142

Utilization of Recycled Materials in Illinois Highway Construction

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16. Abstract

According to the Illinois Environmental Protection Agency's 2000 Annual Landfill Capacity Report "as of Jan. 1, 2001, 53 landfills reported having a combined remaining capacity of 743.4 million gate cubic yards, or 49.3 million gate cubic yards less than on Jan. 1, 2000, a decrease of 6.2 percent." Also, at current waste generation rates "landfill life expectancy in Illinois [is] 15 years barring capacity adjustments." As waste continues to accumulate and availability and capacity of landfill spaces diminish, agencies are increasing application and use of recycled materials in highway construction.

The Illinois Department of Transportation utilizes millions of tons of highway materials annually. The basic building materials in roadway and bridge construction are primarily aggregate, cement, and asphalt. The annual usage of recycled materials is over 1.5 million tons. The educated use of recycled materials can result in reduced cost potentials and may enhance performance; however, not all recycled materials are well suited for highway applications due to limited or compromised performance-based benefits and/or high cost. This report reviews current usage of various recycled materials, as well as discusses reclaimed materials not currently being utilized by the Department.

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UTILIZATION OF RECYCLED MATERIALS
IN ILLINOIS HIGHWAY CONSTRUCTION

2002 Report

by:

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ILLINOIS DEPARTMENT OF TRANSPORTATION

BUREAU OF MATERIALS AND PHYSICAL RESEARCH

SPRINGFIELD, ILLINOIS

MAY 2002

TABLE OF CONTENTS

Introduction

According to the Illinois Environmental Protection Agency's (IEPA) 2000 Annual Landfill Capacity Report "as of Jan. 1, 2001, 53 landfills reported having a combined remaining capacity of 743.4 million gate cubic yards, or 49.3 million gate cubic yards less than on Jan. 1, 2000, a decrease of 6.2 percent." Also, at current waste generation rates "landfill life expectancy in Illinois [is] 15 years barring capacity adjustments." As waste continues to accumulate and availability and capacity of landfill spaces diminish, agencies are increasing application and use of recycled materials in highway construction.

The Illinois Department of Transportation utilizes millions of tons of highway materials annually. The basic building materials in roadway and bridge construction are primarily aggregate, cement, and asphalt. The annual usage of recycled materials is over 1.5 million tons. The educated use of recycled materials can result in reduced cost potentials and may enhance performance; however, not all recycled materials are well suited for highway applications. The two main reasons for not utilizing a reclaimed material are 1) addition of material is a detriment to highway performance, and 2) excessive cost. This report reviews current usage of various recycled materials, as well as discusses reclaimed materials not currently being utilized by the Department.

Eleven recycled materials that the Department has found to perform favorably as valuable supplements or substitutes for conventional materials include: air-cooled blast furnace slag, by-product lime, fly ash, glass beads, granulated blast furnace slag, microsilica, reclaimed asphalt pavement, recycled concrete pavement, steel reinforcement, steel slag, and wet-bottom boiler slag. The information provided for each material outlines the origin, physical properties, engineering value, present use, annual quantities used, and economic impact.

Five additional materials experimented with by other states but are currently not viable resources in Illinois highways, for economic or technical reasons, are the following: bottom ash, crumb rubber, glass aggregate, waste foundry sand, and roofing shingles. Each material's origin, physical properties, potential engineering value, potential application, and departmental concerns regarding each non-utilized material are outlined herein.

The quantities of reclaimed materials used—tonnage, in general—indicated within the report and summarized by the appendix are based on materials use as reported to the Materials Integrated System for Test Information and Communication (MISTIC) for the year 2001. The MISTIC database provides materials quantities according to contracted use, testing and inspection data, as well as construction pay items, all by major materials categories, such as aggregate, concrete, paint, etc. All quantities have summarily been converted to English units as referenced within the report.

Use of recycled materials varies from year to year depending on construction activity as well as type of construction projects in a given season. Also, the ability to use recycled materials relies on their use economically—depending on availability or feasibility under unique contract circumstances. In 2001, the Department used nearly 1.4 million tons (2.8 billion pounds) of recycled materials in highway construction. That is, based upon the federal EPA's estimates of individual waste generation, usage equivalent to nearly one third of the waste generated annually by individuals in the City of Chicago.

RECYCLED MATERIALS UTILIZED IN HIGHWAY CONSTRUCTION

Air-Cooled Blast Furnace Slag

<u>Origin:</u> Iron ore, as well as scrap iron, is reduced to a molten state by burning coke fuel with fluxing agents of limestone and/or dolomite. Simultaneously during the iron production, slag is developed in the blast furnace. Air-Cooled Blast Furnace Slag (ACBFS), one of various slag products, is formed when the liquid slag is allowed to cool under atmospheric conditions. It may later be broken down with typical aggregate processing equipment to meet gradation specifications (1).

<u>Physical Properties:</u> ACBFS is a hard, angular material with textures ranging from rough, porous surfaces to smooth, shell-like fractured surfaces. Though vesicular, the structure's cells are not inter-connected and little absorption to the interior is likely. Physical properties (e.g. unit weight and size) can vary considerably depending on the method of production; for example, high use of scrap iron can lead to higher unit weights (1, 2).

<u>Engineering Value:</u> Crushed ACBFS can be used in nearly all applications utilizing natural aggregates, such as bituminous and portland cement concretes, embankments, or subbases. ACBFS has potentially favorable resistance to polishing, weathering durability, and bearing. However, the material's inherent variability in physical properties can be of concern. For example, included in bituminous concrete pavements, this material provides exceptional frictional properties and increased stability, but its tendency for high surface absorption may require greater amounts of asphalt binder (1, 2).

<u>Present Application:</u> ACBFS is incorporated into portland cement concrete (PCC), bituminous concrete, granular bases and subbases, embankments, and fills. As of August 1999, a self-testing producer control program had been added to specifications regarding bituminous concrete mixes. For the most part, slag is tested as though it were a natural aggregate; unless the application pertains to bituminous concrete, IDOT will not use slag failing LA Abrasion test limits (3).

<u>Quantity Used:</u> 78,910 tons (2001 MISTIC estimate).

<u>Economic Impact:</u> In 2001, the Department spent approximately $1,200,000 using ACBFS.

By-Product Lime

Origin: Limestone (calcium carbonate) heated in a kiln, drives off carbon dioxide and forms lime (calcium oxide). The kiln's exhaust gasses—filtered using electrostatic precipitators, baghouses, or other such methods—are collected and sold as by-product lime. Lime Kiln Dust (LKD) can vary chemically depending on the type of lime being manufactured. It can be categorized according to reactivity, which is based on the amount of free lime and magnesia content—corresponding to lime types: calcitic (chemical lime, quicklime, etc.) or dolomitic (1).

Physical Properties: By-product lime is a very fine, white powdery material of uniform size containing calcium and magnesium carbonates as its principle mineral constituents. Much of LKD's properties are determined in the plant production: feedstock, kiln design, fuel type, and type of dust control/collection method employed (1).

Engineering Value: By-product lime is valued as both a modifying and stabilizing agent in soil treatment. It generally increases the workability of clayey soils by reducing the plasticity index and increasing the optimum moisture content. On the other hand, high levels of free lime content in LKD have been shown to result in poorer dimensional stability (shrinkage, expansion) (1).

Present Application: By-product lime provides a stable, working platform for paving operations. This material aids in the reduction of high moisture borrow soils in embankment construction (2, 3).

Quantity Used: 46,760 tons (2001 MISTIC estimate).

Economic Impact: By-product lime usage is one of the least expensive remedial actions for unstable subgrade soils. Using this material, the Department spent approximately $701,500 in 2001.

Fly Ash

Origin: Fly ash is a by-product produced in large quantities during the day to day operations of coal-fired power plants. In general, the coal source is pulverized and blown into a burning chamber where it ignites to heat boiler tubes. Heavier particles of ash (bottom ash or slag) fall to the bottom of the burning chamber, while the lighter particles (fly ash) remain suspended in the flue gases. Before leaving the stack, these fly ash particles are removed by electrostatic precipitators, baghouses, or other such dust collectors/air pollution control devices (4).

Fly ash is divided into two classes—Classes F and C—based upon the type of coal source. Class F fly ash is produced by burning anthracite or bituminous coal; whereas, Class C fly ash is produced from lignite or sub-bituminous coal (1).

Physical Properties: Fly ash is a fine, powdery silt-sized amorphous residue. Varying amounts of carbon affect the color of fly ash. Gray to black represents increasing percentages of carbon, while tan coloring is indicative of lime and/or calcium content. Fly ash may exhibit pozzolanic properties and, in certain types, cementitious properties (1, 4).

Engineering Value: In PCC, Class F fly ash has pozzolanic properties when introduced to water, whereas Class C fly ash is naturally cememtitious due to its high amount of calcium oxide. Fly ash can be added to PCC to modify pH, change the hydration process (fly ash retards hydration thus lowering heat of hydration), reduce water demand, and reduce permeability (1, 4).

Present Application: Dry fly ash can be used as an inert fill material or supplementary cemetitious material to improve cohesion and stability of bituminous concrete binder and soil embankments. In Illinois, fly ash is used as a fine aggregate or supplementary cementitious material in PCC; however, the Department limits the use of Class F to no more than 15 percent by weight, and Class C to no more than 20 percent by weight. In combination with sand, fly ash may be a supplement or substitute for cement to make a flowable fill, or as grout for concrete pavement sub-sealing (1, 3, 4).

Quantity Used: 95,570 tons (2001 MISTIC estimate).

Economic Impact: The use of fly ash as a supplementary cementitious material cost the Department approximately $2,630,000, aided in the reduction of landfill space need, and reduced emissions and fuel consumption required for cement production.

Glass Beads

Origin: Virgin glass, in general, is a molten mixture of sand (silicon dioxide—a.k.a. silica), soda ash (sodium carbonate), and/or limestone supercooled to form a rigid solid (1). Glass beads, in particular, are a product of recycled soda-lime glass. This material's primary source is from manufacturing and postconsumer waste. At recycling centers, recovered glass is hand sorted by color (clear, amber, and green), and then crushed to customized sizes.

Physical Properties: Glass beads are transparent, sand-sized, solid glass microspheres (3).

Engineering Value: Glass beads can enhance the nighttime visibility of various objects through the fundamentals of retro-reflectivity—light is reflected back to its source, for instance, vehicle headlights.

Present Application: The Department uses two types of glass beads—Type A (uncoated) and Type B (silicone coated, moisture resistant)—depending on the method of application (drop-on or intermix) and the type of pavement marking paint used (solvent-based, waterborne, or thermoplastic). Glass beads are utilized in many traffic control devices including reflective sheeting decals, pavement striping, and pavement marking tape. Essentially all traffic lines on highways contain glass beads, which improve the overall safety of nighttime highway travel. Outside the Department, glass beads are utilized in license plates, movie screens, and reflective fabrics (3, 5).

Quantity Used: 7,310 tons (2001 MISTIC estimate).

Economic Impact: The use of glass beads, as an alternative to their disposal, has created a market for material recovery facilities specializing in waste glass recycling. Since soda-lime glass cannot be re-melted by glass manufacturers, the production of glass beads avoids the necessity of land filling (1). In 2001, the Department spent approximately $2,490,000 on glass beads.

Ground Granulated Blast Furnace Slag

Origin: Blast furnace slags are developed during iron production. Iron ore, as well as scrap iron, is reduced to a molten state by burning coke fuel with fluxing agents of limestone and/or dolomite. Ground Granulated Blast Furnace Slag (GGBFS) is a glassy, granular material resulting from blast furnace slag being rapidly cooled by water immersion, and pulverized to a fine, cement-like material (1, 2, 3).

Physical Properties: GGBFS is a glassy, non-crystalline material varying in size depending on its chemical composition and method of production—its own production as well as that of its iron source (1).

Engineering Value: When ground down to cement-sized fineness, granulated blast furnace slag is pozzolanic; therefore, it can be used in PCC as a mineral admixture, component of blended cement, or substitute for portland cement (1, 2).

Present Application: The primary uses of GGBFS slag are as a fine aggregate substitute, mineral admixture, and component of blended cement. In blended cements, GGBFS has a low heat of hydration, which slows the chemical reaction responsible for strength gain, resulting in a gradual strengthening of the concrete. Consequently, the Department currently allows no more than 25% to be included in PCC (2, 3).

Quantity Used: 530 tons (2001 MISTIC estimate).

Economic Impact: The use of GGBFS as a supplementary cementitious material aided in the reduction of landfill space need, and reduced emissions and fuel consumption required for cement production.

Microsilica

<u>Origin:</u> Microsilica is a by-product of the production of silicon metal or ferro-silicon alloys. It is supplied in densified bulk trucks, large bags, or provided as a water-based slurry. It is most commonly furnished bagged (6).

<u>Physical Properties:</u> Microsilica (SiO_2), also known as silica fume, is a gray powdery material largely consisting of amorphous silicon dioxide, and has a mean particle size between 0.1 and 0.2 µm—100 times finer than portland cement (6).

<u>Engineering Value:</u> Microsilica's high silica content is also high in purity and pozzolanic properties. Reacting with calcium hydroxide (products of cement's pozzolanic reaction), microsilica will produce calcium silicates that will result in denser concrete with higher strengths—increasing compressive strengths up to 100 MPa (14,500 psi) or more—lower permeability, and improved durability. In the specific application of bridge deck overlays, the decrease in permeability slows the rate of corrosion on reinforcing members by impeding chloride or sulfate intrusion (3, 6).

<u>Present Applications:</u> The Department's primary use for microsilica is in bridge deck overlays. Since the late 1980s, over 150 concrete deck overlays have incorporated microsilica. Small amounts of microsilica are also used in high performance shotcrete for structural repairs. Outside of the Department, microsilica is utilized in multi-story building construction (3).

<u>Quantity Used:</u> 115 tons (2001 MISTIC estimate).

<u>Economic Impact:</u> Even though the price of microsilica is substantially higher than that of portland cement, the Department has contributed approximately $50,600 toward its recycling—eliminating disposal costs. Overall, this material has the potential to extend the life of a structure 25 to 30 years, thus lowering its life cycle cost.

Reclaimed Asphalt Pavement

Origin: Reclaimed Asphalt Pavement (RAP) is bituminous concrete material removed and/or reprocessed from pavements undergoing reconstruction or resurfacing. Reclaiming the bituminous concrete may involve either cold milling a portion of the existing bituminous concrete pavement or full depth removal and crushing (1, 3).

Physical Properties: RAP properties largely depend on its existing in-place components. There can be significant variability among existing in-place mixes depending on type of mix, and in turn, aggregate quality and size, mix consistency, and asphalt content. Due to traffic loading and method of processing, RAP is finer than its original aggregate constituents are; it is finest when milled (1).

Engineering Value: RAP is produced by crushing and screening the material to a 1/4- to 1/2-inch in size. It is tested to ensure that the proper applicable gradation and quality is satisfied, and if so, the RAP is mixed with virgin aggregate and asphalt as needed, then placed. Since millings from different projects will have different characteristics, contractors must maintain separate stockpiles of milled material, and the properties of particular stockpiles will change as it used and reused (1, 3).

Present Applications: As of the new policy brought into effect January 2000, the Department allows incorporating RAP into Superpave mixes. The amount of RAP allowed for low volume roads increased from 25 percent to 30 percent. For some non-critical mixes, such as the shoulder, base, and subbase, up to 50 percent RAP is allowed. For high-type binder courses, up to 25 percent is allowed. For surface courses, the amount allowed ranges from 10 percent to 15 percent for all but the highest volume highways. RAP is not allowed in the Department's highest-class bituminous concrete surface or polymer-modified mixes to maintain acceptable friction requirements (3, 7).

The Department also allows RAP to be used in place of aggregate or earth in some non-structural backfill situations. Last year, RAP was used in approximately 40 to 60 percent of the Department's most common surface and base course mixes, and over 60 percent of total shoulder mix tonnage (3, 7).

Quantity Used: 623,000 tons (2001 MISTIC estimate).

Economic Impact: In 2001, the Department has spent approximately $19,940,000 using RAP as a viable aggregate substitute for scarce bituminous resources.

Recycled Concrete Material

Origin: Recycled Concrete Material (RCM), also known as crushed concrete, is reclaimed PCC pavement material. Primary sources of RCM are demolition of existing concrete pavement, bridge structures, curb and gutter, and from central recyclers, who obtain raw feed from commercial/private facilities. This material is crushed by mechanical means into manageable fragments and stockpiled. RCM may include small percentages of subbase soil and related debris (1).

Physical Properties: Comprised of highly angular conglomerates of crushed quality aggregate and hardened cement, RCM is rougher and more absorbent than its virgin constituents. Furthermore, differences among concrete mixes and uses result in varying aggregate qualities and sizes; for example, pre-cast concrete is less variable than cast-in-place (1).

Engineering Value: Crushed concrete's physical characteristics make it a viable substitute for aggregate and can be used as such, for example in granular bases, as well as a material fill, such as riprap. Ultimately, RCM obtained on site may be employed immediately for project use or stockpiled for future use.

The cementitious component has a high amount of alkalinity by nature, and chlorides from deicing salts may be present—a concern in regards to steel reinforcement corrosion. RCM may also contain aggregates susceptible to alkali-silica reactions or D-cracking (1, 3).

Present Application: The Department allows the use of RCM as a coarse aggregate in aggregate surface courses, granular embankments, stabilized bases, and subbase courses provided the project materials' specifications are not compromised. This material has also been widely used as an aggregate in membrane waterproofing and in drainage layers as protection against erosion (3, 8).

Quantity Used: 321,300 tons (2001 MISTIC estimate).

Economic Impact: The use of RCM impacts the economy as a substitute for natural aggregates by reducing landfill space needs. The use and number of central recyclers have increased over the last few years. In 2001, overall departmental spending was approximately $1,600,000.

Steel Slag

Origin: As iron production is to blast furnace slag, so pig iron manufacturing is to steel slag. Impurities (carbon monoxide, silicon, liquid oxides, etc.) are removed from molten steel in a basic oxygen or electric arc furnace, and combined with the fluxing agents to form steel. Depending on the stage of production, three types of steel slag are produced: furnace (or tap) slag, raker slag, ladle (or synthetic) slag, and pit (or cleanout) slag. Ladle slag, which contains high amounts of synthetic fluxing agents, is characteristically different than furnace slag—primary source of steel slag aggregate product—and is not deemed suitable for aggregate usage (1, 10).

Physical Properties: The cooling rates and chemical composition of steel slag production affect physical characteristics, such as density, porosity, and particle size. In general, processed (i.e. crushed) steel slag is more angular, more dense and harder than comparable natural aggregates (9).

Engineering Value: Steel slag has sufficient material properties including favorable frictional properties, high stability, and resistance to stripping and rutting. On the other hand, steel slag may contain amounts of calcium or magnesium oxides, which will hydrate—leading to rapid short-term and long-term expansion, respectively. Also, though normally mildly alkaline, steel slag may be potentially harmful to aluminum or galvanized metals (1, 9, 10).

Present Application: Since 1975, steel slag has been available as an aggregate in pavement materials. It is acceptable only as a coarse aggregate for use in high-type bituminous concrete mixes and seal coats. However, the characteristics of steel slag in HMA have caused some quality control problems. Currently, a self-testing producer control program has been added to the specifications regarding bituminous concrete mixes.

Quantity Used: 195,000 tons (2001 MISTIC estimate).

Economic Impact: In 2001, the Department spent approximately $3,160,000 toward its recycling.

Steel Reinforcement

Origin: Steel reinforcement is made entirely of recycled scrap iron. This material is salvaged from automobiles, appliances, and steel-reinforced structures which include reinforced concrete pavements, bridges, and buildings. Two common forms of steel production are the basic oxygen and electric arc processes. In the electric arc process, “cold” ferrous material, which is generally 100 percent scrap steel, is the major component melted with alloys in an electric furnace. In the basic oxygen process, molten iron is removed from the blast furnace, combined with alloys, and up to 30 percent steel scrap—used as an additive to lower the temperature of the molten composition. In both processes, high-pressure oxygen is blown into the furnace causing a chemical reaction that separates the molten steel and impurities, which can be recycled as slag (1, 11).

Physical Properties: The primary component of steel is iron alloyed with various elements, such as silicon, manganese, chromium, nickel, or copper. In production, carbon, phosphorus, and sulfate may also be present and altered, resulting in different grades of steel (1).

Engineering Value: Steel reinforcement plays an important role in concrete structures; for example, reinforcing in PCC pavements holds cracks together ensuring high aggregate interlock exists across the pavement. Steel reinforcement may also eliminate the use of joints in pavement—potentially producing a longer lasting, smoother riding surface. These same qualities are also desirable in reinforced concrete drainage structures.

Present Application: Steel reinforcement is used to strengthen concrete structures, such as reinforced PCC pavements and bridge decks. Two types of commonly used reinforced concrete pavements are jointed reinforced concrete (JRC) and continuously reinforced concrete (CRC). JRC pavements utilize welded wire fabric, while CRC consists of overlapping longitudinal and transverse reinforced steel bars (3, 11).

Quantity Used: 15,150 tons of rebar; 582,500 SF of welded wire fabric
(2001 MISTIC estimate)

Economic Impact: Reinforced concrete structures are an integral part of Illinois’ transportation system. Overall, reinforcing steel in concrete contributes to the durability and high structural strength of pavements and structures. In 2001, approximately $10,660,000 was spent on reinforcing steel in highway construction.

Wet-Bottom Boiler Slag

Origin: Wet-Bottom Boiler Slag (WBBS or “black beauty”) is a by-product of coal burning in wet-bottom boilers. Slag tap boilers burn pulverized coal and retain up to 50 percent of the accumulated ash as slag—the rest being fly ash. Cyclone boilers burn crushed coal, and retain as much as 80 percent as boiler slag. In both cases, the bottom ash is held at the bottom of the furnace in a molten liquid state, hence the name wet-bottom (1).

Physical Properties: When molten boiler slag comes into contact with water, it immediately fragments becoming coarse, angular, glassy particles. WBBS is a porous, glassy granular particle that is primarily regarded as a single-sized coarse to medium sand. This material is essentially composed of silica, alumina, and iron with small amounts of calcium, magnesium, and sulfates. As long as it is collected from wet-bottom boilers (otherwise it would be considered bottom ash), the composition of the material is governed by the coal source not by the type of furnace (1).

Engineering Value: WBBS is generally a somewhat durable material of uniform size that can be blended with other fine aggregates to meet gradation requirements. This material exhibits less abrasion and soundness loss than bottom ash as a result of its glassy surface texture and lower porosity. In Illinois, WBBS is usually limited to use as a seal coat aggregate on very low volume highways or as an abrasive mixed with deicing salt.

Present Application: WBBS is incorporated as an aggregate in top surface dressing of bituminous surfaces, embankments, trench backfills, sand backfills for underdrains, bedding, porous granular backfills, membrane water proofing, snow and ice control. Department use of WBBS varies greatly from year to year. Also, when used for ice control, a material inspection is not required, thus little documentation exists regarding its use in this fashion. Outside of the Department—local agencies especially—WBBS has been utilized as an aggregate in blasting grit, roofing shingle granules, asphalt paving, and in roadway base and subbase applications (3, 4).

Quantity Used: 0 tons (2001 MISTIC estimate).

Economic Impact: The Department’s records do not indicate utilization of WBBS in 2001, although it was used extensively by local agencies.

RECYCLED MATERIALS NOT UTILIZED IN HIGHWAY CONSTRUCTION

Bottom Ash

<u>Origin:</u> Bottom ash is produced in a dry-bottom coal boiler often found in coal-fired electric power plants. The coal is pulverized and blown into a burning chamber where it immediately ignites; the incombustible portion of this material—not collected in the flue as fly ash—is known as dry bottom ash, which drops down to a water-filled hopper at the bottom of the boiler (1, 4).

<u>Physical Properties:</u> Bottom ash is a coarse, angular material of porous surface texture and size ranging from fine gravel to fine sand, predominantly sand-sized. This material is composed of silica, alumina, and iron with small amounts of calcium, magnesium, and sulfate; as a whole, the quality of the material is governed by the coal source, not by the type of furnace (1).

<u>Engineering Value:</u> Bottom ash may contain pyrites or “popcorn” particles that result in low specific gravities and high losses during soundness (i.e. freeze-thaw) testing. Due to the inherent salt content—and in some cases, low pH—this material may exhibit corrosive properties. This material is highly susceptible to degradation under compaction and loading; as a result, bottom ash is not an acceptable aggregate for most highway construction applications (1, 4, 12).

<u>Potential Application:</u> Other states have utilized bottom ash for snow and ice control, as aggregate in lightweight concrete masonry units, and as raw feed material for portland cement. This material has also been utilized as an aggregate in cold mix emulsified asphalt mixes, base or subbase courses, or in shoulder construction, where the gradation and durability requirements are not as critical. West Virginia and Texas researchers conducted a study in which some of the observations made concluded that performance depends on the amount of pyrites and sulfates present. Also, the quality of the material depends upon how the material was stockpiled before use (1, 4, 12).

<u>Department Concern:</u> Besides the concerns noted above, bottom ash is considered a problematic debris, which plugs drainage structures when used for snow and ice control.

Crumb Rubber

Origin: Shredding waste tires and removing steel debris found in steel-belted tires generates crumb rubber (CR). There are three mechanical methods used to shred apart these tires to CR: the crackermill, granulator, and micromill methods. CR can also be manufactured through the cryogenation method; this method involves fracturing the rubber after reducing the temperature with liquid nitrogen (1).

Physical Properties: CR is fine rubber particles ranging in size from 0.075-mm to no more than 4.75-mm (1).

Engineering Value: CR can be blended into bituminous concrete by either a wet or dry process. In the wet process, the CR acts as an asphalt modifier prior to the addition of aggregates; however, this process requires costly special equipment. In the dry process, CR constitutes a portion of the fine aggregate prior to the addition of the asphalt cement. In this process, limited equipment modification is necessary (1, 13, 14).

Potential Application: During the early Nineties, the Department began efforts to use CR following a mandate—which has since been lifted—imposed by the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA). To address the mandate, eleven experimental crumb rubber bituminous concrete projects were constructed and evaluated, which included ten dry processes and one wet process. For the dry process projects, the material was added into bituminous concrete at two rates: variable and fixed. The variable rate consisted of adding no more than five pounds of CR per ton of bituminous concrete, whereas the fixed rate consisted of adding at least twenty pounds CR per ton of bituminous concrete. Overall findings concluded that the fixed rate wet process method had shown fewer distresses than the control sections of conventional bituminous concrete. On the other hand, the dry processes compared poorly to conventional bituminous concrete. In addition to this, the fixed rate CR areas are currently displaying, on average, slightly higher smooth tire friction values than both the controlled or remaining test sections (13, 14).

Department Concern: Even though the wet process is the only method that has provided an indication of higher performance, its final bid price was considerably higher (over 100 percent) than the average bid price of projects constructed with conventional bituminous concrete in that same year. Also, bituminous concrete suppliers in Illinois do not yet have the equipment required for the wet process. As a result of the higher cost and equipment requirements, implementation is not recommended (13).

Waste Foundry Sand

Origin: Waste foundry sand (WFS) is a by-product of the foundry casting process of ferrous and nonferrous metals; 95 percent of this material is generated from the ferrous casting process. The automotive industry and its suppliers are the primary generators of this material. The presence of heavy metals is of greater concern in nonferrous foundry sands. WFS generated from brass or bronze foundries may contain high concentrations of cadmium, lead, copper, nickel, and zinc (1, 15).

Physical Properties: WFS prior to its use in casting, consists of high quality silica sand or lake sand coated with a thin film of burnt carbon, residual binder, and dust. This material is sub-angular to rounded and has an overall uniform grain size distribution, where the gradations tend to fall within the limits for a poorly graded fine sand. WFS contains metal casting pieces, partially degraded binder, and may also contain some leachable contaminants, including heavy metals and phenols (1).

Engineering Value: WFS grain size distribution is more uniform and somewhat finer than conventional concrete sand. The fineness of this substance contributes to good suspension limiting segregation in flowable fills, which are manmade self-leveling, self-compacting backfills. This material displays favorable durability characteristics with resistance to weathering in bituminous concrete paving applications. The high amount of silica found in this material may result in stripping of the asphalt cement coating aggregate, which contributes to pavement deterioration (1, 15).

Potential Application: The commercial use of this material is extremely limited in the United States. In conjunction with a northwestern Indiana foundry, Indiana DOT has completed a cooperative venture utilizing WFS as embankment material. The major concerns were environmental risks associated with leaching of heavy metals, compaction of the material, foreign object damage to equipment, and dust control. As a result of careful environmental testing and planning, the material performed satisfactorily. Purdue University conducted a study with bituminous concrete samples containing up to 30 percent WFS; this study concluded that including more than 15 percent WFS lowered the unit weight, increased air voids, decreased the flow and stability of the mixes, and reduced the indirect tensile strength (1, 15).

Department Concern: The environmental safety of WFS depends on chemical additives and casted metals utilized with the sand. The Department does not allow use of ferrous foundry waste sand because it is often contaminated with traces of hazardous elements.

Glass Aggregate

Origin: Glass is formed by supercooling a molten mixture of sand (silicon dioxide), soda ash (sodium carbonate), and/or limestone to form a rigid physical state. Glass aggregate is a product of recycled mixed glass from manufacturing and postconsumer waste (1).

Physical Properties: Glass aggregate, also known as glass cullet, is 100 percent crushed material that is generally angular, flat and elongated in shape. This fragmented material comes in color or colorless forms. The size varies depending on the chemical composition and method of production (1).

Engineering Value: When glass is properly crushed, this material exhibits coefficient of permeability similar to coarse sand. Also, the high angularity of this material, compared to rounded sand, may enhance the stability of asphalt mixes. In general, glass is known for its heat retention properties, which can help decrease the depth of frost penetration (1).

Potential Application: Glass aggregate has been investigated by many state DOTs including New York, Washington, and Pennsylvania.

New York DOT uses a limited amount of this material in embankments and bituminous concrete base and binder courses. This is a non-surface mix material because of concerns that it could result in injury claim liability. New York has experienced problems with stripping—asphalt binder not adhering to aggregate—that may be controlled by adding an anti-stripping agent, which in turn adds costs.

Since the 1960s, Washington DOT has used a portion of glass aggregate in bituminous concrete pavements. This aggregate material is also used in backfill for foundations, pipe bedding, and other applications not subject to heavy repeated loading. Washington State has not utilized this material on any recent projects.

Pennsylvania DOT also allows a portion of this material in nonstructural fills and drainage applications, while experimentation with this material in bituminous concrete has yielded results similar to New York's. (16, 17)

Department Concern: Glass aggregate presents problems in both bituminous concrete and PCC pavements. In concrete pavements, this material is problematic due to the deleterious alkali-silica reaction with the cement paste. In bituminous pavements, this material bonds poorly to the asphalt, which results in stripping and raveling problems. In general, waste glass contains impurities such as ceramics, ferrous metal, paper, plastic, and mixed colored cullet; processing and specifications may limit associated problems.

Roofing Shingles

Origin: Waste roofing shingles are generated during the demolition of existing roofs, and from scraps of trimmed asphalt shingles. Consumer aged waste shingles are referred to as tear-off shingles, whereas manufacturer waste is known as roofing shingle tabs or punch-outs, which includes "out-of-spec" and mis-colored or damaged shingles. Both materials are shredded in two to three stages to achieve the desired size (1, 18).

Physical Properties: Roofing shingles are made of a supporting membrane of organic fibers, glass felt, or mat, a saturate of hot asphalt, and coating of mineral fines. These fines may include ceramic or lap granules, backsurfacer sand, and asphalt stabilizer. Different types of roofing shingles exhibit different material properties. Consequently, tear-off shingles are not as characteristically predictable as manufactured tabs and may contain asbestos (1, 18, 19).

Engineering Value: Roofing shingle tabs are used as an asphalt cement modifier often resulting in a stiffer mix with improved temperature susceptibility and rut resistance. Tear-off shingles may be used in the same way, but are difficult to process due to the presence of foreign materials, and may also be in an irreversible age-hardened state. In general, both types may function as a fine aggregate or mineral filler depending on the size of the shredded material. Roofing shingles may be susceptible to moisture-related damage thus mix designs should include an anti-strip or retained stability test (18, 19, 20, 21).

Potential Application: Waste roofing shingles in combination with bituminous concrete mixes have been investigated by many state DOTs, including Pennsylvania, Minnesota, and Iowa.

Pennsylvania has determined that a bituminous concrete modified with properly shredded fiberglass shingle tabs performs as well as a conventional bituminous pavement. Minnesota has had similar results with both felt and fiberglass shingle tabs. Both states were able to reduce the amount of virgin asphalt cement required—a potential for cost savings. Both states have issued provisional specifications allowing limited amounts of processed shingle tabs in bituminous concrete mixes.

Iowa DOT inspected efforts in utilizing bitumen tear-off shingles. One year after construction, the roadway remained workable and virtually dust free. (18, 19, 20, 21)

Department Concern: The Department has concerns regarding the presence of any asbestos in tear-offs, glass felt tabs, and/or from storage cross-contamination. Also of concern, the presence of any foreign debris from nails, wood, and insulation, and the environmental impact of polynuclear aromatic hydrocarbons—present in roofing tars—on plant and paving site air emissions.

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APPENDIX

2001 RECYCLED MATERIALS QUANTITIES						
MATERIAL	**METRIC UNIT**	**CODE**	**QUANTITY**	**ENG. UNIT**	**CODE**	**QUANTITY**
ACBFS [1]	MTON	014CMM18	3,416	TONS	014CM18	168
	MTON	033CMM13	61,652	TONS	043CA06	617
	MTON	033FAM21	4,329	--	--	
	MTON	043CAM06	626	--	--	
	MTON	053CAMO6	809	--	--	
	SUB-TOTAL (TONS)		78,127			785
	TOTAL (TONS)		**78,912**			
	COST@$15.25/TON		**$1,203,411**			
BY-PRODUCT LIME	MTON	003FAM01	6,477	TONS	003FA01	9,807
	MTON	003FAM02	380	TONS	003FA02	249
	MTON	004MFM02	18,712	TONS	004MF02	1,321
	MTON	004MFM03	5,441	TONS	004MF03	1,183
	SUB-TOTAL (TONS)		34,204			12,560
	TOTAL (TONS)		**46,764**			
	COST@$15/TON		**$701,457**			
FLY ASH	MTON	37801M	41,080	CYD	21605	111,896
	MTON	37802M	5,136	CYD	21622	13,220
	CM	21605M	422,981	CYD	21803	1,327
	CM	21614M	258	--	--	
	CM	21803	2,432	LBS/CYD	Avg. Unit Wt. In PCC	130
	CM	21622M	1,644			
	SUB-TOTAL (MTONS)		79,186			7,456
	TOTAL (MTONS)		**86,642**			
	TOTAL (TONS)		**95,566**			
	COST@$27.50/TON		**$2,628,070**			
GLASS BEADS	LBS	60401	9,768,000	LBS	70601	3,880,800
	LBS	60407	968,000	LBS	70602	
	LBS	70609	1,380	--	--	
	SUB-TOTAL (LB.S)		10,737,380			3,880,800
	TOTAL (LB.S)		**14,618,180**			
	TOTAL (TONS)		**7,309**			
	COST@$0.17/LB		**$2,485,091**			
GGBFS [2]	MTONS	37821M	479	--	--	
	SUBTOTAL (MTONS**)**		479			
	TOTAL (TONS)		**528**			
	COST@$57/TON		**$30,090**			
MICROSILICA	KG	37852M	111	CYD	21609	1,620
	CM	21609M	2,436	LBS/CYD	Avg. Unit Wt. In PCC	33
	CM	21622M	1,644			
	SUB-TOTAL (LB.S)		176,443			53,460
	TOTAL (TONS)		**115**			
	COST@$440/TON		**$50,579**			
RAP [3]	MTON	017CAM06	14,430	TONS	017CM01	24,026
	MTON	017CAM10	1,027	TONS	017CM11	2,107
	MTON	017CMM01	47,601	TONS	017CM13	37,675
	MTON	017CMM10	2,059	--	--	
	MTON	017CMM11	82,773	--	--	
	MTON	017CMM12	449	--	--	
	MTON	017CMM13	283,106	--	--	
	MTON	017CMM16	61,894	--	--	
	MTON	017CMM18	13,610	--	--	
	SUB-TOTAL (TONS)		559,165			63,808
	TOTAL (TONS)		**622,973**			
	COST@$32/TON		**$19,935,128**			

2001 RECYCLED MATERIALS QUANTITIES						
MATERIAL	**METRIC UNIT**	**CODE**	**QUANTITY**	**ENG. UNIT**	**CODE**	**QUANTITY**
RCP[4]	MTON	014CMM18	209	TONS	019CA06	14,245
	MTON	019CAM06	14,096	TONS	019CM18	47,309
	MTON	019CAM07	18	TONS	059CA06	22,529
	MTON	019CMM18	162,418	--	--	
	MTON	059CAM06	37,715	--	--	
	MTON	059CAM10	394	--	--	
	MTON	059CMM06	229	--	--	
	SUB-TOTAL (TONS)		237,233			84,083
	TOTAL (TONS)		**321,316**			
	COST@$5/TON		**$1,606,578**			
STEEL SLAG	MTON	039CMM11	5,965	TONS	039CM11	6,227
	MTON	039CMM13	115,625	TONS	039CM13	25,113
	MTON	039CMM16	10,364	TONS	039FA20	8,412
	MTON	039FAM20	6,552	TONS	039FM20	380
	MTON	039FMM20	1,659	--	--	
	SUB-TOTAL (TONS)		154,601			40,131
	TOTAL (TONS)		**194,733**			
	COST@$16.25		**$3,164,409**			
REINFORCEMENT STEEL	SM	62803M01	531	SYD	6280301	5,632
	SM	62803M02	22,023	SYD	6280302	31,934
	--	--		SYD	6280304	179
	SUB-TOTAL (SYD)		26,975			37,746
Welded Wire Fabric	**TOTAL (SF)**		**582,484**			
	COST@$0.35/SF		**$203,869**			
	KG	62901M40	8,910	LBS	6290140	41,415
	KG	62901M300	812	LBS	6290160	4,965,656
	KG	62901M400	35,201	LBS	6290940	133,209
	KG	62904M500	204	LBS	6290960	13,055,840
	KG	62901M60	897,510	--	--	
	KG	62909M40	3,471	--	--	
	KG	62909M400	379,214	--	--	
	KG	62909M60	4,163,026	--	--	
	SUB-TOTAL (LBS)		12,101,808			18,196,120
Rebar	**TOTAL (TONS)**		15,149			
	COST@$690/TON		**$10,452,785**			
WBBS[5]	--	--				
	TOTAL (TONS)		**0.00**			
	COST@$5.50/TON		**$0.00**			

[1]ACBFS: Air-Cooled Blast Furnace Slag
[2]GGBFS: Ground Granulated Blast Furnace Slag
[3]RAP: Recycled Asphalt Pavement
[4]RCP: Recycled Concrete Pavement
[5]WBBS: Wet-Bottom Boiler Slag