauled to the landfill site together with the whole and partial piece shingle scrap.

Rather than pay the economic and social costs of hauling the scrap shingles to a landfill, it is more economical to recycle them into an asphalt concrete mixture. Although some mixtures have been produced that contained up to 20% scrap shingles, most HMA mixtures manufactured to date have consisted of less than 10% shingles by weight of mix. More typically, the range of scrap shingles used has been between 5% and 7%.

MIXTURE DESIGN

Shingle Composition

During the mixture design phase, scrap shingles should be considered to be similar to reclaimed asphalt pavement (RAP). Old HMA pavements are combinations of aggregate and asphalt cement. Scrap shingles are also a blend of aggregate and asphalt cement plus a small quantity of fibers. Although there are some significant differences between RAP and scrap shingles, handling of the two materials is essentially the same during the mixture design process.

The aggregate used in an HMA material is a combination of coarse and fine particles with a small amount of mineral filler added on occasion. In roofing shingles, the aggregate is normally a very fine gradation, generally with 100% of the material passing the 2.36 mm sieve and up to 40% of the aggregate passing the 75 μm sieve. The exact gradation of the aggregate in the shingle depends on the type of shingle being produced, the end use of the shingle, and the specifications of the company manufacturing the shingle.

The asphalt cement used in a conventional asphalt concrete mixture is generally graded on the basis of viscosity with normal grades being more viscous than AC-40 in the southern portion of the United States to as fluid as AC-5 in the northern portion of the continent. The asphalt cement incorporated into shingles is generally air blown and has a viscosity that is significantly greater (stiffer) than the asphalt cement used in HMA. Because of its stiffness, the viscosity of roofing asphalt is not normally measured at 60°C as is normal paving grade asphalt. An AC-20 paving asphalt may have a penetration in the range of 40 to 85; whereas, the penetration of the binder in a new shingle will be in the range of 15 to 20.

The binder content of RAP is usually in the range of 4% to 7%, depending primarily on the maximum size of coarse aggregate used in the mixture. In contrast, in a new shingle, the binder content is in the range of 16 to 25%, by weight of shingle. Thus, the amount of binder in the shingle is much greater on a unit weight basis than is the binder content in RAP. Asphalt content of consumer waste shingles may be greater than 30% because of aggregate loss during service.

In a typical modern shingle, the fiberglass mat makes up about 2% of the weight of the shingle. Most asphalt concrete mixtures do not contain any fibers. Recent practice in many states, however, has been to add polyester or polypropylene fibers to the HMA, normally at a concentration of about 0.3% by weight of mix. If the shingles are added to the new HMA at a rate of 5% by weight, however, the amount of fiberglass material incorporated into HMA would be about 0.1%, considerably less than the conventional additive rate for polyester or polypropylene fibers.

Aggregate Gradation

Because the aggregate used in roofing shingles is usually a blend of sand, limestone filler, and synthetic colored granules, the gradation is generally very fine. (The amount of natural sand typically used is very low, and the aggregate is primarily a blend of manufactured sand and colored granules). The gradation of the fine aggregate (natural sand and/or manufactured sand and mineral filler, if any) normally used in the HMA under consideration will have to be reviewed to determine the effect of the aggregate in the shingles on the gradation of the resulting mix. In some cases, it may be necessary to reduce the amount of fine aggregate normally used in the mixture to accommodate the fines contained in the shingles.

As stated above, it is possible for a typical shingle to have as much as 40% of the aggregate in the shingle pass the 75 μm sieve. While this is a large amount of very fine material, if the shingle scrap is incorporated at a rate of 5% by weight of mix, then only 2% of the aggregate passing the 75 μm sieve will come from the scrap shingles. If the mixture design specifications permit the aggregate passing the 75 μm sieve to be within a range of 2% to 6%, for example, and the amount of material passing that sieve is only 3% in the job mixture, then the shingles can be added without causing the fine aggregate to exceed the specified limit. If, however, the normal aggregate blend contains 5% passing the 75 μm sieve, then the amount of fine aggregate in the HMA job mix formula may have to be reduced somewhat. In addition, the effect of scrap shingle aggregate on the amount of material passing the other sieves other than the 75 μm sieve would need to be determined and compared to the specification limits.

In many cases, the use of shingles can help improve the stability of a mixture. This is because the vast majority of the fine aggregate incorporated into shingles is very angular, freshly crushed material. For compacted HMA mixtures that normally exhibit a low voids in mineral aggregate (VMA) content, the addition of the shingle aggregate can help increase the VMA. Further, incorporation of the small amount of fibers in the shingle scrap can also improve the properties of the HMA.

The gradation of aggregate in scrap shingles should be determined in two ways. First, if possible, the shingle manufacturer should be contacted to determine the type of aggregate material, the percentage of each type of material, and the gradation of each type of material used in the shingles. This information should be used to calculate a composite gradation for the total amount of aggregate in the shingles. Secondly, an extraction test should be conducted on a sample of shredded shingles and the gradation determined. The data obtained in each case should be compared to estimate the gradation of the aggregate being added to the HMA mixture. Because of sampling errors, the gradation of the aggregate obtained from the shingle manufacturer will generally be more accurate than the data determined from the extraction test.

The consistency of the shingle manufacturing process is normally much greater than the consistency of the production of an asphalt concrete mixture, particularly if RAP is being added to the mix. In most cases, the gradation of the aggregate found in a scrap shingle from a given shingle manufacturing plant will be more consistent than will be the gradation of the fine aggregate received from a quarry. Aggregate gradations in consumer waste may vary considerably.

In summary, handling scrap shingles from an aggregate gradation standpoint is not significantly different than handling reclaimed asphalt pavement (RAP). The gradation of the aggregate in the shingles needs to be determined, and a blend of shingle aggregate and the other available conventional aggregate needs to be calculated such that it will fall within the mixture specifications. In some cases, it might be necessary to increase or decrease the amount of shingles incorporated into the mixture from a typical level of 3%. Furthermore, it might be necessary to reduce the amount of normal fine aggregate used in the mixture to accommodate the relatively fine gradation of the aggregate in the shingles.

Asphalt Content and Composition

Shingles typically contain between 15 and 25% air blown asphalt cement. If the scrap shingles contain 18% binder and if the amount of shingles used in the HMA is 5% by weight of mix, up to 0.95% of the asphalt needed in the final mixture may be derived from the shingles. Thus, if a surface course mixture design would normally require 5.00% asphalt cement, only 4.05% new asphalt would be needed in the mixture since 0.95% of the total binder content would come from the added shingle material. Because of age hardening, consumer waste is not likely to contribute all its asphalt to the HMA so that the virgin asphalt content will be affected somewhat less than illustrated here.

From a mixture design standpoint, the amount of asphalt contained in scrap shingles can be determined by performing an extraction test on the shingle and measuring the percentage of binder recovered. In addition, a cross-check can be obtained by contacting the shingle manufacturer and requesting information on the typical quantity of asphalt incorporated into the shingles during production. Once the binder content in the shingles has been determined and verified, it is a simple calculation to determine the maximum contribution of the shingles to the total binder content of the HMA mix. That value is, of course, dependent on the percentage of shingles used in the mixture.

A more difficult question concerns the viscosity of the resultant binder material. Since the asphalt cement used in shingles is air blown, it has a relatively high viscosity. When blended with regular paving grade asphalt such as AC-20, the resulting binder viscosity will typically be above the specification limits. This problem can be handled in a number of ways.

The easiest way to address the viscosity question is to again treat the scrap shingles as RAP and make the same adjustments to the viscosity of the shingle binder material that would be made to a mixture containing asphalt cement from RAP. Depending on the amount of shingles incorporated into the mix, it might not be necessary to make any adjustments to the grade of asphalt cement typically used. This might be true if only 2% or 3% shingles were used in a mixture. If 4% to 6% shingle scrap were used, it might be necessary to use a virgin binder one grade softer than usual (e.g., to an AC-10 grade). If 7% to 10% shingles were used, the virgin asphalt might have to be two grades softer than normal (e.g., an AC-5) or even consider the use of a recycling agent. In this case, the viscosity grade of the new binder would be dependent on both the viscosity of the asphalt cement in the shingles and on the amount of shingles incorporated into the HMA mix.

Another way to address the viscosity question is to use an asphalt cement blending chart (e.g., ASTM D 4887). The viscosity of the oxidized asphalt is entered on one side of the chart and the required viscosity of the resulting mixture is also entered. The viscosity of the asphalt cement or recycling agent needed to bring the oxidized binder material back within the required limits is then read from the chart.

Shingles are often added to an HMA mixture together with RAP material. In these cases, the amount and the viscosity of asphalt cement in both the shingles and in the RAP must be determined. A viscosity blending chart would then be used to determine the grade of virgin asphalt cement or recycling agent needed to provide the required properties to the total binder in the resulting HMA. In summary, the binder content of the shingles, in terms of the amount and the viscosity, is treated in the same manner as when handling the asphalt cement in RAP.

Mixture Preparation

Shredded shingles added to the aggregate during the mixture design mixing process should be less than 12.5 mm in the maximum dimension and preferably less than 6.3 mm. Although the necessary heat is usually available in an asphalt concrete batch or drum mix plant to soften and melt the shredded shingles during plant mixture production, it will normally be necessary to increase the temperature of the new aggregate in the mixture to hasten the melting of the shingle pieces during the laboratory mixture design process. In addition, it will typically be required to increase the mixing time in the laboratory in order to assure that all of the pieces of shingle are melted and properly dispersed into the mix. The amount of the increases in new aggregate temperature and mixing time will depend on the amount of shingles used in the mix.

The addition of shingles may increase the stiffness of the resulting HMA mix due both to the higher viscosity of the blended binder material and the addition of the small amount of fibers to the mix. This may result in an increase in the Marshall stability and the indirect tensile strength of the mixture. Furthermore, because of the angular fine aggregate, fibers, and harder asphalt in the shingles, the VMA in the compacted mixture will usually increase, although this phenomenon may be offset by the increase in filler (aggregate passing the 75 μm sieve) in the mix. Finally, because of a slight increase in mixture stiffness, the air void content of the laboratory compacted mixture may be somewhat higher than the air void content of the conventional mixture unless the compaction temperature is raised to offset this factor. In general, however, if only about 3% shingles are added and the pieces are properly melted and dispersed, the properties of the mixture with the shingles will not be much different than the properties of a normal mixture without shingles.

SHINGLE PROCESSING

Shingle Size Reduction

One primary action that must be taken is to reduce the size of the shingle scrap to that which can be properly processed by the asphalt batch or drum mix plant. Shingle scrap can be obtained in various sizes up to the dimensions of a whole shingle. For efficient processing by an asphalt plant, the maximum dimension of the shingle pieces generally should be smaller than 12.5 mm. This is about the minimum size currently producible for manufacturing waste, but consumer waste can be ground to much smaller sizes.

A variety of types of equipment can be used to reduce the size of the shingle pieces. Hammermills, shredders, and different types of cutting machines have been employed. For most operations, the whole shingles or manufacturing trimmings are loaded into a bin and conveyed into the shredder. Upon exiting the shredder, the shredded pieces are passed over a screen, usually with a 12.5 mm screen cloth. Oversize pieces are returned on a closed-loop conveyor system to the bin for a successive pass(es) through the shredder.

Improvements are needed in the efficiency of the currently available shingle shredding machinery. Most of the machinery presently used was designed for processing materials other than shingles. During hot weather or when the shingle scrap is wet, the equipment sometimes gets bogged down, and it is difficult to achieve the desired particle size or production rate. The production rate of the shredding equipment and the size of the pieces produced depends on the type of machinery used. In many cases, the amount of shingles processed has been relatively low -- in the range of 2.7×10^4 to 4.5×10^4 kg/hour of properly sized shingle scrap. Typically, this amount is adequate if no more than 5% shingle scrap is added to the HMA. Therefore, if shingles are shredded at a rate of 3.6×10^4 kg/hour and if the shingles are incorporated in the HMA at a concentration of 5%, the asphalt plant could produce about 7.3×10^5 kg/hour of HMA and just use up all of the shingles processed. Because of this, many contractors either operate the shingle shredding equipment only intermittently or use the shingles as feed for more than one asphalt plant.

Shingle Stockpiling

During hot weather, prolonged storage (more than a few days) of shredded manufacturing waste in a stockpile may result in major problems. Due to the stickiness of the neat binder in these shingles, there is a tendency for the pieces to clump together under high temperatures and pressure (e.g., at the bottom of the pile). This problem can be avoided by grinding the shingles only when needed (i.e., just before they are to be introduced into the asphalt plant).

In many cases, however, this cannot be efficiently or economically executed. Some contractors, therefore, have mixed shredded manufacturing waste with RAP and stored the blended materials together in a stockpile. For this process, two different feed bins are employed, one for shredded shingles and one for RAP. Various proportions of shingles to RAP have been used, with a ratio of one part shredded shingles to four parts RAP being typical. The blend of shingles and RAP is less likely to consolidate and should be much easier to excavate from the stockpile for delivery into the plant.

For stockpiling shredded manufacturing waste, it may also be possible to blend it with crusher screenings or sand normally used in the HMA mixture. Knowing the properties of this combined material, it can be incorporated into the mixture design.

Another reason to avoid reducing the size of the shingles to small particles until necessary is to minimize the amount of moisture in the shingle stockpile. Stockpiled whole shingles or even shingle trimmings tend to shed water fairly effectively. When the shingles are shredded, however, there is a much greater opportunity for moisture to accumulate in the stockpile among the small particles. As the amount of moisture in the shredded shingles increases, the chance that the shingles will clump together increases and the cost of drying the material in the plant is greater.

Because of the relatively harder aged asphalt in consumer waste, conglomeration during stockpile storage is less likely to be a problem. However, the potential for accumulation of moisture warrants covering the stockpile if rainfall is anticipated.

PLANT PRODUCTION

Cold Feed System

Whether the shredded shingles are used alone or in combination with RAP, the material is typically delivered into the asphalt plant through the RAP cold feed system. Care must be taken not to pack the shingles into the RAP cold feed bin. The front end loader operator must slowly deposit the shingles into the bin, emptying the loader bucket over a period of time (a few minutes) instead of quickly filling the bin in one drop. This procedure is recommended to prevent consolidation of the shingles in the bin and bridging of the material over the discharge conveyor at the bottom of the bin.

Manufacturing waste should not be left in the cold feed bin for a long period of time (even overnight). Because of the stickiness of the neat binder in the shingles, conglomeration of the shingle particles may occur. When mixture production is completed for the day, the cold feed bin should be emptied of shingles or the shingle/RAP blend. Consumer waste, with the relatively harder asphalt, may not present this problem.

Batch Plant Operations

Shredded shingles, like RAP, can be fed into a batch plant in one of three locations: (1) at the bottom of the hot elevator, (2) into the weigh hopper, or (3) directly into the pugmill. If the shingles are deposited into the bottom of the hot elevator, some heat transfer will occur between the new aggregate and the shingles during the trip up the hot elevator, over the screen deck, and into the hot bins. Using this procedure offers the possibility that the hot shingle particles will stick in the screen cloth and blind the screens, causing a change in the gradation of the aggregate entering the individual hot bins. Thus, a preferable procedure is to charge the shredded shingles into either the batch plant weigh hopper or pugmill.

In order to get the proper heat transfer from the new aggregate to the shingles, depending on the amount of shingles added to the mix, it may be necessary to increase the temperature of the new aggregate exiting the dryer. If 5% shingles are introduced into the mix, the temperature of the new aggregate may have to be increased to about 200°C in order to get the shingles to melt in a relatively short period of time and avoid excessively extending the dry or wet mixing cycle in the pugmill.

Alternatively, if the temperature of the new aggregate is not increased, it may be necessary to increase the dry mixing time (i.e., the blending of the new aggregate and the shingle pieces) in order to attain the needed heat transfer and melt the shingle particles. Dry mixing time, not wet mixing time, should be increased in order to avoid exposure of the virgin binder to high temperatures for longer than necessary to properly coat the new aggregate and shingle aggregate particles. In any case, it is very important that all of the shingle particles be completely broken down before the new asphalt cement is added to the pugmill. This may necessitate an increase in the dry mixing time from a normal minimum of one second to as much as 10 to 20 seconds. This increase in dry mixing time, of course, proportionately reduces the production rate of the batch plant.

A combination of an increase in the temperature of the new aggregate and an increase in the dry mixing time can also be employed to assure that the shingle particles are completely melted and distributed throughout the HMA mix. In most cases, it is more efficient to increase the new aggregate temperature compared to increasing the dry mixing time. In every case, no significant quantity of whole shingle pieces should be present in the mixture as it is discharged from the pugmill. Upon delivery from the batch plant pugmill, the shingle-modified HMA should be indistinguishable from a conventional asphalt concrete mixture without shingles.

Drum Mix Plant Operations

The shingles must be fed into a drum mix plant, whether parallel flow or counter flow, through the RAP feed inlet. The shingles cannot be introduced into the new aggregate feed end of the plant due to the production of "blue smoke" when the asphalt in the shingle particles is exposed to the burner flame and the very high temperature exhaust gases. In fact, this combustible material could catch fire. Once the shingles are introduced into the plant through the RAP inlet, the processing of the material is no different than the processing of RAP.

No significant number of whole shingle particles should be visible when the HMA mixture is discharged from the drum mix plant. If distinct shingle particles are present in the mix, it may be necessary to increase the temperature of the new aggregate in the drying end of the drum in order to obtain more heat transfer from the new aggregate to the shingle particles. It may also be necessary to move the asphalt cement injection pipe farther down the drum to permit more mixing time for the shingles and the new aggregate before the virgin asphalt is added to the HMA mix. Nevertheless, the addition of shingles to the drum mix plant is no different than the addition and mixing of RAP in the same plant.

PLACEMENT AND COMPACTION

Mixture Placement

Temporary storage of the shingle modified mixture in the silo, if required, is no different from the storage of a conventional HMA. Delivery of the modified mixture to the paver is also identical to that for conventional HMA. Finally, the placement of the shingle mixture onto the roadway by the paver is normal. As long as the shingles are properly melted and evenly distributed throughout the mix, the paving crew should not notice any significant difference in the workability of the modified mixture as compared to conventional HMA.

If the shingles are not completely melted or are not uniformly distributed, the modified mixture may be stiffer than the conventional mix. Further, if the added virgin asphalt is not low enough in viscosity to sufficiently reduce the viscosity of the binder in the shingles, the modified mixture may be stiffer than the conventional mix. In either case, such a mixture may pull somewhat under the paver screed, and the texture of the surface may be more open. Hand working a stiffer mixture or one containing fibers may be more difficult.

Mat Compaction

If the shingles are completely melted and uniformly dispersed in the HMA, there should be no difference in the amount of compactive effort required to obtain the proper density. Generally, the modified mixture will be slightly stiffer than the conventional HMA and may require a greater compactive effort to attain the required degree of density. This means that the rollers must operate closer to the paver and/or make more passes over a given point in the pavement surface in order to obtain the desired air void content in the mat. If a higher plant temperature is used to effect adequate dispersion of the shingle particles, compaction operations may be no different than that for conventional HMA.

APPENDIX C

SPECIFICATIONS FOR USING ROOFING WASTE IN HOT MIX ASPHALT

SPECIAL SPECIFICATION

ITEM RAS-1

HOT MIX ASPHALT CONCRETE PAVEMENT

CONTAINING RECLAIMED ROOFING SHINGLES

(Note: All changes in Item 340 to accommodate reclaimed asphalt shingles have been underlined)

1. Description. The Item shall govern for the construction of a base course, a level-up course, a surface course or any combination of these courses as shown on the plans, each course being composed of a compacted mixture of aggregate, asphalt cement, and reclaimed asphalt shingles (RAS) mixed hot in a mixing plant, in accordance with the details shown on the plans and the requirements herein.

2. Materials. The Contractor shall furnish materials to the project meeting the following requirements prior to mixing. Additional test requirements affecting the quality of individual materials or the paving mixture shall be required when indicated on the plans.

(1) Aggregate. The aggregate shall be composed of a coarse aggregate, a fine aggregate, and if required or allowed, a mineral filler and may include reclaimed asphalt pavement (RAP) and/or RAS. The use of RAS may be required on the plans. RAS use will be allowed in all mixtures except as specifically excluded herein or on the plans. Samples of each aggregate shall be submitted for approval in accordance with Item 6, "Control of Materials."

Aggregate from each stockpile shall meet the quality requirements of Table 1 and other requirements as specified herein. The aggregate contained in RAS will not be required to meet Table 1 requirements except as shown on the plans.

(a) Coarse Aggregate. Coarse aggregate is defined as that part of the aggregate retained on a 2.00 millimeter sieve. The aggregate shall be natural, lightweight or manufactured, and be of uniform quality throughout. When specified on the plans, certain coarse aggregate material may be allowed, required or prohibited.

Lightweight aggregate is defined as expanded shale, clay or slate produced by the rotary kiln method. Manufactured aggregate is defined as any aggregate other than natural or lightweight.

Lightweight or manufactured materials with the same or similar gradation whose unit weight vary by more than 6.0 percent from that used in the mixture design may require a redesign.

Gravel from each source shall be so crushed as to have a minimum of 85 percent of the particles retained on the 4.75 millimeter sieve with two or more mechanically induced crushed faces, as determined by Test Method Tex-460-A (Part I). The material passing the 4.75 millimeter sieve and retained on the 2.00 millimeter sieve must be the product of crushing aggregate that was originally retained on the 4.75 millimeter sieve.

The polish value of the virgin (not previously used in construction) coarse aggregate used in the surface or finish course shall not be less than the value shown on the plans, when tested in accordance with Test Method Tex-438-A. Unless otherwise shown on the plans, the polish value requirement will apply only to aggregate used on travel lanes. For rated sources, the Materials and Tests Division's Rated Source Polish Value (RSPV) catalog will be used to determine polish value compliance. Unless otherwise shown on the plans, virgin coarse aggregates may be blended in accordance with Test Method Tex-438-A, Part II, Method B, to meet the polish value requirement. When blending is allowed, the blended virgin aggregates shall contain non-polishing aggregates of not less than the percent by volume of the critical size shown below for the specified mixture.

	Type C	Type D	Type F
Retained on the 4.75 mm sieve	50%	50%	
Retained on the 2.00 mm sieve			50%

The polish value of RAP aggregate will not be used in any determination of polish value specification compliance.

(b) Reclaimed Asphalt Pavement (RAP). RAP is defined as a salvaged, milled, pulverized, broken or crushed asphaltic pavement. The RAP to be used in the mix shall be crushed or broken to the extent that 100 percent will pass the 50 millimeter sieve.

The stockpiled RAP shall not be contaminated by dirt or other objectionable materials. Unless otherwise shown on the plans, stockpiled, crushed RAP must have either a decantation of no more than five (5) percent or a plasticity index of no more than eight (8), when tested in accordance with Test Method Tex-406-A, Part I, or Test Method Tex-106-E, respectively. This requirement applies to stockpiled RAP from which the asphalt has not been removed by extraction.

State-owned RAP sources that are designated on the plans will be available for use by the Contractor. Only RAP from state-owned sources will be allowed in mixes using more than 20 percent RAP, unless otherwise shown on the plans. When RAP sources are designated, either in stockpile or existing pavements, the approximate gradation, asphalt content, and asphalt cement properties of this material will be shown on the plans for material existing in pavements, or in a special provision "Local Material Sources for Reclaimed Asphaltic Pavement" for material in existing stockpiles.

Any Contractor-owned RAP that is to be used on this project shall remain the property of the Contractor while stockpiled and shall not be intermingled with State-owned RAP stockpiles. Any unused Contractor-owned RAP material shall be removed from the project site upon completion of the project.

Only RAP from designated sources may be used in surface courses.

Excess RAP removed from designated sources will remain the property of the State and will be delivered to stockpile locations shown on the plans.

(c) Reclaimed Asphalt Shingles (RAS). RAS may consist of manufacturing waste or consumer waste.

Manufacturing waste shingles are defined as new material that is obtained from a roofing shingle production plant. The shingles used in a particular mixture shall be from only one factory source, and shingles from more than one factory source shall not be mixed together. In addition, manufacturing waste shingles used in a particular mixture shall have a consistent binder content and aggregate gradation. Manufacturing waste shingles containing different aggregate types and gradations and different binder contents and viscosities shall not be mixed together. This is a premium product and may be used in hot mix asphalt (HMA) in quantities exceeding 5%.

Consumer waste shingles are those obtained during the removal of existing roofs (tear-offs). Because of the inherent variability of these materials, the RAS content of HMA should be limited to 6%.

The source of the RAS shall be preapproved before they may be used in HMA. The RAS supplier shall certify that the shingles contain no harmful quantities of asbestos in accordance with the guidelines provided by the Environmental Protection Agency.

The addition of RAS to HMA is very similar to the addition of reclaimed asphalt pavement (RAP) to the same mixture. Indeed, both RAS and RAP can be added simultaneously to the same mixture at the same time.

RAS shall have an asphalt content of 15 to 25% by mass of shingle. The gradation of the aggregate in the RAS shall be such that 100% passes the 4.75 mm sieve and a maximum of 40% passes the 75 μm sieve. The RAS shall be preprocessed by the contractor so that 100% of the shingle particles pass the 19 mm sieve and 95% of the shingle particles pass the 12.5 mm sieve. The contractor shall have the option to use up to 5% manufacturing waste shingles in surfacing mixtures and level-up courses and up to 10% manufacturing waste shingles in base course mixtures. The contractor shall have the option to use up to 3% consumer waste shingles in surfacing mixtures and level-up courses and up to 6% consumer waste shingles in base course mixtures.

RAS can be stockpiled in one of two forms: (1) whole and/or partial shingles which have not yet been reduced in size or (2) shingles which have been shredded to meet the maximum size requirements stated above. Stockpiled RAS shall not be contaminated by dirt or other objectionable materials. Unless otherwise shown on the plans, stockpiled RAS shall have either a decantation of 5% or less or a plasticity index of 8 or less when tested in accordance with test method Tex-406-A, Part I, or test method Tex-106-E, respectively. This requirement applies to stockpiled RAS from which the asphalt has not been removed by extraction. Shredded shingles may be blended with a known quantity fine aggregate and stockpiled. Blending with aggregate may be necessary when it is desirable to stockpile shredded manufacturing waste to avoid conglomeration of the sticky shingle particles.

The polish value of the aggregate in the RAS will not be used in any determination of polish value specification compliance.

Any contractor-owned RAS that is to be used on the project shall remain the property of the contractor, while stockpiled. Any unused contractor-owned RAS shall be removed from the project site upon completion of the project.

(d) Fine Aggregate. The fine aggregate is defined as that part of the aggregate passing the 2.00 millimeter sieve and shall be of uniform quality throughout. When specified on the plans, certain fine aggregate material may be allowed, required or prohibited. However, a maximum of 15 percent of the total virgin aggregate may be field sand or other uncrushed fine aggregate.

Screenings shall be supplied from sources whose coarse aggregate meets the Los Angeles abrasion and magnesium sulfate soundness loss requirements shown in Table 1, unless otherwise shown on the plans.

1. Unless otherwise shown on the plans, stone Screenings are required and shall be the result of a rock crushing operation and meet the following gradation requirements, when tested in accordance with Test Method Tex-200-F, Part I.

	Percent by Mass
Passing the 9.5 mm sieve	100
Passing the 2.00 mm sieve	70-100
Passing the 75 μm sieve	0-15

2. Crushed gravel Screenings may be used with, or in lieu of, stone screenings when shown on the plans. Crushed gravel screenings must be the product of crushing aggregate that was originally retained on the 4.75 millimeter sieve and meet the gradation for stone screenings shown above.

Table 1. Aggregate Quality Requirements*.

Requirement	Test Method	Manufactured or Natural Aggregate	Lightweight Aggregate
COARSE AGGREGATE			
Dry Loose Unit Weight, kg/m^3 minimum	Tex-404-A	-	560
Pressure Slaking Value, maximum	Tex-431-A	-	4.0
Freeze Thaw Loss, percent, max.	Tex-432-A	-	7.0
24 Hour Water Absorption, percent, maximum	Tex-433-A	-	12.0
Deleterious Material, percent, maximum	Tex-217-F Part I	1.5	1.5
Decantation, percent, maximum	Tex-217-F Part II	1.5	1.5
Los Angeles Abrasion, percent, maximum	Tex-410-A	40	35
Magnesium Sulfate Soundness Loss, 5 cycle, percent, maximum	Tex-411-A	30**	-
FINE AGGREGATE			
Linear Shrinkage, maximum	Tex-107-E Part II	3	3
COMBINED AGGREGATES* **			
Sand Equivalent Value, Minimum	Tex-203-F	45	45

* Sampled during delivery to the plant or from the stockpile, unless otherwise shown on the plans.

** Unless otherwise shown on the plans.

*** Aggregates, without added mineral filler, RAP, or additives, combined as used in the job-mix formula.

(e) **Mineral Filler.** Mineral filler shall consist of thoroughly dried stone dust, portland cement, lime, fly ash, or other mineral dust approved by the Engineer. The mineral filler shall be free from foreign matter.

When a specific type of mineral filler is specified on the plans, fines collected by the baghouse or other air cleaning or dust collecting equipment shall not be used to meet this requirement. When mineral filler is not specifically required, the addition of baghouse or other collected fines will be permitted if the mixture quality is not adversely affected in the opinion of the Engineer. In no case shall the amount of material passing the 75 micrometer sieve exceed the tolerances of the job-mix formula or the master gradation limits.

When mineral filler is specified or allowed by the Engineer, or baghouse fines are permitted to be added to the mixture, it shall be proportioned into the mix by a vane meter or an equivalent measuring device acceptable to the Engineer. A hopper or other acceptable storage system shall be required to maintain a constant supply of mineral filler to the measuring device.

The measuring device for adding mineral filler shall be tied into the automatic plant controls so that the supply of mineral filler will be automatically adjusted to plant production and provide a consistent percentage to the mixture. When shown on the plans, the measuring device for adding baghouse fines shall have controls in the plant control room which will allow manual adjustment of feed rates to match plant production rate adjustments.

When tested in accordance with Test Method Tex-200-F (Part I or Part III, as applicable), the mineral filler shall meet the following gradation requirements, unless otherwise shown on the plans. Baghouse fines are not required to meet the gradation requirements.

	Percent by Mass or Volume
Passing the 600 μm sieve	95-100
Passing the 180 μm sieve, not less than	75
Passing the 75 μm sieve, not less than	55

(2) Asphalt Material.

(a) Paving Mixture. Asphalt cement for the paving mixture shall be of the grade shown on the plans or designated by the Engineer and shall meet the requirements of Item 300, "Asphalts, Oils and Emulsions." The contractor shall notify the Engineer of the source of the asphaltic material prior to design of the asphaltic mixture. This source shall not be changed during the course of the project without the authorization of the Engineer. Should the source of asphaltic material be changed, the moisture resistance of the new material combination will be evaluated to verify that the requirements of Subarticle 340.3(1) are met.

(b) RAP Paving Mixture. When more than 20 percent RAP is used in the produced mixture, the asphalt in the RAP shall be restored to the properties indicated below. Restoration will be made by adding asphalt recycling agent and/or virgin asphalt cement meeting the requirements of Item 300, "Asphalts, Oils and Emulsions."

The mixture design will include recovery of asphalt from the RAP in accordance with Test Method Tex-211-F. The recovered asphalt shall be blended in the laboratory with the amount of asphalt cement and/or asphalt recycling agent selected for the project. The following tests shall be performed on the laboratory blend:

1. Viscosity, 60°C, Pa • s - Test Method Tex-528-C
2. Thin Film Oven Aging Test - Test Method Tex-510-C
3. Viscosity, 60°C, Pa • s, on residue from the Thin Film Oven Aging Test - Test Method Tex-528-C
4. Penetration at 25°C, 100 g, 5 s, (0.1 mm), on residue from the Thin Film Oven Aging Test - Test Method Tex-502-C

The viscosity in poises equivalent to the residue penetration at 25°C shall be calculated as set forth in Test Method Tex-535-C. The viscosity index of the residue shall then be calculated as follows:

$$\text{Residue Viscosity Index} = \frac{\text{Residue Viscosisty, Pa} \bullet \text{s, equivalent to Penetration at } 25°\text{C, (0.1 mm)}}{\text{Residue Viscosity, } 60°\text{C, Pa} \bullet \text{s}}$$

The aging index of the laboratory blended asphalt shall be determined as follows:

$$\text{Aging Index} = \frac{\text{Residue Viscosisty, } 60°\text{C, Pa} \bullet \text{s}}{\text{Original Viscosity, } 60°\text{C, Pa} \bullet \text{s}}$$

The laboratory blended asphalt shall meet the following requirements:

Residue Viscosity Index, maximum 1500
Aging Index, maximum 3.0

Samples of asphalt recovered from plant produced mixture shall show the asphalt to meet the following requirements when tested in accordance with Test Methods Tex-211-F and Tex-502-C.

	Minimum	Maximum
Penetration, 25°C, 100 g, 5 s, (0.1 mm)	30	55

(c) Tack Coat. Asphaltic materials, shown on the plans or approved by the Engineer, shall meet the requirement of Item 300, "Asphalts, Oils and Emulsions."

(3) Additives. Additives to facilitate mixing and/or improve the quality of the asphaltic mixture or track coat shall be used when noted on the plans or may be used with the authorization of the Engineer.

Unless otherwise shown on the plans, the Contractor may choose to use either lime or a liquid antistripping agent to reduce the moisture susceptibility of the aggregate. The evaluation and addition of antistripping agents will be in accordance with Item 301, "Asphalt Antistripping Agents."

3. Paving Mixtures. The paving mixtures shall consist of a uniform mixture of aggregate, hot asphalt cement, and additives if allowed or required.

An asphalt mixture design is a laboratory process which includes the determination of the quality of the asphalt and the individual aggregates, the development of the job-mix formula, and the testing of the combined mixture.

The job-mix formula lists the quantity of each component to be used in the mix and the combined gradation of the aggregates used.

(1) Mixture Design. The Contractor shall furnish the Engineer with representative samples of the materials to be used in production. Using these materials, the mix shall be designed in accordance with Test Method Tex-204-F to conform with the requirements herein. Unless otherwise shown on the plans, the Engineer will furnish the mixture design for mixtures when using 20 percent or less RAP and/or 6% or less RAS. The Engineer may accept a design from the Contractor which was derived using these design procedures.

The second and subsequent mixture designs, or partial designs, for each type of paving mixture which are necessitated by changes in the material or at the request of the Contractor will be charged to the Contractor when a rate is shown on the plans.

The Contractor shall furnish the mixture design for all mixtures containing more than 20 percent RAP and/or more than 6% RAS. This mixture design shall include, in addition to the results of the tests required for virgin mixes, the results of tests run on the proposed asphalt blend. The Contractor shall furnish the Engineer with representative samples of all materials to be used in the proposed mixture. The Engineer will verify the proposed mixture design.

Should the Engineer's tests find that the proposed mixture design does not meet the requirements of this specification, the Contractor shall furnish another mixture design.

The bulk specific gravity will be determined for each aggregate to be used in the design mixture. If the determined values vary by 0.300 or more, the Volumetric Method, Test Method Tex-204F, Part II, will be used. The bulk specific gravity of aggregates in RAP will be determined on extracted aggregates.

When properly proportioned, for the type specified, the blend of aggregates shall produce an aggregate gradation which will conform to the limits of the master grading shown in Table 2. Unless otherwise shown on the plans, the gradation of the aggregate will be determined in accordance with Test Method Tex-200-F, Part I (Dry Sieve Analysis), to develop the job-mix formula.

The master grading limits for the appropriate type and the proposed job-mix formula will be plotted on a gradation chart with sieve sizes raised to the 0.45 power. This plot must show that the proposed job-mix formula is within the limits of the master grading. Gaps in gradation shown by this plot should be avoided.

The voids in the mineral aggregate (VMA) will be determined as a mixture design requirement only, in accordance with Test Method Tex-200-F, and shall not be less than the value indicated in Table 2.

Unless otherwise shown on the plans, the mixture of aggregate, asphalt and additives proposed for use will be evaluated in the design stage for moisture susceptibility, in accordance with Item 301, "Asphalt Antistripping Agents." The Engineer may waive this test if a similar design, using the same ingredients, has proven satisfactory.

To substantiate the design, trial mixtures shall be produced and tested using all of the proposed project materials and equipment prior to any placement. The Engineer may waive trial mixtures if similar designs have proven satisfactory.

(2) Density. The mixture shall be designed to produce an acceptable mixture at an optimum density of 96.0 percent, when tested in accordance with Test Method Tex-207-F and Test Method Tex-227-F. The operating range of control of laboratory density during production shall be optimum density plus or minus 1.5 percent.

Laboratory density is a mixture design and process control parameter. If the laboratory density of the mixture produced has a value outside the range specified above, the Contractor shall investigate the cause and take corrective action. If three (3) consecutive test results fall outside the specified range, production shall cease unless test results or other information indicate, to the satisfaction of the Engineer, that the next mixture to be produced will be within the specified range.

Table 2. Master Grading Percent Passing by Mass or Volume.

Sieve Size	Type				
	A Coarse Base	B Fine Base	C Coarse Surface	D Fine Surface	F Fine Mixture
37.5 mm	100				
31.5 mm	95-100				
25.0 mm		100			
22.4 mm	70-90	95-100	100		
16.0 mm		75-95	95-100		
12.5 mm	50-70			100	
9.5 mm		60-80	70-85	85-100	100
6.3 mm					95-100
4.75 mm	30-50	40-60	43-63	50-70	
2.0 mm	20-34	27-40	30-40	32-42	32-42
425 µm	5-20	10-25	10-25	11-26	9-24
180 µm	2-12	3-13	3-13	4-14	3-13
75 µm	1-6*	1-6*	1-6*	1-6*	1-6*
VMA % minimum	11	12	13	14	15

* 2-8 when Test Method Tex-200-F, Part II (Washed Sieve Analysis) is used.

(3) Stability. The materials used in the mixture design shall produce a mixture with a stability value of at least 35, unless otherwise shown on the plans, when tested in accordance with Test Method Tex-208-F.

If, during production, the stability value falls below the specified minimum, the Engineer and the Contractor shall closely evaluate other test result values for specification compliance such as gradation, asphalt content, moisture content, crushed faces, etc., to determine the cause and take corrective action. If three (3) consecutive test results fall below the minimum value specified, production shall cease unless test results or other information indicate, to the satisfaction of the Engineer, that the next material to be produced will meet the minimum value specified.

(4) Job-Mix Formula Field Adjustments. The Contractor shall produce a mixture of uniform composition closely conforming to the approved job-mix formula.

If, during initial days of production, it is determined that adjustments to the mixture design job-mix formula are necessary to achieve the specified requirements, or to more nearly match the aggregate production, the Engineer may allow adjustment of the mixture design job-mix formula within the following limits without a laboratory redesign of the mixture. The adjusted job-mix formula shall not exceed the limits of the master grading for the type of mixture specified nor shall the adjustments exceed five (5) percent on any one sieve, 12.5 millimeter size and larger, or three (3) percent on the sieve sizes below the 12.5 millimeter sieve.

When the considered adjustments exceed either the five (5) or three (3) percent limits, and the Engineer determines that the impact of these changes may adversely affect pavement performance, a new laboratory mixture design will be required.

The asphalt content will be adjusted as deemed necessary by the Engineer to maintain desirable laboratory density near the optimum value while achieving other mix requirements.

(5) Types. The aggregate gradation of the job-mix formula shall conform to the master grading limits shown in Table 2 for the type mix specified on the plans.

(6) Tolerances. The gradation of the aggregate and the asphalt cement content of the produced mixture shall not vary from the job-mix formula by more than the tolerances allowed herein. When within applied tolerances, the gradation of the produced mixture may fall outside the master grading limits for any of the sieve sizes from the largest sieve size on which aggregate may be retained down through the 180 micrometer sieve. Only the quantity of aggregate passing the 75 micrometer sieve is further restricted to conform to the master grading limitations shown in Table 2 or as modified in Test Method Tex-229-F. A tolerance of two (2) percent is allowed on the sieve size for each mixture type which shows 100 percent passing in Table 2.

	Tolerance, Percent by Mass or Volume as Applicable
Passing the 31.5 mm to 2.00 mm sieve	Plus or Minus 5
Passing the 425 μm to 75 μm sieve	Plus or Minus 3
Asphalt, mass	Plus or Minus 0.5
Asphalt, volume	Plus or Minus 1.2

The mixture will be tested in accordance with Test Method Tex-210-F, or Test Method Tex-228-F will be used in conjunction with combined cold feed belt samples tested in accordance with Test Method Tex-229-F. Other methods of proven accuracy may be used. The methods of test will be determined by the Engineer. However, mixtures produced by weigh-batch plants and all mixtures containing RAP and/or RAS will be tested for gradation in accordance with Test Method Tex-210-F. If three (3) consecutive tests indicate that the material produced exceeds the above tolerances on any individual sieve, or if two (2) consecutive tests indicate that the asphalt content tolerance is exceeded, production shall stop and not resume until test results or other information indicate, to the satisfaction of the Engineer, that the next mixture to be produced will be within the above tolerances.

When disagreements concerning determination of specification compliance occur between allowed sampling and testing procedures, extracted aggregate testing shall take precedence over cold feed belt testing.

When cold feed belt samples are used for job control, the Engineer will select the sieve analysis method that corresponds with the one used to determine the mixture design gradation. The tolerances will be adjusted as outlined in Test Method Tex-229-F.

4. Equipment.

(1) General. All equipment for the handling of all materials, mixing, placing and compacting of the mixture shall be maintained in good repair and operating condition and subject to the approval of the Engineer. Any equipment found to be defective and potentially having a negative effect on the quality of the paving mixture or ride quality will not be allowed.

(2) Mixing Plants. Mixing plants may be the weigh-batch type, the modified weigh-batch type, the drum-mix type, or the specialized recycling type. All plants shall be equipped with satisfactory conveyors, power units, mixing equipment, aggregate handling equipment, bins and dust collectors.

Automatic proportioning devices are required for all plants and shall be in accordance with Item 520, "Weighing and Measuring Equipment."

It shall be the Contractor's responsibility to provide safe and accurate means to enable inspection forces to take all required samples, to provide permanent means for checking the output of any specified metering device, and to perform calibration and mass checks as required by the Engineer. When cold feed belt sampling is to be used for gradation testing, occasional stoppage of the belt may be necessary unless other means of sampling are approved by the Engineer.

When using fuel oil heavier than Grade No. 2, or waste oil, the Contractor shall insure that the fuel delivered to the burner is at a viscosity of 100 SSU or less, when tested in accordance with Test Method Tex-534-C, to insure complete burning of the fuel. Higher viscosities will be allowed if recommended by the burner manufacturer. If necessary, the Contractor shall preheat the oil to maintain the required viscosity.

The Contractor shall provide means for obtaining a sample of the fuel, just prior to entry into the burner, in order to perform the viscosity test. The contractor shall perform this test or provide a laboratory test report that will establish the temperature of the fuel necessary to meet the viscosity requirements. There shall be an in-line thermometer to check the temperature of the fuel delivered to the burner.

Regardless of the burner fuel used, the burner or combination of burners and types of fuel used shall provide a complete burn of the fuel and not leave any fuel residue that will adhere to the heated aggregate or become mixed with the asphalt.

(a) Weigh-Batch Type.

Cold Aggregate Bin Unit and Proportioning Device. The cold aggregate bin unit shall have at least four bins of sufficient size to store the amount of aggregate required to keep the plant in continuous operation and of proper design to prevent overflow of material from one bin to another. There shall be vertical partitions between each bin and on each end of the bins of sufficient height so that any overflow will be to the front and back, and not allow overflow to the sides or between bins. Overflow that might occur shall not fall onto any feeder belt. The proportioning device shall provide a uniform and continuous flow of aggregate in the desired proportion to the dryer. Each aggregate shall be proportioned from a separate bin.

If RAP and/or RAS is used, a separate cold bin shall be required for each. The RAP feed system shall be equipped with a scalping screen to remove particles over 50 millimeters in size. The RAS feed system shall be equipped with a scalping screen to remove particles over 19 mm in size. The cold bin system shall supply the proper amount of RAP or RAS to the weigh box. Neither RAP nor RAS will be allowed in the hot bins.

When mineral filler is used, as specified in Section 340.2.(1)(d), an additional bin shall be provided.

Dryer. The dryer shall continually agitate the aggregate during heating. The temperature shall be controlled so that the aggregate will not be damaged in the drying and heating operations. The dryer shall be of sufficient size to keep the plant in continuous operation.

Screening and Proportioning. The screening capacity and size of the hot aggregate bins shall be sufficient to screen and store the amount of aggregate required to properly operate the plant and keep the plant in continuous operation at full capacity. The hot bins shall be constructed so that oversize and overloaded material will be discarded through overflow chutes. Provisions shall be made to enable inspection forces to have easy and safe access to the proper location on the mixing plant where representative samples may be taken from the hot bins for testing. The aggregate shall be separated into at least four bins when producing Type "A", Type "B" or Type "C" mixtures, at least three bins when producing Type "D" mixture and at least two bins when producing Type "F" mixture. These bins shall contain the following sizes of aggregates, in percentages by mass or by volume, as applicable.

Type "A" (Coarse-Graded Base Course):

Bin No. 1 - Shall contain aggregates of which 85 of 100 percent will pass the 2.0 mm sieve.
Bin No. 2 - Shall contain aggregates of which at least 85 percent will be of such size as to pass the 12.5 mm sieve and be retained on the 2.00 mm sieve.
Bin No. 3 - Shall contain aggregates of which at least 85 percent will be of such size as to pass the 22.4 mm sieve and be retained on the 9.5 mm sieve.
Bin No. 4 - Shall contain aggregates of which at least 85 percent will be of such size as to pass the 37.5 mm sieve and be retained on the 22.4 mm sieve.

Type "B" (Fine-Graded Base Course):

Bin No. 1 - Shall contain aggregates of which 85 to 100 percent will pass the 2.00 mm sieve.
Bin No. 2 - Shall contain aggregates of which at least 70 percent will be of such size as to pass the 4.75 mm sieve and be retained on the 2.00 mm sieve.
Bin No. 3 - Shall contain aggregates of which at least 75 percent will be of such size as to pass the 9.5 mm sieve and be retained on the 4.75 mm sieve.
Bin No. 4 - Shall contain aggregates of which at least 75 percent will be of such size as to pass the 25.0 mm sieve and be retained on the 9.5 mm sieve.

Type "C" (Coarse-Graded Surface Course):

Bin No. 1 - Shall contain aggregates of which 85 to 100 percent will pass the 2.00 mm sieve

Bin No. 2 - Shall contain aggregates of which at least 70 percent will be of such size as to pass the 4.75 mm sieve and be retained on the 2.00 mm sieve.
Bin No. 3 - Shall contain aggregates of which at least 75 percent will be of such size as to pass the 9.5 mm sieve and be retained on the 4.75 mm sieve.
Bin No. 4 - Shall contain aggregates of which at least 75 percent will be of such size as to pass the 22.4 mm sieve and be retained on the 9.5 mm sieve.

Type "D" (Fine-Graded Surface Course):

Bin No. 1 - Shall contain aggregates of which 85 to 100 percent will pass the 2.00 mm sieve.
Bin No. 2 - Shall contain aggregates of which at least 70 percent will be of such size as to pass the 4.75 mm sieve and be retained on the 2.00 mm sieve.
Bin No. 3 - Shall contain aggregates of which at least 75 percent will be of such size as to pass the 12.5 mm sieve and be retained on the 4.75 mm sieve.

Type "F" (Fine-Graded Mixture):

Bin No. 1 - Shall contain aggregates of which 85 to 100 percent will pass the 2.00 mm sieve.
Bin No. 2 - Shall contain aggregates of which at least 75 percent will be of such size as to pass the 9.5 mm sieve and be retained on the 2.00 mm sieve.

Aggregate Weigh Box and Batching Scale. The aggregate weigh box and batching scales shall be of sufficient capacity to hold and weigh a complete batch of aggregate. The weigh box and scales shall conform to the requirements of Item 520, "Weighing and Measuring Equipment."

Asphaltic Material Measuring System. If an asphaltic material bucket and scales are used, they shall be of sufficient capacity to hold and weigh the necessary asphaltic material for one batch. The bucket and scales shall conform to the requirements of Item 520, "Weighing and Measuring Equipment."

If a pressure type flow meter is used to measure the asphaltic material, the requirements of Item 520, "Weighing and Measuring Equipment," shall apply. This system shall include an automatic temperature compensation device to insure a constant percent by mass of asphaltic material in the mixture.

Provisions of a permanent nature shall be made for checking the accuracy of the asphaltic material measuring device. The asphalt line to the measuring device shall be protected with a jacket of hot oil or other approved means to maintain the temperature of the line near the temperature specified for the asphaltic material.

Mixer. The mixer shall be of the pugmill type and shall have a capacity of not less than 1350 kilograms (of natural-aggregate mixture) in a single batch, unless otherwise shown on the plans. Any mixer that has a tendency to segregate the aggregate or fails to secure a thorough and uniform mixture with the asphaltic material shall not be used. All mixers shall be provided with an automatic timer that will lock the discharge doors of the mixer for the required mixing period. The dump door or doors and the shaft seals of the mixer shall be tight enough to prevent spilling of aggregate or mixture from the pugmill.

Surge-Storage System and Scales. A surge-storage system may be used to minimize the production interruptions during the normal day's operations. A device such as a gob hopper or other device approved by the Engineer to prevent segregation in the surge-storage bin shall be used. The mixture shall be weighed upon discharge from the surge-storage system.

When a surge-storage system is used, scales shall be standard platform truck scales or other equipment such as weigh hopper (suspended) scales and shall conform to Item 520, "Weighing and Measuring Equipment." If truck scales are used, they shall be placed at a location approved by the Engineer. If other weighing equipment is used, the Engineer may require mass checks by truck scales for the basis of approval of the equipment.

Recording Device and Record Printer. The mixture shall be weighed for pavement. If a surge-storage system is used, an automatic recording device and a digital record printer shall be provided to indicate the date, project identification number, vehicle identification, total mass of the load, tare mass of the vehicle, the mass of asphaltic mixture in each load and the number of loads for the day, unless otherwise indicated on the plans. When surge-storage is not used, batch mass will be used as the basis for payment and automatic recording devices and automatic digital record printers in accordance with Item 520, "Weighing and Measuring Equipment," shall be required.

(b) Modified Weigh-Batch Type.

General. This plant is similar to the weigh-batch type plant. The hot bin screens shall be removed and the aggregate control is placed at the cold feeds. The cold feed bins shall be the same as those required for the drum-mix type plant.

Cold-Aggregate Bin Unit and Feed System. The number of bins in the cold-aggregate bin unit shall be equal to or greater than the number of stockpiles of individual materials to be used.

The bins shall be of sufficient size to store the amount of aggregate required to keep the plant in continuous operation and of proper design to prevent overflow of material from one bin to another. There shall be vertical partitions between each bin and on each end of the bins of sufficient height so that any overflow will be to the front and back and not allow overflow to the sides or between bins. Overflow that might occur shall not fall onto any feeder belt. When required by the Engineer, an approved stationary scalping screen shall be placed on top of the field sand bin to eliminate roots and other objectionable material. The feed system shall provide a uniform and continuous flow of aggregate in the desired proportion to the dryer. The contractor shall furnish a chart indicating the calibration of each cold bin in accordance with the manufacturer's recommendations or in a method acceptable to the Engineer.

When mineral filler is used, as specified in Section 340.2.(1)(d), an additional bin shall be provided.

If RAP and/or RAS is used, a separate cold bin for each shall be required. The RAP feed system shall be equipped with a scalping screen to remove particles over 50 millimeters in size. The RAS feed system shall be equipped with a scalping screen to remove particles over 19 mm in size. The cold bin system shall supply a uniform and proper amount of RAP or RAS to the mixture. RAP or RAS may be added at the weigh box. If not added at the weigh box, the system shall include means acceptable to the Engineer to verify that the correct amount of RAP and/or RAS is continuously being fed.

Scalping Screen. A scalping screen shall be required after the cold feeds and ahead of the hot aggregate surge bins.

Dryer. The dryer shall continually agitate the aggregate during heating. The temperature shall be controlled so that the aggregate will not be damaged in the drying and heating operations. The dryer shall be of sufficient size to keep the plant in continuous operations.

Screening and Proportioning. The hot aggregate shall not be separated into sizes after being dried. There shall be one or more surge bins provided between the dryer and the weigh hopper. Surge bins shall be of sufficient size to hold enough combined aggregate for one complete batch of mixture.

Aggregate Weigh Box and Batching Scale. The aggregate weigh box and batching scales shall be of sufficient capacity to hold and weigh a complete batch of aggregate. The weigh box and scales shall conform to the requirements of Item 520, "Weighing and Measuring Equipment."

Asphaltic Material Measuring System. If an asphaltic material bucket and scales are used, they shall be of sufficient capacity to hold and weigh the necessary asphaltic material for one batch. The bucket and scales shall conform to the requirements of Item 520, "Weighing and Measuring Equipment."

If a pressure type flow meter is used to measure the asphaltic material, the requirements of Item 520, "Weighing and Measuring Equipment," shall apply. This system shall include an automatic temperature compensation device to insure a constant percent by mass of asphaltic material in the mixture.

Provisions of a permanent nature shall be made for checking the accuracy of the asphaltic material measuring device. The asphalt line to the measuring device shall be protected with a jacket of hot oil or other approved means to maintain the temperature of the line near the temperature specified for the asphaltic material.

Mixer. The mixer shall be of the pugmill type and shall have a capacity of not less than 1350 kilograms (of natural-aggregate mixture) in a single batch, unless otherwise shown on the plans. Any mixer that has a tendency to segregate the aggregate or fails to secure a thorough and uniform mixture with the asphaltic material shall not be used. All mixers shall be provided with an automatic timer that will lock the discharge doors of the mixer for the required mixing period. The dump door or doors and the shaft seals of the mixer shall be tight enough to prevent spilling of aggregate or mixture from the pugmill.

Surge-Storage System and Scales. A surge-storage system may be used to minimize the production interruptions during the normal day's operations. A device such as a gob hopper or other device approved by the Engineer to prevent segregation in the surge-storage bin shall be used. The mixture shall be weighed upon discharge from the surge-storage system.

When a surge-storage system is used, scales shall be standard platform truck scales or other equipment such as weigh hopper (suspended) scales and shall conform to Item 520, "Weighing and Measuring Equipment." If truck scales are used, they shall be placed at a location approved by the Engineer. If other weighing equipment is used, the Engineer may require mass checks by truck scales for the basis of approval of the equipment.

Recording Device and Record Printer. The mixture shall be weighed for payment. If a surge-storage system is used, an automatic recording device and a digital record printer shall be provided to indicate the date, project identification number, vehicle identification, total mass of the load, tare mass of the vehicle, the mass of asphaltic mixture in each load and the number of loads for the day, unless otherwise indicated on the plans. When surge-storage is not used, batch mass will be used as the basis for payment and automatic recording devices and automatic digital record printers in accordance with Item 520, "Weighing and Measuring Equipment," shall be required.

(c) Drum-Mix Type.

General. The plant shall be adequately designed and constructed for the process of mixing aggregates and asphalt. The plant shall be equipped with satisfactory conveyors, power units, aggregate-handling equipment and feed controls.

Cold-Aggregate Bin Unit and Feed System. The number of bins in the cold-aggregate bin unit shall be equal to or greater than the number of stockpiles of individual materials to be used.

The bins shall be of sufficient size to store the amount of aggregate required to keep the plant in continuous operation and of proper design to prevent overflow of material from one bin to another. There shall be vertical partitions between each bin and on each end of the bins of sufficient height so that any overflow will be to the front and back and not allow overflow to the sides or between bins. Overflow that might occur shall not fall onto any feeder belt. When required by the Engineer, an approved stationary scalping screen shall be placed on top of the field sand bin to eliminate roots and other objectionable material. The feed system shall provide a uniform and continuous flow of aggregate in the desired proportion to the mixer. The Contractor shall furnish a chart indicating the calibration of each cold bin in accordance with the manufacturer's recommendations or in a method acceptable to the Engineer.

The system shall provide positive mass measurement of the combined cold-aggregate feed by the use of belt scales or other approved devices. Provisions of a permanent nature shall be made for checking the accuracy of the measuring device as required by Item 520, "Weighing and Measuring Equipment." When a belt scale is used, mixture production shall be maintained so that the scale normally operates between 50 percent and 100 percent of its rated capacity. Belt scale operation below 50 percent of the rated capacity may be allowed by the Engineer if accuracy checks show the scale to meet the requirements of Item 520, "Weighing and Measuring Equipment," at the selected rate. It shall be satisfactorily demonstrated to the Engineer that mixture uniformity and quality have not been adversely affected.

If RAP and/or RAS is used, a separate cold bin for each shall be required. The RAP feed system shall be equipped with a scalping screen to remove particles over 50 millimeters in size prior to the weighing device. The RAS feed system shall be equipped with a scalping screen to remove particles over 19 mm in size. There shall be adequate cold bin controls to provide a uniform amount of RAP and/or RAS to the mixtures.

When RAP and/or RAS is used, positive mass measurement of these materials shall be provided by the use of belt scales or other approved devices.

Scalping Screen. A scalping screen shall be required after the cold feeds and ahead of the combined aggregate belt scales.

Asphaltic Material Measuring System. An asphaltic material measuring device meeting the requirements of Item 520, "Weighing and Measuring Equipment," shall be placed in the asphalt line leading to the mixer so that the cumulative amount of asphalt used can be accurately determined. Provisions of a permanent nature shall be made for checking the accuracy of the measuring device output. The asphalt line to the measuring device shall be protected with a jacket of hot oil or other approved means to maintain the temperature of the line near the temperature specified for the asphaltic material. The measuring system shall include an automatic temperature compensation device to maintain a constant percent by mass of asphaltic material in the mixture.

Synchronization Equipment for Feed-Control System. The asphaltic material feed-control shall be coupled with the total aggregate mass measuring device to automatically vary the asphalt-feed rate in order to maintain the required proportion.

Mixing System. The mixing system shall control the temperature so that the aggregate and asphalt will not be damaged in the drying, heating and mixing operations. A continuously recording thermometer shall be provided which will indicate the temperature of the mixture as it leaves the mixer.

Surge-Storage System and Scales. A surge-storage system shall be used to minimize the production interruptions during the normal day's operations. A device such as a gob hopper or other device approved by the Engineer to prevent segregation in the surge-storage bin shall be used. The mixture shall be weighed upon discharge from the surge-storage system.

Scales shall be standard platform truck scales or other equipment such as weigh hopper (suspended) scales and shall conform to Item 520, "Weighing and Measuring Equipment." If truck scales are used, they shall be placed at a location approved by the Engineer. If other weighing equipment is used, the Engineer may require mass checks by truck scales for the basis of approval of the equipment.

Recording Device and Record Printer. Automatic recording devices and automatic digital record printers shall be provided to indicate the date, project identification number, vehicle identification, total mass of the load, tare mass of the vehicle, the mass of asphaltic mixture in each load and the number of loads for the day in accordance with Item 520, "Weighing and Measuring Equipment," unless otherwise shown on the plans.

(d) Specialized Recycling Tape.

General. Alternate methods of heating may be used which will not abnormally age the asphalt cement. This type of plant shall be capable of continually producing a minimum of 136 megagrams per hour of completed asphalt mixture that will meet all the requirements of this specification.

Cold-Aggregate Bin Unit and Feed System. The cold-aggregate feed system and controls shall meet all the requirements as listed under the drum-mix type plant.

Scalping Screen. A scalping screen shall be required after the cold feeds and ahead of the combined aggregate let scales.

Dryer. The dryer shall continually agitate the RAP <u>and/or RAS</u> and aggregate during heating. The temperature shall be controlled so that the aggregate and asphalt will not be damaged in the drying and heating operations. The dryer shall be of sufficient size to keep the plant in continuous operation.

Asphalt Material Measuring System. An asphaltic material measuring device meeting the requirements of Item 520, "Weighing and Measuring Equipment," shall be placed in the asphalt line leading to the mixer so that the cumulative amount of asphalt used can be accurately determined. Provisions of a permanent nature shall be made for checking the accuracy of the measuring device output. The asphalt line to the measuring device shall be protected with a jacket of hot oil or other approved means to maintain the temperature of the line near the temperature specified for the asphaltic material. The measuring system shall include an automatic temperature compensation device to maintain a constant percent by mass of asphaltic material in the mixture.

Synchronization Equipment for Feed-Control Systems. The asphaltic material feed-control shall be coupled with the total aggregate mass measuring device to automatically vary the asphalt-feed rate in order to maintain the required proportion.

Mixer. The mixer shall be of the continuous mechanical mixing type. Any mixer that has a tendency to segregate the mixture or fails to secure a thorough and uniform mixture shall not be used. A continuously recording thermometer shall be provided which will indicate the temperature of the mixture as it leaves the mixer.

Surge-Storage System and Scales. A surge-storage system shall be used to minimize the production interruptions during the normal day's operations. A device such as a gob hopper or other device approved by the Engineer to prevent segregation in the surge-storage bin shall be used. The mixture shall be weighed upon discharge from the surge-storage system.

Scales shall be standard platform truck scales or other equipment such as weigh hopper (suspended) scales and shall conform to Item 520, "Weighing and Measuring Equipment." If truck scales are used, they shall be placed at a location approved by the Engineer. If other weighing equipment in used, the Engineer may require mass check by truck scales for the basis of approval of the equipment.

Recording Device and Record Printer. Automatic recording devices and automatic digital record printers shall be provided to indicate the date, project identification number, vehicle identification, total mass of the load, tare mass of the vehicle, the mass of asphaltic mixture in each load and the number of loads for the day in accordance with Item 520, "Weighing and Measuring Equipment," unless otherwise shown on the plans.

(3) Asphaltic Material Heating Equipment. Asphaltic material heating equipment shall be adequate to heat the required amount of asphaltic material to the desired temperature. The heating apparatus shall be equipped with a continuously recording thermometer with a 24-hour chart that will record the temperature of the asphaltic material at the location of highest temperature.

(4) Spreading and Finishing Machine. The spreading and finishing machine shall be approved by the Engineer and shall meet the requirements indicated below.

(a) Screed Unit. The spreading and finishing machine shall be equipped with a heated compacting screed. It shall produce a finished surface meeting the requirements of the typical cross sections and the surface tests.

Extensions added to the screed shall be provided with the same compacting action and heating capability as the main screed unit, except for use on variable depth tapered areas and/or as approved by the Engineer.

The spreading and finishing machine shall be equipped with an approved automatic dual longitudinal screed control system and automatic transverse screed control system. The longitudinal controls shall be capable of operating from any longitudinal grade reference including a string line, ski, mobile string line, or matching shoe.

The Contractor shall furnish all equipment required for grade reference. It shall be maintained in good operating condition by personnel trained in the use of this type of equipment.

The grade reference used by the Contractor may be of any type approved by the Engineer. Control points, if required by the plans, shall be established for the finished profile in accordance with Item 5, "Control of the Work." These points shall be set at intervals not to exceed 15 meters. The Contractor shall set the grade reference from the control points. The grade reference shall have sufficient support so that the maximum deflection shall not exceed two (2) millimeters between supports.

(b) Tractor Unit. The tractor unit shall be equipped with a hydraulic hitch sufficient in design and capacity to maintain contact between the rear wheels of the hauling equipment and the pusher rollers of the finishing machine while the mixture is being unloaded.

No portion of the mass of hauling equipment, other than the connection, shall be supported by the asphalt paver. No vibrations or other motions of the loading equipment, which could have a detrimental effect on the riding quality of the completed pavement, shall be transmitted to the paver.

The use of any vehicle which requires dumping directly into the finishing machine and which the finishing machine cannot push or propel to obtain the desired lines and grades without resorting to hand finishing will not be allowed.

(5) Material Transfer Equipment. Equipment to transfer mixture from the hauling units or the roadbed to the spreading and finishing machine will be allowed unless otherwise shown on the plans. A specific type of material transfer equipment shall be required when shown on the plans.

(a) Windrow Pick-Up Equipment. Windrow pick-up equipment shall be constructed in such a manner that substantially all the mixture deposited on the roadbed is picked up and loaded into the spreading and finishing machine. The mixture shall not be contaminated with foreign material. The loading equipment shall be designed so that it does not interfere with the spreading and finishing machine in obtaining the required line, grade and surface without resorting to hand finishing.

(b) Material Feeding System. Material feeding systems shall be designed to provide a continuous flow of uniform mixture to the spreading and finishing machine. When use of a material feeding system is required on the plans, it shall meet the storage capacity, remixing capability, or other requirements shown on the plans.

(6) Motor Grader. The motor grader, when used, shall be a self-propelled power motor grader and shall be equipped with smooth tread pneumatic tired wheels unless otherwise directed. It shall have a blade length of not less than 3.6 meters and a wheelbase of not less than 4.8 meters.

(7) Rollers. Rollers provided shall meet the requirements for their type as follows:

(a) Pneumatic-Tire Roller. The roller shall be an acceptable medium pneumatic tire roller conforming to the requirements of Item 213, "Rolling (Pneumatic Tire)," Type A, unless otherwise specified on the plans. Pneumatic-tire rollers used for compaction shall provide a minimum 550 kilopascals ground contact pressure. When used for kneading and sealing the surface only, they shall provide a minimum of 380 kilopascals ground contact pressure.

(b) Two-Axle Tandem Roller. The roller shall be an acceptable self-propelled tandem roller weighing not less than 7.2 megagrams.

(c) Three-Wheel Roller. This roller shall be an acceptable self-propelled three wheel roller weighing not less than 9.1 megagrams.

(d) Three-Axle Tandem Roller. This roller shall be an acceptable self-propelled three axle roller weighing not less than 9.1 megagrams.

(e) Trench Roller. This roller shall be an acceptable self-propelled trench roller equipped with a sprinkler for keeping the wheels wet and an adjustable road wheel so that the roller may be kept level during rolling. The drive wheel shall be not less than 500 millimeters wide. The roller under working conditions shall produce not less than 5800 kilograms per meter of roller width and be so geared that a speed of approximately three (3) kilometers per hour is obtained in low gear.

(f) Vibratory Steel-Wheel Roller. This roller shall have a minimum mass of 5.4 megagrams. The compactor shall be equipped with amplitude and frequency controls and shall be specifically designed to compact the material on which it is used.

(8) Straightedges and Templates. When directed by the Engineer, the Contractor shall provide acceptable 3-meter straightedges for surface testing. Satisfactory templates shall be provided as required by the Engineer.

(9) Alternate Equipment. When permitted by the Engineer, equipment other than that specified herein which will consistently produce satisfactory results may be used.

5. Stockpiling, Storage and Mixing.

(1) Stockpiling of Aggregates.

(a) Weigh-Batch Plant. Prior to stockpiling of aggregates, the area shall be cleaned of trash, weeds, grass and shall be relatively smooth and well drained. The stockpiling shall be done in a manner that will minimize aggregate degradation, segregation, mixing of one stockpile with another, and will not allow contamination with foreign material.

The plant shall have at least a two-day supply of aggregates on hand before production can begin and at least a two-day supply shall be maintained through the course of the project, unless otherwise directed by the Engineer.

No stockpile shall contain aggregate from more than one source.

Coarse aggregates for mixture Types "A", "B" and "C" shall be separated into at least two stockpiles of different gradation, such as a large-coarse-aggregate and a small-coarse-aggregate stockpile, except when the use of large percentages of RAP preclude the need for two virgin coarse aggregate stockpiles.

When shown on the plans, coarse aggregates for Type "D" mixtures shall also be separated into at least two stockpiles.

No coarse-aggregate stockpile shall contain more than 15 percent by mass of material that will pass a 2.00 millimeter sieve.

Fine-aggregate stockpiles may contain coarse aggregate in amounts up to 20 percent by mass. This requirement does not apply to stone screenings stockpiles, which must meet the gradation requirements shown in Section 340.2.(1)(c), unless otherwise shown on the plans.

Prior to starting RAP and/or RAS stockpiling operations, the Contractor shall develop and submit in writing to the Engineer an acceptable stockpile production procedure and management plan which will ensure that homogeneous stockpiles of RAP and RAS are available. Stockpiles of contractor-owned RAP and/or RAS material shall be completely established at the plant site prior to submission of mixture design samples and shall be of sufficient quantity to meet the material requirements of the project for which they are prepared. When shown on the plans, plant site stockpiles composed of RAP or RAS from designated sources shall be of the minimum size shown on the plans prior to submission of mixture design samples.

When required by the Engineer, additional material shall not be added to stockpiles that have previously been sampled for approval.

Equipment of an acceptable size and type shall be furnished to work the stockpiles and prevent segregation and degradation of the aggregates.

(b) Modified Weigh-Batch Plant. The stockpiling requirements for aggregate shall be the same as required for a drum-mix type plant.

(c) Drum-Mix Plant. When a drum-mix plant is used, the following stockpiling requirements for coarse aggregates shall apply in addition to the aggregate stockpiling requirements listed under Section 340.5.(1)(a).

Once a job-mix formula has been established in accordance with Article 340.3, the virgin coarse aggregates delivered to the stockpiles shall not vary on any grading size fraction by more than plus or minus eight (8) percentage points from the percentage found in the samples submitted by the Contractor and upon which the job-mix formula was based. Should the gradation of virgin coarse aggregates in the stockpiles vary by more than the allowed tolerance, the Engineer may stop production. If production is stopped, new aggregates shall be furnished that meet the gradations of the aggregates submitted for the job-mix formula, or a new mix design shall be formulated in accordance with Article 340.3.

When the volume of production from a commercial plant makes sampling of all coarse aggregate delivered to the stockpiles impractical, cold feeds will be sampled to determine stockpile uniformity. Should this sampling prove the stockpiles non-uniform beyond the acceptable tolerance, separate stockpiles which meet these specifications may be required.

(d) Specialized Recycling Plant. The stockpiling requirements for aggregate shall be the same as required for drum-mix type plant.

(2) Storage and Heating of Asphaltic Materials. The asphaltic material storage capacity shall be ample to meet the requirements of the plant. Asphalt shall not be heated to a temperature in excess of that specified in Item 300, "Asphalts, Oils and Emulsions." All equipment used in the storage and handling of asphaltic material shall be kept in a clean condition at all times and shall be operated in such a manner that there will be no contamination with foreign matter.

(3) Feeding and Drying of Aggregate. The feeding of various sizes of aggregate, RAP, and RAS, if applicable, to the dryer shall be done through the cold aggregate bins and the proportioning device in such a manner that a uniform and constant flow of materials in the required proportions will be maintained. The aggregate shall be dried and heated to the temperature necessary to produce a mixture having the specified temperature.

(4) Mixing and Storage.

(a) Weigh-Batch Plant. In introducing the batch into the mixer, all aggregate shall be introduced first and shall be mixed thoroughly for a minimum period of five (5) seconds to uniformly distribute the various sizes throughout the batch before the asphaltic material is added. The asphaltic material shall then be added and the mixing continued for a wet mixing period of not less than 15 seconds. The mixing period shall be increased if, in the opinion of the Engineer, the mixture is not uniform or the aggregates are not properly coated.

Temporary storing or holding of the asphaltic mixture by the surge-storage system will be permitted during the normal day's operation. Overnight storage will not be permitted unless authorized in the plans or by the Engineer. The mixture coming out of the surge-storage bin shall be of equal quality to that coming out of the mixer.

(b) Modified Weigh-Batch Plant. The mixing and storage requirements shall be the same as is required for a standard weigh-batch plant.

(c) Drum-Mix Plant. The amount of aggregate and asphaltic material entering the mixer and the rate of travel through the mixing shall be so coordinated that a uniform mixture of the specified grading and asphalt content will be produced.

Temporary storing or holding of the asphaltic mixture by the surge-storage system will be required during the normal day's operation. Overnight storage will not be permitted unless authorized in the plans or by the Engineer. The mixture coming out of the surge-storage bin shall be of equal quality to that coming out of the mixer.

(d) Specialized Recycling Plant. The mixing and storage requirements shall be the same as that stated for the drum-mix plant.

(e) Discharge Temperature. The Engineer will select the target discharge temperature of the mixture between 120°C and 175°C. The mixture, when discharged from the mixer, shall not vary from this selected temperature more than 15°C, but in no case shall the temperature exceed 180°C.

(f) Moisture Content. The mixture produced from each type of mixer shall have a moisture content not greater than one (1) percent by mass when discharged from the mixer, unless otherwise shown on the plans and/or approved by the Engineer. The moisture content shall be determined in accordance with Test Method Tex-212-F.

(g) RAP. If RAP is used, it shall be mixed and blended so that there is no evidence of unseparated particles in the mixture as it leaves the mixer.

6. Construction Methods.

(1) General. It shall be the responsibility of the Contractor to produce, transport, place and compact the specified paving mixture in accordance with the requirements herein.

The asphaltic mixture, when placed with a spreading and finishing machine, or the tack coat shall not be placed when the air temperature is below 10°C and is falling, but it may be placed when the air temperature is above 5°C and is rising.

The asphaltic mixture, when placed with a motor grader, shall not be placed when the air temperature is below 15°C and is falling, but may be placed when the air temperature is above 10°C and is rising.

The air temperature shall be taken in the shade away from artificial heat.

Mat thicknesses of 40 millimeters and less shall not be placed when the temperature of the surface on which the mat is to be placed is below 10°C.

Mixtures with lightweight coarse aggregate shall not be placed when the temperature of the surface on which the mat is to be placed is below 10°C.

Additional surface temperature requirements may be shown on the plans.

It is further provided that the tack coat or asphaltic mixture shall be placed only when the humidity, general weather conditions and temperature and moisture condition of the base, in the opinion of the Engineer, are suitable.

If, after being discharged from the mixer and prior to placing, the temperature of the asphaltic mixture is 10°C or more below the selected discharge temperature established by the Engineer, all or any part of the load may be rejected and payment will not be made for the rejected material.

(2) Tack Coat. The surface upon which the tack coat is to be placed shall be cleaned thoroughly to the satisfaction of the Engineer. The surface shall be given a uniform application of tack coat using asphaltic materials of this specification. This tack coat shall be applied, as directed by the Engineer, with an approved sprayer at a rate not to exceed 0.2 liter residual asphalt per square meter of surface. Where the mixture will adhere to the surface on which it is to be placed without the use of a tack coat, the tack coat may be eliminated by the Engineer. All contact surfaces of curbs and structures and all joints shall be painted with a thin uniform application of tack coat. During the application of tack coat, care shall be taken to prevent splattering of adjacent pavement, curb and gutter and structures. The tack coat shall be rolled with a pneumatic tire roller when directed by the Engineer.

(3) Transporting Asphaltic Concrete. The asphaltic mixture shall be hauled to the work site in tight vehicles previously cleaned of all foreign material. The dispatching of the vehicles shall be arranged so that all material delivered is placed and all rolling completed during daylight hours unless otherwise shown on the plans. In cool weather or for long hauls, covering and insulating of the truck bodies may be required. If necessary, to prevent the mixture from adhering to the body, the inside of the truck may be given a light coating of release agent satisfactory to the Engineer.

(4) Placing.

(a) The asphaltic mixture shall be dumped and spread on the approved prepared surface with the spreading and finishing machine. When properly compacted, the finished pavement shall be smooth, of uniform texture and density and shall meet the requirements of the typical cross sections and the surface tests. In addition, the placing of the asphaltic mixture shall be done without tearing, shoving, gouging or segregating the mixture and without producing streaks in the mat.

Unloading into the finishing machine shall be controlled so that bouncing or jarring the spreading and finishing machine shall not occur and the required lines and grades shall be obtained without resorting to hand finishing, except as shown under Section 340.6.(4)(d).

Unless otherwise shown on the plans, dumping of the asphaltic mixture in a windrow and then placing the mixture in the finishing machine with windrow pick-up equipment will be permitted. The windrow pick-up equipment shall be operated in such a manner that substantially all the mixture deposited on the roadbed is picked up and loaded into the finishing machine without contamination by foreign material. The windrow pick-up equipment will be so operated that the finishing machine will obtain the required line, grade and surface without resorting to hand finishing. Any operation of the windrow pick-up equipment resulting in the accumulation and subsequent shedding of accumulated material into the asphaltic mixture will not be permitted.

(b) When approved by the Engineer, level-up courses may be spread with a motor grader.

(c) The spreading and finishing machine shall be operated at a uniform forward speed consistent with the plant production rate, hauling capability, and roller train capacity to result in a continuous operation. The speed shall be slow enough that stopping between trucks is not ordinarily required. If, in the opinion of the Engineer, sporadic delivery of material is adversely affecting the mat, the Engineer may require paving operations to cease until acceptable methods are provided to minimize starting and stopping of the paver.

The hopper flow gates of the spreading and finishing machine shall be adjusted to provide an adequate and consistent flow of material. These shall result in enough material being delivered to the augers so that they are operating approximately 85 percent of the time or more. The augers shall provide means to supply adequate flow of material to the center of the paver. Augers shall supply an adequate flow of material for the full width of the mat, as approved by the Engineer. Augers should be kept approximately one-half to three-quarters full of mixture at all times during the paving operation.

(d) When the asphaltic mixture is placed in a narrow strip along the edge of an existing pavement, or used to level up small areas of an existing pavement, or placed in small irregular areas where the use of a finishing machine is not practical, the finishing machine may be eliminated when authorized by the Engineer.

(e) Adjacent to flush curbs, gutters and structures, the surface shall be finished uniformly high so that when compacted it will be slightly above the edge of the curb or structure.

(f) Construction joints of successive courses of asphaltic material shall be offset at least 150 millimeters. Construction joints on surface courses shall coincide with lane lines, or as directed by the Engineer.

(g) If a pattern of surface irregularities or segregation is detected, the Contractor shall make an investigation into the causes and immediately take the necessary corrective action. With the approval of the Engineer, placement may continue for no more than one full production day from the time the Contractor is first notified and while corrective actions are being taken. If the problem still exists after that time, paving shall cease until the Contractor further investigates the causes and the Engineer approves further corrective action to be taken.

(5) Compacting.

(a) The pavement shall be compacted thoroughly and uniformly with the necessary rollers to obtain the compaction and cross section of the finished paving mixture meeting the requirements of the plans and specifications.

(b) When rolling with the three-wheel, tandem or vibratory rollers, rolling shall start by first rolling the joint with the adjacent pavement and then continue by rolling longitudinally at the sides and proceed toward the center of the pavement, overlapping on successive trips by at least 300 millimeters, unless otherwise directed by the Engineer. Alternate trips of the roller shall be slightly different in length. On super-elevated curves, rolling shall begin at the low side and progress toward the high side, unless otherwise directed by the Engineer.

When rolling with vibratory steel-wheel rollers, equipment operation shall be in accordance with Item 217, "Rolling (Vibratory)," and the manufacturer's recommendations, unless otherwise directed by the Engineer. Vibratory rollers shall not be left vibrating while not rolling or when changing directions. Unless otherwise shown on the plans or approved by the Engineer, vibratory rollers shall not be allowed in the vibrating mode on mats with a plan depth of less than 40 millimeters.

The motion of the rollers shall be slow enough to avoid other than usual initial displacement of the mixture. If any displacement occurs, it shall be corrected to the satisfaction of the Engineer. The roller shall not be allowed to stand on pavement which has not been fully compacted. To present adhesion of the surface mixture to the steel-wheel rollers, the wheels shall be kept thoroughly moistened with water, but an excess of water will not be permitted. Necessary precautions shall be taken to prevent the dropping of diesel, gasoline, oil, grease or other foreign matter on the pavement, either when the rollers are in operation or when standing.

(c) The edges of the pavement along curbs, headers and similar structures, and all places not accessible to the roller, or in such positions as will not allow thorough compaction with the rollers, shall be thoroughly compacted with lightly oiled tamps.

(d) Rolling with a trench roller will be required on widened areas, in trenches and other limited areas where satisfactory compaction cannot be obtained with the approved rollers.

(6) In-Place Compaction Control. In-place compaction control is required for all mixtures. Unless otherwise shown on the plans, air void control shall be required.

(a) Air Void Control. The Contractor shall be responsible for determining the number and type of rollers to be used to obtain compaction to within the air void range required herein. The rollers shall be operated in accordance with the requirements of this specification and as approved by the Engineer.

Unless otherwise shown on the plans, rolling with a pneumatic-tire roller to seal the surface shall be provided. Rolling with a tandem or other steel-wheel roller shall be provided if required to iron out any roller marks.

Asphaltic concrete shall be placed and compacted to contain from five (5) to nine (9) percent air voids. The percent air voids will be calculated using the maximum theoretical specific gravity of the mixture determined according to Test Method Tex-227-F. Roadway specimens, which shall be either cores or section of asphaltic pavement, will be tested according to Test Method Tex-207-F. The nuclear-density gauge or other methods which correlate satisfactorily with results obtained from project roadway specimens may be used when approved by the Engineer. Unless otherwise shown on the plans, the Contractor shall be responsible for obtaining the required roadway specimens at his expense and in a manner and at locations selected by the Engineer.

If the percent air voids in the compacted placement is greater than nine (9) percent but is 10 percent or less, production may proceed with subsequent changes in the construction operations and/or mixture. If the air void content is not reduced to between five (5) and nine (9) percent within one production day from the time the Contractor is notified, production shall cease. At that point, a test section as described below shall be required.

If the percent air voids is more than 10 percent, production shall cease immediately and a test section shall be required as described below.

In either case, the Contractor shall only be allowed to place a test section of one lane width, not to exceed 300 meters in length, to demonstrate that compaction to between five (5) and nine (9) percent air voids can be obtained. This procedure will continue until a test section with five (5) to nine (9) percent air voids can be produced. Only two (2) test sections per day will be allowed. When a test section producing satisfactory air void content is placed, full production may then resume.

Increasing the asphalt content of the mixture in order to reduce pavement air voids will not be allowed.

If the percent air voids is determined to be less than five (5) percent, immediate adjustments shall be made to the plant production by the Contractor, as approved by the Engineer, within the tolerances as outlined in Subarticle 340.3.(4), so that an adequate air void level results.

The Contractor is encouraged to perform supplemental compaction testing for his own information.

(b) Ordinary Compaction Control. When the requirement of air void control has been removed by plan note, one (1) three-wheel roller, one (1) pneumatic-tire roller, and one (1) tandem roller shall be furnished for each compaction operation except as provided below or approved by the Engineer. The use of a tandem roller may be waived by the Engineer when the surface is already adequately smooth and further steel-wheel rolling is shown to be ineffective. With approval of the Engineer, the Contractor may substitute a vibratory roller for the three-wheel roller and/or the tandem roller. Use of at least one (1) pneumatic-tire roller is required. Additional or heavier rollers shall be furnished if required by the Engineer.

(c) Compaction Cessation Temperature. Regardless of the method required for in-place compaction control, all rolling for compaction shall be completed before the mixture temperature drops below 80°C.

(7) Ride Quality. Unless otherwise shown on the plans, Ride Quality will be required in accordance with Item 585, "Ride Quality for Pavement Surfaces."

(8) Opening to Traffic. The pavement shall be opened to traffic when directed by the Engineer. The contractor's attention is directed to the fact that all construction traffic allowed on the pavement open to the public will be subject to the State laws governing traffic on highways.

If the surface ravels, flushes, ruts or deteriorates in any manner prior to final acceptance of the work, it will be the Contractor's responsibility to correct this condition at his expense, to the satisfaction of the Engineer and in conformance with the requirements of this specification.

7. Measurement. The quantity of asphaltic concrete will be measured by the composite mass or composite volumetric method.

(1) Composite Mass Method. Asphaltic concrete will be measured by the megagram of the composite "Asphaltic Concrete" of the type actually used in the completed and accepted work in accordance with the plans and specifications for the project. The composite asphaltic concrete mixture is hereby defined as the asphalt, aggregate, RAP, RAS and additives as noted in the plans and/or approved by the Engineer.

If mixing is done by a drum-mix plant or specialized recycling plant, measurement will be made on scales as specified herein.

If mixing is done by a weigh-batch plant or modified weigh-batch plant, measurement will be determined on the batch scales unless surge-storage is used. Records of the number of batches, batch design and the mass of the composite "Asphaltic Concrete" shall be kept. Where surge-storage is used, measurement of the material taken from the surge-storage bin will be made on truck scales or suspended hopper scales.

(2) Composite Volumetric Method. The asphaltic concrete will be measured by the cubic meter of compacted "Asphaltic Concrete" of the type actually used in the completed and accepted work in accordance with the plans and specifications for the project. The composite asphaltic concrete mixture is hereby defined as the asphalt, aggregate, RAP, RAS, and additives as noted in the plans and/or approved by the Engineer. The volume of the composite asphaltic concrete mixture shall be calculated by the following formula:

$$V = \frac{W}{1000\ G_a}$$

V = Cubic meters of compacted "Asphaltic Concrete"
W = Total mass of asphaltic concrete in kilograms
G_a = Average actual specific gravity of three (3) molded specimens as prepared by Test Method Tex-206-F and determined in accordance with Test Method Tex-207-F

If mixing is done by a drum-mix plant or specialized recycling plant, the mass "W" will be determined by scales as specified herein.

If mixing is done by a weigh-batch plant or modified weigh-batch plant and surge-storage is not used, mass will be determined by batch scales and records of the number of batches, batch designs and mass of asphalt and aggregate shall be kept. Where surge-storage is used, measurement of the material taken from the surge-storage bin will be made on truck scales or suspended hopper scales.

(3) Ride Quality. Ride quality will be measured as described in Item 585, "Ride Quality for Pavement Surfaces."

Payment.

(1) The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for the "Asphaltic Concrete" of the type specified.

Measurement Method	**Bid Item**	**Unit of Measure**
Composite Mass	Asphaltic Concrete	Megagram
Composite Volumetric	Asphaltic Concrete	Cubic Meter

The payment based on the unit bid price shall be full compensation for quarrying, furnishing all materials, additives, freight involved, for all heating, mixing, hauling, cleaning the existing base course or pavement, tack coat, placing, rolling and finishing asphaltic concrete mixture, transportation RAP and RAS from designated sources, transporting any excess RAP and RAS to locations shown on the plans, and for all manipulations, labor, tools, equipment and incidentals necessary to complete the work.

(2) When surface Test Type-B, as specified in Item 585, "Ride Quality for Pavement Surfaces," is used, a bonus or deduction for each 0.1609 kilometer section of each travel lane will be calculated in dollars and cents. A running total of this will be determined for each day's production. The bonus or deduction for ride quality will be paid for separately from the payment for the material placed.

(3) All templates, straightedges, core drilling equipment, scales and other weighing and measuring devices necessary for the proper construction, measuring and checking of the work shall be furnished, operated and maintained by the Contractor at his expenses.

(4) State owned RAP from sources designated on the plans will be available at no cost to the Contractor.