Quality Metrics for Recycled Concrete Aggregates in Municipal Roads

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ABSTRACT

Increasing portions of municipal resources are being allocated to construct and preserve their infrastructure while ensuring a sustainable balance is achieved between depletion of natural aggregate reserves and maximizing the use of recycled and reclaimed materials. Incorporating recycled concrete aggregate (RCA) as a base/subbase into municipal roads can result in a quality product and long term performance while promoting environmental stewardship and cost effective solutions.

Demolishing old concrete structures, crushing the concrete and using the crushed materials as aggregates is not new and its use has been well documented. However, due to a lack of experience, familiarity and local data pertaining to the use of RCA material, municipalities have been reluctant to routinely incorporate this material in their construction works.

Through the use of a case study, this paper provides guidance for municipal practitioners on how to incorporate quality RCA material in a responsible manner, with a greater sense of confidence. The benefits associated with RCA and project specific details on raw material quality, production, quality control, laboratory testing, environmental compliance, and specification development are presented from both the owners and contractor’s perspective.

Keywords: Reclaimed and recycled construction material, recycled concrete aggregates, sustainability, quality control, long term performance

1 INTRODUCTION

As quality aggregate sources are depleted, there is a growing attention given to aggressively incorporating recycled and industrial by-product materials into new and rehabilitated pavements. Utilization of aggregate derived from recycled concrete reduces the demand for virgin aggregates, thereby conserving a non-renewable resource facing potential shortage in the future. The use of recycled concrete also protects the landscape and the environment by deferring the need to open new quarries, reducing the impact on landfills and decreasing energy consumption associated with processing and hauling.

Concrete recycling is a relatively simple process. Demolishing old concrete structures, crushing the concrete, and using the crushed materials as aggregates is not new and has been well established in North America [1]. The material is generally referred to as Recycled Concrete Aggregate (RCA). Both RCA and Reclaimed Concrete Material (RCM) are often used interchangeably, referring to processed (screened to remove contaminants/metals and crushed) concrete material. The RCA is typically reused as granular base and/or subbase replacement on roadway projects, but it has also been used in Portland cement concrete and hot mix asphalt layers, rip-rap, general fill, embankment fill and other applications. The RCA can be processed to produce well graded, 100% crushed, angular material that has high strength (equivalent to 100% crushed natural aggregates) with good drainage properties.

2 OVERVIEW

In 1992, the Ministry of Natural Resources (MNR) carried out a study referred to as the State of the Aggregate Resources in Ontario Study ("SAROS") which was later updated in 2009 [1]. The purpose of the SAROS study was to provide factual data on the state of the aggregate resource in Ontario. Authors of the MNR report indicated that based on current trends, within the next 10 to 20 years, the availability of high quality aggregate sources located close to the Greater Toronto Area (GTA) may become scarce. The report also suggests that there is a greater need for aggregate recycling; however, due to a lack of available data, agencies are reluctant to use recycled aggregate materials.

Aggregate consumption data in Ontario [2] indicates that:

- On average, 179 million tonnes of aggregates are used each year (from 2000 to 2009).
- Approximately 81% is used in construction - close to half is used by public authorities for the construction and maintenance of the public infrastructure.
- Ontario Ministry of Transportation (MTO) is the largest single consumer of aggregates in the province, the average annual consumption (2001-2011) is 10.9 million tonnes
- Collectively, municipalities are the largest consumers of aggregates in Ontario using approx. 55 million tonnes per year.
- Between 2005-2008, approximately 20% of the aggregates used by MTO in provincial highway road construction came from recycling or recovered materials
- Recycled materials, where available, are used by MTO in new hot mix asphalt and road base, subbase or shoulders on Provincial highways.
- Ontario Provincial Standard Specifications (OPSS) permit the use of recycled/reclaimed materials in lieu of natural aggregates. Aggregates in road base and subbase allow for up to 100% RCA [3].

Nearly three million tonnes of recyclable concrete, asphalt and aggregates recovered from construction sites in the GTA now sit in piles to be processed. Although the Ontario government, through the MTO, and some municipalities have been leaders in using recycled aggregates for years, many municipalities' specifications do not allow recycled aggregates to be used in construction projects. Processed properly, these aggregates meet all the performance requirements and provide a suitable alternative to primary aggregates which come directly from pits and quarries. [4] The challenge with demolished concrete is not the material itself, but rather the handling, sorting, processing, stockpiling and lack of technical knowhow and overall quality control at facilities that manufacture RCA material.

Municipalities have been reluctant to routinely incorporate RCA in their construction works for various reasons [5] including:

- Agency resistance to adopting new materials and construction technology (conservatism)
- Obsolete specifications
- Liability/performance concerns with innovative technologies
- Environmental constraints on recyclable materials that are not applied to conventional materials
- Lack of technical guidance
- Industry processing and pricing that are based on new materials
- Widely scattered distribution or small quantities of potentially recyclable materials
- Collection, storage, and processing costs
- Inadequate research and development budgets

Through the use of a case study, this paper provides guidance for municipal and provincial transportation practitioners on how to incorporate quality RCA material in a responsible manner, with a greater sense of confidence. The benefits associated with RCA and project specific details on raw material quality, production, quality control, laboratory testing, environmental compliance, and specification development are presented from both the owners and contractor's perspective.

3 BENEFITS OF CONCRETE RECYCLING

The economic, environmental and societal benefits of reusing concrete include:

- Typical crushing costs of RCA are similar to virgin aggregates, therefore owners benefit from RCA being close to market
- Conservation of natural aggregate and other resources
- Reduced haulage when RCA is closer to market than virgin aggregates
- Reduced greenhouse gas (GHG) emissions; and
- Capture of CO_2 from the atmosphere (sequestration of CO_2)

Best practices for concrete recycling and guide specifications for using RCA in base/subbase materials and new concrete can be found in many sources including [6].

4 CASE STUDY - PROJECT DETAILS

The case study represents a six kilometre section of Highway 7 spanning from Bayview Avenue to Warden Avenue through the Town of Richmond Hill and the City of Markham in the Regional Municipality of York. This Highway 7 project, classified as Phase H3 of the vivaNext Project is among several other contracts within the Region to upgrade rapid transit in the area. The prime contractor to the Regional Municipality of York and Metrolinx for the design and construction of H3 is a partnership between Kiewit and EllisDon (KED). The centreline rapidways along

Highway 7 will be fully segregated, at grade bus lanes with signal priority. The project includes the construction of 22 stations at various locations along the rapidway and the design and implementation of related infrastructure and facilities.

Brennan Paving and Construction (BPC) was subcontracted by the prime contractor to perform various works throughout the contract including the supply of the Granular A (crushed granular base material) and Granular B Type I (granular subbase material). Upon approval from the Region, RCA was supplied for roadway, medians, boulevards, entrances, crosswalks, driveways, intersection ramping, and platforms on this contract, designated as either Granular A or Granular B Type I. The relevant specification for construction of these aggregate bases is Ontario Provincial Standard Specification (OPSS) 314 entitled Construction Specification for Untreated Granular, Subbase, Base, Surface Shoulder, and Stockpiling. OPSS 314 references material specifications OPSS 1001 Material Specification for Aggregates – General and OPSS 1010 Material Specification for Aggregates – Base, Subbase, Select Subgrade, and Backfill Material. Further to the OPSS specifications, the contract did not indicate any further special provisions related to the aggregates specified for base or subbase.

5 QUALITY MEASURES

The performance of RCA is directly influenced by the practices exercised by the manufacturer and the quality assurance measures imposed by the owner. The manufacturer and constructor must control the quality of the material from the time the old concrete is extracted from its original location to placement of the new material. OPSS 1010 is a clear example of the expectations desired by the owner and is currently being used by both MTO and municipalities. With designation of this specification, the owner then chooses the frequency and type of testing to be performed for basis of acceptance.

BPC retained Miller Paving Ltd. (Miller) to produce and supply the RCA for use as base/subbase on the H3 project. The RCA supplier has been manufacturing quality recycled aggregates since the 1980’s in various locations across Ontario with strict attention to Best Practices and internal Quality Management System (QMS). There are several key components for consideration to ensure the aggregates are manufactured properly and will perform as expected, including:

- The existing material comes from a known site and supplier
- Pre-approval for concrete structures including footings, floor slabs, and poured concrete walls is required prior to dumping
- The loads are inspected individually for deleterious materials before and after dumping
- The presence of materials such as wood, plastic, organics, cinder blocks, bricks, tiles or any clay-based materials are cause for rejection of the load
- Reinforcing Steel bars are removed from the loads prior to feed stockpiling while metals are removed by a magnet within the crushing system
- Crushing is performed according to Best Practices
- Testing is carried out at enhanced frequencies and procedures
- Stockpiling and loading of materials are performed to prevent segregation

The Quality Control (QC) testing carried out by the supplier on RCA is at a higher frequency than the minimums specified in OPSS so as to ensure consistency and specification compliance. A review of the RCA supplier’s QC results indicated that the quality of recycled aggregates produced are consistent, and in full conformance with OPSS 1010. It was noted that the standard deviations for the QC results was consistent with those for virgin quarried aggregates.

It is imperative to practice the same attention to quality detail on the construction site when the RCA is placed, graded, and compacted to ensure the desired performance is obtained. The quality measures taken during the RCA placement process are consistent with quarried and pit virgin aggregates. Placement and grading operations are performed to minimize segregation and breakdown of the RCA by placing the material at the correct location so as to limit excessive material relocation within the site. Water is applied to the material to ensure construction and public traffic do not cause fugitive dust and to provide the necessary lubrication to ensure that the desired density is achieved with the appropriate compaction effort in accordance with OPSS 501, Construction Specification for Compacting.

6 LABORATORY TESTING

The RCA manufactured for the H3 project on Highway 7 was taken from the supplier's Markham asphalt and aggregate materials site where virgin and recycled aggregates are available to the market. The RCA stockpile is used to supply various commercial, municipal, and MTO contracts for parking lots, city streets, rural roadways, and freeways as base aggregate and shoulder applications. The material quality is verified according to the requirements published in OPSS 1010 and among the last several years, analysed has shown excellent quality and consistency. Tables 1 and 2 exhibit gradation summaries and physical property for the RCA supplied to the job.

Table 1: Summary of Supplier's Quality Control Gradation Test Results from 2012

Sieve Designation	Specification	Minimum	Maximum	Average	Standard Deviation
26.5 mm	100	100	100	100	0
19 mm	85-100	87.9	94.6	91.9	1.8
13.2 mm	65-90	69.3	83.8	76.8	4.0
9.5 mm	50-73	52.8	67.9	60.0	4.5
4.75 mm	35-55	35.8	46.1	40.6	3.5
1.18 mm	15-40	20.0	29.3	24.9	3.1
0.300 mm	5-22	7.3	11.6	9.6	1.2
0.075mm	2-8	2.3	4.3	3.2	0.5

The average gradation results from 2012 are at the middle of the specification limits with the finer end being very clean. The cleanliness on the bottom end helps to minimize dust due to construction and public traffic after placement in the field. These benefits were important for Highway 7 due to the volume of traffic and the extent of commercial buildings located adjacent to the roadway.

Table 2: Summary of Suppliers Quality Control Physical Property Test Results from 2012

Laboratory Test	MTO Test Number	Specification	2012 Average Results
Micro-Deval Abrasion (Coarse Aggregate), % maximum loss	LS-618	25	13.3
Micro-Deval Abrasion (Fine Aggregate),	LS-619	30	15.5

Table 2: Summary of Suppliers Quality Control Physical Property Test Results from 2012

Laboratory Test	MTO Test Number	Specification	2012 Average Results
% maximum loss			
Amount of Contamination	LS-630	Note 1	No contaminants
Plastic Fines	LS-631	Non-Plastic	Non-Plastic
Percent Crushed Particles, % minimum	LS-607	60	94.6
Asphalt Coated Particles, Coarse Aggregates, % maximum	LS-621	30	21.9

Note 1: Granular A may contain up to 15% by mass crushed glass or ceramic material or both. Granular A shall not contain more than 1.0% by mass of any combination of wood, clay brick, gypsum, gypsum wall board or plaster.

7 QUALITY ASSURANCE

Pavement practitioners would argue that there are three key factors to a long lasting pavement: drainage, drainage, and drainage. One of the concerns raised by York Region was that RCA would breakdown under construction traffic and the heavy rollers used to achieve the specified compaction, and therefore would not drain as well as conventional Granular A or Granular B. To address York Region's concern, Golder Associates Ltd. (Golder), the Geotechnical Engineering Consultant proposed additional laboratory testing to evaluate the RCA which included the following:

- Gradation testing on samples obtained from an on-site stockpile and from samples extracted from the road after placement and compaction;
- Standard Proctor Maximum Dry Density (SPMDD) of the RCA from the stockpile and after compaction; and
- Permeability testing (constant head test) of the RCA from the stockpile and after compaction

Initially, the supplier's QC Gradation and Physical Property test results were reviewed and once it was deemed to be consistent and in compliance with the relevant OPSS, the following testing frequency was specified for Quality Assurance (QA) testing:

- Gradation testing on the stockpiled RCA and compacted RCA at a frequency of one (1) test for every 3,700 m^2 (one lane-km) where RCA was used as base and subbase;
- SPMDD and Permeability testing on the stockpiled RCA and the compacted RCA at a frequency of one (1) test for every 7,400 m^2 (two lane-km) where RCA was used as base and subbase.

The RCA material supplied was used to replace the recommended thickness of granular base as well as the subbase. Generally, when Granular A material is used to replace Granular B Type 1 subbase, the thickness of the subbase is reduced to about two-thirds (2:3) of the recommended subbase thickness to account for the higher quality of the base material. However, on the H3 project, the prime contractor replaced the subbase with an equal thickness of RCA material. The total thickness of the RCA material placed as base/subbase was typically 800 mm in the widening areas.

Tests were carried out on RCA material sampled from the supplier's Markham location stockpile while the compacted samples were obtained by excavating shallow test pits after the material was placed and compacted on site.

Quality Assurance Test Results

The QA gradation test results on the compacted RCA are summarized in Table 3.

Table 3: Summary of QA Gradation Test Results

Sieve Designation	Specification	Minimum	Maximum	Average
26.5 mm	100	100	100	100
19 mm	85-100	92	96	94
13.2 mm	65-90	80	87	84
9.5 mm	50-73	65	76	72
4.75 mm	35-55	46	58	54
1.18 mm	15-40	21	39	32
0.300 mm	5-22	9	21	15
0.075mm	2-10	3.1	8.7	4.5

The gradation results from the compacted RCA show that the material satisfies the requirements of OPSS 1010 for Granular A. Moreover, the average fines content (percent passing the 75 µm sieve) was less than 5 percent indicating that the RCA was clean on the fine end of the gradation spectrum and significant breakdown of the RCA after compaction did not occur.

The constant head test procedure was used to evaluate the permeability of the RCA (ASTM D2434-68 "*Standard Test Method for Permeability of Granular Soils*"). The results from the Standard Proctor testing and Permeability testing are summarized in Table 4.

Table 4: QA SPMDD and Permeability Test Results

	RCA from Stockpile	**Compacted RCA**
Standard Proctor	1,970 kg/m^3	1,990 to 2,020 kg/m^3
Permeability	1.56×10^{-4} cm/sec	1.29×10^{-4} cm/sec

8 OBSERVATIONS

The RCA material delivered to the site was free of any contaminant such as wood, plastic, gypsum, gypsum board, glass and ceramics. While care was taken when placing the material to minimize moving the material from one location to another, minimum additional effort was required to achieve the recommended level of compaction which was 100 percent of SPMDD for both the material placed as base as well as subbase. Water trucks were used to aid in the compaction of the granular materials on-site; however, the amount of water required for compaction of the RCA was typical of that required for virgin Granular A material. Ponding of water or white effluent (or leachate) was not observed during the compaction of the RCA.

9 DISCUSSION

The gradation testing carried out on the stockpile samples for both QC and QA testing were consistent (low standard deviations) and satisfied the requirements specified in OPSS 1010 for Granular A. The testing carried out on the compacted samples (QA testing) indicated the gradation was slightly finer when compared to the stockpile samples and the OPS specifications. The fines content of the compacted samples tested ranged from about 3 to 9 percent and averaged about 4.5 percent, well within the limits specified in OPSS 1010.

The SPMDD testing carried out on compacted RCA samples showed that the density was slightly higher than the density of the stockpile samples. The minor increase in density is likely due to the slight breakdown of the RCA during compaction; however, it should be noted that this increase in density is often exhibited after compaction of virgin Granular A samples as well.

The results from the permeability tests showed that the stockpile samples had permeability in the range of 1.3×10^{-4} to 2.0×10^{-4} while the compacted RCA samples had permeability in the range of 1.7×10^{-5} to 2.5×10^{-4}. Typically, good quality granular base/subbase materials used in Ontario have permeability in the range of 10^{-4} to 10^{-3} cm/sec compared to a permeability of 10^{-6} cm/sec or less for poor quality granular base/subbase materials [7]. The permeability results from the compacted as well as the stockpiled RCA sampled are within the typical range for good quality Granular base/subbase material.

10 CONCLUSIONS

Due to depleted virgin aggregates from pits and quarries (especially within developed areas such as the GTA), it is evident that there is a need to ensure sustainable aggregate resources. RCA is a viable and economical solution to conserve high quality aggregates for more onerous infrastructure projects such as bridges and buildings. As shown in the Case Study presented in this paper, RCA can be used successfully as replacement of granular base and/or subbase provided appropriate measures are taken from the time the old concrete is demolished to the placement and compaction of the new material. The conclusions resulting from this Case Study are beneficial to contractors, municipalities, and engineers and are provided below:

Production Control is Critical: Key Player – Contractors

- The suppliers should not only have the knowledge, experience, and the necessary equipment, but should also show a <u>commitment to stringent quality control measures</u> to produce material satisfying the project specifications;
- Knowing the source of the material, screening for contaminants, vigorous quality control laboratory testing, proper storage and handling of the material are imperative to achieving a quality product.

Specifications: Key Player – Owner's & Municipalities

- A good quality RCA material will generally not be provided if it is not specified in the contract;
- Owners and municipalities should provide the requirements to satisfy quality RCA. Testing should be listed in the contract so that contractors know what to bid on. In addition to tests for gradation and physical properties, permeability testing should be included both on virgin and compacted RCA samples.
- Gradation – to check whether the material is breaking up under heavy compaction equipment and check fines content.
- Permeability – is an important parameter for pavements and critical for drainage of the RCA

Pavement Design: Key Player – Engineers & Consultants

RCA can be used as base and subbase provided:

- There is good control of production
- In addition to the tests specified in OPSS 1010, permeability testing is carried out to evaluate the drainage characteristics of the material and gradation samples of the compacted RCA are tested to verify the material does not breakup under construction and general traffic loading
- Additional QA testing is carried out on samples after compaction to check whether the gradation and permeability are satisfactory
- Using RCA as a replacement for granular subbase (generally Granular B, Type1) may result in a higher quality material and a reduction of the overall pavement structure may be justified.

Additional benefits of using RCA related to sustainability are:

- RCA can be a less costly alternative, especially for larger municipalities where significant amounts of old concrete is available for crushing and recycling facilities are close to market
- In addition to being cost effective, there are environmental and social benefits to using RCA and constructing sustainable pavements – Tools such as PaLATE (Pavement Lifecycle Analysis Tool for Environment and Economic effects) and GoldSET (Golder Sustainability Evaluation Tool) are available to assess these benefits
- Use of RCA will count towards achieving LEED®, Green Roads, and MTO's GreenPave certification

Many municipalities are still reluctant to use RCA; however, it is understood that this is primarily due to the unfamiliarity with RCA rather than disregarding the sustainable benefits. As can be seen from the QC and QA results, the vivaNext roadway widening project is a very good example of using RCA to replace the granular base/subbase on road construction projects. RCA can be used for road construction, trench backfilling, parking lots, boulevard construction, etc. Adequate controls and specifications are required to monitor the quality of the RCA material not only during production and placement, but also after placement by carrying out tests on the compacted material.

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