Utilization of Recycled and Reclaimed Materials in Illinois Highway Construction in 2010

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16. Abstract

The Illinois Department of Transportation published Physical Research Report 158, "Utilization of Recycled Materials in Illinois Highway Construction in 2009" in March 2011. That report provided an update of the types and quantities of recycled materials used by the Department in highway construction. This report is a revised version of the previously titled report. Revisions include updated quantities, costs, and current applications. The quantities of recycled and reclaimed materials used—tonnage, in general—indicated within the report and summarized in the appendix are based on materials use as reported to the Materials Integrated System for Test Information and Communication (MISTIC) for calendar year 2010. Quantities of materials used can vary greatly and are dependent upon the type of projects being constructed in a given year and the size of the highway program. Fluctuations in commodity prices will influence the economic impact of a given recycled material. Material costs in this report were determined using the cost information gathered in early 2011.

Even though a savings may be realized up front, there is no guarantee that field performance will be the same or better. A small economic savings during initial construction may be negated by a large increase in maintenance or rehabilitation costs incurred to address performance problems. Many of the recycled materials utilized have a well researched and documented history of good performance. IDOT is in the process of adopting test procedures that will help ensure performance is not compromised for materials newly utilized.

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UTILIZATION OF RECYCLED AND RECLAIMED MATERIALS IN ILLINOIS HIGHWAY CONSTRUCTION IN 2010

by:
Michael Brownlee

ILLINOIS DEPARTMENT OF TRANSPORTATION
BUREAU OF MATERIALS AND PHYSICAL RESEARCH
SPRINGFIELD, ILLINOIS

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Introduction

The Illinois Department of Transportation (IDOT) published Physical Research Report 158, "Utilization of Recycled Materials in Illinois Highway Construction in 2009" in March 2011. That report provided an update of the types and quantities of recycled materials used by IDOT in highway construction. This report is a revised version of the previously titled report. Revisions include updated quantities, costs, and current applications. Quantities of materials used can vary greatly and are dependent upon the type of projects being constructed in a given year and the size of the highway program. Fluctuations in commodity prices will influence the economic impact of a given recycled material. Material costs in this report were determined using the cost information gathered in early 2011.

IDOT utilizes millions of tons of highway materials annually. The basic building materials in roadway and bridge construction are primarily aggregate, cement, and asphalt binder. The educated use of recycled materials can result in cost savings 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.

Even though a reduced cost may be noticed up front, there is no guarantee that field performance will be the same or better. A small economic savings during initial construction may be negated by a large increase in maintenance or rehabilitation costs incurred to address performance problems. For example, one year loss in pavement life of a hot-mix asphalt pavement bid at $80 per ton would have a true cost of $85.33 per ton of mix. Use of many materials such as reclaimed asphalt shingles and high percentages of reclaimed asphalt pavement do not have enough documented performance data to quantify the true savings/cost. It will take several years of usage to determine performance trends. IDOT is in the process of adopting test procedures that will help ensure performance is not compromised.

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

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

The quantities of recycled and reclaimed materials used—tonnage, in general—indicated within the report and summarized in the appendix are based on materials use as reported to the Materials Integrated System for Test Information and Communication (MISTIC) for calendar year 2010. 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 2010, IDOT used more than 1.7 million tons (3.4 billion pounds) of recycled materials in highway construction.

RECYCLED AND RECLAIMED MATERIALS UTILIZED IN HIGHWAY CONSTRUCTION

2010

Air-Cooled Blast Furnace Slag

Origin:	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 crushed and screened with typical aggregate processing equipment to meet gradation specifications. (1)
Physical Properties:	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)
Engineering Value:	Crushed ACBFS can be used in nearly all applications utilizing natural aggregates, such as hot-mix asphalt (HMA), portland cement concrete (PCC), 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 HMA pavements, this material provides exceptional frictional properties and increased stability, but its tendency for high surface absorption may require greater amounts of asphalt binder. ACBFS provides outstanding durability and weight savings of 10 to 20 percent over natural aggregate materials in the same applications. Of all the blast furnace slag produced in the United States that is reportedly utilized, 90 percent is ACBFS. (1, 2)
Present Application:	ACBFS is incorporated into PCC, HMA, granular bases and subbases, embankments, and fills. As of August 1999, a self-testing producer control program had been added to specifications regarding HMA mixes to eliminate mix issues due to variability. For the most part, slag is tested as though it were a natural aggregate; unless the application pertains to HMA, IDOT will not use slag failing LA abrasion test limits. (3)
Quantity Used:	1,639 tons (2010 MISTIC estimate)
Economic Impact*:	In 2010, the Department spent approximately $11,768 using ACBFS.

* Costs are based upon early 2011 prices.

By-Product Lime

Origin:	Heating limestone (calcium carbonate) in a kiln drives off carbon dioxide and forms lime (calcium oxide). The exhaust gases from the kiln are filtered using electrostatic precipitators, baghouses, or other such methods. The filtered solids are collected and sold as by-product lime. Lime Kiln Dust (LKD) can vary chemically depending on the type of lime manufactured. It can be categorized according to reactivity, which is based on the amount of free lime and magnesia content. The corresponding lime types are 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 dependent on 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 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. LKD can also be used as mineral filler in HMA. (3)
Quantity Used:	15,910 tons (2010 MISTIC estimate)**
Economic Impact*:	By-product lime usage is one of the least expensive remedial actions for unstable subgrade soils. In 2010, the Department spent approximately $556,850 using By-Product Lime.

* Costs are based upon early 2011 prices.

** The quantities for the Physical Research Report 158 were higher than this report because those quantities erroneously included a material that does not meet the definition of this recycled material.

Crumb Rubber

Origin:	Crumb rubber (CR) is produced by grinding reclaimed, used/worn out tires to certain gradations and removing unusable debris including steel and fibers. In lieu of grinding, CR can also be cooled cryogenically with nitrogen and crushed with a hammer mill. (1)
Physical Properties:	CR is rubber particles reduced to 100 percent passing the No. 8 sieve. Tire rubber normally contains synthetic rubber, natural rubber, carbon black, steel, polyester, chemicals, and trace metals in varying concentrations. (1)
Engineering Value:	CR can be used in multiple areas of roadway construction. The Department uses CR in a reflective crack control system. While other states allow CR to be used in HMA with a wet or dry process, Illinois only allows the wet process. The wet process uses CR as modifier in the liquid asphalt while the dry process uses it as a fine aggregate replacement. (3, 4)
Potential Application:	Most crack sealants used throughout the state contain a percentage of CR. The Department has experimented with CR in HMA. It was determined that the wet process, while creating a superior pavement to the conventional method, was not cost effective. The dry process was much less costly; however, it was found to be of no benefit to pavement performance. (5, 6) Patents on the wet process have expired, and another method growing in popularity is called Terminal Blending. This method involves blending the CR homogeneously at low temperatures with the asphalt at the asphalt refinery. The blend is then shipped directly to the plant to be combined with the aggregate. (4) A high temperature CR product is being marketed outside of Illinois. This product has promise as it can be PG graded using standard tests. The low temperature terminal blend has a disadvantage in that it cannot be graded.
Quantity Used:	44,256 lbs (2010 MISTIC estimate)
Economic Impact*:	Results from an earlier study indicated that final bid prices for crumb rubber were considerably higher than traditional HMA mix. As a result of the higher cost and equipment requirements, implementation was not recommended. (5, 6) Currently the Department has a special provision for use of CR. Due to the higher costs of the mix, this option is only used when other modifiers are not available. The quantity listed above was calculated as a percentage of crumb rubber used in hot-pour joint sealant at a rate of 5 percent by weight. In 2010, the Department spent approximately $7,081 using crumb rubber in hot-pour joint sealant.

* Costs are based upon early 2011 prices.

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, a 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. Fly ash is captured from the flue gases using electrostatic precipitators (ESP) or in filter fabric collectors, commonly referred to as baghouses. The physical and chemical characteristics of fly ash vary among combustion methods, coal source, and particle shape. (7) 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, 8)
Engineering Value:	In PCC, Class F fly ash has pozzolanic properties when introduced to water, whereas Class C fly ash is naturally cementitious 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, and generally extends the cement in the mix. (1, 8)
Present Application:	Dry fly ash can be used as an inert fill material or supplementary cementitious material to improve cohesion and stability of soil embankments. In Illinois, fly ash is used as a mineral admixture in concrete mixtures. 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 subsealing. Its use is a recommended alternate when mix designs incorporate high alkali cements and potentially reactive aggregates that could result in alkali-silica reaction (ASR). Fly ash can also be used as mineral filler in HMA. (1, 3, 8, 9)
Quantity Used:	56,487 tons (2010 MISTIC estimate)
Economic Impact*:	In 2010, the use of fly ash as a supplementary cementitious material cost the Department approximately $2,541,915, aided in the reduction of landfill space need, and reduced emissions and fuel consumption required for cement production. It should be noted that the sources of usable fly ash in Illinois have been reduced due to power plant modifications to remove mercury from flue gasses. As a result, large quantities of fly ash used are imported from out of state.

* Costs are based upon early 2011 prices.

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 enhance the nighttime visibility of various objects through the fundamentals of retro-reflectivity - light is reflected back to its source, for instance, vehicle headlights. As pavement markings are applied, the glass beads are applied to the surface. If the beads are over-embedded or under-embedded, the marking becomes less retro-reflective. Outside the Department, glass beads are utilized in various ways, including but not limited to, license plates, movie screens, and reflective fabrics.
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. (3)
Quantity Used:	15,241,600 lbs (2010 estimate from testing quantities)
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 2010, the Department spent approximately $4,069,507 on glass beads.

* Costs are based upon early 2011 prices.

Glass Cullet

Origin:	Glass Cullet is produced from recycled glass that is crushed and screened to a designated size. In Illinois, only recycled glass food or beverage containers are allowed to be used. There is a percentage limit of ceramics, china dishes, plate glass, and thin walled container glass that can be accepted. Containers that used to contain hazardous or toxic materials, automobile glass, TV monitors, and lighting fixtures are prohibited from use due to their unique chemical compositions. (1)
Physical Properties:	Glass Cullet is recycled glass ground down to 100 percent passing the 3/8 inch sieve. Glass, chemically, is normally close to 70 percent silica with the other 30 percent being comprised of soda ash, limestone, and chemicals to give it desired properties, normally color. For the recycling industry, the varying colors of glass can be a problem during the recycling process. For construction uses however, the color normally does not matter. (1)
Engineering Value:	The use of glass cullet as an aggregate in HMA or PCC is not common. The high silica content invites the risk of ASR in concrete. While the angular surface of glass would suggest positive results in HMA, there is a frequent occurrence of stripping where the asphalt “strips” off the glass, causing a weak mix and poor performance. Glass cullet is most frequently used as a fill material. Its angular characteristics allow it to keep stability when compacted and it retains little to no moisture. (10, 11)
Present Application:	Currently, many other departments use glass cullet for multiple applications. These include uses as a mix in gravel backfill, borrow material, and certain classes of foundation. A recently developed specification allows for use of glass cullet in Illinois as Porous Granular Embankment (PGE) and is available upon request.
Quantity Used:	No quantities used at time of this report.
Economic Impact:	The Department is unable to determine.

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 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. Concrete produced with GGBFS has reduced permeability and reduced heat of hydration. Use in the form of GGBFS presumably makes up the remaining 10 percent (when paired up with the 90 percent used as ACBFS) of blast furnace slag produced in the United States. (1, 2)
Present Application:	The primary uses of GGBFS are as a fine aggregate substitute, mineral admixture in concrete mixtures, and component of blended cement. Its use is a recommended alternate when mix designs incorporate high alkali cements and potentially reactive aggregates that could result in ASR. (2, 3)
Quantity Used:	256 Tons (2010 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. In 2010, the Department spent approximately $15,360 using GGBFS.

* Costs are based upon early 2011 prices.

Microsilica

Origin:	Microsilica, which is also known as Silica Fume, is a by-product of producing silicon metal or ferrosilicon alloys. When silicon metal and alloys are placed in electric furnaces, the smoke from raw materials such as quartz, coal, and woodchips is collected, creating Silica Fume. (12)
Physical Properties:	Microsilica is a gray powdery material primarily consisting of amorphous (non-crystalline) silicon dioxide (SiO_2) and has a mean particle size between 0.1 and 0.2 µm - 100 times finer than portland cement. (12)
Engineering Value:	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. To gain the most benefits from using silica fume, the concrete must be cured effectively. (3, 12)
Present Application:	The Department allows the use of microsilica in concrete mixtures. Its use is a recommended alternate when mix designs incorporate high alkali cements and potentially reactive aggregates that could result in ASR. Outside of the Department, microsilica is utilized in multi-story building construction. (3)
Quantity Used:	270,000 lbs / 135 Tons (2010 MISTIC estimate)
Economic Impact*:	Even though the price of microsilica is substantially higher than that of portland cement, the benefits of improved performance of concrete and its elimination from the waste stream outweigh the increase in cost. In 2010 the Department spent approximately $135,000 using microsilica.

* Costs are based upon early 2011 prices including delivery.

Reclaimed Asphalt Pavement

Origin:	Reclaimed Asphalt Pavement (RAP) is HMA material removed and/or reprocessed from pavements undergoing reconstruction or resurfacing. Reclaiming the HMA may involve either cold milling a portion of the existing HMA pavement or full-depth removal. (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 mix type, and in turn, aggregate quality and size, mix consistency, and asphalt binder content. Depending on the method of processing, RAP can be finer than its original aggregate constituents. (1)
Engineering Value:	RAP is processed by crushing and screening the material. A series of testing is required to determine asphalt binder content, gradation, and quality. As allowed, the RAP is mixed with virgin aggregate and asphalt to produce new HMA. Since millings from different projects will have different characteristics, contractors must maintain separate RAP stockpiles. RAP can also be used in some aggregate applications. (1, 3)
Present Application:	The special provision for RAP has been revised several times as testing and understanding of interaction was understood. For the special provision that was in effect for this reporting period, the allowable amounts of RAP varied between 10 and 50 percent depending on the type of mix and volume of traffic on the project. RAP is allowed in all Department mixes, and the policy is currently being revised to maximize the amount of allowable RAP without adversely affecting performance of the pavement. The Department also allows RAP to be used in place of aggregate or earth in some non-structural backfill situations. (3, 13)
Quantity Used:	1,097,485 tons (2010 MISTIC estimate)
Economic Impact*:	In 2010, the Department spent approximately $25,757,973 using RAP as a viable aggregate substitute for scarce natural and manufactured resources.

* Costs are based upon early 2011 prices.

Reclaimed Asphalt Shingles

Origin:	Reclaimed Asphalt Shingles (RAS) are waste roofing shingles obtained from shingle manufacturer's scrap or from roofs of apartment buildings (four or fewer units) and/or single family dwellings that are not subject to the National Emission Standards for Hazardous Air Pollution. Material received from the manufacturer is termed manufacturer's salvaged, whereas old shingles removed from residential dwellings are termed post-consumer tear-offs. These materials, kept separate throughout the process, are tested for asbestos, ground to the desired size, and then delivered to asphalt plants ready for incorporation into HMA. (14)
Physical Properties:	Roofing shingles are made of a supporting membrane of organic fibers, glass felt or mat, a saturate of hot asphalt containing mineral fines, and a coating of fine aggregate. This aggregate may include lap granules, backsurfacer sand, slag, and specialized aggregate to prevent the growth of bacteria. Different types of roofing shingles exhibit different material properties. Consequently, tear-off shingles are not as characteristically predictable as manufacturer's salvaged shingles and may contain regulated asbestos-containing material in rare cases. (15)
Engineering Value:	RAS, once screened for asbestos containing material and removal of nails and other debris is complete, can be incorporated into HMA. When ground down to a workable gradation, RAS can be introduced into an asphalt mix during production. RAS contains between 20 and 30 percent asphalt binder, thus reducing the virgin asphalt needed in the mix and resulting in a cost savings to the Department. Further savings are achieved with the incorporation of the fine aggregate and mineral filler that are also found in RAS in lieu of a portion of the volume of these aggregates needed in HMA. However, the addition of RAS will make a stiffer mix than designed. Therefore, it is common to use a softer grade of asphalt binder when producing HMA with RAS. (14, 15) The United States disposes of roughly 11 million tons of asphalt shingles per year. This application provides IDOT an economical process to reuse what would otherwise be discarded. (16)
Present Application:	IDOT first developed specifications for HMA to utilize shingles in August 2010. In 2011, Public Act 097-0314 was passed and IDOT has further developed specifications, policies, and procedures to implement the act. As a result, there are now four suppliers approved to provide shingles in Illinois. The percentage of RAS allowed in the HMA mix is limited to 5 percent of the mix. The data on usage, which is expected to greatly increase, will be indicated in the 2011 report. (14)
Quantity Used:	No quantities used in 2010.
Economic Impact:	The Department is unable to determine.

Recycled Concrete Material

Origin:	Recycled Concrete Material (RCM), also known as crushed concrete, is reclaimed PCC from the 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 ASR or D-cracking. (1, 3)
Present Application:	The Department has experimented with RCM in HMA. Currently, 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, 17)
Quantity Used:	381,929 tons (2010 MISTIC estimate)
Economic Impact*:	The use of RCM impacts the economy as a substitute for natural aggregates by reducing landfill space needs. In 2010, the Department spent approximately $4,266,147 using RCM.

* Costs are based upon an average price of all gradations from early 2011 prices.

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, 18)
Physical Properties:	The primary components of steel are 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 structures.
Present Application:	Dowel bars are used in Jointed Plain Concrete (JPC) pavement to create load transfer at uniformly spaced joints. Welded wire fabric is used in pavement, concrete pipe, prestressed/precast products, concrete structures, etc. Steel reinforcing bars (rebar) are used to strengthen concrete structures, such as reinforced PCC pavements and bridge decks. Continuously reinforced concrete (CRC) pavement uses overlapping longitudinal and transverse steel reinforcing bars to control the tight transverse cracks that naturally form throughout the length of the pavement to evenly transfer loads. (3, 18)
Quantity Used:	3,521,632 lbs / 1,761 tons of dowel bar; 691,657 lbs / 346 tons of welded wire fabric; 25,228,355 lbs / 12,614 tons of rebar (2010 MISTIC estimate)
Economic Impact*:	In 2010, the Department spent approximately $14,217,240 on reinforcing steel in highway construction: $1,620,120 using dowel bars; $336,312 using welded wire fabric; and $12,260,808 using rebar.

* Costs are based upon early 2011 prices.

Steel Slag

Origin:	As iron production is to blast furnace slag, so is steel production 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, several 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 — the primary source of steel slag aggregate product — and is not deemed suitable for aggregate usage. (1, 19)
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. (20)
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, 19, 20)
Present Application:	Since 1975, steel slag has been available as an aggregate in pavement materials. It is acceptable as both coarse aggregate and fine aggregate for use in high-type HMA mixes and seal coats. However, the variable specific gravity of steel slag in HMA has caused some quality control problems. Currently, a self-testing producer control program has been added to the specifications regarding HMA mixes. The availability of steel slag is dependent on the production of steel, which has been lower in recent years.
Quantity Used:	158,559 Tons (2010 MISTIC estimate)
Economic Impact*:	In 2010, the Department spent approximately $1,411,175 using Steel Slag.

* Costs are based upon early 2011 prices.

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 and 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 allowed to be incorporated as an aggregate in top surface dressing of bituminous surface treatments, 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, 8)
Quantity Used:	Due to the majority of use being for snow and ice control, records are not kept on this material.
Economic Impact:	The Department is unable to determine.

RECYCLED AND RECLAIMED MATERIALS NOT UTILIZED IN HIGHWAY CONSTRUCTION

2010

Bottom Ash

Origin:	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, 8)
Physical Properties:	Bottom ash is a coarse, typically grey to black in color, 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)
Engineering Value:	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, 8, 21)
Potential Application:	Bottom Ash is used as a filler material for structural applications and embankments, aggregate in road bases, sub-bases, and pavement, feed stock in the production of cement, aggregate in lightweight concrete products, and snow and ice traction control material. (1, 8, 21)
Department Concern:	Besides the concerns noted above, bottom ash is considered a problematic debris, which plugs drainage structures when used for snow and ice control.

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, 22)
Physical Properties:	Prior to its use in casting, WFS 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 may display favorable durability characteristics with resistance to weathering in HMA 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, 22)
Potential Application:	The commercial use of this material is extremely limited in the United States. Two main challenges to using waste foundry sand are environmental issues and an engineering value. Transportation cost of foundry sand is the most limiting factor to its use. (1, 22)
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.

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APPENDIX

2010 Recycled and Reclaimed
Materials Quantities

2010 RECYCLED AND RECLAIMED MATERIALS QUANTITIES

MATERIAL	UNIT COST[1]	TOTAL QUANTITY[2]	TOTAL COST TO DEPARTMENT
ACBF SLAG[3]	$7.18/TON	1,639 TONS	$11,768
BY-PRODUCT LIME	$35/TON	15,910 TONS	$556,850
CRUMB RUBBER[4]	$0.16/LB	44,256 LBS	$7,081
FLY ASH	$45/TON	56,487 TONS	$2,541,915
GLASS BEADS	$0.267/LB	15,241,600 LBS	$4,069,507
GGBF SLAG[5]	$60/TON	256 TONS	$15,360
MICROSILICA	$1,000/TON	135 TONS	$135,000
RAP[6]	$23.47/TON	1,097,485 TONS	$25,757,973
RCM[7]	$11.17/TON	381,929 TONS	$4,266,147
STEEL REINFORCEMENT DOWEL BAR[8]	$920/TON	1,761 TONS	$1,620,120
STEEL REINFORCEMENT WELDED WIRE FABRIC[9]	$972/TON	346 TONS	$336,312
STEEL REINFORCEMENT REBAR	$972/TON[10]	12,614 TONS	$12,260,808
STEEL SLAG	$8.90/TON	158,559 TONS	$1,411,175

[1]Note about prices used.

[2] Quantities were calculated as the total amount assigned to projects in calendar year 2010. Prior to summation of values, metric values were converted to English values using the conversion factors located in Appendix B of the *Standard Specifications for Road and Bridge Construction.*

[3]ACBF SLAG: Air-Cooled Blast Furnace Slag

[4]CRUMB RUBBER: This material quantity was calculated as 5 percent of the quantity of hot pour joint sealant used in 2010.

[5]GGBF SLAG: Ground Granulated Blast Furnace Slag

[6]RAP: Reclaimed Asphalt Pavement

[7]RCM: Recycled Concrete Material

[8]DOWEL BARS: IDOT uses several sizes of dowel bars; however the most common sizes are 1.50 in. and 1.25 in. Quantities were calculated using an average of these two common bars at 1.375 in. Industry tables show that the weight per foot for a 1.375 in. bar is 5.05 lb per ft. Therefore, an 18 in. piece of dowel bar at this diameter would weigh 7.57 lb.

[9]WELDED WIRE FABRIC: The average size of welded wire fabric used by IDOT is a 6X12 W6.5XW4.0. The 6X12 indicates the spacing of the wires and the W6.5XW4.0 is the size of the wires. The Wire Reinforcement Institute has tables that list the weight (lb) per 100 sq yd for each wire size and spacing. According to the table, the weight of a 6X12 W6.5XW4.0 is 62.67 lb per 11.1 sq yd; which is equivalent to 5.6459 lb per sq yd.

[10]Prices are quoted using epoxy coated rebar.