USE OF WASTES, SURPLUS MATERIALS AND BYPRODUCTS IN TRANSPORTATION CONSTRUCTION

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ABSTRACT

The increasing emphasis on the 3 Rs - reduce, reuse and recycle - and the need for sustainable development to preserve/conserve our natural resources, has led to more responsible management of wastes (‘residuals’), surplus materials and byproducts. Materials that had previously been disposed of through landfilling include old asphalt and old concrete, slags, fly ash, foundry sands, kiln dusts, waste glass, roofing waste (trimmings and old shingles), rubber tires, etc., and increased uses for these materials are being identified in construction applications.

There are significant limiting factors to be faced and surmounted for enhanced residuals and byproducts use in transportation facilities construction and maintenance such as: inherent variability, collection, storage and processing costs, lack of technical guidance and specifications, environmental constraints and agency conservatism. This paper summarizes recent research and practical hands-on experience in the use of residuals, surplus materials and byproducts gained through the design and construction of actual transportation projects and includes: old concrete use in roller compacted concrete pavements (Milton, Ontario); waste glass in binder course asphalt concrete (Metro Toronto); rubber tires in surface and binder course asphalt concrete mixes (Region of Haldimand-Norfolk); and developments in the use of steel slag aggregates in hot-mix asphalt (Ontario).

This positive practical experience supports the appropriate uses of residuals, surplus materials and byproducts in construction applications and fosters the objectives of sustainable development and reduction in landfilling of potentially valuable resources.

The current and potential reuse and recycling of top-ranking wastes, surplus material and byproducts (old asphalt, old concrete, blast furnace slag, fly ash, steel slag, silica fume, nickel and copper slags, bottom ash, mine waste rock, waste tires, kiln dusts, waste foundry sand, waste glass and waste shingles) as bulk and cementitious materials in transportation construction is summarized. Factors limiting the use of wastes as pavement construction materials such as inherent variability, collection, storage and processing costs, lack of technical guidance and specifications, environmental constraints and agency conservatism are addressed from a materials engineering technical perspective. While the transportation construction industry reuse and recycling of wastes and byproducts makes an important contribution to reduced landfill disposal, the overall impact on aggregates and energy conservation will continue to be modest. It is important for sustainable development to nurture and expand the use of wastes to avoid the landfilling of potential construction materials.

INTRODUCTION

It is now some fifteen years since Canada participated in the largely aggregates and energy conservation motivated OECD study "Use of Waste Materials and Byproducts in Road Construction" that identified the then demonstrated and potential uses of alternative materials (wastes, byproducts and surplus materials) in transportation construction [1,2,3]. Now, the construction industry environmental focus is on sustainable development with emphasis on waste reuse and recycling to sharply reduce landfilling, coupled still with materials and energy conservation. As part of a recent study for the Ontario Ministry of Natural Resources [4], the Canadian OECD contribution has been
updated through a survey of Provincial and State transportation departments, and review of the extensive related technical literature (Dialog™ TRIS data base, for instance), to cover current wastes and byproducts uses for bulk (aggregate, filler, engineered fill, etc.) and cementitious (blended cement, cement kiln feed, stabilizer, etc.) applications.

The overall economic, environmental and technical feasibility evaluation of wastes and byproducts for reuse and recycling, with focus on pavement construction materials, was based on: adequate quantity of waste or byproduct available at location, or economically collectable, to justify development of processing systems, with due consideration of cost savings through dumping charges and/or reduced landfill fees; transportation costs (distances) from processing locations to sites reasonable in terms of competition with conventional materials; processed waste or byproduct not potentially harmful during proper handling and use (leachable toxic constituents do not exceed environmental standards, dusting controlled, etc.); and physical, mechanical and chemical characteristics of the processed waste or byproduct (or economically-modified material) meet reasonable, applicable specifications for the contemplated bulk or cementitious applications. Emphasis was placed on the economically-viable, environmentally-friendly, technically-sound reuse and recycling of wastes and byproducts with, of course, the overall benefit of materials, energy and landfill conservation. The general limiting factors on increased waste reuse and recycling were kept in perspective during the evaluation: agency conservatism; obsolete specifications; inadequate research budgets; liability concerns with innovation; environmental constraints that are not applicable or too severe; industry structure generally based on new materials use; wide distribution of wastes; collection, storage and processing costs; lack of technical guidance; and the inherent variability of many wastes and byproducts.

RANKING OF WASTES AND BYPRODUCTS

A ranking of the wastes and byproducts of greatest interest for reuse and recycling in transportation construction is summarized in Table 1. This ranking is based on a survey of transportation departments and an overall evaluation of availability, technical suitability, favourable economics and positive environmental impact [2,3,4]. The number of users of each waste or byproduct is indicated in Table 1 along with the important development of specifications. In addition to the fourteen wastes and byproducts ranked, there are a number of other materials such as demolition wastes, mine tailings and wood waste that are available in some areas for specific applications (wood waste for lightweight fill, for instance) [1].

There will tend to be an Ontario ‘bias’ in describing the wastes and byproducts of greatest interest in following sections (old asphalt, old concrete, blast furnace slag, fly ash, steel slag, silica fume, nickel and copper slags, bottom ash, mine waste rock, waste tires, kiln dusts, waste foundry sand, waste glass and waste shingles), given the information available from the MNR study. However, the wastes and byproducts reuse and recycling trends described seem to be typical for highway projects and larger urban areas in Canada and the United States. For instance, a recent study of the recycling potential of construction and demolition wastes for Vermont (waste resulting from the construction, renovation and demolition of buildings, roads, bridges, docks, etc.) indicated similar findings as experienced in the Greater Toronto Area (GTA): two-thirds of the waste was generated from transportation construction activities and one-third from buildings; and old asphalt was the largest amount of waste generated (46 percent) and recycled (50 percent) [5]. The quantities involved can be large, for instance some 534,000 tonnes of processed reclaimed asphalt pavement (RAP) for recycled hot mix (RHM) and
783,000 tonnes of recovered concrete material (RCM) crushed for granular base in the GTA during 1990, but are still modest overall in comparison to annual aggregates use of some 60 million tonnes in the GTA.

OLD ASPHALT

The cold and hot recycling of old asphalt from pavement resurfacing and reconstruction projects has become a key component of the Canadian paving industry described in several Canadian Technical Asphalt Association papers [6,7,8]. A range of in-place and plant cold and hot asphalt recycling equipment and methods, with asphalt technology design and testing guidance, are now widely available: blended granular (uniform blending of processed reclaimed asphalt pavement (RAP) with granular or crushed concrete for base, subbase and shoulder use); full-depth cold processing (pulverizing the pavement for use as granular base); cold in-place train with emulsion addition (Figure 1); hot in-place surface recycling (use of preheaters and heat reformer for heating/scarifying/ rejuvenating/remixing up to a 50 mm depth of old asphalt to new hot mix quality and placing an integral hot-mix overlay in one pass [7]); and hot-mix plant recycling which is the most common type of asphalt recycling across Canada and considered standard asphalt technology (use of processed RAP (Figures 2 and 3) in batch, drum and drum-batch (Figure 4) hot-mix plants to produce quality recycled hot mix (RHM) [6]. There are a number of studies available showing no environmental problems (leachate) associated with RAP storage and use [8].

Production of quality RHM incorporating a high RAP content (40 percent or more RAP in drum or drum-batch hot-mix plants, noting an upward practical RAP limit of about 50 percent for ‘blue smoke’ control) requires a consistent processed RAP, appropriate new asphalt cement properties, representative Marshall mix design, proper hot-mix plant operations and quality control/quality assurance to conventional hot-mix asphalt (HMA) requirements. For cold and hot in-place asphalt recycling, evaluation of the existing pavement for adequate structural capacity and recycling process suitability is very important [7]. Research on the fatigue endurance and rutting resistance of RHM is required to extend the use of RHM to high stability, rut resistant binder course applications.

OLD CONCRETE

Reclaimed portland cement concrete materials (RCM or old concrete) are generated during the removal or demolition of concrete elements of roads, runways and structures, mainly in urban areas. To avoid landfill restrictions and dumping fees, the RCM can be economically processed and used on site (demolition waste processing, GTA Skydome site, for instance); hauled to clean engineered fill sites such as shore protection and/or stockpiled for processing and use as granular, typically at hot-mix plant sites (Figures 2 and 5). After processing (crushing, reinforcing steel removal and screening, Figure 5), the processed RCM can be used as granular or aggregate in hot-mix asphalt (HMA), stabilized base and/or portland cement concrete (PCC). Some ready-mix concrete waste is also taken to RCM stockpiles, but this will probably decrease with the use of stabilization additives in the ready-mix industry.

Processed RCM, used as coarse aggregate in PCC, has a high absorption and generally yields concrete of lower strength at equal water/cement ratio and slump than conventional aggregates. If the fine processed RCM is used, the concrete workability is significantly decreased. For PCC use, the sulphate (old plaster, for instance), chloride and reactive aggregates content of the RCM must be strictly controlled [9]. Use in cement treated base (econcrete, for instance) rather than PCC appears to be more promising. RCM was recently incorporated successfully into a large roller compacted concrete pavement for a
commercial composting facility in Milton, Ontario. For these reasons, the use of processed RCM is mainly in granular base in urban areas where transportation costs are favourable. There do not appear to be any economic, environmental (10) or technical impediments to the use of the available processed RCM as granular base. Contractors like the way processed RCM 'locks' up in granular base with a high yield (working on soft subgrades, for instance), but care must be taken to avoid segregation with crushed RCM.

BLAST FURNACE SLAG

Blast furnace slag is the easiest byproduct from Table 1 to deal with technically, as aggregate applications are generally covered by agency specifications and cementitious use is covered in detail by the Canadian Standards Association (CSA). While used in several provinces, blast furnace slag in Canada is only produced in Ontario, about 1.7 million tonnes in 1990. Blast furnace slag results from the fusion of fluxing stone with coke ash and the siliceous and aluminous residues remaining after the reduction and separation of iron from the ore. The blast furnace operation is a continuous process with the carefully controlled raw materials being fed in (burden) and the uniform products, molten iron and slag (about 20 percent by mass of iron production), being drawn off at regular intervals. Selective cooling of the molten slag results in four distinct types of blast furnace slag [11,12]:

1. air-cooled (solidified under ambient conditions), which finds extensive use in conventional aggregate applications (major type generally);
2. expanded or foamed (solidified with controlled quantities of water, air and/or steam), which is mainly used as lightweight aggregate (minor type);
3. pelletized (solidified by water and air-quenching in conjunction with a spinning drum), which is used both as lightweight aggregate and in slag cement manufacture when suitably vitrified (process developed in Hamilton and is now the major type produced in Ontario); and
4. granulated (solidified by quick water-quenching to a glassy state), which is mainly used in slag cement manufacture (use now developing quickly in Ontario).

Air-cooled blast furnace slag is used as aggregate in granular base, hot-mix asphalt (HMA) and portland cement concrete (PCC). The three prime cementitious applications for glassy blast furnace slag (granulated or suitably pelletized) are: portland blast furnace slag cements produced by intergrinding various portions of glassy slag with portland cement clinker; super-sulphated cement produced by intergrinding glassy slag, anhydrite and portland cement; and ground granulated blast furnace slag (GGBFS) for blending or addition at the mixer as partial portland cement replacement. The GGBFS route, as covered by CSA Standards (CSA-A362, A23.5 and A363), is generally being followed in Ontario and appears to be the preferred approach for new slag cement production world wide [13].

The only potential impediment to the continued use of blast furnace slag in granular applications is a concern with leachates (there is often a 'sulphur' odour and some coloration of water contacting fresh blast furnace slag). Emery and MacKay's testing and review of the technical literature have not indicated any leachate toxicity concerns for suitably processed blast furnace slag used as granular base (and steel slag from primary production), and it appears that the United States EPA will continue to exclude blast furnace slag from solid waste classification, based on favourable leachate testing [12].
FLY ASH AND BOTTOM ASH

Fly ash and bottom ash are coproducts resulting from the combustion of pulverized coal in thermal power generation plants [14]. The power plants can use a dry fly ash and bottom ash 'disposal' process, or wet 'disposal' process which can limit cementitious and aggregate applications. The fly ash consistency at each plant varies with the power generation level, type of coal being burned and the dust control system employed.

The most important use of fly ash (and granulated slag and silica fume), from both a technical and conservation viewpoint is in cementitious applications such as blended hydraulic cements, supplementary cementing materials, cemented mine backfill, stabilization (base and liquid wastes) and cement kiln feed. Cementitious uses for fly ash, silica fume and granulated (and suitably pelletized) blast furnace slag, are summarized in CAN/CSA-A23.1-M90 (Concrete Materials and Methods of Concrete Construction) and given in detail in CAN/CSA-A362-M89 (Blended Hydraulic Cement), CAN/CSA-A363-1988 (Cementitious Hydraulic Slag) and CAN/CSA-A23.5-M86 (Supplementary Cementing Materials). Blended hydraulic cements must meet the requirements of CSA Standard A362 and are specified as:

<table>
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<th>Type</th>
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<tr>
<td>10S</td>
<td>Portland Blast Furnace Slag</td>
</tr>
<tr>
<td>10SM</td>
<td>Slag-Modified Portland</td>
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<tr>
<td>10F</td>
<td>Portland Fly Ash</td>
</tr>
<tr>
<td>10FM</td>
<td>Fly Ash-Modified Portland</td>
</tr>
<tr>
<td>10SF</td>
<td>Portland Silica Fume</td>
</tr>
</tbody>
</table>

Supplementary cementing materials must meet the requirements of CSA Standard A23.5 (and CSA Standard A363 for Type H) and are specified as:

<table>
<thead>
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<th>Type</th>
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<tr>
<td>N</td>
<td>Natural pozzolan</td>
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<tr>
<td>F</td>
<td>Fly ash (Class F - normally from burning anthracite or bituminous coal.)</td>
</tr>
<tr>
<td>C</td>
<td>Fly ash (Class C - normally from burning lignite or sub-bituminous coal.)</td>
</tr>
<tr>
<td>G</td>
<td>Ground granulated blast furnace slag</td>
</tr>
<tr>
<td>H</td>
<td>Cementitious hydraulic slag</td>
</tr>
<tr>
<td>U</td>
<td>Silica fume</td>
</tr>
</tbody>
</table>

Fly ash surplus to cementitious applications is either used as filler in HMA, engineered fill (construction fill for highway overpasses, for instance), quarry rehabilitation or stockpiled at power plant sites [14]. While there is some concern with the potential environmental impact of fly ash in fill applications (leachable constituents), and some agencies consider fly ash a special waste requiring an environmental assessment for use (Ontario Ministry of the Environment, for instance), current experience indicates that there are generally no leachate problems with fly ash fills and/or suitable engineering provisions are made to address any concerns. The appropriate environmental ‘classification’ of fly ash is an area requiring technical guidance and documentation.

Bottom ash (about 15 percent of total ash production) is commonly used as granular subbase, generally following leachate testing and environmental approval. For instance, bottom ash is being used for parking lot construction in the GTA.
Processes have been developed for the use of fly ash in lightweight aggregate production.

STEEL SLAG

Steel slag went from an Ontario industrial byproduct of little construction use in 1970 to nearly full utilization in Southern Ontario in hot-mix asphalt (HMA), particularly HL 1, DFC and OFC surface course mixes requiring good frictional and stability characteristics (Figure 6), with some utilization in Northern Ontario, Quebec, Nova Scotia, Manitoba (Winnipeg) and Saskatchewan (Regina). However, steel slag aggregates were excluded in late 1991 from HMA use in Ontario due to extensive map-cracking performance problems [15,16]. This cracking (Figure 7) appears to be related to deleterious soft lime and/or lime-oxide particles, but other mechanisms may also be involved. Key Ontario producers and processors of steel slag, working with the Ontario Ministry of Transportation, have determined the causes of the steel slag aggregates HMA poor performance, and are now working to produce a consistent high quality steel slag aggregate for HMA use. The Canadian steel slag use in HMA of some 500,000 tonnes in 1990 indicates the importance of resolving the map-cracking performance problem to regain this important byproduct aggregate use.

The various steelmaking processes generally introduce important restrictions in the use of steel slags compared to blast furnace slags. Steel slags have a high bulk density and potential expansive nature (volume changes up to 10 percent attributable to the hydration of calcium and magnesium oxides), while blast furnace slags have a relatively low bulk density and are stable. Since serious damage may result from indiscriminate use of steel slags in confined applications, potential long-term volume changes must be checked before such usage. Obviously, steel slags should not be used in concrete (PCC) since expansion will result in rapid destruction of the concrete.

The use of steel slag in HMA has developed as a suitable aggregate use in a number of steel production areas and was started in the Hamilton-Toronto area in 1969. With the exception of the current extensive map cracking of steel slag HMA in Southern Ontario that must now be resolved, considerable practical experience has shown the positive features of steel slag aggregate in dense-graded and open-graded HMA such as high stability, good stripping resistance and excellent frictional properties [15]. However, in addition to the cracking, there have been problems with the consistency and overall quality of steel slag aggregate that must be dealt with during mix designs and process control, which are largely a function of its batch production as a byproduct of the primary steel production. Steel companies and steel slag aggregate processors/suppliers must be careful to mitigate the potential impact of steel slag batch production and composition, and unique features such as potential expansion.

SILICA FUME

Silica fume is the finely divided residue, resulting from the production of silica or silica-containing alloys (Quebec only province with plants), which is carried from the production furnace with the exhaust gases and collected in electrostatic precipitators. Silica fume is an extremely fine powder (about 100 times finer than portland cement) and a highly reactive pozzolan. Silica fume is used as a supplementary cementing material in high strength concrete and for enhanced concrete durability (reduced permeability) [17]. The applicable CSA standards for the use of silica fume are summarized in the fly ash cementitious uses section above.
NICKEL AND COPPER SLAGS

Nickel and copper slags are often considered together, as they are both essentially iron silicate nonferrous slags, very similar in chemical composition and applications [11,15,18]. Nickel slag is produced at Sudbury (air-cooled and granulated) and Thompson (granulated), and copper slag at Sudbury (air-cooled and granulated), Timmins (granulated) and Flin Flon (air-cooled). The Sudbury air-cooled nickel and copper slag (typically coproduced and/or coprocessed), some one million tonnes per year, is fully used as quality rail ballast while granulated nickel and copper slag is generally stockpiled or disposed of in mine/mill operations. A small quantity of granulated nickel slag is processed in Thompson for shot blasting. The challenge is clearly to find aggregate and/or cementitious uses for the granulated nickel and copper slags.

The use of Sudbury air-cooled nickel and copper slags in road and railway construction has been the subject of a fair amount of research [18]. The iron silicate slag is dumped and allowed to air cool so that a ‘clinker’ is formed, and then crushed and processed as required. Nickel and copper slag from Sudbury has been used for fifty years as railway ballast, even in Southern Ontario, and has established itself as being the best material used. The processed slag is heavy, tough, hard, angular, and packs well under ties to form a better support for track than rock ballast [11]. It is likely that ballast, and some highway base, applications will continue to fully utilize Ontario air-cooled nickel and copper slag production.

There is a wide range of applications for granulated nickel and copper slags that should be considered, noting the considerable CANMET research that has already been completed for cementitious applications [18]:

- cementitious applications:
  - cemented mine backfill, blended cement, base stabilization, waste treatment and sludge stabilization (these applications require grinding to a high fineness and activation with cement); and
- aggregate uses:
  - winter sand, fine aggregate in HMA (stripping potential?), sand blasting media, roofing granules, granular subbase and engineered fill.

MINE WASTE ROCK

Mining and mineral processing operations are generally the largest source of solid wastes in Canada [1,19]. Mining wastes are made up of broken rock from open pits and underground mines (mine waste rock), coarse mill rejects from screening and separation processes, and mill tailings. Most of these mine wastes have limited potential for reuse as aggregates due to their fineness, high impurity content, leachability, acid generation and/or remote location. However, some mine waste rock may be of interest because of favourable location and suitable physical and chemical characteristics for use as granular, ballast, PCC aggregate, HMA aggregate, engineered fill, etc. For instance, byproduct coarse and fine trap rock from roofing granule manufacture at Havelock, Ontario is considered to be an aggregate and is used in HMA surface course mixes as a ‘premium’ quality aggregate. There appears to be little current potential for the use of mine tailings.

WASTE TIRES

The recycling of waste tires in asphalt mixes has received extensive media attention following the recent Hagersville, Ontario fire, particularly in contrast to higher volume wastes such as shingles and demolition materials. About 26 million scrap passenger tire equivalents are generated in Canada each...
extending this study to cover a full range of waste foundry sand uses for the Ontario Ministry of the Environment. While waste foundry sand is generally considered to be nonhazardous, constituents such as heavy metals and phenols in some waste foundry sand may preclude many fill applications, and waste foundry sand appears to have a high corrosion potential. With the increasing cost of landfilling, and limited uses for waste foundry sand, the regeneration of waste foundry sand for reuse in the foundry may become more attractive as the technology is well developed.

At present, the most practical use of waste foundry sand appears to be as fine aggregate in HMA, provided care is taken that the foundry sand is 'clean' and there is not a stripping potential. Experience indicates that up to about 15 percent 'clean' foundry sand can be incorporated in HMA, subject to Marshall mix design and immersion Marshall testing.

WASTE GLASS

The appropriate technology for handling collected glass is obviously recycling back into containers. However, some collected glass is contaminated (with ceramics, for instance) or not suitable for recycling for various reasons. Such waste glass can be used as aggregate in Glashphalt, which was developed in the 1970s [24]. For Glashphalt, waste glass is typically incorporated to replace 20 percent of the aggregate in binder course HMA, with one percent hydrated lime for adhesion/anti-stripping added. Such use of waste glass is currently permitted by the Metro Toronto Transportation Department in some binder course applications [16] as a result of successful trials in Metro Toronto Works Department facilities. With the event of blue box recycling programs, the amount of available scrap glass will probably remain small and other uses such as mixing in granular subbase are far simpler and contribute equally to aggregates conservation.

WASTE SHINGLES

There is a fairly large volume of waste shingles (about 220,000 roofs replaced per year in Canada with 2 tonnes of waste shingle per roof, or some 440,000 tonnes plus scrap from shingle production) going to landfills that could possibly be recycled in HMA to recover the fibre, aggregate, filler and asphalt cement content [25]. This is now being done regularly in the United States and the necessary recycling equipment for hot mix plants has been developed. Small trials have been completed in Southern Ontario and this use of waste singles may develop as an alternative to landfilling.

CONCLUSION

It has only been possible to give a brief overview of the current and potential reuse and recycling of the fourteen wastes and byproducts of greatest interest for aggregate and cementitious applications in construction. There is obviously much scope for the cost-effective, technically-sound use of wastes in pavement construction with resulting materials, energy and landfill conservation.

REFERENCES


year (about one per person), or about 220,000 tonnes. Ontario trials of both asphalt rubber (rubber part of binder) and rubber-modified asphalt concrete (RUMAC, rubber essentially as aggregate) are in progress, and both technologies are used commercially in the United States [20]. In 1992, approximately 12.7 km of 2 lane roadway in the Regional Municipality of Haldimand-Norfolk were paved with rubber modified asphalt in both surface and binder course. This was the first project to use an Ontario-produced cryogenic crumb rubber.

The main contribution to aggregates conservation through use of waste tires in roads will be in any extension to pavement service life, reported to be about doubled [20]. However, both rubber asphalt and RUMAC have high initial costs, there is not agreement on the service life improvements, suitability for hot recycling has not been established and there are no recognized Canadian technical standards for rubber asphalt and RUMAC. There also appears to be hot-mix industry resistance to the use of waste tires in roads. Regardless, the use of old tires in roads has become the focus of much environmental attention and pressure, perhaps to the detriment of the systematic evaluation and use of other wastes and byproducts as construction materials.

LIME AND CEMENT KILN DUSTS

Most of the dust generated during the manufacture of portland cement or hydrated lime is produced during the calcining process in kilns. As the raw materials are heated and tumbled in the kiln, dust particles are created and then carried out with the exhaust gases at the upper end of the kiln. These gases are cooled and the accompanying dust particles are captured by efficient dust collection systems. The composition of cement and lime kiln dusts is quite variable from source to source due to raw materials and process variations. Cement kiln dust is made up of a variable amount of fine calcined and uncalcined feed materials (finely pulverized limestone and argillaceous minerals), fine cement clinker, fuel combustion byproducts and condensed alkali compounds. Lime kiln dust is made up of variable amounts of fine lime, 'unburnt' limestone and combustion byproducts [21].

While Canadian cement and lime kiln dust use is currently minimal, significant amounts have been used in the past, and continue to be used in the United States for pozzolanic base stabilization [21], wet soil conditioning and waste stabilization and solidification [22]. For instance, Emery and MacKay are currently involved with the solidification of 100,000 tonnes of wet fly ash using about 10 percent lime kiln dust addition. The increased use of cement and lime kiln dusts to replace lime in stabilization processes will make a modest contribution to cementitious materials conservation. There is also the potential for use of cement and lime kiln dusts as fillers in HMA [23].

WASTE FOUNDRY SAND

Waste foundry sand consists of high quality silica sand that is bonded to form the mould for ferrous and nonferrous castings. The most common bonding material is bentonite ('green sand' - 85 percent silica sand, 10 percent bentonite and 5 percent coal), with chemical bonding systems (3 percent organic binder such as phenolic urethane) also used. The availability of waste foundry sand, predominantly from iron and steel foundries, tends to be centred in heavy equipment and car manufacturing areas of Canada. The disposal of waste foundry sand is becoming costly so that construction materials uses are being investigated.

A 1990 Waterloo University study for the Canadian Foundry Group considered uses such as brick or mortar sand, PCC sand, HMA sand, cement kiln feed, fill applications and foundry industry reuse. Emery and MacKay are currently


16. METRO, "Specification for Hot Mix, Hot Laid Asphaltic Concrete", MT 701, Revision 1, Metric, Municipality of Metropolitan Toronto, Transportation Department, Toronto, 41 p., 1991.


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<th>RANK (b)</th>
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<td>Miscellaneous (e)</td>
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(a) Summarized from a survey of transportation departments completed during the first quarter of 1991. Also includes specific city and demonstration uses. Survey response achieved was 100 percent.

(b) Rank is based on an overall evaluation of current and potential uses in terms of material availability, technical suitability, favourable economics and positive environmental impact [1,2,3,4];

c. P - Provinces. Number out of 10 Provinces plus Yukon and NWT.

d. S - States. Number out of 50 States plus District of Columbia.

e. Miscellaneous materials used include boiler slag, demolition waste, dredge spoil, mine tailings, phosphate slag, resins/lignins, tall oil, used oil, waste gypsum, waste plastic and wood waste. User numbers not applicable (NA).
FIGURE 1  Recycling of old asphalt pavement using cold in-place train with emulsion.
(Full width milling machine, oversize millings crusher, mixer adding HF150P emulsion, paver and roller train.)

FIGURE 2  Reclaimed concrete material (RCM) and reclaimed asphalt pavement (RAP) stockpiles.
(The RCM on the left is crushed for use as granular base and the RAP is processed for use in recycled hot mix (RHM).)
FIGURE 3 Portable reclaimed asphalt pavement (RAP) processing plant. (This crushing and screening plant is readily moved between hot-mix plants. Large processed RAP stockpile in the background.)

FIGURE 4 Drum-batch hot-mix plant producing high quality, high ratio recycled hot mix (RHM). (The new aggregate feed is to the right and the processed reclaimed asphalt pavement (RAP) feed is mid-drum entry at the middle. RAP use in drum plants is generally limited to about 50 percent for gaseous emissions control.)
FIGURE 5  Old concrete (RCM) processing plant producing granular base. (This portable crushing and screening plant has provision for breaking large pieces of concrete (top right) and removing reinforcing steel (pile in foreground).)

FIGURE 6  Placing steel slag aggregates dense friction course (DFC). (Steel slag coarse and fine aggregates are used in the DFC. The DFC is typically 55 to 60 percent passing 4.75 mm with about 5.8 percent asphalt cement.)
FIGURE 7  Extensive map cracking of steel slag aggregates dense friction course (DFC).
(It appears that this map cracking is related to deleterious soft lime and/or lime oxide particles.)