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ABSTRACT

Numerous waste materials result from manufacturing operations, service industries, sewage treatment plants, households and mining. Legislation has been enacted by several states in recent years to either mandate the use of some waste materials or to examine the feasibility of such usage. The hot mix asphalt (HMA) industry has been pressured in recent years to incorporate a wide variety of waste materials into HMA pavements. This has raised the following legitimate concerns: (a) engineering concerns such as effect on the engineering properties (for example, strength and durability), impact on production, and future recyclability; (b) environmental concerns such as emissions, fumes, odor, leaching, and handling and processing procedures; and (c) economic concerns such as life cycle costs, salvage value, and lack of monetary incentives.

The waste materials can broadly be categorized as follows: (a)industrial wastes such as cellulose wastes, wood lignins, bottom ash and fly ash; (b) municipal/domestic wastes such as incinerator residue, scrap rubber, waste glass and roofing shingles; and (c) mining wastes such as coal mine refuse.

A general overview of preceding waste materials including the research work done in the past and their potential for use in HMA pavements is given in this paper.

WASTE MATERIALS IN HOT MIX ASPHALT - AN OVERVIEW

Prithvi S. Kandhal

Numerous waste materials result from every aspect of society including manufacturing, service industries, sewage treatment plants, households and mining. The disposal of waste products is primarily done as follows:

(a) Landfills
(b) Incineration, and
(c) Recycling in other products

However, problems are being experienced because of the insufficient capacity of landfills, air pollution associated with incinerators, and limited alternatives for recycling. Legislation has been enacted by several states in recent years to either mandate the use of some waste materials or to examine the feasibility of such usage. About 450 million megagrams (Mg) of hot mix asphalt (HMA) are produced in the United States at a cost of about $12 billion. The HMA industry has been pressured in recent years to incorporate a wide variety of waste materials into HMA pavements. This has raised the following legitimate concerns (*1*).

ENGINEERING CONCERNS

The following concerns must be addressed from the engineering viewpoint.

Properties of HMA

Since the waste material will replace and/or modify the properties of asphalt cement binder and/or HMA, it will affect the engineering properties (such as strength and durability). Therefore, the HMA containing the waste material must be reevaluated thoroughly and carefully both in the laboratory and the field.

Impact on Production

Some waste materials require a change in the HMA production equipment and/or processes and, therefore, the production is likely to be affected.

Future Recyclability

It is not known in many instances whether the HMA containing a waste material can be effectively recycled in the future without any problems. For example, HMA containing significant amounts of ground tire rubber has not been recycled as yet. Such recycling may pose air pollution problems.

Consistent Quality

The waste material may vary in quality (chemical or physical properties) and, thus, affect the engineering properties and durability of the hot mix asphalt.

ENVIRONMENTAL CONCERNS

The following concerns must be dealt with from an environmental viewpoint, especially when very tight emission and environmental controls are already in place on HMA production facilities.

Emissions/Fumes/Odor

It is quite likely that some waste materials will have emissions/fumes/odor problems because HMA is produced at high temperatures. These problems might also be faced when recycling HMA containing the waste material in the future.

Leaching

Component(s) of waste materials maybe susceptible to leaching from HMA pavements and thus cause storm water and/or ground water pollution.

Handling and Processing Procedure

These procedures are not fully developed for all waste materials. Some waste materials could be hazardous and could pose health related risks to workers in the HMA industry.

ECONOMIC CONCERNS

From an economic viewpoint, the following concerns must also be addressed.

Price

Mandated use of waste materials is likely to raise the price of HMA. For example, virgin aggregates are generally available locally at lower costs compared to waste materials such as waste glass which must be hauled.

Life Cycle Costs

Life cycle costs need to be determined for HMA pavements containing waste materials. It is quite possible that the waste material may not affect the initial engineering properties of the HMA pavement but reduce its service life.

Disposal Costs

If the HMA containing the waste materials cannot be recycled, then its disposal costs need to be determined.

Salvage Value

Salvage values of HMA containing the waste materials are not known.

Lack of Incentive

At the present time there is a lack of monetary incentives to use the waste materials in HMA.

CATEGORIZATION OF WASTE MATERIALS

The waste materials can broadly be categorized as follows (*2*). Some waste materials which have been used experimentally or routinely in HMA are also given for each category.

(a) Industrial Wastes
- Cellulose Wastes
- Wood Lignins
- Bottom Ash

- Fly Ash

(b) Municipal/Domestic Wastes

- Incinerator Residue
- Sewage Sludge
- Scrap Rubber
- Waste Glass
- Roofing Shingles

(c) Mining Waste

- Coal Mine Refuse

By-products from industrial processes, such as blast furnace slags, steel slags and sulphur were considered waste materials at one time. However, these products are now generally used on a routine basis and, therefore, will not be discussed. A detailed discussion of some selected waste materials used in HMA follows.

CELLULOSE WASTES

Cellulose wastes include agricultural wastes (crop residues, foresting wastes), manufacturing wastes (food processing, wood and paper industry), and urban refuse (municipal solid waste, manufacturing plant trash). A pyrolysis process has been used o convert cellulosic waste to a binder (3). However, the resulting binder was not suitable for direct use as a substitute for asphalt cement because its theological properties did not meet the performance criteria. The binder was also not compatible with asphalt cement. A pyrolysis-hydrogenation process, however, produced an oil which was suitable for use as an extender of asphalt cement in paving operations. Based on limited experiments the durability of a HMA wearing course mixture containing hydrogenated pyrolysis oil was not found significantly different from that containing the reference asphalt cement only. Extensive laboratory and field experiments are needed to evaluate the compatibility and performance of the cellulosic oils when used with asphalt cements from various sources.

WOOD LIGNINS

Wood lignin is a high volume waste produced in the manufacture of paper products. Attempts have been made to convert wood lignin to a highway binder material and use it either alone as a substitute for asphalt cement or as an extender for asphalt cement in HMA mixes (4). Suitable lignin-asphalt binder formulations were prepared from lignins from both major manufacturing processes, that is, kraft and sulfite processes. None of the binder formulations was suitable alone as a substitute paving binder. However, a 30 percent replacement of asphalt cement appeared feasible with no significant effect on physical properties. Kraft lignin appeared insoluble in asphalt cement. Lignin-asphalt cement binders are stiffer and require slightly higher binder content than conventional HMA mixtures. Precoating of the coarse aggregate has been recommended to reduce the binder content in HMA mixtures. Based on limited laboratory experiments, Terrel et al. (4) concluded that HMA mixtures containing lignin-asphalt binders can be designed to match the structural strength of HMA mixtures containing conventional materials.

BOTTOM ASH

Bottom Ash is a waste material from coal burning power plants. It is the slag which builds up on the heat-absorbing surfaces of the furnace, and which subsequently falls to the bottom of the furnace and collected in an ash hopper. The bottom ash is categorized as dry bottom ash or wet bottom ash depending upon the boiler type used. The ash which is in solid state at the furnace bottom is called dry bottom ash. The ash which is in molten state when it falls in water is called either wet bottom ash or more commonly boiler slag (5).

Extensive laboratory studies were performed on representative samples of Indiana bottom ashes, to determine their physical, chemical and mechanical properties (6). Depending upon the source, bottom ashes can have different physical and chemical properties. These studies showed that the bottom ashes are non-hazardous in nature and have minimal effects on ground water quality. However, the bottom ashes can be highly corrosive and, therefore, should not be placed very near to any metal structure.

Laboratory studies (7, 8) have also been conducted to evaluate the feasibility of using bottom ashes as a partial or full replacement of natural aggregates in HMA mixes and develop guidelines for their use. The properties of HMA containing bottom ash are dependent on ash content. Generally, as the ash content is increased, the optimum asphalt content is increased, the mixture density is decreased, and the air voids and voids in the mineral aggregate are increased. The stability of HMA mix decreases up to an ash content of 30 percent and then levels off. The mix containing bottom ash is susceptible to rutting. However, the mix is highly resistant to moisture induced damage (stripping). It was concluded from these studies that the properties of most dry and wet bottom ashes can meet the specifications for conventional aggregates.

Wet bottom ash (or boiler slag) can improve the skid resistance of HMA wearing courses. West Virginia obtained satisfactory performance from HMA wearing course mixes containing 50 percent boiler slag (9). Lignite boiler slag has also been used to resurface residential streets in Texas. The HMA mix contained 75 percent boiler slag, 25 percent limestone screenings, and 6 to 7 percent asphalt content (*10*).

FLY ASH

Fly ash is the fine particulate matter which is precipitated from the stacks of pulverized coal-fired boilers at electrical power generating plants. It represents nearly 75 percent of all ash wastes generated in the United States. The quality of fly ash is affected by the type of coal used, the ash content of the coal, the degree to which the cd has been pulverized prior to combustion, and type of ash collectors utilized. These variables, therefore, impart a wide range of physical and chemical properties to the fly ash. It is composed of finely divided pieces of siliceous glass which range from 1 to 50 microns in diameter (*11*).

Fly ash has primarily been used as a mineral filler in HMA mixtures in several states such as Illinois, Michigan, Montana, North Dakota, and West Virginia (*11*). Because the fly ash particles are extremely fine, it is quite likely to act as an extender of asphalt cement in HMA mixtures. Therefore, caution should be exercised when using fly ash in rut-resistant HMA mixtures for heavy duty pavements.

INCINERATOR RESIDUE

According to the estimates of the U.S. Environmental Protection Agency (EPA), about 23 million megagrams (Mg) of municipal solid waste (MSW) was incinerated in the United States in 1988 (*12*). It is projected that about 41 million Mg and 50 million Mg of MSW will be incinerated in the years 1995 and 2000, respectively. Two ash products: bottom ash and fly ash, result from incinerating MSW. Bottom ash is the unburned and incombustible residue left on the boiler grates after incineration, and consists of large particles (0.1-100 mm) of slag, glass, rocks, metal, and other materials. Fly ash consists of burned or partially burned organic material particles which are usually 1-500 micron in size (5). The heterogeneous character of these two incinerator residues causes a wide variation in composition from one plant to another.

The incinerator residue is not suitable for use in HMA mixtures unless it is processed further. The Franklin Institute Research Laboratory in Philadelphia developed a process of densifying (fusing) the unfused incinerator residue and converting it into useful construction materials. The incinerator residue is ground with a hammer mill, preheated at 688°C, and then melted and fused at 1093°C to form a column of semi-molten product which is later cooled and crushed to aggregate sizes (*11*). Preliminary laboratory evaluation by the Pennsylvania Department of Transportation (*13*) indicated that the fused incinerator residue was not suitable for HMA mixtures because it did not comply with the specified gradation, particles were flat and elongated, and the HMA mixture did not meet design criteria for stability, air voids, or voids in the mineral aggregate. Subsequent improvements in the process (*14*, *15*) produced a high quality aggregate material which performed well in a HMA surface course installation in Harrisburg, Pennsylvania (*16*).

Several installations using unfused incinerator residue as an aggregate in HMA mixtures were made during the 1974-1979 period in Texas, Pennsylvania, Washington, DC, and Massachusetts (*2*). Details of these installations are given in the literature (*17*, *18*, *19*, *20*, *21*, *22*). The following recommendations have been made: (a) residues should be well-burned out (loss on ignition should be less than 10 percent), (b) HMA mixtures for base courses containing 50 percent natural aggregate and 50 percent incinerator residue hold the most promise, and (c) 2 percent lime should be added to minimize stripping problems.

TIRE SCRAP RUBBER

About 285 million tires are discarded every year in the United States. Of these, about 55 million are retreaded or reused (resold), and about 42 million are diverted to various alternative uses such as combustion for generating power and additive to HMA mixes. The remaining 188 million tires are added to stockpiles, landfills or illegal dumps. According to EPA estimates, 2 to 3 billion discarded tires are available at the present time (*23*). Several states have enacted legislation to regulate the scrap tire problem. At the national level, Section 1038 of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 specifically addresses the study and use of the scrap rubber by the highway industry.

Crumb rubber obtained from tires can either be ambient ground (grinding at room temperature or above) or cryogenically ground (grinding below embrittlement temperature, liquid nitrogen is often used). Ambient ground crumb rubber has a sponge-like surface. Due to very high surface area this rubber reacts with asphalt cement reasonably fast. Cryogenically ground rubber usually has undesirable particle morphology (structure). This process produces clean flat surfaces which, in turn, reduces the reaction rate with hot asphalt cement. Cryogenically ground rubber also gives lower elastic recovery compared to the ambient ground rubber (*24*).

The use of crumb rubber to modify asphalt cement has been developed over the past 25 years. Crumb rubber is primarily used in HMA mixes by two processes:

Wet Process (Asphalt-Rubber)

The wet process blends the crumb rubber with the asphalt cement prior to incorporating the binder into the project. The modified binder is commonly called “asphalt-rubber.” Generally, 18-26 percent crumb rubber (16 mesh) by weight of asphalt cement is reacted with asphalt cement at 190 to 218/C for 1 to 2 hours. The blend is formulated at elevated temperatures to promote potential chemical and physical bonding of the two constituents. The first technology which applied the “wet process” is called the “McDonald Process.” This process is also used for constructing stress absorbing membrane (SAM) and stress absorbing membrane interlayer (SAMI), and manufacturing crack sealers. SAM is a seal coat which uses asphalt-rubber as a binder. When SAM is placed as an interlayer it is called SAMI.

Dry Process (Rubber-Modified Mix)

This process mixes the crumb rubber with aggregate before incorporating the asphalt cement. About 3-5 percent of coarse rubber particles (1.6-6.4 mm) by weight of aggregate are generally used. The natural aggregate is usually gap-graded to accommodate the rubber particles as aggregate. The amount of crumb rubber used in the dry process can be 2-4 times that used in the wet process. The first application of the "dry process" in the United States is called the "PlusRide Process." It has been claimed that ice debonds easily from the pavement surface consisting of rubber-modified mixture because of higher than usual resiliency of the mix.

Details of Wet Process

The wet process (asphalt-rubber) will now be discussed in more detail. To produce an acceptable asphalt-rubber binder it is necessary to establish the digestion temperature and time for a specific combination of asphalt cement and crumb rubber. Viscosity of the blend is checked at different time intervals during the blending and digestion process. Viscosity of the blend increases with digestion time and then levels off. Achieving a reasonably constant viscosity indicates that the initial reaction is nearly complete and the binder is ready to use. This initial reaction is not well understood, but appears to be due to a chemical and physical exchange between the asphalt cement and rubber particles in which the rubber swells in volume causing an increase in viscosity. Continued mixing of asphalt cement and rubber after initial reaction can begin to reduce the viscosity of the blend as the rubber particles break down during mixing. However, breakdown of rubber particles is not rapid, and may require several hours at high temperatures.

If the asphalt-rubber blend is too viscous an extender oil is usually added. However, if less than 10 percent crumb rubber (by weight of asphalt cement) is used, extender oil is not needed.

The asphalt-rubber blend should be used as soon as possible after the initial reaction. Until used it should be recirculated continuously. Blends have been allowed to cool in storage tanks and reheated prior to use without difficulty.

When asphalt-rubber binder is used in HMA mixes the following mixing temperature ranges have been used:

Dense-graded HMA mixes: 163-190°C
Open-graded HMA mixes: 135-163°C

Stack emissions can be higher because of the elevated mixing temperatures.

HMA mixes containing asphalt-rubber binder should not be subjected to prolonged storage in a silo. Processing the mix through a surge silo is acceptable. Diesel fuel should not be used on truck beds as a release agent because it makes the mix stick more to the bed. Use of lime water, soap solution or silicone emulsion is recommended instead.

It is necessary to maintain the mix temperature within the desired range during placement of the mix. Static steel wheel rollers are generally used for compaction. Rubber-tired rollers tend to pick-up the mat. Vibratory rollers tend to tear and shove the mat. If the roadway has to be opened to the traffic right after compaction and the traffic has a tendency to pick-up the mat, it is recommended to apply 0.5-1 kg of concrete sand per square meter of the mat surface.

Recyclability of the HMA containing crumb rubber is a very important issue which must be addressed before using scrap tire crumb rubber on a large scale. There is no experience at the present time in recycling such mixes. It is quite likely that recycling these mixes in the future could pose air pollution problems during production. What will happen to the asphalt-rubber binder during recycling? How will the recycled mix be designed? If these concerns are not addressed it may not be possible to recycle the HMA mixes containing crumb rubber. In that case we will have to dispose the RAP (reclaimed asphalt pavement) which will be much worse than the problem of disposing tires.

In 1988, under a legislative mandate, the Florida Department of Transportation (FDOT) began a concerted effort to evaluate the potential use of tire scrap rubber in HMA pavements. FDOT commissioned the National Center for Asphalt Technology (NCAT) to prepare a state-of-the-art report on the use of ground tire rubber (GTR) in HMA and recommend a strategy to use GTR in Florida HMA mixes. This report (*24*) was published in August 1989. Since then, FDOT has constructed three demonstration projects. At the present time FDOT is implementing the following recommendations:

- Use GTR in friction courses only. Typically FDOT resorts to 75 mm cold milling (25 mm friction course + 50 mm structural course) which is recycled. If the friction course contains GTR, only 1/3 of the RAP will contain GTR.
- Dense-graded friction courses: Use 3-5 percent GTR by weight of asphalt cement. In the past, 18-20 percent GTR has been used as mentioned earlier. Use No. 80 mesh GTR. In the past, 16 mesh GTR has generally been used. Finer GTR is appropriate for the Florida friction course mixes which approach sand-asphalt mixtures. Moreover, the finer GTR size reacts with asphalt cement more easily, and thus a continuous blending of asphalt cement and GTR becomes possible.
- Open-graded friction courses: Use 5-10 percent GTR by weight of asphalt cement. Use No. 40 mesh GTR.

FDOT does a considerable amount of hot recycling every year. Since the RAP will contain low amounts of GTR, no problems are anticipated in recycling the HMA pavements in the future. It is estimated that state-wide use of GTR will increase the price of HMA mixes in Florida by 15 percent.

New Concepts

The “McDonald process” (wet process) and “PlusRide” (dry process) as discussed earlier are patented processes. However, the original patent on the “McDonald process” has expired in 1992. Recently some newer concepts which include the generic dry process, chunk rubber asphalt concrete and continuously blended asphalt rubber, have been introduced (*23*).

The generic dry process allows incorporation of crumb rubber in available “generic” aggregate gradation rather than gap-graded aggregate required in the PlusRide system. Experimental field applications of generic dry process have been made in New York, Florida, Iowa, Kansas, Oregon, and Illinois (*23*).

Chunk rubber asphalt concrete concept has been developed by the Cold Regions Research and Engineering Laboratory (CRREL) of the U.S. Army Corps of Engineers. This concept uses a large maximum crumb rubber size (4.75 -12.5 mm), and an aggregate gradation to provide space for the rubber aggregate. However, this concept has been confined to laboratory only and no field installations have been made.

The continuous blending asphalt rubber concept has been used by Florida DOT (FDOT) as described earlier. It is a wet process which uses fine crumb rubber (180 : or No. 80 mesh) to avoid reaction tanks, and to facilitate continuous blending. The performance of FDOT experimental sections is being monitored.

WASTE GLASS

When crushed waste glass is incorporated in HMA mix the resulting mixture is sometimes referred to as “glasphalt.”

Several laboratory and field evaluations of glasphalt were conducted in the early 1970s in the U. S. and Canada. After no significant interest for a decade, the potential use of glasphalt is now being reassessed. Three states—Connecticut, Virginia and Florida—have recently conducted feasibility studies and issued research reports (*25*, *26*, *27*).

The Connecticut report gives an excellent review of literature on both laboratory and field evaluations of glasphalt since 1969:

- Glasphalt was successfully mixed and placed in at least 45 locations in the U.S. and Canada between 1969 and 1988. However, most glasphalt has been placed on city streets, driveways and parking lots, and not on high-volume, high-speed highways.
- Potential problems with glasphalt include: loss of adhesion between asphalt and glass; maintenance of an adequate level of skid resistance, especially with coarse particles; breakage of glass and subsequent ravening under studded tires; lack of adequate and consistent supply of glass; and increased production costs (estimated at $5/Mg more than the conventional HMA mix in Connecticut).
- Glasphalt should be used only as a base course to alleviate potential skid resistance and surface ravening problems.
- No more than a maximum of 9.5 mm glass should be used in glasphak, with hydrated lime added to prevent stripping.

The Virginia report is based on laboratory evaluation and economic analysis of glasphalt. Two glass contents, 5 percent and 15 percent, and two asphalt contents were used in the laboratory evaluation of Virginia S-5 surface HMA mix (12.5 mm top size). A densely graded recycled glass with a maximum nominal size of 9.5 mm was used.

The following are significant conclusions:

- The use of glass tends to reduce the VMA and air voids in Marshall specimens; therefore, optimum asphalt content will also be reduced.
- Neither resilient modulus nor indirect tensile strengths are adversely affected by the addition of up to 15 percent glass.
- Although both wet strength and retained tensile strength laties (TSR) were unaffected by the percentage of glass, some separation at the asphalt/glass interface was observed.
- A maximum of 15 percent crushed recycled glass should be allowed (100 percent passing a 9.5 mm sieve and a maximum of 6 percent passing a 75 pm sieve) in HMA mixes.
- There is little monetary incentive to use recycled glass at the present time because the cost of glass varies considerably.
- An experimental section should be laid prior to extensive use of waste glass.

The Florida Department of Transportation tested three HMA mixtures to determine the effects of crushed glass:

1. Control mix (9.5 mm nominal maximum size)
2. 15 percent coarse glass mixture—same as the control mixture except that 15 percent of the screenings were replaced with coarse (9.5 mm-2.06 mm nominal size) crushed glass.
3. 15 percent fine glass mixture—same as the control mixture except that 15 percent of the screenings were replaced with fine (2.06 mm-75 :m nominal size) crushed glass.

AC-30 asphalt cement with and without antistripping agent was used to prepare Marshall specimens which were also tested for tensile strength. The following conclusions were drawn based on the limited laboratory evaluation:

- Marshall stability values decreased by 15-20 percent and dry indirect tensile strength decreased by 20 percent when 15 percent of the screenings were replaced with either coarse or fine glass.
- Moisture conditioning of Marshall specimens caused a 15 percent and 50 percent decrease in tensile strength when coarse and fine glass, respectively, were incorporated into the mixture. Retained tensile strength ratio (TSR) values indicated that the antistripping additive was ineffective in reducing the moisture damage.
- It is unlikely that the use of crushed glass in HMA mixtures will be economically feasible when suitable local materials are available at or near the HMA facility.

The City of New York places 360,000 Mg of HMA containing 10 percent waste glass every year. This amounts to an annual consumption of 36,000 Mg of glass.

ROOFING SHINGLES

Approximately 90 million roofing shingle squares are produced per year by 77 plants in the United States. About 1/3 of the shingles are used on new houses and the remaining 2/3 of the shingles are used for reroofing houses. When a house is reroofed, often an equivalent amount of old shingles is removed and discarded. Moreover, each roofing plant generates scrap materials and seconds that can range from 5 to 10 percent of the production capacity. The disposal of old shingles and the scrap material has created a difficult disposal problem (*28*).

It is estimated that roofing waste contains about 36 percent asphalt content, 22 percent hard rock granules (minus No. 10), 8 percent filler and smaller amounts of miscellaneous materials (*29*).

Roofing shingles have been used successfully in the HMA paving of the parking lots at Disney World, Florida. Shingles need to be shredded to at least 12.5 mm or smaller prior to introduction in the mix to ensure meltdown and uniform dispersion in the HMA mixture. According to cost estimates (*28*), the HMA cost can be reduced by $3.08 per megagram (Mg) by introducing only 5 percent organic shingles.

COAL MINE REFUSE

Anthracite Coal Refuse

The principal source of anthracite coal is in northeastern Pennsylvania. Anthracite coal mine refuse is composed of unprocessed mine refuse and processed coal breaker refuse. It is a gray slate-like material containing oxides of silicon, aluminum, iron, calcium, magnesium, sodium and potassium. More than 50 percent of average anthracite refuse is greater than 25.4 mm in size (*11*).

The Pennsylvania Department of Transportation (PennDOT) conducted a laboratory evaluation of unburnt (raw) anthracite refuse as an aggregate in HMA mixtures (*30*). The aggregate particles were very absorptive, particularly in sizes larger than the 4.75mm sieve, and could not be coated completely with asphalt cement. Freeze-thaw failures also occurred in less than half the cycles of a control mix. Anthracite refuse must be incinerated before use in the HMA mix. Four HMA paving projects in Luzeme County of Pennsylvania were constructed with crushed incinerated anthracite refuse (*31*). The performance in terms of skid resistance and wear was reported to be satisfactory.

Bituminous Coal Refuse

The principal sources of bituminous coal are located in Kentucky, West Virginia and Pennsylvania. Bituminous coal refuse is somewhat similar to anthracite refuse in appearance. The University of Kentucky evaluated the use of bituminous coal refuse in HMA mixtures in 1964 (*32*). The mixtures containing 100 percent coal refuse were susceptible to moisture induced damage.

SUMMARY

Recycling of waste materials in highway construction should be encouraged. However, it is necessary to address the engineering concerns, environmental concerns and economic concerns mentioned in this paper before any large scale use of these materials. The use of waste materials should not be mandated. HMA containing a waste material should perform as well or better than conventional HMA. It should also be environmentally safe both for the first construction and future recyclability.

This paper discusses laboratory and/or field evaluation of several waste materials which have been used in HMA. It is recommended to construct demonstration projects to evaluate the performance of HMA containing waste materials. Waste materials should not be used as a standard practice until the performance data is available from the demonstration projects.

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