Crushing and Processing Reclaimed Concrete for City of Saskatoon Rehabilitation of Road Structures

Prepared by:

Curtis Berthelot, Ph.D., P. Eng.:
PSI Technologies Inc., 221 Jessop Ave., Saskatoon, SK Canada S7N 1Y3
Phone: (306) 477-4090, Fax: (306) 477-4190, cbertheloth@pavesci.com

Colin Wandzura, E.I.T., PSI Technologies Inc., 221 Jessop Ave., Saskatoon, SK Canada
S7N 1Y3, Phone: (306) 477-4090, Fax: (306) 477-4190, cwandzura@pavesci.com

Rielle Haichert, E.I.T., PSI Technologies Inc., 221 Jessop Ave., Saskatoon, SK Canada S7N 1Y3
Phone: (306) 477-4090, Fax: (306) 477-4190, rhaichert@pavesci.com

Brian Taylor, P.Eng., PSI Technologies Inc., 221 Jessop Ave., Saskatoon, SK Canada S7N 1Y3
Phone: (306) 477-4090, Fax: (306) 477-4190, btaylor@pavesci.com

Duane Guenther, P.Eng., City of Saskatoon, 222 3rd Avenue North, Saskatoon, SK Canada,
S7K 0J5, Phone: (306) 975-7894, Fax: (306) 975-7651, Duane.Guenther@saskatoon.ca

Sheri Praski, P.Eng., City of Saskatoon, 1030 Avenue H South, Saskatoon, SK Canada
S7M 1X5, Phone: (306) 975-2487, Fax: (306) 975-2553, Sheri.Praski@saskatoon.ca

Paper prepared for presentation
at the New Realities with Recycling Materials Session
of the 2010 Annual Conference of the
Transportation Association of Canada
Halifax, Nova Scotia

ABSTRACT

In 2009, the City of Saskatoon implemented the "Green Streets" Infrastructure Program. This paper evaluated the technical results of crushing and processing stockpiled hot mix asphalt concrete (HMAC) and Portland cement concrete (PCC) materials used in the City of Saskatoon "Green Streets" Infrastructure Program for road reconstruction.

Given the limited success of conventional crushing technologies, an innovative impact crusher with a screener and magnetic metallic extruder was employed to process the concrete rubble materials for the City of Saskatoon's "Green Streets" Infrastructure Program. Impact crushing production rates averaged between 100 MT and 300 MT per hour, generating up to five alternate sized materials at once with minimal waste in 2009. Recycled HMAC and PCC materials produced in 2009 had at least 30 percent improved mechanistic mechanical properties than virgin source counterparts. Through the implementation of the City of Saskatoon's "Green Streets" Infrastructure Program, on-site recycling methods and recycled materials were used to construct a number of test sections over the 2009 construction season using recycled HMAC and PCC in the road structures.

(172 words)

INTRODUCTION

Presently, the City of Saskatoon, like many urban centres, is challenged with rehabilitating, maintaining, and operating several thousand lane kilometers of roads. Increased structural deterioration of road infrastructure and a subsequent need for rehabilitation and reconstruction is a serious asset management challenge facing the City of Saskatoon (1). The structural deterioration of the City's road infrastructure is a function of a number of conditions, including severe climatic conditions.

Firstly, much of the City's urban road network is ageing and has been in operation past its design life. A history of reduced preservation budgets and timely maintenance has increased the City's infrastructure deficit (1). Keeping up with the rehabilitation and maintenance of existing road assets in combination with the expansion and construction of new roads in the city has proved to be a difficult task for most urban centres, and the City of Saskatoon is no exception.

Specifically, in recent years, the City of Saskatoon has seen an increase in the amount of road infrastructure hot mix asphalt concrete (HMAC) and Portland cement concrete (PCC) rubble available at the City's landfills (2, 3). The City's landfill is approaching its service life and the cost of landfilling these rubble materials is significantly increasing to reflect the value of fillable landfill airspace. Therefore, the City diverts HMAC and PCC rubble from the City's landfill and stockpiles the material.

In addition, road construction and rehabilitation costs have increased substantially over the years (2, 3). This is primarily due to a reduction in the availability of quality construction materials, specifically high quality virgin aggregates. Over the years, virgin aggregate pits have been depleted in many regions in the province of Saskatchewan, particularly in urban areas. For example, virgin aggregate sources in the Saskatoon area have generally been exhausted and are now being transported from pit sources up to 100 kilometers from the City limits (1, 2, 3, 4). The cost of quality virgin aggregates is increasing due to growing demand and increased haul distances. Farther haul distances result in the consumption of more transport energy and further road damage.

A need to establish sustainable solutions to the City of Saskatoon's structural road deterioration was determined based on the City's ageing road network. This need, combined with a demand for new road construction and road rehabilitation, the increased cost and environmental concern of locating and transporting virgin quality aggregates, and strong commercial and new housing developments, resulted in the City of Saskatoon implementing the "Green Street" Infrastructure Program in early 2009. The overarching objective of the Program was to investigate the ability to reclaim and recycle HMAC and PCC rubble and to reuse it as value-added engineered road structural materials. The "Green Street" Infrastructure Program included crushing reclaimed HMAC and PCC rubble, characterizing these materials in the laboratory, and using them in field test sections.

BACKGROUND

The City of Saskatoon generates and stockpiles as much as 100,000 MT of HMAC and PCC rubble annually from road infrastructure rehabilitation and utility repairs (2, 3, 4). As pictured in Figure 1, stockpiled HMAC and PCC rubble materials are typically comprised of large pieces of concrete and are significantly contaminated with deleterious materials including dirt and debris, subgrade fines, and reinforcing steel. The main sources of HMAC and PCC rubble are rehabilitated roads, roadside curbs and medians, sidewalks, and building demolition.

In 2007, the City recognized an opportunity to reclaim, reuse, and recycle these rubble materials. Initially, conventional jaw and cone crushing equipment was used to crush the reclaimed HMAC and PCC rubble. However, conventional equipment reduced the crushing efficiency, production rate, and the quality of the final crushed HMAC and PCC material, typically generating only low value subbase and backfill materials. Unfortunately, there was little incentive to improve the crushing process by the local industry that also supplied virgin source aggregate materials.

As a result, in the fall of 2007, the City of Saskatoon issued a request for proposals to mobilize an impact crusher that could crush reclaimed HMAC and PCC rubble at improved production rates and end-product quality. Pavement Scientific International (PSI) Technologies Inc. acquired and mobilized a state-of-the-art impact crusher, pictured in Figure 2, and set forth with crushing stockpiled City of Saskatoon HMAC and PCC rubble. The impact crusher was specifically designed for crushing HMAC and PCC rubble and employed integrated screens and a magnetic metallic extruders to reduce contamination.

Following positive results of reclaimed HMAC and PCC impact crushing in 2008, the City of Saskatoon set forth the “Green Street” Infrastructure Program in early 2009. Under the “Green Street” Infrastructure Program, the impact crusher was modified in 2009 to further improve the quality of the crushed HMAC and PCC rubble. A paper further discussing “Green Streets” in its entirety is included in these conference proceedings (5). In addition, further documentation of this Program may be found elsewhere (2, 3, 4, 5).

OBJECTIVE

The purpose of this paper is to discuss the crushing and processing methods of stockpiled HMAC and PCC materials used in the City of Saskatoon “Green Streets” Infrastructure Program.

SCOPE

This paper is limited to discussing the crushing and processing of reclaimed HMAC and PCC for the City of Saskatoon between fall 2007 and end of 2009. This paper summarizes the initial crushing of City of Saskatoon reclaimed HMAC and PCC rubble and crushing performed under the “Green Streets” Infrastructure Program. Average stockpile results presented include gradations and asphalt content (where applicable). In addition, triaxial frequency sweep testing results of gyratory compacted samples presented include the mechanical properties of dynamic modulus, radial microstrain, and phase angle. Crushed HMAC and PCC material properties are compared to a conventionally crushed granular base material as a baseline.

FIRST GENERATION IMPACT CRUSHING

First generation impact crushing employed integrated screens and magnetic metallic extruder. In 2008, first generation impact crushing produced crushed HMAC and PCC materials of improved quality and reduced contamination when compared to conventional crushed granular base material (6). As seen in Figure 3, the conventional granular base met the City of Saskatoon (COS) granular base specification along with the impact crushed first generation HMAC material. The first generation PCC was found to be coarse in comparison to the COS base course specification. Daily stockpile gradations were found to be consistent during first generation crushing (2). In addition, daily HMAC samples taken in the spring 2008 showed an average 4.4 percent asphalt cement by mass of the first generation crushed HMAC stockpile (2).

Initial end-product goals set forth by the City of Saskatoon in 2008 were to crush 40,000 MT of HMAC rubble and 20,000 MT of PCC rubble to a gradation within the City of Saskatoon's granular base specification. These goals were met and an additional 45,000 MT of HMAC and 25,000 MT of PCC rubble were added to the crushing contract in 2008. The first generation materials was found to be good quality materials when compared to conventional granular base materials.

In 2008, PSI Technologies gained considerable experience and knowledge regarding processing of highly diverse and contaminated HMAC and PCC rubble feedstock materials. The primary challenge encountered during the 2008 first generation crushing was the amount and type of deleterious materials contained within the rubble feedstock piles. In addition, large pieces of rubble were difficult to manage and often plugged the crusher.

SECOND GENERATION IMPACT CRUSHING

Based on learnings in 2008 with first generation crushing, second generation crushing was implemented with reconfigured equipment under the "Green Street" Infrastructure Program in 2009. Figure 4 shows the reconfigured impact crusher. The crusher was reconfigured such that a secondary screening deck was added to increase the capacity of the system as well as produce up to five different sized materials at once. Modifications to the reconfigured impact crusher also included a grizzly deck to collect the fines and fine material.

In addition to the reconfigured crushing equipment, material processing prior to crushing was implemented, as seen in Figure 5. Second generation crushing targeted the removal of deleterious material, metal, fines, and fine sand content prior to impact crushing HMAC and PCC rubble. The PCC rubble is broken up and rebar is removed using the jackhammer or the concrete muncher – a material de-densifying grappler, as seen in Figure 5. By processing the material, specifically the PCC rubble, deleterious material was eliminated prior to crushing and the efficiency of the crusher was increased due to less downtime associated with the crusher plugging up. By focusing on managing the upstream feedstock rubble material, a higher quality of rubble material was crushed with minimal waste.

In 2009, second generation impact crushing produced crushed HMAC and PCC materials of improved quality from first generation crushed material. As seen in Figure 6, up to five alternate sized PCC or HMAC materials could be crushed at once. Materials varied in size and included well graded (GW) base course, open graded base course (OGBC), open graded drainage rock, and crushed rip rap. Figure 7 shows the OGBC crushed HMAC and PCC material, for example.

Figure 8 shows the gradations of each type of HMAC and PCC material crushed in 2009. As seen in Figure 8, the second generation crushing and processing protocols significantly improved the quality and quantity of crushed HMAC and PCC end-product material from 2008 (first generation) to 2009 (second generation). The refinement in crushing technology and the addition of processing resulted in various gradations. For example, reclaimed HMAC rubble could be crushed to a GW 19 mm material that met the COS granular base specification or an OBGC 25 mm material that met the COS crushed rock specification. Furthermore, a 65 mm HMAC rock was crushed coarse of the COS crushed rock specification. Second generation crushed PCC rubble material resulted in a 19 mm GW PCC, a 19 mm and 25 mm OGBC PCC, and a 65 mm crushed PCC rock. In addition, the second generation-installed grizzly deck allowed for the PCC fines and fines sand to be removed from the crusher.

Processing the HMAC and PCC rubble and crushing it with the reconfigured equipment enabled several high quality materials to be crushed at once with minimal waste. These materials varied in top size from 19 mm to 150 mm and included well graded base course, open graded base course, open braded drainage rock, and crushed rip rap. In total, in 2009, 80,000 MT of HMAC and 80,000 MT of PCC were crushed.

TECHNICAL RESULTS OF IMPACT CRUSHED HMAC AND PCC RUBBLE

Typical City of Saskatoon granular base specification require California bearing ratio (CBR) characterization to provide a relative measure of material strength and moisture. However, preliminary CBR results for recycled HMAC and PCC materials were low compared to conventional granular base material, which does not reflect observed field performance (3). It was determined that CBR characterization using impact compacted samples was unsuitable for the characterization of recycled HMAC and PCC materials. Therefore, laboratory testing using the rapid triaxial test apparatus was used to evaluate the mechanistic properties of gyratory compacted recycled HMAC and PCC samples.

Unlike other tests, such as the California bearing ratio test, which are empirical in nature, rapid triaxial frequency sweep testing mechanistically can characterize the structural behaviour of unconventional road materials under realistic field state conditions. Specifics of the rapid triaxial test apparatus and associated stress states and frequencies selected to represent realistic field state conditions are presented elsewhere (7). Presented herein are the results from a high deviatoric stress state which represents a material placed in the upper layers of a relatively thin flexible pavement structure. In addition, presented herein are the results of varied load rate was from a relatively slow load rate (0.5 Hz) to represent slow moving truck traffic within an urban environment to a relatively fast load rate (10 Hz) to represent typical highway speed applications.

Based on the rapid triaxial frequency sweep characterization performed, the recycled materials were all found to provide a higher dynamic modulus, as well as improved Poisson's ratio, phase angle, and radial strain relative to the conventional granular base course materials. The mechanistic characterization of the recycled road materials demonstrates the improved quality of recycled HMAC and PCC materials with second generation crushing techniques. Presented in Figure 9 through Figure 11 are the mechanistic material properties of dynamic modulus, radial microstrain, and phase angle at a high stress state for granular base and recycled HMAC and PCC materials, characterized using rapid triaxial frequency sweep testing. Information on rapid triaxial testing may be found elsewhere (7).

Dynamic modulus is used to quantify material stiffness under dynamic loading and triaxial stress states (7). As seen in Figure 9, the recycled materials were all found to provide an improved mechanical response relative to the conventional granular base course materials. Overall, the first and second generation recycled HMAC performed significantly better than convention granular materials and recycled PCC. The HMAC rubble material was found to provide higher sensitivity to load frequency, which is an indication of the cohesive effects of the residual asphalt cement in the material system. Based on the mechanistic characterization it was also found that open graded base coarse (OGBC) gradations provided improved mechanical material constitutive behavior relative to well graded (GW) materials.

Radial microstrain behaviour of materials is believed to be an indication of the potential for a road material to exhibit lateral shear failure (7). As seen in Figure 10, crushed HMAC material radial strain behaviour was found to be highly sensitive to load frequency, which is an indication of the cohesive effects of the residual asphalt cement in the material system. Based on the mechanistic characterization it was also found that OGBC gradations provided improved mechanical material constitutive behaviour relative to GW materials. It was also interesting to note that the conventional low fracture granular base and conventional crushed HMAC rubble exhibited failure at the severe stress states.

Phase angle of materials is a linear viscoelastic material property believed to be an indication of the potential viscoelastic stiffness effects within the material system (7). As seen in Figure 11, the OGBC provided improved mechanical material constitutive behaviour relative to GW materials. The conventional low fracture granular base and conventional crushed HMAC rubble exhibited failure at the severe stress states. It was interesting to note a significant increase in phase angle was observed with the recycled HMAC materials relative to the recycled PCC materials. This is due to the effects of the residual asphalt cement within the recycled asphaltic rubble material.

SUMMARY AND CONCLUSIONS

Since 2007, the City of Saskatoon has been met with great success in terms of its HMAC and PCC rubble crushing. The implementation of the "Green Street" Infrastructure Program has led to creating sustainable road infrastructure for the City of Saskatoon. The implementation of the City of Saskatoon's "Green Streets" Infrastructure Program and on-site recycling methods for reclaimed HMAC and PCC materials have been positive in all technical aspects. Impact crushing rates were found to be efficient, generating up to five alternate sized materials at once with minimal waste. These materials varied in size and included well graded base course, open graded base course, open graded drainage rock, and crushed rip rap.

Overall, HMAC and PCC recycled aggregate materials produced in 2009 had at least 30 percent improved mechanistic mechanical properties as structural materials relative to virgin source counterparts. Crushing stockpiled HMAC and PCC material has helped the City of Saskatoon meet its sustainability needs in terms of economic, environmental and social needs.

Test sections constructed under the "Green Streets" Infrastructure Program in 2009 used approximately 30,000 MT of crushed HMAC material as an engineered black base layer and approximately 70,000 MT of crushed PCC material as a stress dissipation drainage layer in the rehabilitated road structure. In addition, in-place reclaimed asphalt pavement was remixed and reused in the rehabilitated road structure of each test section.

At present, no HMAC or PCC rubble is disposed on in the City's landfill. In addition, the City hopes to achieve the status of being *aggregate neutral*.

ACKNOWLEDGMENTS

The authors would like to thank the City of Saskatoon for their support in the "Green Street" Infrastructure Program.

REFERENCES

(1) Prang, C. and Berthelot, C. 2009. Performance Valuation Model for Urban Pavements. Transportation Research Board of the National Academies Annual Meeting, Jan 10-15, 2009. Washington, D.C. CDROM Proceedings Paper #09-3637.

(2) Berthelot, C., Haichert, R., Podborochynski, D., Wandzura, C., Taylor, B., Bews, R., Guenther, D., Prang, C. Use of Recycled Asphalt Concrete and Portland Cement Concrete in Road Substructure Construction. Transportation Research Board of the National Academies Annual Meeting, 2009. Washington, D.C. CDROM Proceedings Paper.

(3) Berthelot, C., Haichert, R., Podborochynski, D., Wandzura, C., Taylor, B., Guenther, D., April, 2010. Mechanistic Laboratory Evaluation and Field Construction of Recycled Concrete Materials for Use in Road Substructures. Transportation Research Record, Journal of the Transportation Research Board of the National Academies, Washington, D.C. USA.

(4) PSI Technologies Inc. 2010. Sustainable "Green Street" Road Rehabilitation Using Recycled Asphaltic Concrete, Portland Cement Concrete, and Other Waste Rubble Materials, Year One Final Report. Report. Saskatoon, Saskatchewan.

(5) Berthelot, C., Haichert, R., Podborochynski, D., Wandzura, C., Guenther, D., Taylor, B., Praski, S. 2010. Summary of City of Saskatoon "Green Street" Infrastructure. Presented at the 2010 Transportation Association of Canada Annual Conference. Halifax, Nova Scotia.

(6) City of Saskatoon. 2005. AGGREGATES Granular Base Course, Division 3, Section 03005, pp. 1-6, Saskatoon, SK.

(7) Crockford, W. Berthelot, C, Tritt, B., and Sinados, C. Rapid Triaxial Test. *Journal of the Association of Asphalt Paving Technologists*, Vol. 71, 2002, pp. 712-724.

LIST OF FIGURES

Figure 1 Stockpiled HMAC rubble (left) and stockpiled PCC rubble (right)

a) Front view

b) Back view

Figure 2 Impact crusher (2008)

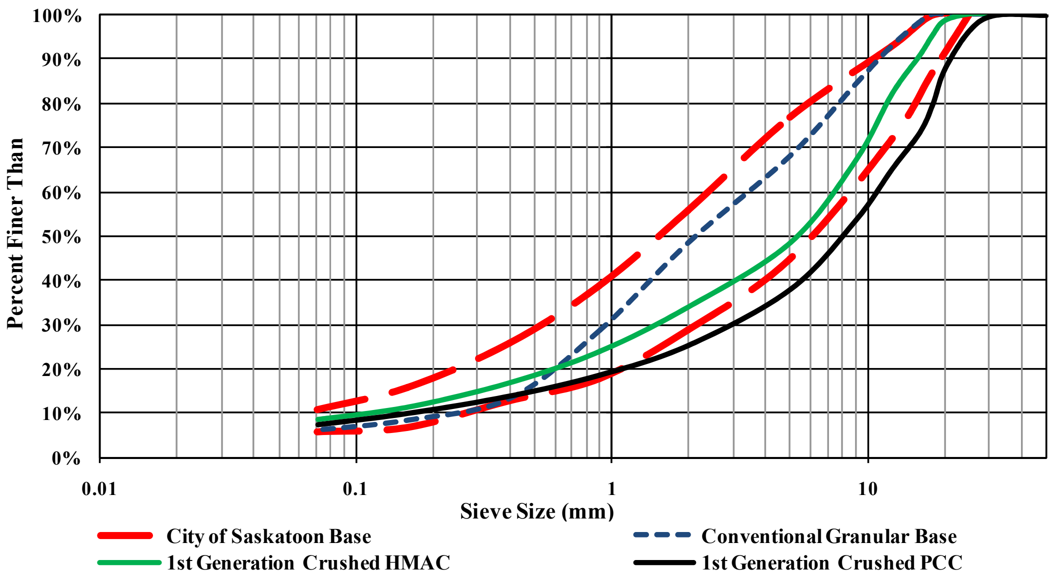
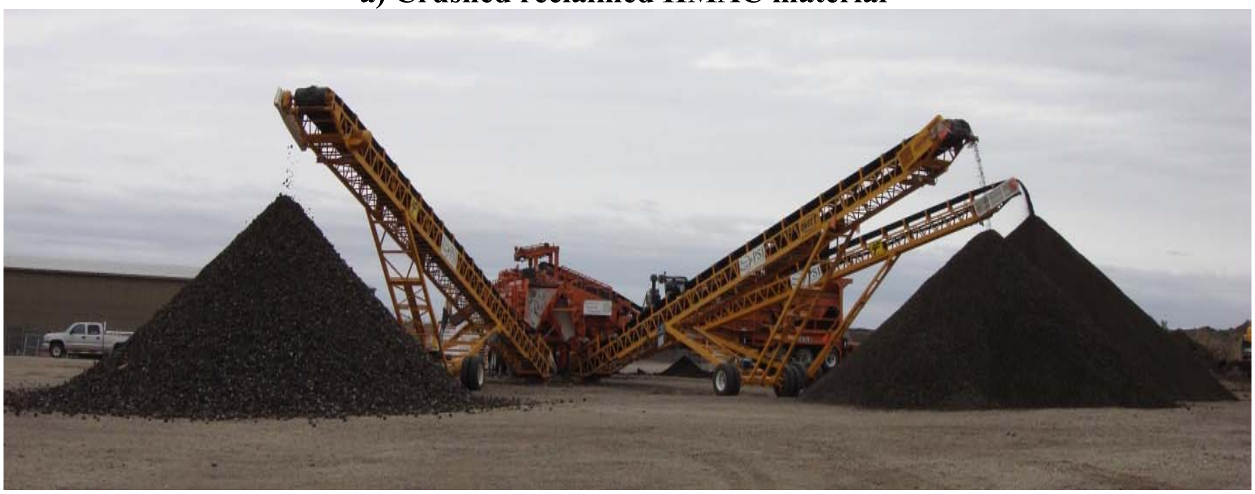


Figure 3 Grain size distribution of first generation impact crushed material

Figure 4 Reconfigured impact crusher (2009)

Figure 5 PCC rubble processing: jackhammer (left) and muncher (right) (2009)

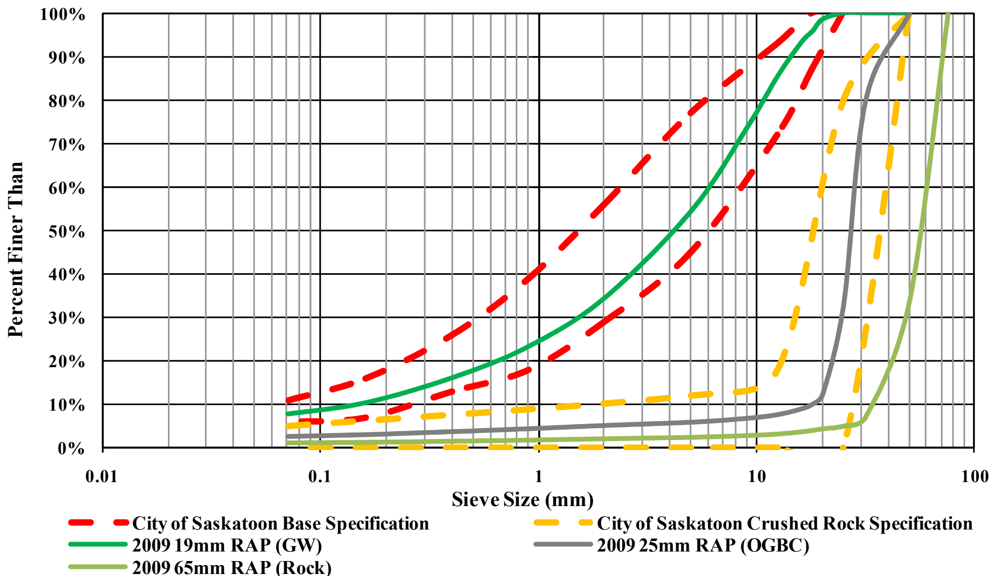
a) Crushed reclaimed HMAC material



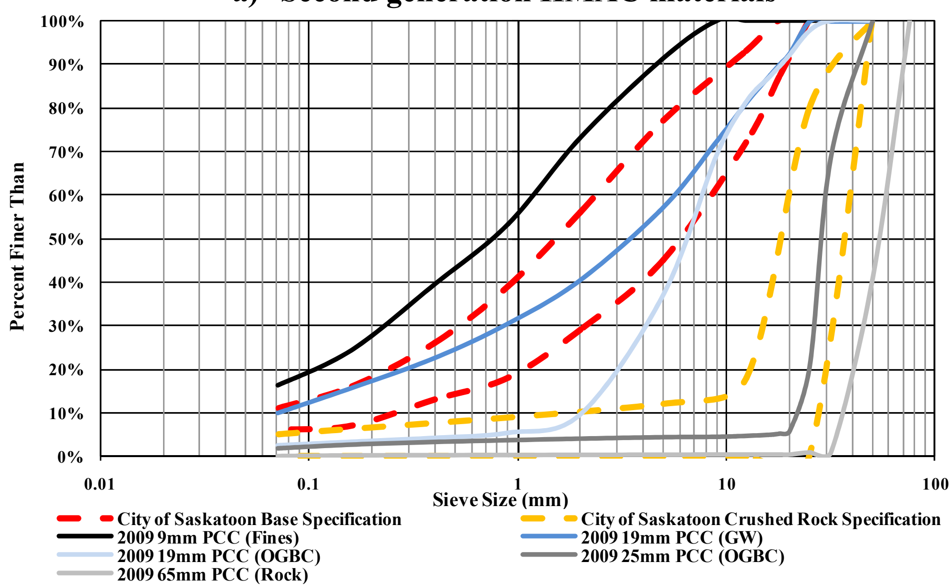
b) Crushed reclaimed PCC material

Figure 6 Second generation crushed materials (2009)

Figure 7 Second generation impact crushed HMAC and PCC material (OGBC)



a) Second generation HMAC materials



b) Second generation PCC material

Figure 8 Grain size distribution of second generation impact crushed material

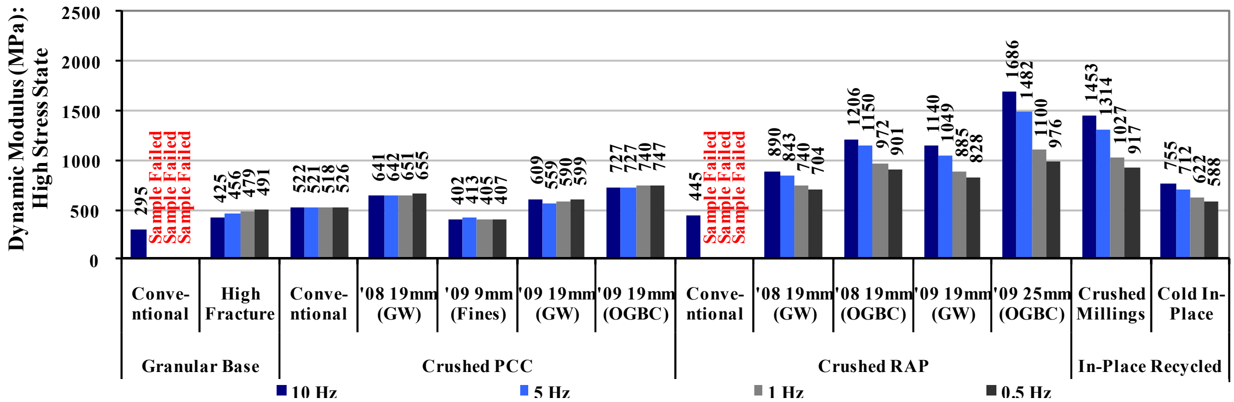


Figure 9 Dynamic modulus of granular base and recycled HMAC and PCC materials

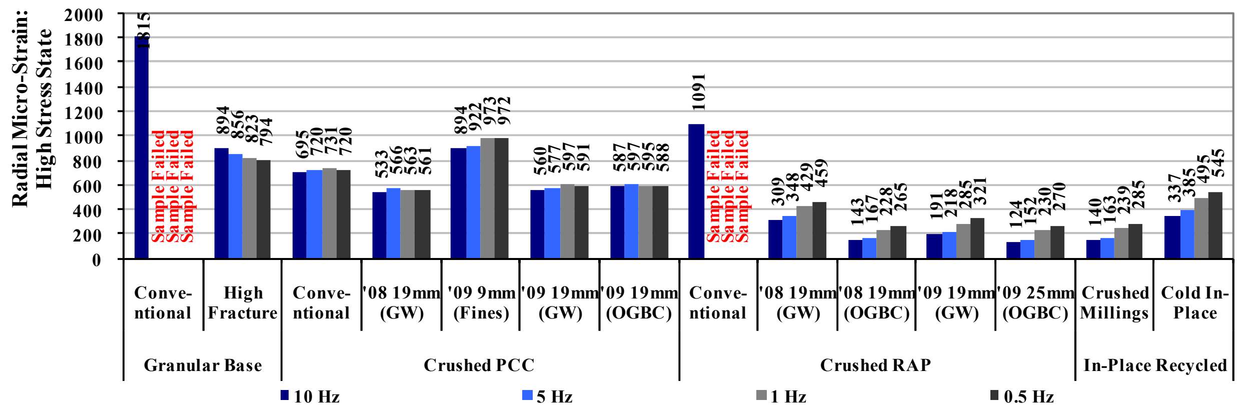


Figure 10 Radial microstrain of granular base and recycled HMAC and PCC materials

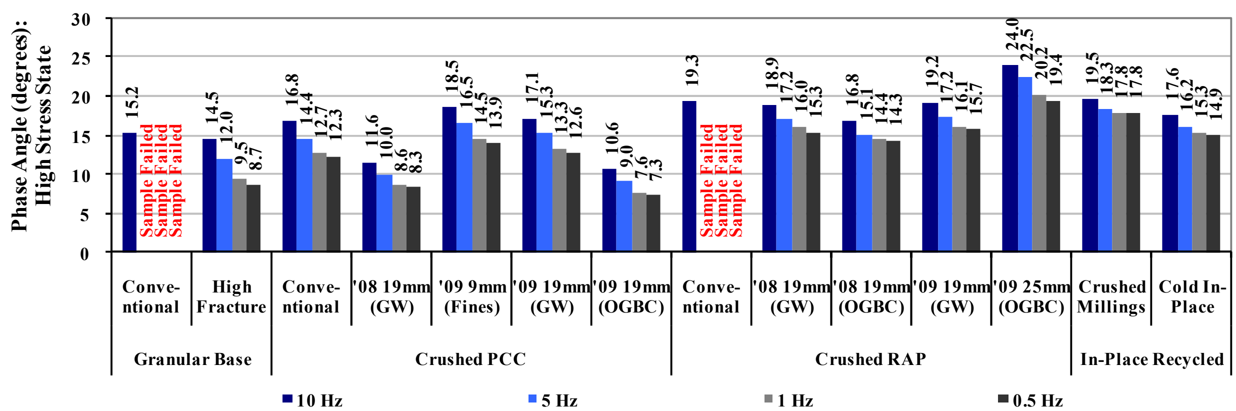


Figure 11 Phase angle of granular base and recycled HMAC and PCC materials