Utilization of Recycled and Reclaimed Materials in Illinois Highway Construction in 2012

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16. Abstract

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Since the 1950s, IDOT has experimented with the use of various recycled and reclaimed materials and incorporated them into many aspects of constructing and maintaining its 16,000 centerline miles of highways. These green and ecofriendly choices are helping with the effort to lower the negative impact society has on the environment, as well as conserve virgin materials to extend the limited quantities for future use. This report will present the types of recycled and reclaimed materials currently being used by IDOT for highway construction and maintenance, as well as those materials the Department does not currently utilize due to other factors. IDOT will continue to review current and new options for using recycled and reclaimed materials in order to carry out the mission of providing safe, cost-effective transportation for Illinois.

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UTILIZATION OF RECYCLED AND RECLAIMED MATERIALS IN ILLINOIS HIGHWAY CONSTRUCTION IN 2012

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ABSTRACT

What does it mean to recycle? The first thought that comes to mind is keeping glass or plastic items out of the garbage, or maybe placing paper in the recycling bin to reduce the number of trees cut down. To recycle means to convert an item into reusable material or return it to its previous state. Looking at it from that perspective, there are many other items in the world in addition to glass, plastic, and paper that are recyclable. Another way to reduce the amount of waste material going into landfills is to develop “Beneficial Uses” for select materials that have value in highway construction. These materials are termed reclaimed, which means to rescue from an undesirable state and restore to the previous natural state. The Illinois Department of Transportation (IDOT) recognizes the economic and environmental values of the materials made available through these processes.

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The contents of this report reflect the views of the author, who is responsible for the facts and accuracy of the data represented in this report. The contents do not necessarily reflect the official views or policies of IDOT. This report does not constitute a standard, specification, or regulation at IDOT.

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LIST OF ABBREVATIONS

ACBFS: Air-Cooled Blast Furnace Slag

ASR: Alkali-Silica Reactivity

CR: Crumb Rubber

CRCP: Continuously Reinforced Concrete Pavement

GBFS: Granulated Blast Furnace Slag

GGBFS: Ground Granulated Blast Furnace Slag

GTR: Ground Tire Rubber

HMA: Hot-Mix Asphalt

JPCP: Jointed Plain Concrete Pavement

JRCP: Jointed Reinforced Concrete Pavement

LKD: Lime Kiln Dust

MISTIC: Materials Integrated System for Test Information and Communication

PCC: Portland Cement Concrete

RAP: Reclaimed Asphalt Pavement

RAS: Reclaimed Asphalt Shingles

RCM: Recycled Concrete Material

SMA: Stone Matrix Asphalt

WBBS: Wet-Bottom Boiler Slag

WFS: Waste Foundry Sand

WWR: Welded Wire Reinforcement

INTRODUCTION

As time progresses and society evolves, people are coming to an understanding that natural resources that were once abundant are now being depleted at an alarming rate. The well-known quote "You have to use what you have" rings true, especially with the Illinois Department of Transportation (IDOT). IDOT understands the importance of this concept and is making a conscious effort to find ways to incorporate this philosophy into many aspects of constructing and maintaining roadways.

To recycle means to convert an item into reusable material or return it to its previous state. Several materials IDOT uses in construction projects are recycled from other processes. Another way to reduce the amount of waste material going into landfills is to develop "Beneficial Uses" for select materials that have value in highway construction. These materials are termed reclaimed, which means to rescue from an undesirable state and restore to the previous natural state. In addition to the recycled materials, IDOT has also found ways to use reclaimed materials instead of new materials.

When developing policies for use of recycled and reclaimed materials, IDOT considers the value of the material with regard to potential cost savings and/or environmental impact. If the materials IDOT recycles and reclaims were not used, they would be destined for the landfill which requires following regulations for disposal. During development of the policies and procedures for beneficial use of these materials, IDOT works with the Illinois Environmental Protection Agency to abide by regulations. By doing this, IDOT is guiding its efforts toward greener and more ecofriendly practices.

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. In addition to construction, IDOT is responsible for maintaining over 16,000 centerline miles of highways.

The educated use of recycled and reclaimed materials can result in reduced cost potentials as long as they provide equivalent or enhanced performance compared to the virgin materials used in the same application. However, not all recycled and reclaimed materials are well suited for highway applications. There are instances where IDOT has found that a recycled or reclaimed material has a potential application, but the negative aspects outweigh the positive aspects. In those cases IDOT has elected to not utilize that recycled or reclaimed material.

This report presents current usage of various recycled and reclaimed materials that have been incorporated into agency practice, and discusses those recycled and reclaimed materials not currently being utilized by the Department. The quantities of recycled and reclaimed materials used, indicated within the report and summarized in Appendix A, are based on materials use as reported to the Materials Integrated System for Test Information and Communication (MISTIC) for calendar year 2012. 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.

RECYCLED AND RECLAIMED MATERIALS UTILIZED IN 2012

IDOT has evaluated the use of many recycled and reclaimed materials since the 1950s. Based upon these evaluations, the Department has identified 13 different materials that perform favorably as valuable supplements or substitutes for conventional materials. These materials are: air-cooled blast furnace slag, by-product lime, crumb rubber, fly ash, glass beads, ground granulated blast furnace slag, microsilica, reclaimed asphalt pavement, reclaimed asphalt shingles, recycled concrete material, reinforcing steel (dowel bars, rebar, and welded wire reinforcement), steel slag, and wet-bottom boiler slag.

This is IDOT's fifth report summarizing the use of reclaimed and recycled materials in highway construction. The report format has been revised from previous reports to reflect use of these materials in various aspects of building and maintaining Illinois's highway network.

Transportation agencies are constantly trying to stretch budgets to maintain roadways and structures. Determining the monetary aspect of recycled and reclaimed materials in the overall scheme of construction projects is complex. A brief explanation of IDOT's view of the economic impact of these materials is included.

For this report, the utilized materials were separated into several categories of highway construction and maintenance: Pavement/Bridge, Subgrade Improvement/Fill Material, and Maintenance/Traffic Control. Information provided for each utilized material presents the origin, physical properties, engineering value, and current application. Additionally, a designation of Primary Use or Secondary Use is shown for materials with multiple applications. The designation is based upon the quantity of that particular material used by IDOT for that particular application.

Information presented in this report was obtained from a long list of sources and organized according to subject matter within a section. Rather than listing a footnote with each statement, the list of all sources used for information about a material within a specific application is provided after the subtitle for that material. Photos and images used for illustration purposes reference the source directly below the caption of the photo.

Economic Impact

Determining a true cost or savings with regard to using recycled and reclaimed materials is extremely difficult. Manufacturers and suppliers set construction material prices based on many factors, including competition in the region, expenses incurred during production, regulatory fees, transportation of the material, and quantities sold per purchase. With the current economic conditions, transportation agencies find it challenging to maintain highways and meet the level of service demanded by the motoring public. A simplistic mindset is that using reclaimed and recycled materials saves money over using new materials. This, however, is not always the case.

Reclaimed and recycled materials can be less expensive than virgin materials; however, the out-of-pocket expense incurred by the agency is not the only aspect that should be evaluated. If price were the only factor that mattered, those reclaimed and recycled materials that are more costly than the virgin counterpart would simply not be used. However, a key factor is whether the impact to the environment can outweigh the financial impact to an agency. IDOT is not only concerned with meeting budgetary needs, but also protecting the environment. Therefore, policies have been set to use materials that fit within IDOT's budget and promote environmental awareness.

Other factors can also make cost or savings determination difficult. Some materials are used as part of a mixture and IDOT pays for the mixture rather than the individual component. Therefore, it is difficult to separate out the cost of the reclaimed or recycled material and compare it against other virgin materials.

To measure the economic impact of using reclaimed and recycled materials in IDOT construction projects, this report will present the equivalent value of the reclaimed or recycled material as it relates to what that material would cost if it were purchased individually. This number does not consider environmental value because of its subjective nature, but it does give an approximation of the value of the material that is saved from being hauled to a landfill. Appendix A provides a table with the equivalent value of each material per unit (pounds or tons) that was obtained by contacting material producers and suppliers in early 2012.

Pavement/Bridge Category

The largest use of highway materials by IDOT is for the construction and rehabilitation of pavements and bridges. For the purposes of this report, pavement is defined as the main structure of the lanes carrying traffic and paved shoulders (unpaved shoulders will be included in the category of Subgrade Improvement/Fill Material). Figure 1 shows the recycled and reclaimed materials used in the Pavement/Bridge Category. Because every material is not compatible with all types of pavements, the category has been divided into two types of pavement – Hot-Mix Asphalt (HMA) and Portland Cement Concrete (PCC). Each pavement type is then further separated into divisions and materials are listed in the division(s) in which they are used. Those divisions consist of Additive, Aggregate, and Binder Replacement for HMA pavements; and Aggregate, Cement Replacement/Mineral Additive, and Reinforcing Steel for PCC pavements.

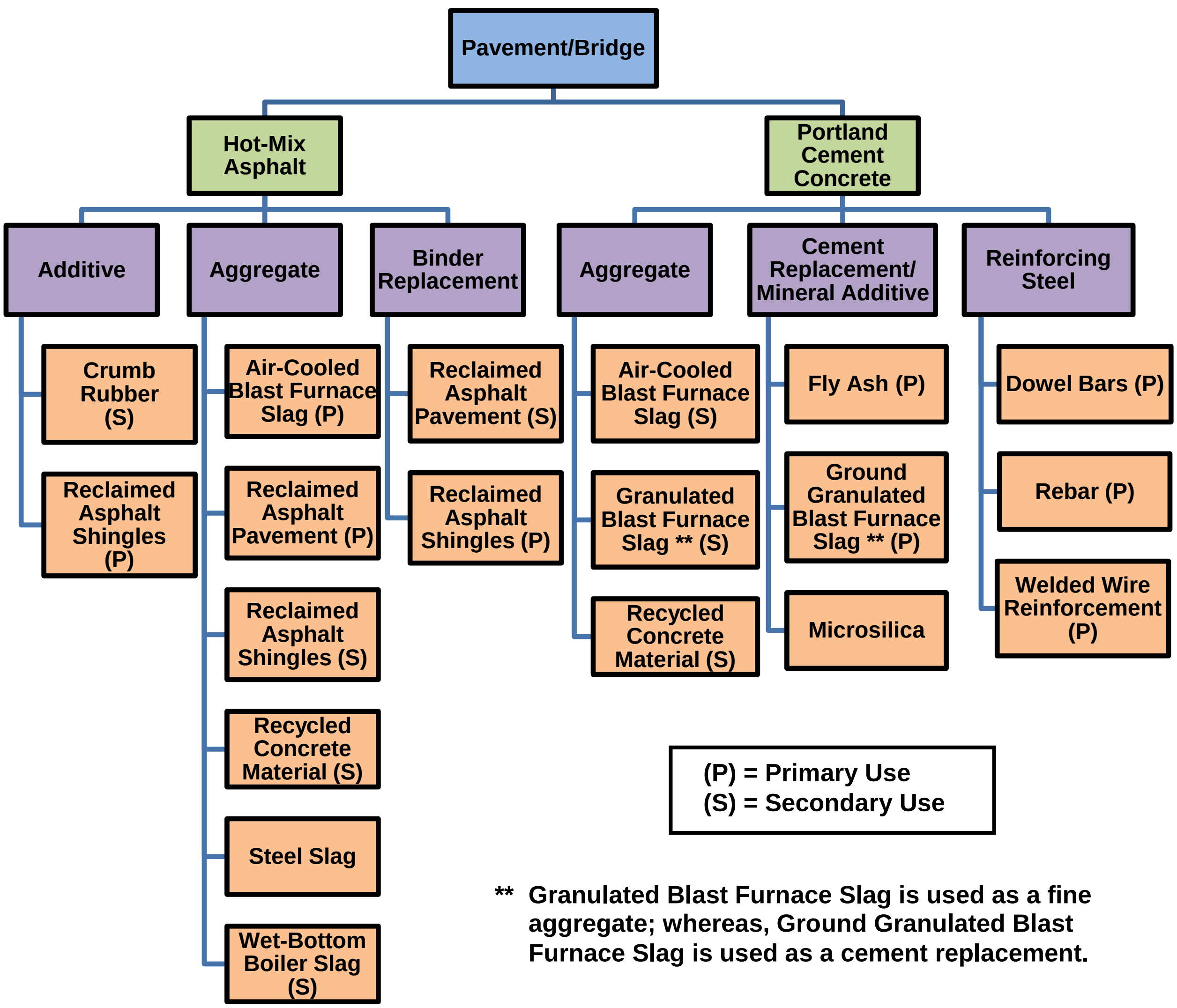

Figure 1. Recycled and Reclaimed Materials Used in the Pavement/Bridge Category.

Hot-Mix Asphalt Pavement Type

Pavements in Illinois are constructed and rehabilitated with HMA, including full-depth HMA, HMA overlays, HMA stabilized subbase, and paved shoulders. HMA is composed of aggregate, liquid asphalt binder, and various additives. IDOT has identified reclaimed and recycled materials that can be used as alternatives to virgin materials for each of these components. Materials for this pavement type are listed under three divisions: Additive, Aggregate, and Binder Replacement.

Additive Division

Various additives are necessary in HMA to address potential mixture problems such as moisture susceptibility, mixture flexibility, or mixture stability. The materials in the Additive Division of the HMA Pavement Type consist of crumb rubber and reclaimed asphalt shingles.

Crumb Rubber [References: 1, 2, 3, 5]

Crumb rubber (CR), also known as ground tire rubber (GTR), is produced by grinding reclaimed, used/worn out tires to certain gradations and removing unusable debris such as steel and fibers. In lieu of grinding, some states allow the CR to be cooled cryogenically with nitrogen and crushed with a hammer mill.

Tire rubber normally contains synthetic rubber, natural rubber, carbon black, steel, polyester, chemicals, and trace metals in varying concentrations. Figure 2 shows the various sizes of CR after being processed. For use in HMA mixtures, IDOT requires CR particles to be reduced to 100 percent passing the No. 16 sieve (particle size of approximately 1/16 inch).

Figure 2. Various Sizes of Processed Crumb Rubber.
[Source: http://www.bruckmanrubber.com/products-and-services/crumb-rubber]

Some states allow CR to be used as an additive in HMA with either a wet or dry process; however, Illinois currently only allows the wet process. The wet process uses CR as a modifier in the asphalt binder at the HMA plant. The dry process uses CR as an HMA modifier through fine aggregate replacement. IDOT 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.

Patents on the wet process have expired, and another method growing in popularity is called Terminal Blending. This method involves blending the CR homogeneously with the asphalt binder at the terminal. The blend is then shipped directly to the HMA plant to be combined with the aggregate and other components.

In 2012, the Bureau of Materials and Physical Research developed the Special Provision for Ground Tire Rubber (GTR) Modified Asphalt Binder. This special provision does allow the use of crumb rubber as a modifier for asphalt binder through terminal blended asphalt. However, GTR modified asphalt binder has a disadvantage in that it cannot be accurately evaluated, or performance graded, the same way as virgin asphalt binder, unless the current test method is altered. With the limitations of the crumb rubber modified asphalt binder, this application is a secondary use for IDOT.

Reclaimed Asphalt Shingles [References: 1, 2, 6, 7, 8, 9, 10, 11]

Reclaimed asphalt shingles (RAS) are waste roofing shingles obtained from either shingle manufacturer's scrap or construction debris from roofs of apartment buildings (four or fewer units) and/or single family dwellings which 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 the presence of asbestos (a potential environmental and health hazard), ground to the desired size, and then delivered to asphalt plants ready to incorporate into HMA.

Asphalt shingles are made of a supporting membrane of organic felt, cellulose, or fiberglass mat; asphalt and fillers; and a coating of fine aggregate. Figure 3 shows pictures of shingles before (collected from old roofs on homes or producer's scraps) and after being processed (ground).

Figure 3. Post-Consumer Reclaimed Asphalt Shingles Pre- and Post-Processing.
[Source: http://www.roofingshinglerecycling.com/]

This application is one of the primary uses of RAS for IDOT projects. The fiberglass or cellulose fiber found in RAS can serve as the fibers needed in a specialized HMA mixture called Stone Matrix Asphalt (SMA) which is used for high-volume roadways and high-stress intersections. This use of RAS eliminates the need to add fiber to these mixtures, resulting in a substantial savings. Another benefit of RAS in HMA is the mineral filler which can serve as an anti-strip agent to protect from moisture susceptibility. 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.

Aggregate Division

A vast majority (90 to 95 percent) of the materials used in HMA is aggregate. Natural aggregate is a resource that cannot be renewed, so alternatives are necessary to stretch the limited quantity of aggregate in order to have supplies last as far into the future as possible. Also, most of the natural aggregate in Illinois is limestone or dolomite which do not necessarily provide the level of friction needed on high-volume facilities. To meet these friction demands, natural aggregates must be hauled from great distances, which increases mixture costs. The alternative is to use waste slags which have excellent friction properties. IDOT utilizes six recycled and reclaimed materials as potential aggregates in HMA. These six materials are: air-cooled blast furnace slag, reclaimed asphalt pavement, reclaimed asphalt shingles, recycled concrete material, steel slag, and wet-bottom boiler slag.

Air-Cooled Blast Furnace Slag [References: 1, 2, 12]

Air-cooled blast furnace slag (ACBFS) is one of various slag products that can be generated during the production of iron. Slag is developed in the blast furnace when iron ore or scrap iron is reduced to a molten state by burning coke fuel with fluxing agents of limestone and/or dolomite. Figure 4 is an example of a blast furnace and shows how the slag is generated.

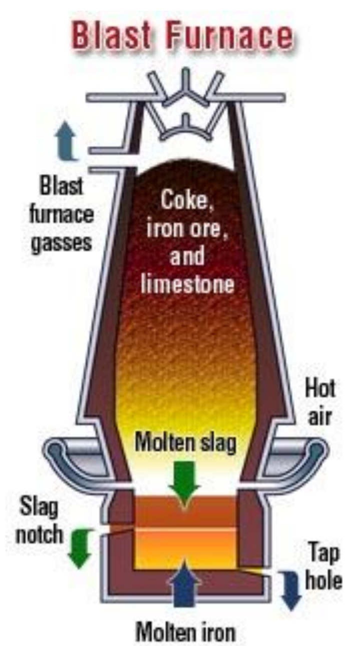

Figure 4. Blast Furnace During Production of Iron.
[Source: http://www.nationalslag.org/blastfurnace.htm].

When the liquid slag is allowed to cool under atmospheric conditions, the final product is called ACBFS, due to the method in which it was cooled. If a different cooling process is used, the material is known as another type of slag (e.g. expanded slag, granulated slag, etc.). ACBFS may be crushed and screened with typical aggregate processing equipment to meet gradation specifications. Of all the blast furnace slag produced in the United States that is reportedly utilized, approximately 90 percent is ACBFS.

As shown in Figure 5, ACBFS is a hard, angular material with textures ranging from rough, porous surfaces to smooth, shell-like fractured surfaces. Although the particles have many openings on the surface, 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.

Figure 5. Air-Cooled Blast Furnace Slag as a Coarse Aggregate.
[Source: http://www.nationalslag.org/blastfurnace.htm].

Crushed ACBFS can be used in both HMA and PCC pavement applications, but IDOT primarily uses it in HMA pavements. ACBFS has potentially favorable resistance to polishing, weathering durability, and heavy loads. However, the material's inherent variability in physical properties can be of concern. For example, when included in HMA pavements, this material provides exceptional frictional properties and increased stability. But its tendency for high surface absorption, because of the increased surface area from the porous texture, may require greater amounts of liquid asphalt binder. The variable specific gravity of ACBFS in HMA has caused some quality control problems. As a result, a self-testing producer control program has been added to the specifications regarding HMA mixes.

Reclaimed Asphalt Pavement [References: 1, 2, 4, 5, 13]

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.

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. Therefore, RAP must be stockpiled according to its aggregate quality and gradation to ensure mix requirements are met for the layer of pavement that is being constructed. Depending on the method of processing, RAP can be finer than its original aggregate constituents. Figure 6 shows two RAP stockpiles being established with different gradations.

Figure 6. Stockpiles of Reclaimed Asphalt Pavement.
[Source: http://www.fhwa.dot.gov/pavement/recycling/rap/]

The Department's special provision for RAP has been revised several times throughout the years. RAP is allowed in all Department HMA mixes, which makes this application the primary use of RAP. The policy is continually being revised to maximize the amount of RAP that is allowed in the mix without adversely affecting performance of the pavement. For the special provisions 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. Additionally, the RAP and RAS special provisions were combined into one document.

Reclaimed Asphalt Shingles [References: 1, 2, 6, 7, 8]

Aggregate material components of RAS include fine aggregate and mineral filler. Both of these components are used in HMA mixtures and can therefore replace a portion of these materials to reduce costs. However, this is a secondary use of RAS compared to its use in the applications as an additive or binder replacement.

Recycled Concrete Material [References: 1, 2, 4, 14]

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 and private facilities. This material is crushed by mechanical means into manageable fragments and stockpiled. Depending on the removal process, RCM may include small percentages of subbase soil and related debris. Figure 7 shows an example of a RCM stockpile.

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.

Currently, the Department allows the use of RCM as a coarse aggregate in aggregate surface courses. Also, because of its angular shape and high strength, it is a durable, polish resistant aggregate that can be used in HMA on high-volume roadways. This material has also been widely used as an aggregate in membrane waterproofing and in drainage layers and as protection against erosion.

Figure 7. Stockpile of Recycled Concrete Material.
[Source: http://www.andalereadymix.com/products-recycled-concrete.php]

RCM may help to reduce moisture susceptibility in HMA mixtures; however, it has a high absorption which requires a higher percentage of liquid asphalt binder. Due to the potential increased cost of the higher binder percentage, this application is a secondary use of RCM.

Steel Slag [References: 1, 2, 4, 12, 15, 16]

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. Figure 8 shows internal views of an oxygen furnace and an electric arc furnace during the production of steel slag. Figure 9 shows an example of steel slag as a coarse aggregate.

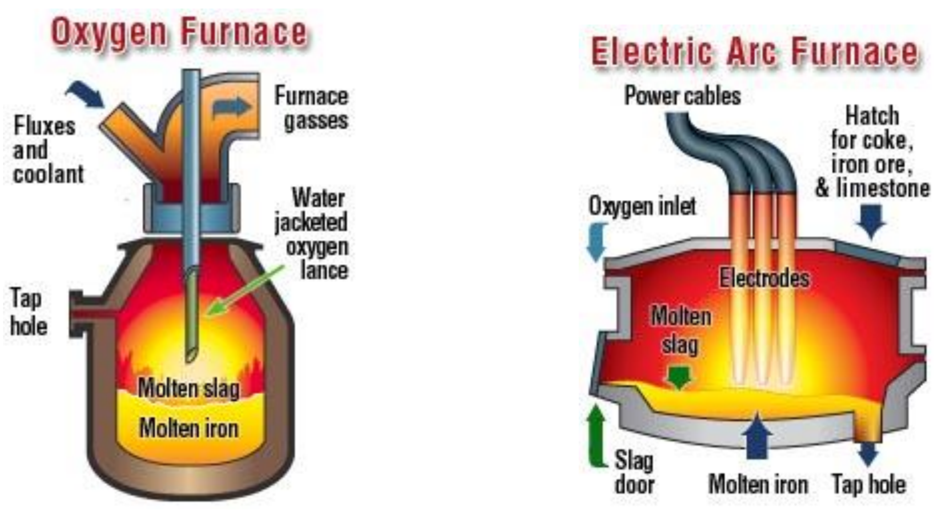

Figure 8. Internal View of Steel Slag Production Using Oxygen and Electric Arc Furnaces.
[Source: http://www.nationalslag.org/steelslag.htm]

Figure 9. Steel Slag as a Coarse Aggregate.
[Source: http://www.bvslag.com/steel_slag_uses.htm]

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. Ladle slag is not deemed suitable for aggregate usage.

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.

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.

Since 1975, steel slag has been available as an aggregate in pavement materials. It is acceptable as both a 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. Similar to ACBFS, steel slag has a self-testing producer control program that 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.

Wet-Bottom Boiler Slag [References: 1, 2, 5]

Wet-bottom boiler slag (WBBS or "Black Beauty") is a by-product of burning coal 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.

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. Figure 10 shows a picture of WBBS and shows the dark color which explains the name ”Black Beauty”. 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.

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.

Figure 10. Wet-Bottom Boiler Slag (aka “Black Beauty”).
[Source: http://www.caer.uky.edu/kyasheducation/boilerslag.shtml]

WBBS is allowed to be incorporated as an aggregate in top surface dressing of bituminous surface treatments and for membrane waterproofing. IDOT does not typically use WBBS in these treatments, but local agencies do use this material for these purposes. Contractors also use WBBS as an aggregate in blasting grit, asphalt paving, and in roadway base and subbase applications for private work.

Binder Replacement Division

The most expensive component of HMA is liquid asphalt binder. Use of reclaimed materials to replace virgin liquid asphalt binder can provide cost savings to IDOT. Two reclaimed materials that are sources of asphalt binder replacement are reclaimed asphalt pavement (RAP) and reclaimed asphalt shingles (RAS).

Reclaimed Asphalt Pavement [References: 1, 2, 4, 8, 13]

Binder replacement is a secondary use of RAP when compared to its use as an aggregate. RAP is HMA material removed and/or reprocessed from pavement undergoing reconstruction or resurfacing. Residual asphalt binder in RAP can be used to reduce the amount of virgin liquid asphalt binder used in a new mixture. However, the residual asphalt binder from the RAP is much harder than typical paving grades of asphalt binder. To address this issue, there is a maximum limit of RAP that can be added to the HMA mixture, depending on the application, and softer grades of virgin asphalt binder are used to counteract overall hardness of the asphalt.

For example, if the original pavement had 5 percent asphalt binder, was milled up and reused as RAP in a new HMA mixture with a design of 5 percent asphalt binder, then for 50 percent or 20 percent RAP added to the mix, you would use 2.5 percent or 4 percent virgin asphalt binder, respectively. Typical IDOT mixtures use anywhere from 10-50 percent of RAP. With that percentage of RAP in the mixture and following the binder replacement principle, the amount of virgin asphalt binder needed in the mixture would be around 2.5-4.5 percent.

Reclaimed Asphalt Shingles [References: 1, 2, 6, 7, 8, 9, 10, 11]

RAS is a good source for binder replacement, after screening for asbestos-containing material and removing nails and other debris. 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 liquid asphalt binder needed in the mix and resulting in a cost savings to the Department. This reclaimed asphalt binder, however, is much harder than typical paving grades of liquid asphalt binder, requiring both a maximum limit and blending with softer grades of virgin liquid asphalt binder.

The United States disposes of roughly 11 million tons of asphalt shingles per year. Adding RAS to HMA provides IDOT an economical process to reuse what would otherwise be discarded and reduce the material cost of HMA.

The Department continues to maintain a specification for the use of RAS in HMA. This specification allows the use of RAS from manufacturer's salvaged or from post-consumer tear-offs. The percentage of RAS allowed in the HMA mix is limited to 5 percent of the mixture to minimize pavement cracking potential. Physical Research Report (PRR) 163 "Use of Reclaimed Asphalt Shingles in Illinois: 2nd Edition" presented additional details on use of RAS as required by Public Act 097-0314. A copy of this report can be obtained at: http://www.dot.il.gov/materials/research/pdf/prr163.pdf.

Portland Cement Concrete Pavement Type

The other type of pavement in the Pavement/Bridge Category is Portland Cement Concrete (PCC). Materials used for this pavement type have also been separated into three divisions: Aggregate, Cement Replacement/Mineral Additive, and PCC Reinforcing Steel.

Aggregate Division

Similar to the composition of HMA, a large percentage of the materials used in PCC is aggregate (60 to 80 percent). However, PCC requires a higher quality of aggregate compared to HMA because of potential structural distresses. Finding alternatives to natural aggregates can help reduce the overall mixture cost. Two reclaimed/recycled materials that are suitable options for use in PCC are granulated blast furnace slag and recycled concrete material.

Granulated Blast Furnace Slag [References: 1, 2, 4, 12]

Similar to ACBFS, granulated blast furnace slag (GBFS) is developed during iron production. Figure 11 shows an example of this material.

Figure 11. Granulated Blast Furnace Slag as a Fine Aggregate.
[Source: http://www.asa-inc.org.au/granulated-blast-furnace-slag.php]

The sand-sized structure is a result of the blast furnace slag being rapidly cooled by water immersion. GBFS is a glassy, non-crystalline material that will vary in size depending on its chemical composition and method of production, both its own production as well as that of its iron source. This material's use as a fine aggregate substitute is secondary to grinding it for use as a cement replacement/mineral additive in PCC.

Recycled Concrete Material [References: 1, 2, 4, 14]

In addition to use as an aggregate in HMA, RCM is also allowed as an aggregate in PCC. Sound, durable aggregate known as "A Quality" aggregate is required for PCC pavement. This higher type aggregate is in smaller supply throughout Illinois compared to lower quality aggregates. Because the aggregates within RCM previously met quality requirements, it provides an additional supply of high quality aggregate for PCC pavement and structures.

Even though crushed concrete's physical characteristics make it a viable substitute for aggregate, RCM may be a potential source of problems for new PCC pavement. The cementitious (cement-like) component of RCM has a high amount of alkalinity, and chlorides from deicing salts may be present—a concern with regard to steel reinforcement corrosion. RCM may also contain aggregates susceptible to Alkali-Silica Reactivity (ASR) or Durability Cracking (D-Cracking) which cause structural deterioration of the concrete. For example, aggregates may have met initial testing requirements for D-Cracking susceptibility; however, after being used in a previous pavement/bridge application, the aggregate may have reached the limit of resistance to this distress and could begin deteriorating in a new pavement/bridge. Because of the potential material durability issues, this application is a secondary use of RCM on IDOT projects.

Cement Replacement/Mineral Additive Division

Portland cement with the addition of water and other additives is the binding material in PCC. However, manufacturing cement can cause environmental hazards. Several reclaimed/recycled materials have cementitious properties and can serve as a substitute for a portion of the Portland cement in the mixture or they can serve as an additive to improve performance of the mixture. Materials under the Cement Replacement/Mineral Additive Division are: fly ash, ground granulated blast furnace slag, and microsilica.

Fly Ash [References: 1, 2, 4, 17]

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 or 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.

Fly ash is divided into two 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.

Fly ash is a fine, powdery silt-sized 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. Figure 12 shows a pile of grayish black fly ash. Fly ash may exhibit pozzolanic or cement-like properties.

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 the pH, change the hydration process (fly ash retards hydration, thus lowering heat of hydration), reduce water demand, reduce permeability, and generally extend the cement in the mix.

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 used 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 ASR. The primary use of fly ash in Illinois construction projects is as a cement replacement.

Figure 12. Stockpiles of Fly Ash.
[Source: http://www.sustainablebrands.com/news_and_views/feb2012/what-waste]

Ground Granulated Blast Furnace Slag [References: 1, 2, 4, 12]

Granulated blast furnace slag that is pulverized to a fine, cement-like material as shown in Figure 13 is known as ground granulated blast furnace slag (GGBFS). When ground this fine, GGBFS is pozzolanic and can be used in PCC as a mineral additive, component of blended cement, or substitute for Portland cement. Considering the two applications for blast furnace slag (granulated and ground granulated), this application is the primary use.

Figure 13. Ground Granulated Blast Furnace Slag.
[Source: http://www.slagcement.org/Sustainability/whatisslag.html]

Concrete produced with GGBFS has reduced permeability and reduced heat of hydration. GGBFS (10 percent) and ACBFS (90 percent) account for all of the blast furnace slag produced in the United States.

Typical uses of GGBFS are as a mineral additive in concrete mixtures, and as a 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. ASR is detrimental to concrete because it causes expansion and cracking in concrete.

Microsilica [References: 4, 18]

Microsilica, 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 with filters, and the fine material recovered from the filters is silica fume.

Microsilica is a gray powdery material that primarily consists of 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. Microsilica is available in both liquid and powder forms. Figure 14 shows the powder form of microsilica which is the most common form used in IDOT projects.

Figure 14. Microsilica in Powder Form.
[Source: IDOT Photo – BMPR Cement Testing Laboratory]

Microsilica's high silica content is also high in purity and pozzolanic properties. Reacting with calcium hydroxide (a product of cement's pozzolanic reaction), microsilica will produce calcium silicates resulting 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 benefit from using silica fume, the concrete must be cured properly.

IDOT allows the use of microsilica in concrete mixtures. It is typically used as a mineral additive, but may be used as an alternate to cement when mix designs incorporate cements with high alkalinity and potentially reactive aggregates that could result in ASR.

Reinforcing Steel Division [References: 1, 4, 19, 20]

The third division of PCC is Reinforcing Steel. Reinforcing steel consists of three types of steel reinforcement for concrete: dowel bars, rebar, and welded wire reinforcement.

Steel reinforcement is made almost entirely of recycled scrap iron. This material is salvaged from automobiles, appliances, and steel-reinforced structures including reinforced concrete pavements, bridges, and buildings. Two common forms of steel production are the basic oxygen and electric arc processes. In the basic oxygen process, molten iron is removed from the blast furnace, combined with alloys, and up to 30 percent steel scrap, which is used as an additive to lower the temperature of the molten composition. In the electric arc process, "cold" ferrous material (generally 100 percent scrap steel) is the major component melted with alloys in an electric furnace. 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.

The primary components of steel are various iron alloys using elements such as silicon, manganese, chromium, nickel, or copper. In production, carbon, phosphorus, and sulfate may also be present and percentages altered, resulting in different grades of steel.

Steel reinforcement plays an important role in concrete structures. The following explains the use of each type of steel reinforcement in pavements.

Dowel Bars

Dowel bars are used in Jointed Plain Concrete Pavement (JPCP) to create load transfer at uniformly spaced joints. As the joints open with temperature changes, the concrete has the potential to lose the aggregate interlock across the joint. Dowel bars are used to transfer the load from one slab of pavement to the next and minimize potential loss of the subgrade material that can occur from a combination of heavy loads and moisture in the subgrade. Figure 15 shows dowel bars in a partially constructed concrete pavement.

Figure 15. Dowel Bars in a Partially Constructed Concrete Pavement.
[Source: http://www.pavementinteractive.org/article/dowel-bar/]

Rebar

Rebar, short for reinforcement bar, in PCC pavements holds cracks together ensuring high aggregate interlock to provide load transfer across the cracks. Steel reinforcement also eliminates the use of joints in PCC pavement, which can promote a longer-lasting, smoother riding surface. This type of pavement is called Continuously Reinforced Concrete Pavement (CRCP). Figure 16 shows the overlapping longitudinal rebar used to control the transverse cracks that naturally form throughout the length of the pavement and keep them tight to evenly transfer loads across the cracks.

These same qualities are also desirable in bridges and other reinforced concrete structures. Rebar used in these applications is fabricated into various shapes that are tied together to create a support system, like a skeleton, within the concrete structure.

Figure 16. Rebar Assembled for CRC Pavement.
[Source: http://www.fhwa.dot.gov/pavement/concrete/pubs/hif12039/]

Welded Wire Reinforcement

Welded wire reinforcement (WWR) is used in pavement, concrete pipe, prestressed/precast products, concrete structures, etc. Figure 17 shows one size of WWR, but many sizes are available, depending on the application. In the past, IDOT constructed jointed reinforced concrete pavements (JRCP) with long joint spacings and WWR in the panels. However, this pavement type developed midpanel cracks that lost aggregate interlock and faulted, resulting in poor performance. While other states continue to build JRCP, IDOT currently only uses JPCP which has short joint spacing and no WWR in the panels.

IDOT specifications, as well as state and federal laws, require that only steel made in America can be used on highway projects. This not only helps with recycling materials but also provides job opportunities.

Figure 17. Stack of Welded Wire Reinforcement
[Source: http://www.stetsons.com/reinforcing_steel/welded_wire_fabric/]

Subgrade Improvement/Fill Material Category

In addition to pavement, aggregate can be also used to improve subgrade as a construction platform and as unpaved shoulder or fill material. Figure 18 shows the listing of recycled and reclaimed materials IDOT used in the category of Subgrade Improvement/Fill Material. Materials included in this category are: by-product lime, fly ash, reclaimed asphalt pavement, recycled concrete material, and wet-bottom boiler slag.

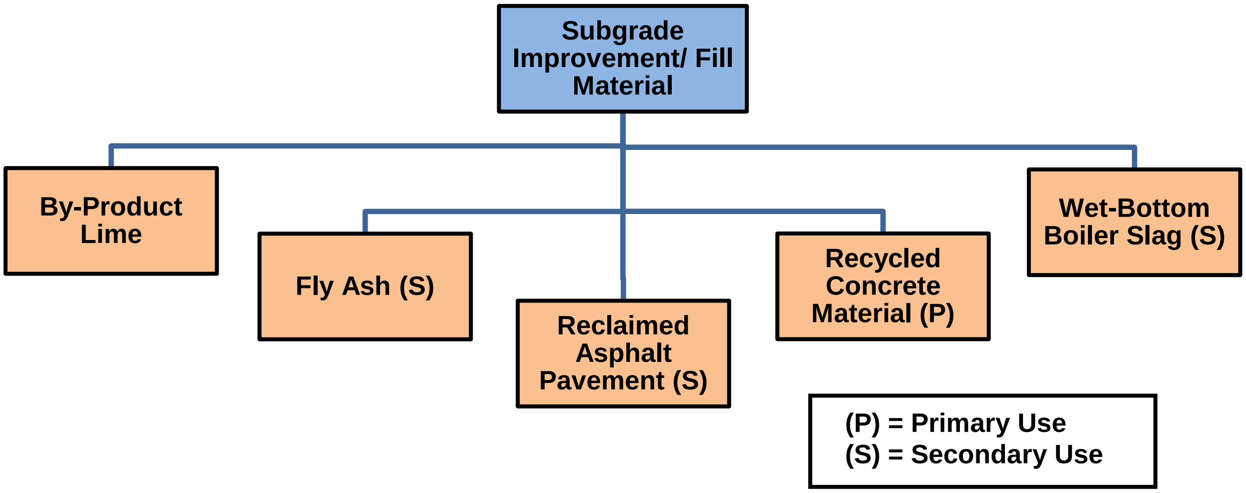

Figure 18. Recycled and Reclaimed Materials Used in the Subgrade Improvement/Fill Material Category.

By-Product Lime [References: 1, 2, 4, 21]

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 a by-product, non-hydrated lime called lime kiln dust (LKD). 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. Figure 19 shows an example of LKD. Much of LKD's properties are dependent on plant production: feedstock, kiln design, fuel type, and type of dust control/collection method employed.

In addition to by-product, non-hydrated lime, IDOT also allows by-product, hydrated lime. This material is generated as a residual product during the process of manufacturing hydrated lime. Even though this material is suitable for use as a subgrade improvement, very little is seen on IDOT projects due to insufficient quantities available.

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). By-product lime also aids in the reduction of high moisture borrow soils in embankment construction.

Figure 19. Lime Kiln Dust.
[Source: http://limestabilization.com/lime-products]

Fly Ash [References: 1, 2, 4, 21, 22]

As a secondary use in Illinois construction projects, dry fly ash can be used as an inert fill material or supplementary cementitious material to improve cohesion and stability of soil embankments. IDOT allows Class C and Class F fly ash. Both classes of fly ash provide benefits to improve construction and working platform properties of various soils. Having two options of fly ash can permit use of local soils rather than removing and replacing.

Reclaimed Asphalt Pavement [References: 1, 2, 4, 23, 24, 25]

The Department also allows RAP to be used in place of aggregate or soil in some non-structural backfill situations. All pavements require 12 inches of improved subgrade which can be either modified soil or aggregate. IDOT allows RAP to be blended with natural aggregate for use as aggregate subgrade; however, it cannot exceed 40 percent of the total material in the subgrade due to stability concerns. An issue with RAP use in the subgrade is the potential for expansion due to materials such as steel slag. Due to concerns regarding the potential for expansion, special provisions through 2012 limited the amount of steel slag or other expansive material in RAP to a maximum of 10 percent when used for aggregate subgrade. Research has indicated expansion of steel slag RAP is minimal and the limitation was removed in 2013.

One option to reduce the amount of blending required is to split the 12 inches of improvement into lifts. RAP alone may be used when it is limited to the top 3 inches as a capping layer. This layer must be well graded and 100 percent of the RAP must pass the 1-1/2 inch sieve. Also, the capping layer must be used with specific gradations of aggregate for the lower 9 inches.

These limitations were identified because of work done through an experimental IDOT project. Figure 20 shows a test section of RAP being used in that project. During that study, sections that used RAP for the entire depth showed severe rutting which may have been a result of the lack of fine material.

Figure 20. Test Location S180R - 12 in. of Surface Millings after 20± Load Passes.
[Source: IDOT Photo – Gregory Heckel, District 6]

Recycled Concrete Material [References: 1, 2, 4, 14]

RCM's physical characteristics make it a viable substitute for aggregate material used in granular bases, as well as a material fill, such as riprap. Figure 21 shows the angular shape and composition of RCM.

Figure 21. Crushed Concrete (1- to 3-in. Topsize) for Use as Rip Rap or Aggregate Subgrade.
[Source: http://www.eaglelandscapesupply.com/1-3-crushed-concrete.html]

Ultimately, RCM obtained on site may be used immediately or stockpiled for future use. Currently, the Department allows the use of RCM on granular embankments, stabilized bases, and subbase courses, provided the project materials' specifications are not compromised. This application is the primary use of RCM.

Wet-Bottom Boiler Slag [References: 1, 2, 4]

WBBS is allowed for use in embankments, trench backfills, sand backfills for underdrains, bedding, and porous granular backfills. WBBS is also allowed to be utilized in roadway base and subbase applications. However, these applications are secondary to other applications. In 2012, there were no records that indicated WBBS was used for fill material.

Maintenance/Traffic Control Category

Figure 22 shows the recycled and reclaimed materials IDOT used in the category of Maintenance/Traffic Control. This list of materials consists of crumb rubber, glass beads, and wet-bottom boiler slag.

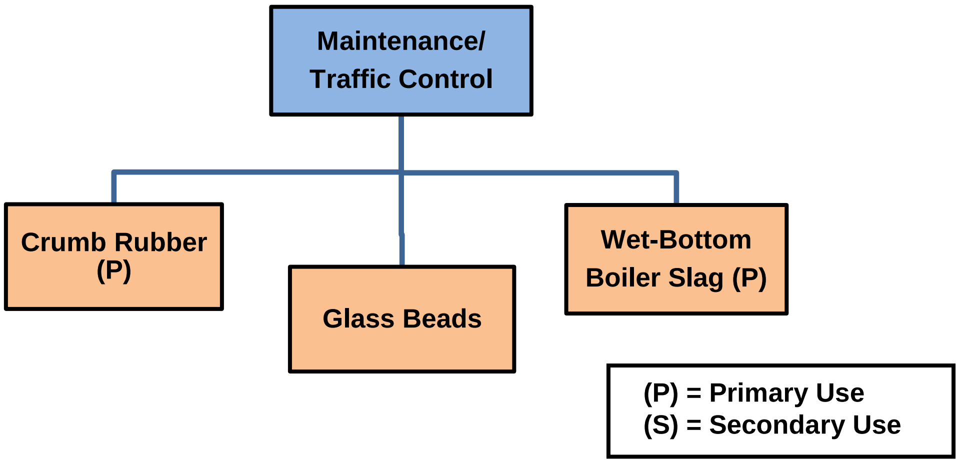

Figure 22. Recycled and Reclaimed Materials Used in the Maintenance/Traffic Control Category.

Crumb Rubber [References: 1, 2]

CR can be used in multiple areas of roadway construction. The Department uses CR as a component in one type of reflective crack control system and in crack sealant. Most crack sealants as seen in Figure 23 contain a percentage of CR. Preventive maintenance using crack sealing is the primary use of CR for IDOT.

Figure 23. Sealing Cracks with Rubber Modified Sealant.
[Source: http://jlpsealcoat.com/pavement-parking-lot-crack-sealing/]

Glass Beads [References: 1, 2, 4]

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. Glass beads, in particular, are a product of recycled soda-lime glass. This material's primary source is from manufacturing and post-consumer waste. At recycling centers, recovered glass is hand sorted by color (clear, amber, and green), and then crushed to customized sizes.

Glass beads are transparent, sand-sized, solid glass microspheres that 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: license plates, movie screens, and reflective fabrics.

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 all pavement marking materials, including paint, tapes, and thermoplastic as shown in Figure 24. Essentially all traffic lines on highways contain glass beads, improving the overall safety of nighttime highway travel through increased visibility.

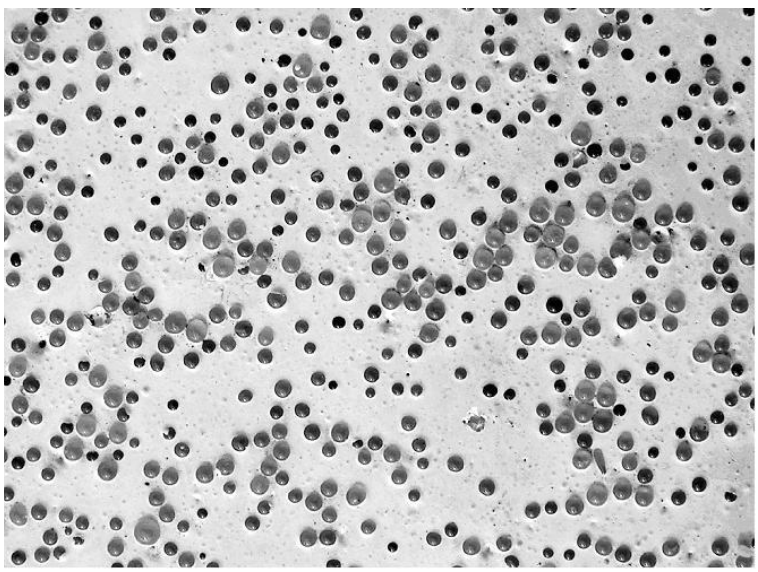

Figure 24. Glass Beads in Thermoplastic Pavement Marking.
[Source: http://onlinemanuals.txdot.gov/txdotmanuals/pmh/inspection_during_application.htm]

Wet-Bottom Boiler Slag [References: 1, 2, 4]

IDOT's primary use of WBBS is for snow and ice control, as the hard angular particles improve traction. However, when used in this application a material inspection is not required, thus no quantities were noted in MISTIC. Local agencies also blend WBBS with salt to extend the quantities of de-icing materials.

RECYCLED AND RECLAIMED MATERIALS NOT UTILIZED IN 2012

Through the years IDOT considered other reclaimed and recycled materials that are accepted by other agencies. However, there are other factors that have either raised concerns for the Department or deterred the use of the material. The main reasons for not utilizing a reclaimed material are 1) addition of material is a detriment to highway performance, 2) excessive cost, and 3) no approved source in the state.

Three such materials experimented with by other states but currently not considered viable resources in Illinois highways, for reasons stated above, are: bottom ash, glass cullet, and waste foundry sand. This portion of the report presents the material's origin, physical properties, potential engineering value, and potential application for the materials not utilized by IDOT. Additionally, information is provided regarding departmental concerns precluding the material's use in construction projects.

Bottom Ash [References: 1, 2, 17, 26]

Bottom ash is produced in dry-bottom coal boilers 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.

Bottom ash is a coarse, typically gray to black in color, angular material of porous surface texture. The size ranges from fine gravel to fine sand, but is predominantly sand-sized as shown in Figure 25. 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.

Figure 25. Ground Bottom Ash.
[Source: http://www.caer.uky.edu/kyasheducation/bottomash.shtml]

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. Because this material is highly susceptible to degradation under compaction and loading, bottom ash is not an acceptable aggregate for most highway construction applications.

Bottom ash is used as a filler material for structural applications and embankments, or as aggregate in road bases and subbases. It is also used as a feed stock in the production of cement, aggregate in lightweight concrete products, and snow and ice traction control material.

In addition to the concerns noted above, bottom ash is considered a problematic debris which plugs drainage structures when used for snow and ice control.

Glass Cullet [References: 1, 2, 27, 28]

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 limited percentage of ceramics, china dishes, plate glass, and thin walled container glass that can be accepted. Containers used to contain hazardous or toxic materials, automobile glass, TV monitors, and lighting fixtures are prohibited from use due to their unique chemical compositions.

Glass cullet is recycled glass ground down to 100 percent passing the 3/8-inch sieve. Chemically, glass is typically 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. Figure 26 shows the various types of glass cullet in storage bays at a recycling faculty.

The use of glass cullet as an aggregate in HMA or PCC is not common. The high silica content increases the risk of ASR in concrete. While the angular surface of glass would suggest positive results in HMA, frequently the asphalt “strips” off the glass, causing a weak mix and poor performance. Glass cullet is most frequently used as a fill material as its angular characteristics allow it to maintain stability when compacted and it retains little to no moisture.

Many other departments of transportation use glass cullet for multiple applications, including 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.

Figure 26. Various Bays Stockpiling Glass Cullet.
[Source: http://www.gabbertcullet.com/backlot.html]

Waste Foundry Sand [References: 1, 2, 29]

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, zinc, and other undesirable materials.

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. Figure 27 shows an example of a stockpile of WFS. WFS contains metal casting pieces, partially degraded binder, and may also contain some leachable contaminants, including heavy metals and phenols.

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

The commercial use of this material is extremely limited in the United States. Transportation cost of foundry sand is the most limiting factor to its use. Two additional challenges to using waste foundry sand are environmental issues and minimal engineering value.

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.

Figure 27. Stockpile of Ground Waste Foundry Sand.
[Source: http://www.afsinc.org/government/AFSFirst.cfm?ItemNumber=7887&navItemNumber=528]

CONCLUSION

The Illinois Department of Transportation is progressing in a positive direction with the steps and implementation processes currently being used with recycled and reclaimed materials in highway construction. Available funding and project needs are the determining factors in how much recycled/reclaimed materials are utilized by IDOT. In 2012, the Department used almost 1.2 million tons (2.4 billion pounds) of recycled materials in highway construction, which is similar to the quantity used the previous year. It would take about 48,000 semi-tractor trailers to haul this quantity of material. If this number of trucks were lined up end-to-end, the line would stretch from Cairo, IL to Rockford, IL and then over to Joliet, IL.

Currently there is not enough documented performance data to determine the true life-cycle savings/cost of some of the materials in this report (e.g. reclaimed asphalt pavement and reclaimed asphalt shingles). It will take several years of usage to determine performance trends and to produce enough data to analyze. IDOT is in the process of adopting test procedures that will help ensure performance is not compromised while utilizing the recycled/reclaimed materials and collecting data.

Overall, IDOT is making every possible effort to sustain the natural resources of our state, while providing long-lasting roads. Using recycled and reclaimed materials is just one way to make our resources stretch to meet the demands of IDOT's mission to provide safe, cost-effective transportation for Illinois.

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APPENDIX

2012 UTILIZED RECYCLED AND RECLAIMED MATERIALS QUANTITIES AND EQUIVALENT VALUES

MATERIAL	UNIT EQUIVALENT VALUE	QUANTITY[1]	TOTAL EQUIVALENT VALUE TO DEPARTMENT
AIR-COOLED BLAST FURNACE SLAG	$5.50/TON	2,776 TONS	$15,268
BY-PRODUCT LIME	$38/TON	10,119 TONS	$384,522
CRUMB RUBBER[2]	$0.20/LB	866,449 LBS	$173,290
FLY ASH	$40/TON	66,703 TONS	$2,668,120
GLASS BEADS	$0.25/LB	12,368,400 LBS	$3,092,100
GROUND GRANULATED BLAST FURNACE SLAG	$55/TON	7,462 TONS	$410,410
MICROSILICA	$1,000/TON	13 TONS	$13,000
RECLAIMED ASPHALT PAVEMENT	$34.40/TON	837,089 TONS	$28,795,861
RECLAIMED ASPHALT SHINGLES	$40/TON	12,412 TONS	$496,480
RECYCLED CONCRETE MATERIAL	$7/TON	170,591 TONS	$1,194,137
STEEL REINFORCEMENT *DOWEL BARS*[3]	$1008/TON	2,528 TONS	$2,548,224
REBAR[4]	$1008/TON[4]	19,974 TONS	$20,133,792
WELDED WIRE REINFORCEMENT[5]	$750/TON	2,076 TONS	$1,557,000
STEEL SLAG	$19/TON	56,324 TONS	$1,070,156
WET-BOTTOM BOILER SLAG[6]	N/A	N/A	N/A
	GRAND TOTALS	1,194,684 TONS	$62,552,360

[1] Quantities were calculated as the total amount assigned to projects in Calendar Year 2012. 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.*

[2] CRUMB RUBBER: This material quantity was calculated as 5 percent of the quantity of hot-poured joint sealant used in 2012.

[3] 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.

[4] REBAR: Prices are quoted using epoxy coated rebar.

[5] WELDED WIRE REINFORCEMENT: The average size of welded wire reinforcement 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 (lbs) 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 lbs per 11.1 sq yd; which is equivalent to 5.6459 lbs per sq yd.

[6] WET-BOTTOM BOILER SLAG: No records were found in MISTIC that indicated WBBS was used for any IDOT projects in 2012.