An Experimental Study to Investigate the Effect on Tensile strength and Dynamic modulus of the addition of Portland cement to Cold In-Place Recycled Asphalt Using Indirect Tensile and Dynamic Modulus Tests

Taha Younes Ph.D Candidate, Department of Civil and Environmental Engineering University of Waterloo

Susan L. Tighe, Deputy Provost and Associate Vice-President Integrated Planning and Budgeting, Norman W. McLeod Professor in Sustainable Pavement Engineering, Department of Civil and Environmental Engineering, University of Waterloo

Paper prepared for presentation at the Innovations in Pavement Management, Engineering and Technologies Session of the 2019 TAC-ITS Canada Joint Conference, Halifax, NS

Acknowledgements:

The authors would like to thank MTO for their financial contribution to this research. In addition, the authors would like to express their gratitude to MCAsphalt Company and their laboratory personnel for providing training and their time and effort in helping with the mix design and testing.

Abstract

Cold In-Place Recycling (CIR) is an established pavement rehabilitation technique that involves reusing an existing asphalt pavement. The process generally utilizes 100% Reclaimed Asphalt Pavement (RAP) that is mixed with an emulsified asphalt. In this study, which is a project in partnership with the Ontario ministry of Transportation and various industry partners in Ontario, CIR mixes with a slow setting emulsion were prepared in the Centre of Pavement and Transportation Technology (CPATT) Laboratory at the University of Waterloo. In order to study the effect of Portland cement on the mechanical properties of Cold in Place Recycling, different percentages of Portland cement (0%, 0.25%, 0.5%, 0.75%, 1.5% and 3%) were added to the mixes. The mixes tested using the Indirect Tensile and Dynamic Modulus Tests to determine the strength and stiffness of the mixes. Furthermore, the moisture susceptibility was controlled by conditioning the specimens for 24 hours at 25 degrees Celsius. The results showed that increasing the percentage of Portland cement lead to an increase in the strength and the stiffness of the CIR mixes.
Keywords: Cold In-Place Recycling, Emulsified Asphalt, Strength, Stiffness, Portland Cement

1. Introduction

Road construction maintenance and repair cost Canadian governments a substantial portion of their budgets every year. An increase in the population requires improvements in the quality of roads. However, sometimes due to limitations of budget, contractors, and government agencies have to maintain and rehabilitate the roads at a low cost and hence a lower than optimum quality. Adopting cost-effectiveness and environmentally friendly techniques to improve the quality of road rehabilitation and maintenance has become one of the priorities for governments and many contractors (Johnson, 2000). The classic method of road maintenance and rehabilitation is to lay a new layer of hot mix asphalt (HMA) after preparing the old pavement. In some cases, when a road is severely distressed, milling off the top layer of the pavement is required, and then a new HMA layer is placed (Abiodun, 2014). This traditional way of maintenance and rehabilitation provides a good surface quality; however, it has drawbacks. Some of these drawbacks are the user delays caused by the required long construction period of HMA, the high cost and the large amount of energy needed to produce the HMA and the reconstruction of the base layer. Furthermore, this classic way of rehabilitation is not considered to be environmentally friendly due to the greenhouse gasses that are released during the process. For the above-mentioned reasons, governments, contractors, and designers have put much effort into overcoming these disadvantages. Designers have been driven to utilize more environmentally friendly alternatives. Designs have been made to improve the efficiency of the pavement structure and to reduce traffic and construction delays (Alkins et al, 2008). In the light of this scenario, recycling methods have become more acceptable around the world (Lewis et al, 1999). Reclaiming methods for asphalt include Hot In-Place Recycling, and Cold In-Place Recycling, partial and full depth reclamation (Abiodun, 2014).

Cold Mix Asphalt (CMA) is one of the rehabilitation techniques, in which 100% of Reclaimed Asphalt Pavement (RAP) is used. This technique is carried out in place (Bhavsar, 2015). There are several benefits of using CMA such as: reducing project costs since there is no off-site hauling of aggregate (Alkins et al, 2008), and the fuel consumption and the emissions of carbon dioxide and nitrous oxide are reduced as well (Chesner, 2011). The CMA procedure is considered to be a sustainable rehabilitation technique in terms of environmental and economic benefits (Mallick et al, 2008). In Ontario, there are two rehabilitation techniques that use CMA to rehabilitate pavement distresses such as fatigue and transverse, thermal, and reflective cracks. The two techniques, which involve removing and milling about one quarter of the existing pavement, are Cold In-Place Recycling with an emulsified asphalt binder (CIR) and Cold In-Place Recycling with Expanded Asphalt Mixture (CIREAM). However, the focus of this study is on the behavior of Cold In-Place Recycling with an emulsified asphalt binder (CIR), and Portland cement additives.

2. Literature Review

CIR is a pavement rehabilitation technique that reuses the existing asphalt pavement to reduce the life cycle cost and environmental impact of the pavement structure. This process allows for the preservation of aggregates and asphalt cement and for processing the recycled pavement materials in-situ (Davidson et al, 2003).

Ontario has been using Cold In-Place Recycling with emulsified asphalt binder (CIR) since 1990 (Lane et al, 2014). The CIR treatment depth depends on the type of recycling agent. For instance, if the recycling agent is only an asphalt emulsion or an emulsified recycling agent, the CIR treatment depth is usually between 65 and 100mm. However, when chemical additives such as Portland cement, lime, and fly ash are used, the CIR depth can be extended to 150 mm. In some cases where there is reflective cracking, a minimum depth of 70 % of the full depth of the existing pavement is required to be milled to mitigate reflective cracking (Davidson et al, 2003).

Chemical additives are used to improve the early strength, reduce moisture damage, and achieve rapid curing of the recycled material; hence, allowing the road to remain unaffected by traffic before being overlaid with HMA or a Seal Coat (Mo et al, 2012). The construction process diagram for CIR is shown in Figure (1).

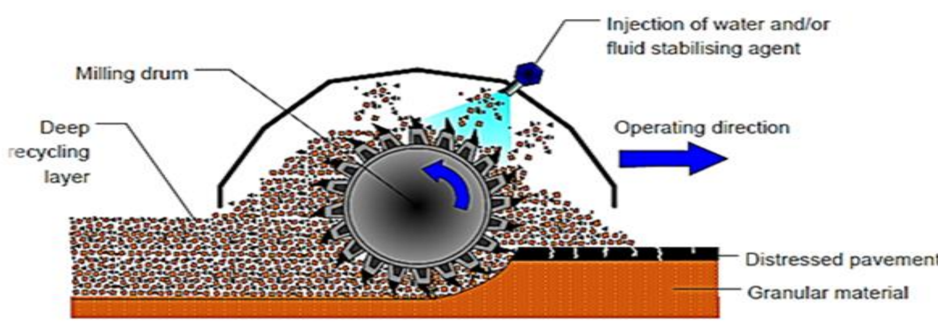

Figure 1CIR Field Placement Process Diagram (Wirtgen, 2001)

Emulsifying agents are chemicals that are used to stabilize the suspension of asphalt in water. The emulsified agents contain about 40% water and 60% asphalt (Abiodun, 2014). This ratio is important to obtain the maximum density, stability and air voids for the mixture (Kazmierowski et al, 1999). Some countries use the modified Marshall method for mixture design, the mixture design contains 3% water (consisting of emulsion water, RAP water content (0.3%) and additional water added to the mixture), and 2.5 to 4.5% by weight of the total mixture is asphalt emulsion. The volume fraction of air voids should be between 9 and 14 %, which is considered the only design criterion for optimum asphalt emulsion content in this modified method (Kavussi & Modarres, 2010). According to the Ministry of Transportation Ontario (MTO) Laboratory Standard (LS-300) the total liquid content (including emulsion or water) that is added to mixes is 4.5% asphalt cement (MTO-LS, 1996). According to Ontario Provincial Standard Specification, (OPSS. PROV 333), the design fraction of the emulsified asphalt shall be a minimum of 1.2% of the mass of the RAP material.

The emulsified agent provides the right setting time, makes emulsification easier by reducing the interfacial tension between the asphalt and water, determines the charge on emulsion droplets, and influences the physical properties of the emulsion (Read et al, 2003). CIR presents two major limitations: the weather requirements during the application and curing periods. CIR has advantages such as ease of processing, a wide availability in the industry, a low temperature during the process, good resistance to deformation, and a wide availability of standard test methods and specifications. However, there are some disadvantages associated with it: it is expensive (some of the emulsifiers are expensive as is transporting the water), and the curing time is long, hence, the development of the strength is slow (Bhavsar, 2015). CIR presents two major limitations: the weather requirements during application and curing periods. CIR has to be carried out in dry and warm weather (Kazmierowski et al., 1999); and the Ministry of Transportation Ontario (MTO) specifies a minimum 14-day curing period for CIR to meet the requirements in terms of compaction and moisture before application of the HMA overlay.

A combination of cementitious and asphalt stabilizing agents is thought to be efficient (Jitareekul, 2009). The most commonly used cementitious stabilizing agents are Portland cement, lime, and fly ash. Niazi and Jalili (2009) conducted an experiment to study the effect of Portland cement on the properties of CIR mixtures. Different Portland cement percentages were used (0, 0.5, 1, 1.5, and 2). The results showed that Portland cement can increase tensile strength and Marshall Stability, resistance to moisture damage, resilient modulus, and resistance to permanent deformation of CIR mixes. The increase in stability and strength of the pavement mixture are linked to the shorter curing time that is needed since the Portland cement reduces the breaking time of asphalt emulsions. Furthermore, it was found that the use of 2% Portland cement resulted in the highest resilient modulus value since Portland cement stiffens the binder. Material and Mix design

2.1 Material Collection and Preparation

The reclaimed asphalt concrete mixture used in this research was a Southern Ontario RAP. This RAP was first air dried for 72 hours in order to decrease the moisture. Then, extraction and pentation tests were performed to determine the percent of asphalt binder in the RAP and the stiffness of the binder. The extraction and penetration tests were performed in accordance with MTO Laboratory standard method LS-282 (MTO-LS, 2009). Higher values of penetration mean a softer binder consistency. Value of 11 mm correspond to a very stiff binder consistency (Pavement Interactive, 2007).

The RAP material mainly consisted of crushed rock material, trap rock, limestone and some gravel. The gradation of the mixture was determined following [ASTM C136] standard test method. The gradation is presented in Figure (2). These materials have a maximum aggregate size of 16 mm (OPSS 1150, 2010)

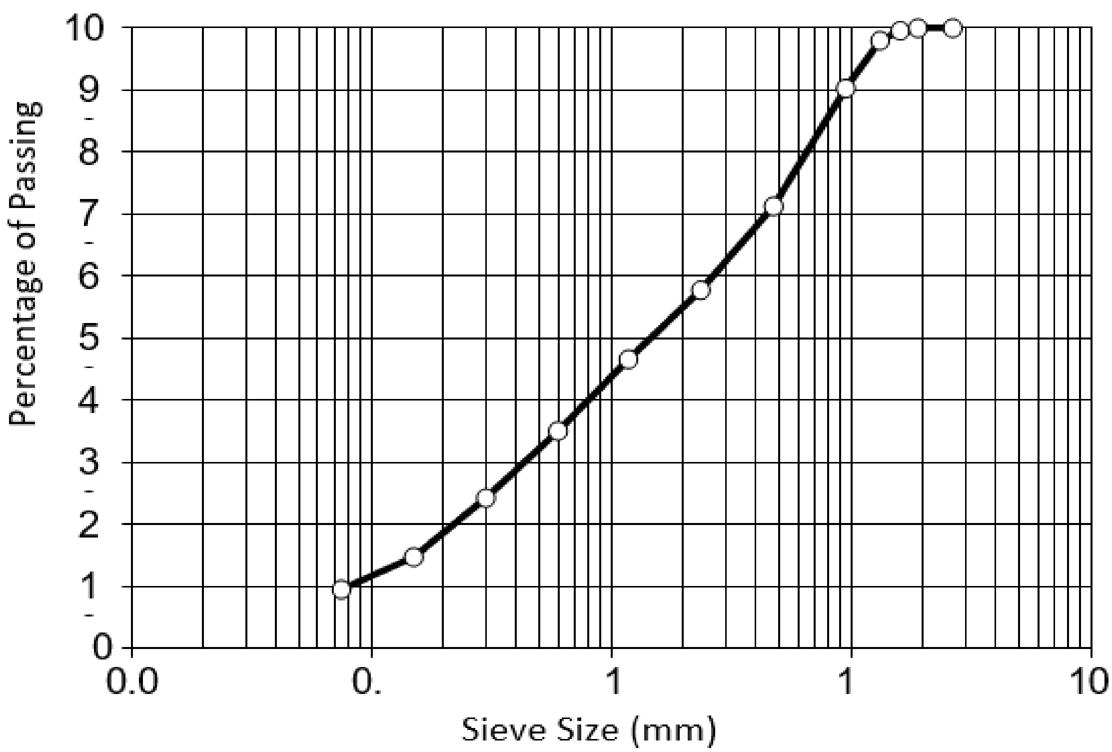

Figure 2 Gradation of CIR Mixture

2.2 Mix Design Preparation

To determine the optimum emulsion percentage to obtain a mixture with the properties of a new asphalt concrete, there are different methods for mixture design of cold-in-place recycled asphalt concrete (Rogge et al. 1992). The most commonly used is the modified Marshall method. This method was used in this study.

4500 gm of RAP material was prepared and put in an oven at 40°C for an hour and then water was added such that the total final liquid content of the mixture was 4.5% of the dry weight. Then Cationic Slow Setting emulsion-CSS-1H was added to the mixture and put in the oven to cure for 1 hour at 40 °C. Mixes with five different percentages of emulsion were prepared. The percentages of emulsion were 2.5%, 3%, 3.5%, 4% and 4.5% of the mass of the reclaimed aggregate in increments of 0.5% AC. 500 gm of the cured RAP material was taken for moisture content measurement and its mass was recorded to the nearest 0.1 gm. Three replicates for each mix were prepared using a modified Marshall procedure to produce specimens with a height of 63 mm. 50 blows per side were applied using a mechanical compactor. The specimens were then placed in an oven for 24 hours at 40 °C and re-compacted in the same order as previously with 25 blows on each side. Finally, the molded specimens were placed on their side in the oven for 24 hours at 40 °C. The mixes were all constructed in accordance with MTO LS-300 (MTO-LS, 1996) for CIR. Then, the bulk density of the specimens was measured using [ASTM D 2726], the maximum theoretical density of the mixtures was measured using [ASTM D2041, 2041], and the air voids content of the specimens was calculated. Then, the Marshall stability of the specimens was measured. Figure 3(a, b, c, d and e) shows mix design requirements: the air voids, dry stability, bulk relative density, dry flow, maximum relative density, wet stability, ratio stability (dry/wet), and wet flow number, with emulsified asphalt content. The Marshall Stability and flow test provide a performance prediction measure for the Marshall Mix design method. The stability portion of the test measures the maximum load supported by the test specimen at a loading rate of 50.8 mm/minute as shown in Figure (4). The flow value was recorded in 0.25 mm increments at the same time the maximum load was recorded. Based on the mix designs, a 3.8% Emulsion content has met the CIR mix design requirements with air voids of 12.56%, stability of 27920 N, and a flow number of 24.

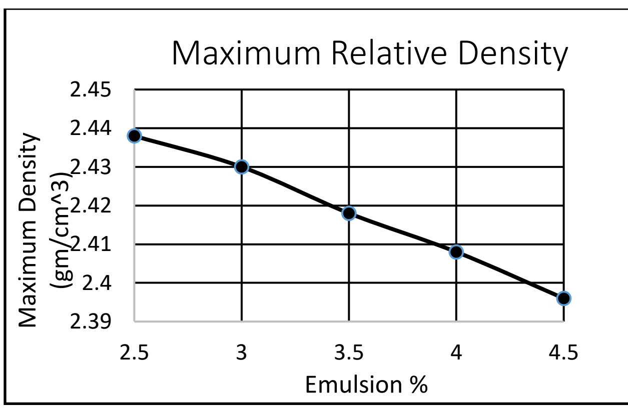

Figure 3 *(a)*

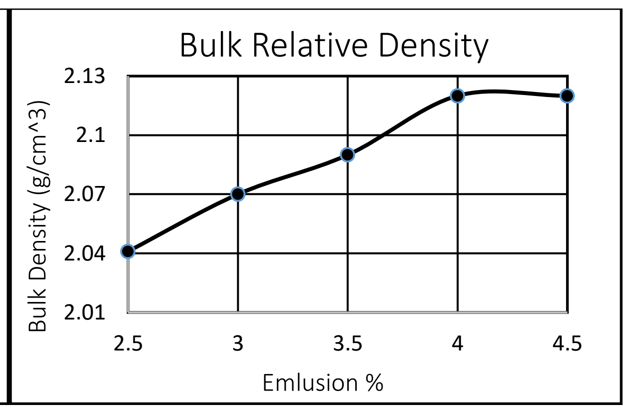

Figure *3 (b)*

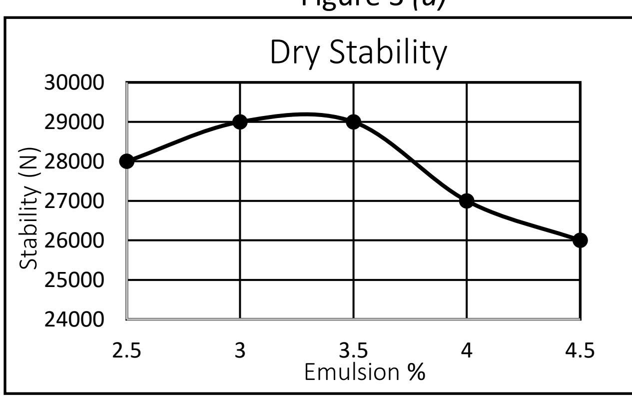

Figure *3 (c)*

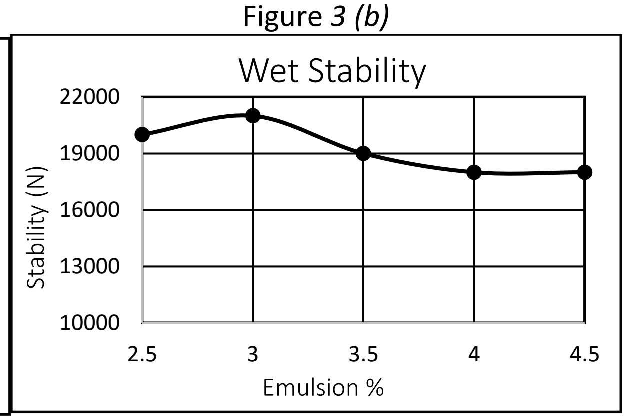

Figure *3 (d)*

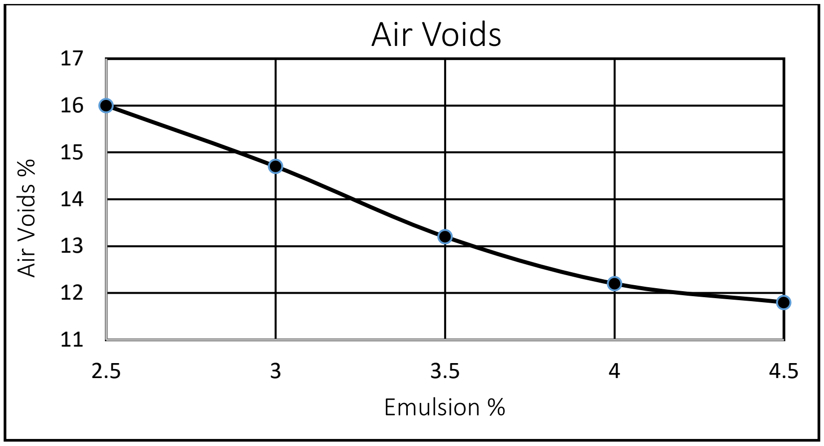

Figure *3 (e)*

Figure 3 (a,b,c,d and e) Mix Design Requirements

Furthermore, after the optimum emulsion content had been determined, different percentages of Portland cement (0%, 0.25%, 0.5%, 0.75%, 1.5% and 3%) were added to the mixture. The Specimens were made using a Superpave gyratory compactor. The vertical stress level and the angle of gyration for compacting the specimens, were selected to be 600kPa, and 1.25˚, respectively. After compaction, the specimens were cured for one day at room temperature and, then at 40˚C for a duration of 2 days in the oven.

Figure 4 Marshall Stability Test

3. Experimental program

3.1 Indirect Tensile Test

The tensile strength of the asphalt mixtures was evaluated by loading a specimen along a diametral plane. This loading is applied at a constant compressive loading rate using two strips on opposite sides. A relatively uniform tensile stress develops perpendicular to the direction of the applied load and causes the specimen to fail by splitting along the vertical diameter. The static indirect tensile strength of a specimen was determined using the procedure outlined in [ASTM D 6931]. A loading rate of 50.8 mm/minute was adopted. The test set up is shown in Figure (5). The maximum force required for failing the specimen was monitored, and, the tensile strength of the mixtures was calculated using Equation (1).

:

$$ITS = \frac{2000*P}{\pi*t*D} \quad (1)$$

where

St = IDT strength, kPa

P = maximum load, N

t = specimen height immediately before test, mm, and D = specimen diameter, mm

Figure 5 Indirect Tensile Test Set up

In total, 36 specimens were prepared and compacted using a Superpave Gyratory Compactor in the CPATT lab. These 36 specimens were divided into six groups. Each group of the six groups contained of 6 specimens containing 0%, 0.25%, 0.5%, 0.75%, 1.5%, and 3% Portland cement by weight of the total mix. The group that contained 0% of Portland cement served as a control. The mixes were compacted using a SuperPave Gyrotry Compactor to achieve an air voids content of 7%. Also, in each group, three specimens were non-conditioned (dry), and the other three remaining conditioned in water at 25 ˚C for 24 hours to measure the water susceptibility of the mixtures.

3.2 Dynamic Modulus

The main objective of utilizing a dynamic modulus test is to evaluate the CIR mixtures properties under different temperatures and frequencies and to observe the effect of the emulsion type on their stiffness. The specimens were prepared and compacted using the Superpave Gyratory Compactor in the CPATT lab. The specimens were compacted with target air voids values of 8 % ± 0.5 %, which came down to about 7% ± 0.5 % once the samples were cored and cut. The compacted specimens were kept at room temperature for 24 hours to allow the mixture to lose moisture and gain strength. After that, the specimens were put in an oven at 60 ^{o}C for 48 hours.

Tests were performed on all the mixes with their different dosages of Portland cement (0%, 0.25 %, 0.5%, 0.75%, 1.5% and 3%) according to the procedure given in AASHTO TP 6207, Standard Test Method for Determining Dynamic Modulus of Hot-Mix Asphalt Concrete Mixtures. The test specimens were subjected to a repetitive, compressive, sinusoidal loading. Three Linear Variable Differential Transducers (LVDTs) were used to measure the deformation of test specimen. Each specimen was examined at six loading frequencies (0.1, 0.5, 1.0, 5.0, 10.0 and 25 Hz) and five temperatures (-10, 4, 21, 37, and 54 ˚C). For each temperature, the specimens were conditioned and then subjected to compression loading at the six frequencies. The test set up is shown in Figure (6).

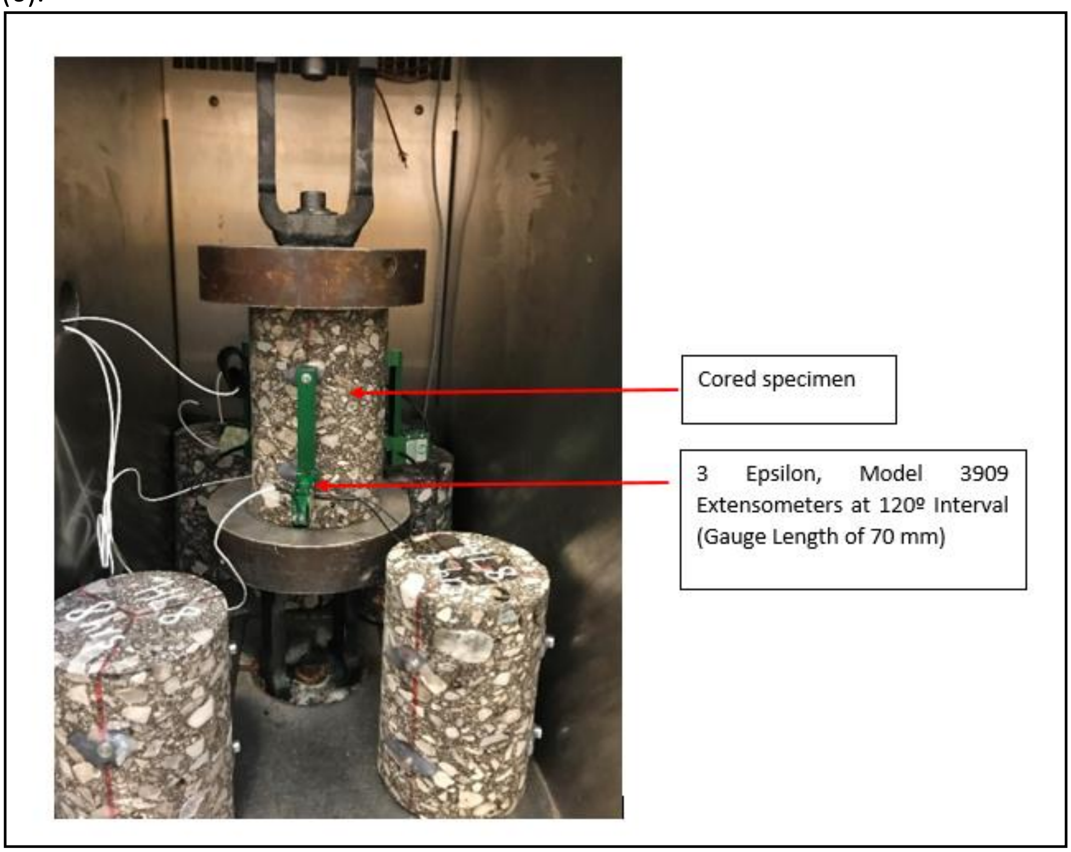

Figure 6 Dynamic Modulus Set up

4. Tests Results Analysis and Discussion

Figure (7) shows the variation of the indirect tensile strength with the variation of cement content. It is clearly shown that as the percentage of Portland cement increases the indirect tensile strength increases and the Poisson's ratio decreases. As can be seen from Figure (7) the indirect tensile strength for the non-conditioned specimens (dry) containing 0.25%, 0.5%, 0.75%, 1.5% and 3% Portland cement increased by 3%, 8%, 19.5%, 25.5% and 31% of the control sample strength, respectively.

Also, the ratios of indirect tensile tests (wet /dry) are shown in Figure (8). It is clearly shown that as the Portland cement increases, the ratio increases. Moreover, it is worthy of mention that the ratio exceeded 50%, which indicates that the mixture met the requirement for indirect tensile strength. This is due to the fact that as the percentage of Portland cement increases, the mixtures become stiffer and less ductile. Furthermore, two modes of failure were observed. Some of the specimens failed by developing cracks along the diameter of the specimen, and others failed due to excessive deformation near the loading strip and cracking in the central section of the specimen as shown in Figure (9).

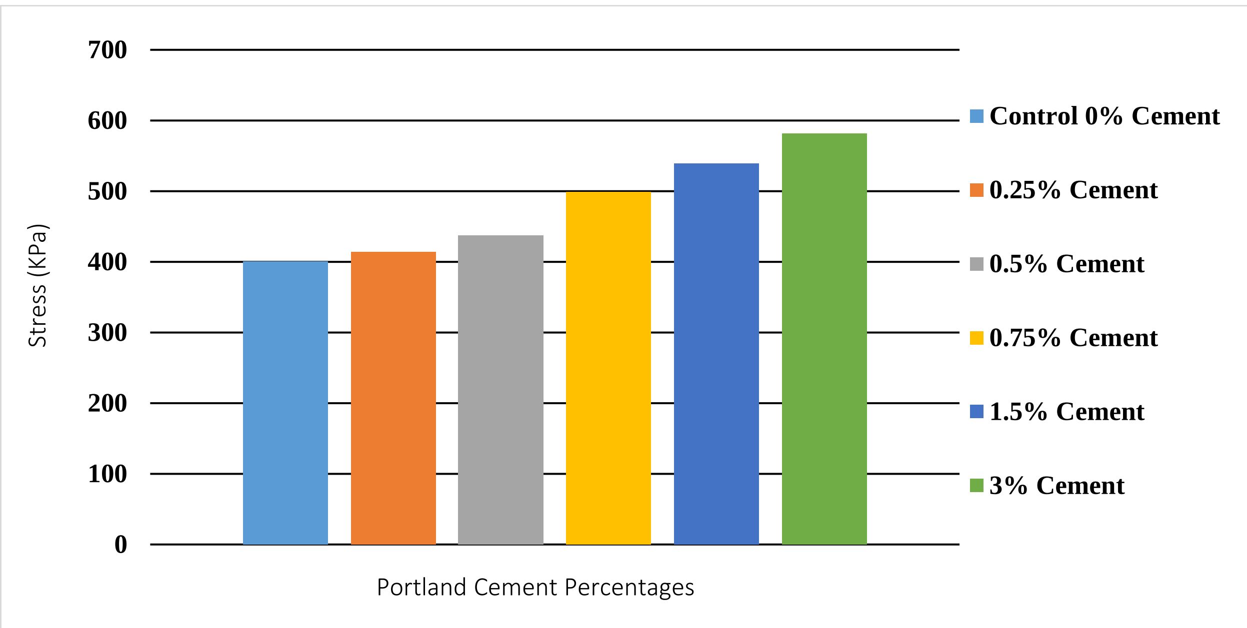

Figure 7 Indirect Tensile Strength of the Cement Stabilized Recycled Asphalt

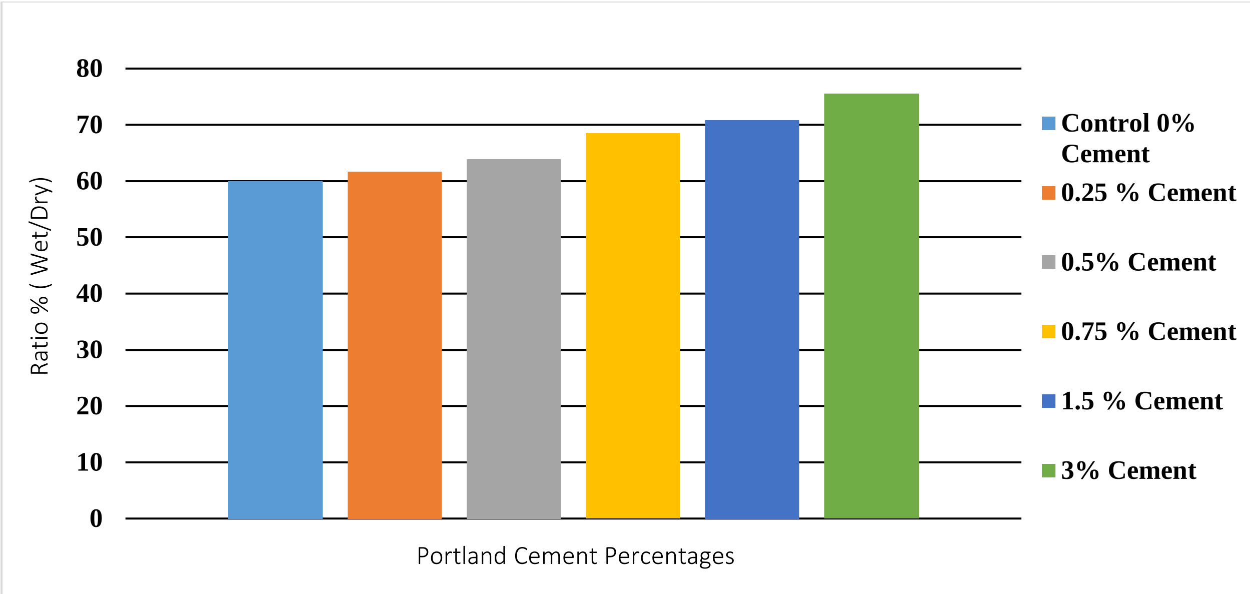

Figure 8 Ratio (Wet/Dry) of Indirect Tensile Strength of the Cement Stabilized Recycled Asphalt

Figure 9 Mode of Faliure of Indirect Tensile Specimens

Figure (10) shows a Master Curve for the Dynamic modulus test results. As can be seen, the results show that the Dynamic modulus of the mixtures increases with increasing cement content and decreases with increasing temperature.

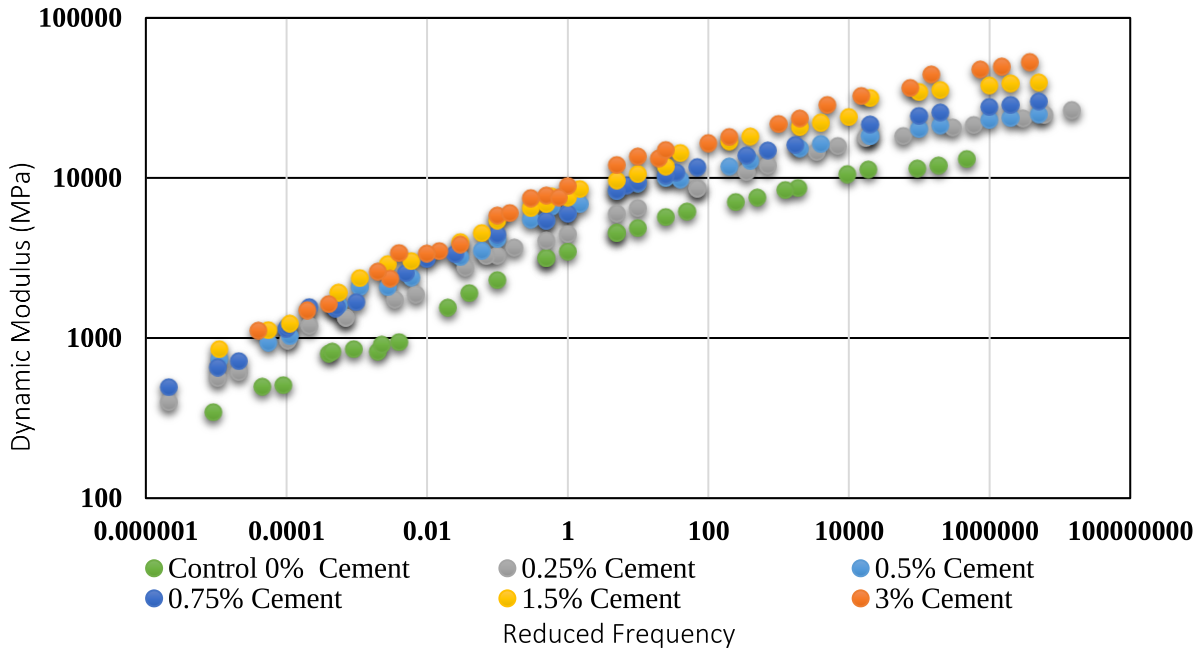

Figure 10 Master Curve of CIR Specimens with different Portland Cement Percentage

Adding more cement to the mixture leads to a cementation effect which increases the bond between the aggregate particles resulting in an increasing the stiffness of the mixtures. Also, as the temperature decreases, the emulsion stiffness increases, which results in an increase in the stiffness of the mixtures. Furthermore, it can be noted that as the temperature decreases, the rate of variation of the stiffness with cement content increases. That indicates that the effect of Portland cement on the stiffness is more dominant at low temperatures. However, as the temperature increases, the emulsion becomes softer and the stiffness of the mixture is affected by the emulsion mortar. Therefore, the addition of Portland cement is less effective in increasing the stiffness.

As it is difficult to visualize the differences between the samples in the log-log master curve, Figure (11) was used to better represent the influence of the cement on the stiffness. Each ratio value represents the stiffness of the mix with 3% cement (called E3%) divided by the stiffness of the control mix (called EControl). Figure (11) clearly shows that the complex modulus value for the mixes with 3% cement is approximately four times higher than that of control mixes.

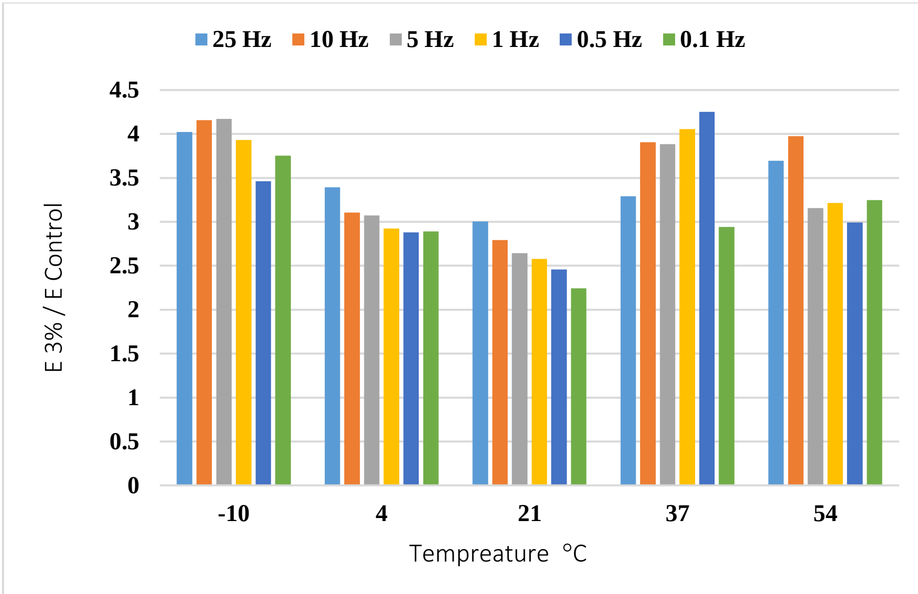

Figure 11 Modulus Ratio Value (E3%/ E control) of the Tested Mixes

Similarly, Figure (12) shows the effect on the ratio (E0.25 cement /EControl) of adding 0.25% cement to the mixture. Each ratio value represents the stiffness of the mix with 0.25% cement (called E0.25%) divided by the stiffness of the control mix (called EControl). It is shown that adding 0.25% cement led to an increase of the stiffness to approximately twice that of the control mixes.

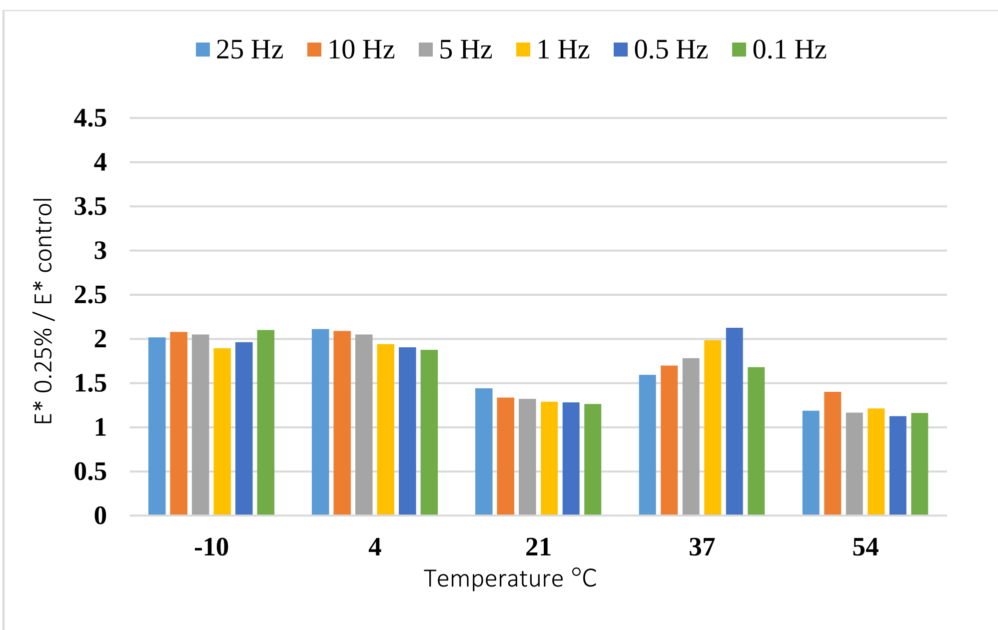

Figure 12 Modulus Ratio Value (E 0.25 %/ E control) of the Tested Mixes

Finally, Figure (13) shows the ratio of E3% cement and E1.5% cement. It is obvious that there is an increase in the stiffness of the mixes with 3% cement as compared with the one with 1.5% cement. The increase of the stiffness terminated at approximately 1.5 %. . Figure 13 shows that at least at 54C the increase is 30% or more.

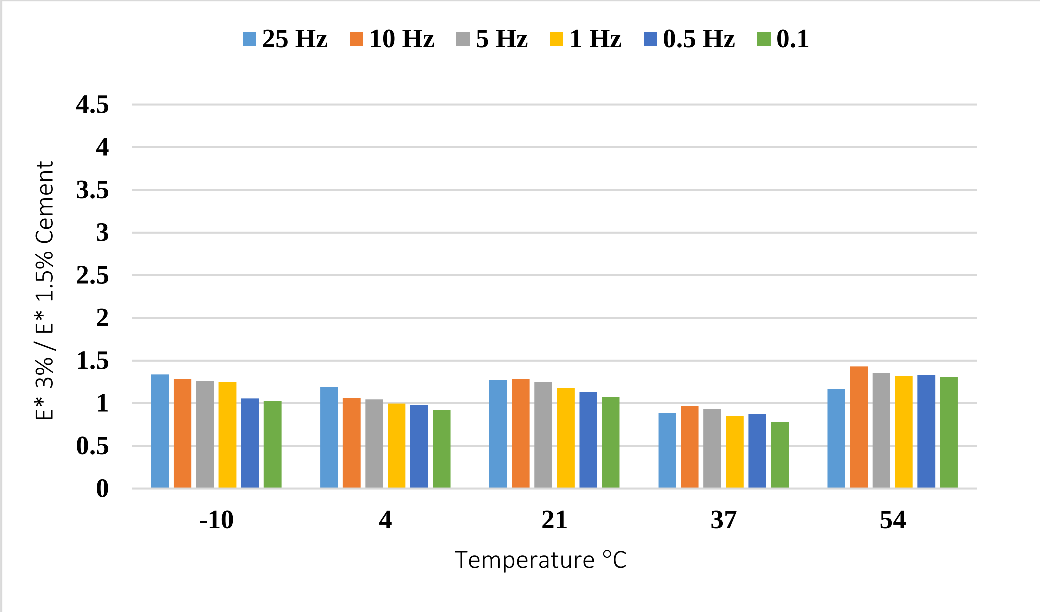

Figure 13 Modulus Ratio Value (E 3 %/ E1.5) of the Tested Mixes

5. Conclusion

Experiments were conducted on specimens made from reclaimed asphalt concrete mixed with an optimum emulsified asphalt at various cement contents. The following conclusions can be drawn from this study.

1- The indirect tensile strength of the mixtures increases with increasing cement content.
2- The ratio of indirect tensile tests (wet /dry) increases with increasing cement content
3- The stiffness of the mixtures increases with increasing the cement content up to 1.5 % and decreasing temperature.

6. References

Abiodun, S. (2014). Cold In-Place Recycling with Expanded Asphalt Mix (CIREAM).

Alkins, A., Lane, B., & Kazmierowski, T. (2008). Sustainable Pavements: Environmental, Economic, and Social Benefits of In Situ Pavement Recycling. Transportation Research Record: Journal of the Transportation Research Board, (2084), 100-103.

ASTM. (2014). Standard test method for sieve analysis of fine and coarse aggregates; (2014) ASTM C136.

ASTM. (2012). Standard Test Method for Indirect Tensile (IDT) Strength of Bituminous Mixtures; ASTM D6931-12. West Conshohocken, PA.

ASTM. (2003). Standard test method for Theoretical Maximum Specific Gravity and Density of Asphalt Mixtures; (2003) ASTM D2041/D2041M.

Bhavsar, J. (2015). Comparing Cold In-Place Recycling (CIR) and Cold In-Place Recycling with Expanded Asphalt Mixture (CIREAM).

Chesner, W., Stein, C., Justus, H., Kearney, E., & Cross, S. (2011). Evaluation of Factors Affecting Long-term Performance of Cold in-Place Recycled Pavements in New York State. Transportation Research Record: Journal of the Transportation Research Board, (2227), 13-22.

Davidson, J. Keith, and Jean-Martin Croteau. (2003). Best practices in cold in-place recycling. Proceedings of Annual Meeting Asphalt Emulsion Manufacturers Association, Nashville, USA. 2003.

Jitareekul, P. (2009). An Investigation into Cold In-Place Recycling of Asphalt Pavements. The University of Nottingham: Nottingham, UK.

Johnson, A. M. (2000). Best practices handbook on asphalt pavement maintenance (No. MN/RC-2000-04).

Kavussi, A., & Modarres, A. (2010). A Model for Resilient Modulus Determination of Recycled Mixes with Bitumen Emulsion and Cement from ITS Testing Results. Construction and Building Materials, 24(11), 2252-2259.

Kazmierowski, T., Marks, P., & Lee, S. (1999). Ten-year Performance Review of In-Situ Hot-Mix Recycling in Ontario. Transportation Research Record: Journal of the Transportation Research Board, (1684), 194-202.

Lewis, A. J. N., & Collings, D. C. (1999). Cold In-Place Recycling: A Relevant Process for Road Rehabilitation and Upgrading. In CAPSA 99, 7 th Conference on Asphalt Pavements for Southern Africa (pp. 1-11).

Lane, B., & Lee, W. (2014). Comparing 10 Year Performance of Cold In-Place Recycling (CIR) with Emulsion versus CIR with Expanded Asphalt on Highway 7, Perth, Ontario. Transportation Association of Canada.

Mo, L., Li, X., Fang, X., Huurman, M., & Wu, S. (2012). Laboratory Investigation of Compaction Characteristics and Performance of Warm mix Asphalt Containing Chemical Additives. Construction and Building Materials, 37, 239-247

MTO-LS. (1996). Preparation of Marshall Specimens for Cold In-Place Recycled Mixtures; MTO LS-300.Ontario.

MTO-LS. (2009). Quantitative Extraction of Asphalt Cement and Analysis of Extracted Aggregate from Bituminous Paving Mixtures; MTO LS-282. Ontario.

MTO-LS. (1996). Preparation of Marshall Specimens for Cold In-Place Recycled Mixtures; MTO LS-300. Ontario.

Niazi, Y., & Jalili, M. (2009). Effect of Portland Cement and Lime Additives on Properties of Cold In-Place Recycled Mixtures with Asphalt Emulsion. Construction and Building Materials, 23(3), 1338-1343.

Ontario Provincial Standard Specification (OPSS 333), (2007), No author given, "Construction Specification for Cold In-place Recycling," Ministry of Transportation Ontario.

OPSS 1150. (2010). Material Specification for Hot Mix Asphalt. Ontario Provincial Standard Specification.

Wirtgen. (2004). Wirtgen Cold Recycling Manual (2 nd).Windhagen, Germany: Wirtgen Group.

Pavement Interactive. (2007, August 16). Materials: Penetration Grading. Retrieved from Pavement Interactive: http://www.pavementinteractive.org/article/penetration-grading/

Read, J., & Whiteoak, D. (2003). The Shell Bitumen Handbook. Thomas Telford.