Recycling Road Building Materials and Experience with Full Depth Reclamation in the Ontario Provincial Highway System.

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ABSTRACT:

The Ontario Ministry of Transportation (MTO) has been committed to recycling road building materials as it makes sound economic and environmental sense. Demands are placed on the aggregate industry to find and secure high-quality aggregate materials to renew and restore Ontario highways. Over the past thirty years, there has been a dramatic demand for contractors to recycle and reclaim materials originating from Ontario’s transportation networks. In southern Ontario, the demand for road-building and construction aggregates has increased primarily due to increased economic activity and population expansion in the Greater Toronto Area (GTA). Provincial legislations including the recently approved Greenbelt Plan, the Niagara Escarpment Plan (NEP), and the Oak Ridges Moraine Conservation Plan (ORMCP) have made finding and securing available high-quality aggregates a more significant challenge. In the north, greater hauling distances increase the costs of importing construction aggregates and disposal of recovered materials.

Since the early 1970s MTO aggregate specifications have allowed the use of reclaimed materials as a component of unbound aggregate base. From an engineering perspective, reclaimed materials must meet the same requirements as natural aggregates. Specifications based on laboratory testing have been developed to allow the use of recycled materials in order to promote conservation of natural resources. Aggregates in road base/subbase may include up to 50% reclaimed asphalt pavement when used in conjunction with full depth reclamation (FDR). Samples of granular base material were collected from various FDR projects around the province and tested in response to reports that several recently constructed pavements using full depth reclamation have been experiencing premature cracking problems. Samples were subjected to a series of laboratory tests including permeability, California Bearing Ratio, gradation (both before and after testing) and percentage of asphalt coated particles. Test results indicate a clear correlation between the strength and the percentage of asphalt coated particles present in the blend. The results also indicated that samples with the highest percentages of fines (material passing the 75µm sieve) also have the lowest coefficients of permeability. The results from these lab tests provide a better understanding of the properties and long-term performance of reclaimed asphalt pavement incorporated into the granular base.

INTRODUCTION

Ontario is one of the most prosperous provinces of Canada whose population reached 12.5 million in 2005, representing 39 percent of the country's population (1). Southern Ontario has experienced significant progress in recent years becoming one of the fastest growing regions in North America.Two-thirds of Ontarians and one-quarter of all Canadians live within the Greater Golden Horseshoe (GGH) which extends around the western end of Lake Ontario. This region is home to 8.1 million people, both the most populous and the most heavily urbanized region in the country. Eleven of the 16 municipalities with a population of more than 100,000 lie in a corridor that runs from Hamilton to Oshawa, which is the largest continuous urban network in Canada, and home to more than 5.3 million people (2). Provincial highways, municipal roads and associated infrastructure are the backbone of the transportation system of this region vital for sustained growth and future prosperity. This growth is fuelled by economic opportunities and expectations of high quality living.

Increased economic activity and population growth generates a steady demand for construction aggregates. The Ontario Stone, Sand and Gravel Association reports that Ontario consumes an average of 175 million tonnes of natural aggregate annually. Total aggregate production in Ontario reached 179 million tonnes in 2006 (3). Since 1993, there has been a steady increase in aggregate demand and consumption within the province. This trend is expected to continue into the future. The Ontario Ministry of Transportation (MTO) manages 16,525 km of provincial highways, more than 2800 structures, 29 remote airports and 8 ferry services. It is estimated that more than 90 percent of all Ontarians live within 10 km of a provincial highway (1). MTO natural aggregate use ranges from 7 to 15 million tonnes annually depending on the level of available funding and the type of provincial highway work undertaken. It has been estimated that for the next two decades a significant demand for aggregate materials will be required for MTO highway initiatives. Similar increases in aggregate consumption by municipalities are also anticipated.

Today, many demands are being placed on the aggregate industry in the search for high-quality materials to build and maintain Ontario highways. The need to construct more durable pavements to carry a growing traffic fleet, increased economic activity and population density within the Greater Toronto Area (GTA) and the wise use of local aggregate deposits to reduce transportation costs, energy use and pollution are a few of these demands. In addition, a balanced approach is fundamental to the use of natural resources for competing needs and long term sustainability. Provincial legislation, including the recently approved Greenbelt Plan, the Niagara Escarpment Plan (NEP), and the Oak Ridges Moraine Conservation Plan (ORMCP), have made finding and securing high-quality aggregate sources a more significant challenge. Access to available materials is increasingly limited by growing environmental and permitting regulations, restrictive zoning laws, land uses and other economic considerations. The siting of pits and quarries has become very controversial and contentious in the GGH. The Niagara Escarpment and Oak Ridges Moraine are major aggregate source areas that have traditionally fed the GTA markets. Over 75% of their production is destined for the GTA. In addition, demand has increased for aggregate from the Carden Plain limestone quarries (east of Lake Simcoe). High-quality aggregates travel longer distances to fill supply gaps within the GTA.

MTO PAVEMENT RECYCLING

MTO is committed to providing and promoting transportation services in a manner that sustains a healthy environment. MTO encourages the reduction, reuse and recycling of materials in all areas of highway construction and maintenance. The main purpose is the conservation of non-renewable resources. Recycling eliminates the need to transport materials from the site while significantly reducing the need to import new aggregates, thereby reducing greenhouse gas (GHG) emissions and conserving natural resources.

Since the early 1970s, MTO has been involved with recycling highway construction materials, as it makes sound economic, environmental, and engineering sense. Serious recycling initiatives were first undertaken because of increasing asphalt cement costs, efforts to Reduce, Reuse, and Recycle (3R's) and environmental disposal difficulties. Within the appropriate engineering and environmental limitations, recycling highway construction materials can be a cost-saving measure. Other benefits to recycling road-building materials include minimizing the use of natural non-renewable aggregates, energy conservation and the reduction of GHGs, as well as reduction of waste headed to landfills.

MTO strives to achieve a high proportion of pavement recycling in an attempt to incorporate all materials generated from highway construction back into the pavement structure. Bituminous pavements are designed to give a high level of performance during their working life therefore high quality aggregates are used in their construction. Ninety-five percent (by mass) of hot mix asphalt (HMA) is made up of aggregate, so that pulverizing the existing asphalt pavement not only saves natural aggregate resources but also ensures the reuse of high quality materials. Even when the pavement materials have been recovered, the original quality of the aggregates remains. Local aggregates are conserved and additional transportation costs are avoided.

Recycled Asphalt Pavement (RAP) is the most common material produced on pavement rehabilitation jobs. Designers first reuse the RAP back into hot mix applications since this produces maximum cost savings. Except for premium surface courses, HMA may be substituted with RAP at contractor's option up to 40% (by mass) depending on the type of mix, the traffic category and the location within the pavement structure. Recycled hot mix must meet the same technical requirements as a new HMA.

Excess RAP material surplus to the HMA requirements is then made available to be blended with granular and subbase material up to allowable limits. MTO specifications allow up to 40% RAP in granular base course for most construction and maintenance contracts. A higher percentage is allowed if Full Depth Reclamation (FDR) is carried out. Any remaining material may be incorporated into fills, subject to applicable environmental restrictions. The net result is that 100% of the RAP generated from a project is now used in recycled hot mix, or granular base and shoulders on the King's highways, municipal roads, subdivisions, and parking lots.

Reclaimed Concrete Material (RCM) is normally generated through the demolition of Portland cement concrete roads, bridges and other structures (Figure 1). Processing of the old concrete includes crushing, removal of reinforcing steel and screening. RCM generally consists of high-quality and well-graded aggregates that are bonded by a hardened cementitious paste. RCM has traditionally been used as clean engineering fill for gabion basket material, bulk fill material in water, shoreline protection material (Toronto's Leslie Street Spit, for instance) and up to 100% as an unbound granular base course material as allowed by Ontario Provincial Standard Specification (OPSS) 1010. Other agencies in North America have had success utilizing processed RCM in hot-mix asphalt, stabilized base, engineered fill, surface treatments and in some cases Portland cement concrete pavement applications. However, there are certain engineering properties that may limit the use of RCM as an aggregate, in Portland cement concrete. MTO is currently funding research into this area as a means of increasing its application.

Larger quantities of RAP than RCM are produced from capital construction activities on provincial highways because asphalt pavement constitutes most of the highway system. In most cases, both RAP and RCM become the property of the contractor who would use it directly on the provincial contract. In other cases, recovered materials may be transferred directly to another transportation agency such as a municipality.

MTO allows the use of several in-situ recycling methods for Hot Mix Asphalt (HMA) pavement, depending on the nature of existing pavement condition. When there is a need only to repair shallow defects and improve ride, Hot-in-Place (HIR) asphalt pavement recycling (heating and scarifying of pavement surface) may be used. Cold in-Place (CIR) asphalt pavement recycling, used to correct structural defects within the HMA pavement, involves milling of a thicker portion of the pavement, remixing with an asphalt emulsion and re-laying the new pavement mix without the need for off-site transportation.

Table 1 summarizes the tonnages of recycled materials incorporated as aggregates into granular base for MTO contracts between 2000 and 2004. This table indicates a relatively uniform annual use of recycled products for this application. The five-year total was slightly more than 6.8 million tonnes (18% of the total granular quantity used by MTO, 2000 - 2004). Year 2000 was an aggressively high capital construction year..

Table 2 summarizes the tonnages of Recycled Hot Mix and Recycling Optional, HIR, CIR, and Cold-in-Place Recycling with Expanded Asphalt Mix (CIREAM) products that have been placed in total hot mix since 2000. The only exception is 2001, where a lot of data was not available. The five-year total was calculated to be 798,225 tonnes (9% of the total hot mix quantity used by MTO, 2000 - 2004). Unfortunately, missing data presents problems with the annual totals and especially with the five-year average totals. The largest and most consistent contributor is the CIR data. HIR has only one year of representation, which is 2003, and CIREAM was only utilized on one job in 2002.

FDR is a widely used pavement rehabilitation technique. As can be seen from the tables, FDR significantly dominates the processes by which highway pavement materials are reclaimed. Between the years 2002 and 2004, on average, FDR produced more that 1 million tonnes of material annually that was subsequently placed back into construction or repair of the existing facilities.

The basic piece of FDR equipment is the road reclaimer machine, which uses rotary cutting drums to cut and mix existing pavements. Existing conditions of the pavement and underlying granular base course aggregates can affect the resulting particle size distribution (gradation) of the pulverized blend. Control of the reclaimer gate openings, drum height, rotational speed of the cutting drum or forward speed may all be adjusted in order to help control the size distribution of the final product. Figure 4 shows a pavement with "alligator cracks" prior to pulverizing. Figure 5 shows the same pavement at the same location following the passing of the reclaimer. When these types of cracks are present, they may cause the cutting drum to lift up the asphalt layer in large chunks instead of being pulverized uniformly by the cutting drum.

Once the reclaimer has completed pulverizing, a grader is then used to further mix the materials to ensure uniformity and to spread out and shape the reclaimed material to the desired grade and slope. Water is added to the mixture followed by a compactor (usually a smooth-wheeled vibratory roller) to smooth and compact the pulverized material to the required density.

MTO'S FULL DEPTH RECLAMATION EXPERIENCE

The FDR process recycles the full depth of the existing pavement and a portion of the underlying granular base course and is well suited for the treatment of severely distressed pavements. FDR is not recommended when there is extensive distortion or deterioration due to poor quality granular base, subbase, subgrade or drainage failures. The resulting material, a mixture of RAP and granular base course aggregates, is shaped and compacted to form a new base course for subsequent pavement layers (see Figure 2). Treatment depths typically range from 100 – 300 mm. More recently in Ontario, expanded asphalt (foamed asphalt cement created by steam injection) has been added to the process with traditional FDR (and CIR) techniques, which increases the overall strength of recycled base course. This enables a reduced thickness of the new HMA pavement.

Early MTO history of pavement recycling with granular base is described in detail in Materials Information report MI 139; "The Use of Recovered Bituminous & Concrete Materials in Granular and Earth" (4). MTO first began experimenting with FDR in test sections in 1971. The first actual on-site pulverization was on a contract in Terrace Bay in 1976 where a mix was used in a ratio of 65:35 (RAP: granular). By the late 1980's MTO has reclaimed 100% of HMA pavement materials in recycled hot mix or as granular materials for road base and shoulders. Since 1988, MTO has pulverised and reclaimed, on average, more than 2.2 million square metres a year of the provincial highway pavement system. FDR accounts for the largest quantity of materials generated from in-place recycling on MTO projects Figure 3.

CASE STUDIES

Two FDR contracts are highlighted here that were brought to the attention of the MTO Materials Engineering and Research Office (MERO) due to the existence of early pavement distress cracking in the first few years of service. It is not concluded that the early cracking was specifically related to the reclamation process. However, these projects were used to initially focus attention on the FDR process and conduct this study.

CASE 1. NORTHEASTERN ONTARIO

A section of highway was reconstructed in 1997 using FDR to a depth of 200 mm (actual depths varied). The pavement rehabilitation consisted of pulverizing in-place the existing pavement and underlying granular material, adding new material and resurfacing with a single lift of HMA. The existing pavement consisted of two 50 mm lifts of HMA, which was pulverised along with 100 mm of the granular base. Although the pulverized product was intended to form the new granular base course, it did not meet the required grade of the roadway and an additional 100 mm lift of new granular aggregate was added. The highway was paved with a single 50 mm lift of HMA.

Within 3 years of paving, regular centreline and (predominantly) transverse cracks appeared. In certain areas, multiple transverse cracks (on-echelon fatigue cracking) appeared, indicating possible base or subbase failure. There was also a fair bit of rutting in this highway with a depression between the centre of the lane and the edge of pavement. The rutting could have been caused by poor compaction either of the HMA, the new granular base or the pulverized material.

Addition studies were conducted on this section of pavement to determine if the premature failure was the result of design, material, or construction. Information from these studies indicated the possibility that over-heating of the asphalt cement during construction lead to early thermal fatigue of the pavement surface. Poor drainage characteristics identified in the new granular base and pulverized material are also considered to have resulted in a reduced load bearing capacity eventually leading to the observed fatigue cracking and rutting of the pavement.

CASE 2. NORTHWESTERN ONTARIO

In northwestern Ontario a segment of highway was paved in the fall of 2000. FDR was performed to 100 mm using the existing 50 mm layer of HMA and 50 mm of the underlying granular base course. Within 2 years of paving, centreline and multiple transverse cracks had appeared. Detailed investigations were not carried out for this pavement to determine probable causes for the premature failure with respect to design, construction or materials. TA complicating factor is that transverse cracks are usually associated with thermal fatigue of the asphalt cement as a result of aging or insufficient capacity to allow for contraction during cold periods.

FDR SPECIFICATIONS

Currently, there are several standards that have been developed for use for FDR of asphalt pavement and underlying granular materials. The provincial standard is OPSS 330, Construction Specification for In-Place Full Depth Reclamation of Bituminous Pavement and Underlying Granular. OPSS 330 includes requirements that govern milling depths of existing pavement, final depths of pulverising, blending ratios and test methods for conformance. For MTO applications, OPSS 330 is modified by the standard special provision SSP 330S01 that was put into place in 1988. The modification includes reduction on the maximum particle size from 50 mm to 26.5 mm, an upper limit on the fine aggregate fraction (not more than 75% passing the 4.75 mm sieve) and various other operational constraints. The specification also includes a requirement for scarifying and fine grading of the existing graded surface to be carried out immediately prior to the placement of any additional granular material or asphalt paving.

For general granular base and subbase production, MTO specifications allow maximum of 40% by mass of asphalt coated particles. For FDR, the specifications allow 50% RAP by volume. For most MTO designs, the granular base layer is 150 mm thick and is available for blending with an equivalent thickness of overlying HMA. The granular subbase layer is generally not included with the pulverized material as it may contain particles that are too large for the reclaimer to handle effectively. It has been found that base courses consisting of 100% RAP generally have poor performance requiring frequent repairs. Performance improved when regular depths of hot mix were used and eventually the amount of RAP in natural granular bases was reduced (5).

There are currently no formal measures or sampling procedures included in the specifications. Samples for testing are not taken by the contractor for QC purposes. QA samples may be obtained by the Contract Administrator prior to acceptance but are also not generally taken. On-site, the uniformity of the RAP material is generally assessed visually for segregation and surface defects. Large pieces of asphalt pavement are manually removed from the treatment area and are usually discarded into the roadside ditch or placed in front of the reclaimer for further reduction. This latter action is seldom taken. Overall, the current process results in a large variability of the final product.

A typical production rate for pulverizing a 2-lane highway is about 2 km per day. This allows three passes of the machine per day or 6 km per day in total distance travelled. Following grading and compaction, the pulverised section is usually reopened to traffic on 2-lane highways. This process and the rapid production rates lead to a significant lag in implementing a sampling and testing program that adequately characterizes the material in any useful way. Materials have to be retrieved from the full depth of the pulverized layer without contaminating it with any underlying aggregates. Test results may not be available until 48 hours or later, at which time the pulverized material may well be paved over. Large pieces of RAP left behind may lead to stress concentrations in the overlying asphalt layer, resulting in surface distortions and cracking.

MATERIAL QUALITY STUDY

MTO conducted a study over two summers in 2002 and 2003 to characterise the properties of full depth pulverized pavement layers. RAP/granular materials from 20 FDR construction projects throughout the province were sampled for testing. A total of 58 samples were taken at various stages of construction - immediately after pulverization or at some further time following grading and compaction, but prior to paving. Sampling consisted of at least two sets of samples at two separate locations for each stage of construction. Careful attention was made to avoid sampling any underlying granular materials. The sample locations and distances generally consisted of sampling 50 m apart and at 1 m and 2 m offsets from the centreline.

Laboratory testing was done to determine common properties amongst the samples and to help draw conclusions about the long-term performance and durability of the material. The materials were tested for Gradation, % Asphalt Coated Particles (%ACP), Proctor density, Permeability, and California Bearing Ratio (CBR). Test results are summarized in Table 3.

Gradation

Gradation of the samples was determined by sieve analysis (MTO Test Method LS-602). Tests were performed on samples of as-received material in order to compare field samples with MTO specification requirements for road base granular materials (Granular A). Additional gradation testing on selected samples was completed on compacted materials extracted after completion of permeability testing. As-received sample masses were minimum 10 kg samples, while compacted materials extracted from the permeability mold were approximately 3 kg. Previous laboratory studies carried out by MTO have shown improved accuracy and precision from larger samples.

The percentage of coarse aggregate (material retained on 4.75 mm sieve) was recorded to see if a correlation existed with the other variables. The amount of fines (material passing the 75µm sieve) was also recorded as this parameter is closely linked to the permeability and drainage characteristics of the material. Only 1 of the samples did not meet the 4.75 mm sieve requirements for granular base (maximum 75% passing 4.75 mm sieve). Only 4 out of the 42 samples had fines that exceeded the 75µm sieve requirement for granular base (maximum 8.0%).

Percent Asphalt Coated Particles

MTO Test Method LS-621 was performed in order to determine the percent by mass of asphalt coated particles blended with the natural aggregates in the samples. An asphalt coated particle is defined as a coarse aggregate particle in which asphaltic material covers more than one-third of the original aggregate surface. If a particles of RAP is less than one-third coated, the particle is considered to behave as a natural aggregate. A matrix particle (sand and asphalt cement) is also included as an asphalt coated particle.

The %ACP was done on 52 of the samples. Some samples were omitted due to the lack of sufficient material to conduct the test. The %ACP ranged from 0.5% to 89.0%, with an average value of 58.9%. Values generally exceeded the general requirement with only 15 out of the 52 samples (29%) with less than 50% ACP.

Compaction Testing

Compaction testing for Proctor density (MTO Test Method LS-707) was performed on 14 randomly selected samples. The remaining samples were used for CBR tests instead. An average optimum moisture content value of 5% was determined from the 14 samples. This moisture content was assumed for the remaining samples when preparing samples for Permeability and CBR tests. Densities obtained during these tests averages around 2.0 t/m^3. Typical values for compacted natural aggregate materials is around 2.2 t/m^3. Lower densities are most likely due to the coarser aggregate grading and the presence of RAP particles in the mix.

Permeability

A total of 57 samples were tested for drainage characteristics using constant head permeability by MTO Test Method LS-709. The average permeability coefficient was 1.47 x 10^{-2} cm/s with more than half the test results less than 5.94 x 10^{-3} cm/s. Permeability values greater than 10^{-4} cm/s are characteristic of relatively free-draining material used as granular base in Ontario. Lower values usually result in early pavement failure.

California Bearing Ratio

CBR tests were performed on selected samples as a means of determining the relative stability and strength of the pulverized RAP/granular materials. The Standard Test Method for CBR of Laboratory-Compacted Soils (ASTM D1883) was used. All samples were compacted at a moisture content of 5.0%.

A random selection of 36 samples underwent a standard CBR test ("A" test) where the compacted samples were soaked for 48 hours and then drained for 2 hours prior to testing. To examine the effect on longer drainage times, an additional 12 duplicate samples from the original selection were soaked for 48 hours and then drained for up to a maximum of 5 days ("B" test) prior to testing.

For the "A" test, CBR values within the samples ranged from 3.4% to 61.1% with an average value of 21.9%. Typical CBR values for granular base materials are expected to be much greater indicating the pulverized RAP/ granular mixes are not meeting the expected strengths.

The results of the "B" test range from 8.6% to 47.8% with an average value of 21.0%. These results identify that the strength of the materials did not increase with a longer drainage time.

DISCUSSION

Gradation test results indicate that the pulverized mixes predominantly met the expected particle size distribution for a dense graded granular material suitable for road base. Low amounts of fines also help ensure adequate drainage of the materials as well. The amount of RAP blended with the underlying granulars during the FDR process for the field samples is surprisingly high. For FDR, a 50:50 blend is maintained on a volumetric basis. Assuming a 150 mm layer of granular base, excess overlying pavement thicknesses are milled until 150 mm is achieved. Reduction in the underlying granular base layers or insufficient milling of the hot mix pavement would have resulted in high proportions of RAP materials. Sampling may have had an inherent bias as well. The exact reasons for the high %ACP values for these samples collected in this study are not known.

The strength of materials intended as a base course is of primary importance. CBR values were plotted versus the percentage of asphalt coated particles (Figure 6). This plot shows the high amounts of %ACP in the various pulverized mixes and the corresponding low CBR values that resulted. Even at low %ACP values within acceptable limits, CBR values rarely exceed 40%. In the 1989 study (4), similar tests were done on laboratory mixes. The results are compared in Figure 7. There is a significant difference between the results from the two studies especially in the lower %ACP values. Samples in the earlier study were tested for CBR immediately after compaction without any curing/drainage time. Further testing was conducted and the results indicated an increase in strength with increased curing time. It was also determined that the CBR values decrease with increasing fineness. Both studies show that granular base mixed with large amounts of RAP is much weaker than natural granular base.

The current results from this study indicate only 42% of the samples tested had an increase in strength from the "A" test (drained 2 hrs) compared to the "B" test (drained 5 days). These results indicate that strength may not necessarily increase with longer curing times.

Permeability values were plotted against the percentage of fines (Figure 8). Excessive fines result in very low permeability and poor drainage of the granular base. The permeability of RAP materials should be similar to that of natural aggregates. Granular base materials should have the drainage characteristics of a clean sand material with a coefficient of permeability of 10^{-4} cm/s or better (5).

CONCLUSIONS

Based on the results of the testing from 20 different FDR construction projects around the province there is a clear indication that the process results in a material that does not conform to standard requirements for an engineered road base material. FDR is fundamental recycling strategy that significantly increases sustainability of existing aggregate resources. MTO has depended on this approach for almost 30 years and has seen improvements in equipment and technique, yet there seems to be something missing. In the field sampling program, only 3 out of the 58 samples (or 5% of the samples) could meet both granular base specification requirements for gradation (both coarse and fine) and % ACP.

Neither the permeability nor the CBR tests have actual requirements in the specifications although there are known parameters which are desirable for a granular base. It is interesting to note that none of the samples had a CBR value higher than 80%, therefore none of them were able to meet the expected value of 90 – 125% for a base material. It is a concern that so many of the samples from construction projects all over Ontario were unable to meet the basic requirements outlined in the specifications for a granular base material.

There is a need to follow-up on the performance of these 20 pavements from the years that they were constructed. There may also be a need to obtain actual strengths of the pulverized material that lie beneath these projects. Falling Weight Deflectometer testing at the sample locations would be useful in achieving this. In the laboratory, additional information could be obtained from conducting resilient modulus testing of selected samples retrieved from the field.

FDR has established itself as a valuable and cost effective solution when rehabilitating existing roads. Although Ontario has been experiencing some problems with FDR, it is an important option when designing and constructing MTO highways. MTO specifications need to better address and account for the issues concerning FDR so it can remain viable as a low cost method of rehabilitating existing pavements.

MTO is committed to the goal of recycling to conserve aggregate resources for future generations while maintaining a safe, efficient, high-quality highway system. Other recycling goals include energy conservation, reduction of GHG, less waste to the landfills and cost savings over traditional rehabilitation methodologies. MTO will continue to look at successfully accomplishments of other jurisdictions in terms of incorporating reclaimed materials into highway reconstruction and maintenance.

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Table 1. Quantities of recycled /reclaimed products used as granular base aggregate by MTO, 2000 – 2004 (tonnes)

Recycled Product	2000	2001	2002	2003	2004	Average
Recycled Asphalt Pavement (RAP)	202,257	34,618	94,369	260,820	22,060	122,825
Recycled Concrete Material (RCM)	142,602	7,760	32,445	69,104	127,551	75,892
Full Depth Reclamation (FDR)	2,805,440	606,190	802,770	481,340	651,400	1,069,428
Full Depth Reclamation and Expanded Asphalt Stabilization (FDR/EAS)	64,470	-	2,590	33,640	175,880	69,145
Lightweight Granulated Blast Furnace Slag	38,964	71,620	79,840	14,929	4,626	42,000
Totals	**3,253,733**	**720,188**	**1,012,014**	**859,833**	**981,517**	**1,379,290**
Total	**6,827,306**					

Table 2. Quantities of recycled /reclaimed products used in Hot Mix by MTO, 2000 – 2004 (tonnes)

Recycled Product	2000	2001	2002	2003	2004	Average
Recycled Hot Mix (RHM)	187,427	-	74,560	46,892	-	102,960
Recycling Optional (R/O)	-	-	-	70,216	24,240	47,228
Hot In-Place Recycling (HIR)	-	-	-	38,880	-	38,880
Cold In-Place Recycling (CIR)	98,330	3,020	18,530	64,460	149,000	66,668
CIR with Expanded Asphalt Mix (CIREAM)	-	-	22,670	-	-	22,670
Totals	**285,757**	**3,020**	**115,760**	**220,448**	**173,240**	**278,406**
Total	**798,225**					

Table 3. Summary of test results from RAP/granular samples obtained from 20 FDR projects on provincial highways

Test/Value		# of Samples	Average Value	Maximum Value	Minimum Value
%Coarse Aggregates (Retained 4.75 mm sieve)	Before Compaction	50	46.8	76.2	24.5
	After Compaction	43	49.8	83	22.7
% Fines (Passing 75ųm Sieve)	Before Compaction	56	4.9	10	0.1
	After Compaction	42	5.1	10	0.3
Coefficient of Permeability (cm/s)		57	1.47×10^{-2}	2.30×10^{-1}	4.11×10^{-5}
% Asphalt Coated Particles		52	58.9	89.2	0.5
Proctor Density @ 5% moisture (gm/cm^3)	MWD	14	2.086	2.349	1.190
	MDD	14	1.986	2.235	1.820
CBR, %	A	36	21.9	61.1	3.4
	B	12	21.0	47.8	8.6

Figure 1. Reclaimed concrete material from an MTO bridge structure being prepared for crushing into aggregate for granular base


Figure 2. Full depth reclamation product - pulverised pavement and underlying granular material blended to produce new aggregate base material

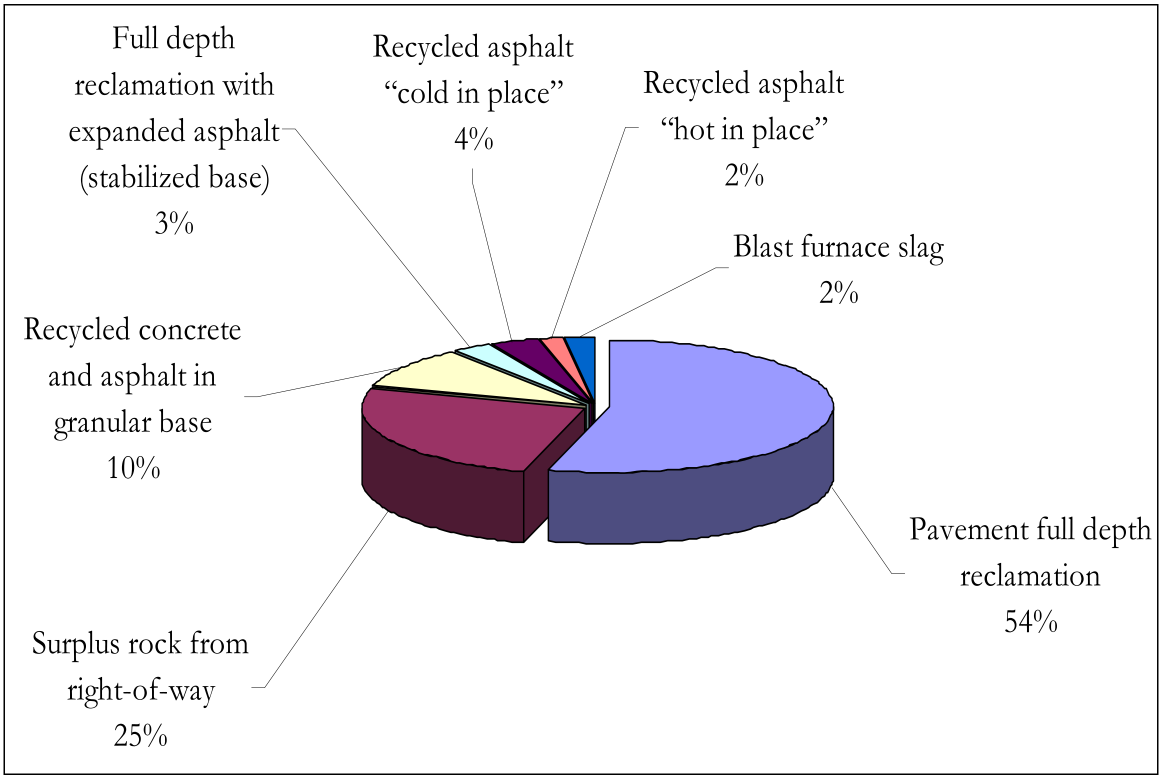

Figure 3. Reclaimed materials sources used by MTO, 2000 – 2004

Figure 4 "Alligator" cracks in pavement prior to pulverizing (direction of travel shown)

Figure 5. Pavement with “alligator” cracks after pulverization

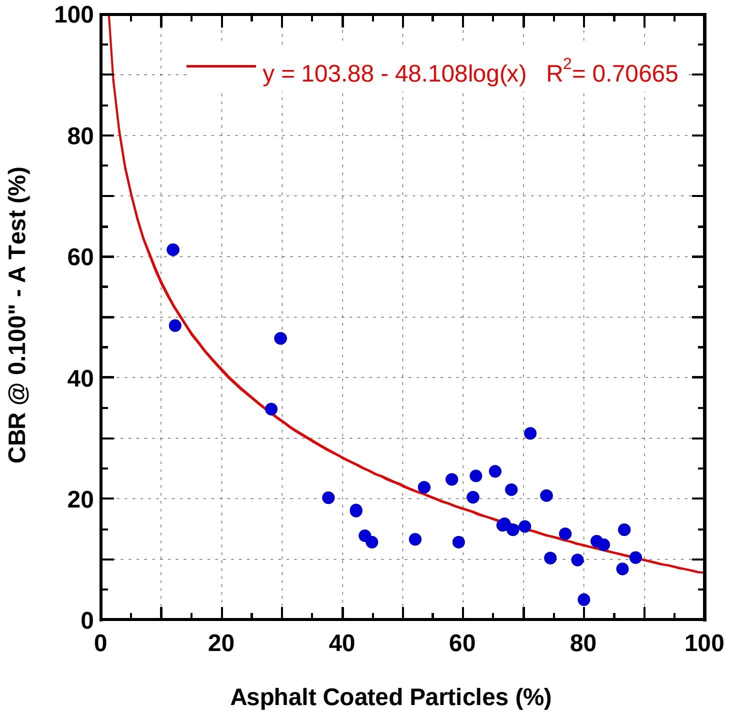

Figure 6. CBR "A" Test vs. % Asphalt Coated Particles

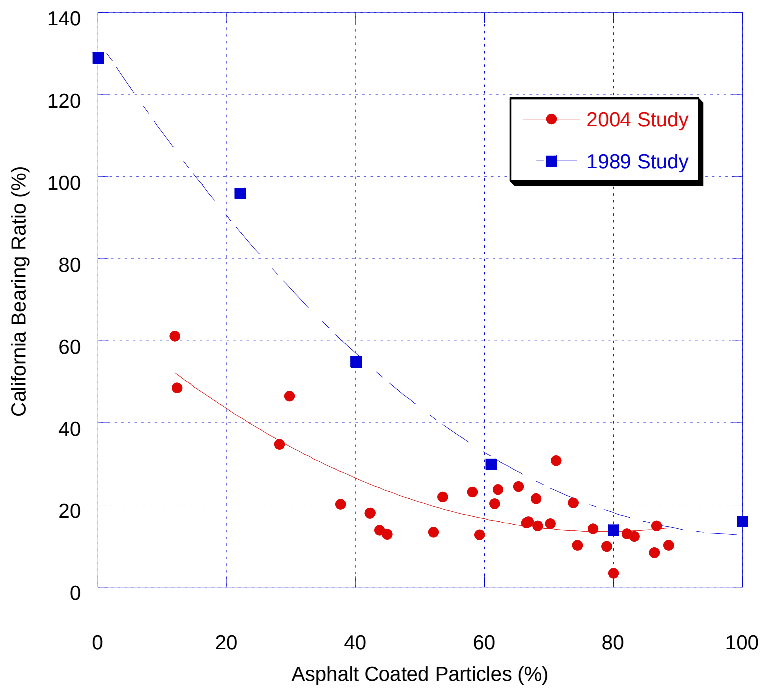

Figure 7. Comparison of current study CBR results compared to 1989 study results

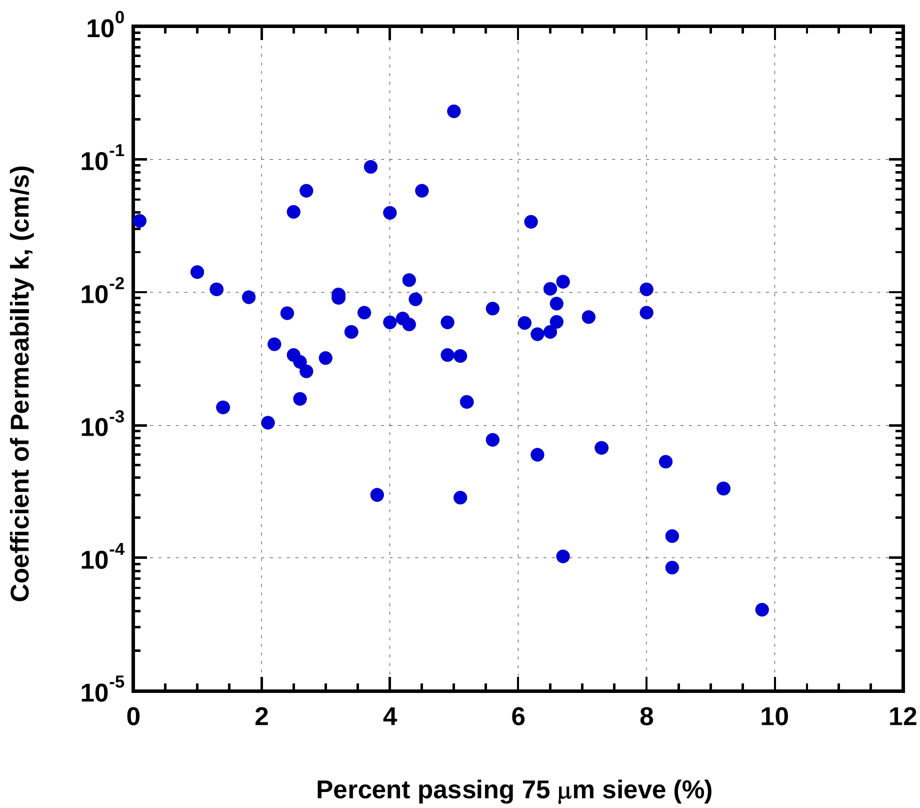

Figure 8. Permeability vs. % material passing the 75 um sieve (before compaction