Building Tomorrow's Society

*Bâtir la Société de Demain*

Fredericton, Canada

June 13 – June 16, 2018/ *Juin 13 – Juin 16, 2018*

# INVESTIGATION OF TREATED CRCA IN HMA MIXTURES THROUGH EVALUATING LOW TEMPERATURE CRACKING

Al-Bayati, Hanaa Kh[1,3], Tighe, Susan[2]
1 PhD Candidate, Centre for Pavement and Transportation Technology (CPATT), Department of Civil and Environmental Engineering, Faculty of Engineering, University of Waterloo, Waterloo, Canada
2 Canadian Society for Civil Engineering, Norman W. McLeod Professor in Sustainable Pavement Engineering, Director of Centre for Pavement and Transportation Technology (CPATT), Department of Civil and Environmental Engineering, Faculty of Engineering, University of Waterloo, Canada
3 halwan@uwaterloo.ca

**Abstract:** One of the most important concerns for asphalt pavement in the cold regions of the world is the prospect of thermal cracks or low-temperature cracks. This is mainly attributed to the development of stresses, which exceed the pavement strength, leading to pavement cracking at extremely low temperatures. To evaluate the performance at low temperatures, the thermal stress restrained specimen test (TSRST) is performed to assess the influence of (CRCA) addition into asphalt mixtures based on Ontario Superpave specifications. The effect of different CRCA types with various proportions on the fracture stress and fracture temperature of asphalt mixtures is also examined. To achieve the objective, two different types of CRCA with various percentages (0%, 15%, and 30%) were chosen. The impact of treated CRCA on the behaviour of asphalt mixtures at low temperatures is further evaluated by applying combinations of various treatment methods. Heat treatment at 300°C followed by a short mechanical treatment is applied to enhance the physical and mechanical properties of CRCA. The application of the combination technique of heat treatment at 300 °C and short mechanical treatment method is very successful in improving various RCA properties. The addition of both CRCA types into the asphalt mixtures at various proportions is successful in achieving all MTO requirements for volumetric properties. While the application of the combination of various treatments leads to a significant reduction in the average fracture temperature, there is no impact for this technique on the fracture stress of the asphalt mixtures.

## 1 INTRODUCTION

Asphalt concrete is the basic material utilized in road construction worldwide (TAC 2013). Generally, it consists of approximately 95% aggregate and 5% asphalt material. According to the ministry of natural resources Ontario (MNRO), the average consumption of aggregate reached approximately 179 million tonnes per year in Ontario during the period 2000-2009, while this average is projected to amount to approximately 191 million tonnes between 2020 and 2029 (MNR 2010). Simultaneously, waste materials are increasing with the growth in the population due to rising demand for new highways, commercial buildings, housing developments, and infrastructure projects. This results in tremendous amounts of waste ending up in landfills every year. Due to considerable consumption and economic growth, the required natural resources will not only be depleted but will eventually be exhausted (Bolden 2013).

To reduce the exhaustion of natural materials, reduce waste materials in landfills and minimize environmental concerns, the application of waste materials in asphalt mixtures is becoming increasingly utilized worldwide. Among different waste materials, recycled concrete aggregate (RCA) is the main waste material that has been successfully applied in base aggregates and Portland cement concrete (PCC) aggregates. However, there were limited investigations into the utilization of RCA in the asphalt pavement mixtures (Mills-Beale & You 2010) due to the poor quality of RCA characteristics compared to natural aggregate (NA). Such properties include high water absorption, low density, and high porosity that result from the existence of adhered mortar on the RCA surface (Zhang et al. 2016). Recently, the use of RCA in the asphalt mixtures has become an attractive topic for many researchers worldwide (Shen & Du 2004, Paranavithana & Mohajerani 2006, Wong et al. 2007, Du & Shen 2007, Pérez et al. 2009, Wu et al. 2013, Pasandín & Pérez 2014, Radević et al. 2017). The successful use of RCA in the base and sub-base applications is the main reason behind examining the feasibility of using RCA in asphalt mixtures. It is believed that the problem correlated with RCA can be eliminated through the coating of RCA particles with a layer of asphalt cement (Zhang et al. 2016).

## 2 LITERATURE REVIEW

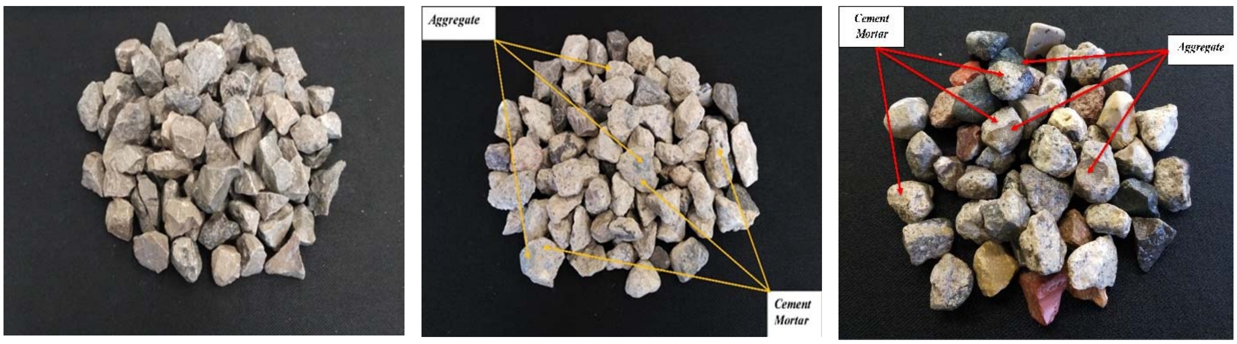
One of the most widespread concerns of asphalt pavements in the cold regions of the world is thermal cracks or low temperature cracks (Velasquez et al. 2008, Tan et al. 2012, Akentuna et al. 2016). At low temperature, the upper part of the pavement section is contracted, whereas the granular base holds the pavement's bottom section in place and prevents it from contraction ((http://dotapp7.dot.pdf). Then, when the developed stresses exceed the strength of the pavement (Tim 1995, Akentuna et al. 2016, Liu et al. 2017), the low-temperature cracks occur. Low-temperature cracks are the main cause of pavement degradation, increasing pavement roughness and reducing service life in the northern climates (http://dotapp7.dot.pdf). As previously mentioned, various studies have been conducted to investigate the use of RCA in hot mix asphalt (HMA) mixtures. Pérez et al. (2009) evaluated the resistance of asphalt mixtures that included RCA with NA aggregate with respect to fatigue cracking. Two different mixtures, a semi-dense mixture and a coarse mixture were used, and one type of RCA was used to prepare various HMA mixtures. Fatigue tests and dynamic modulus tests were performed to evaluate the asphalt mixtures. The results revealed that the fatigue behaviour for the coarse mixture with 50% RCA is similar to the behaviour of the same mixture without RCA. Additionally, the semi-dense mixture with 50% RCA had lower fatigue behaviour compared to the same mixture without RCA. The findings also indicated that the mixture that included RCA had a higher dynamic modulus than mixtures without RCA. The study concluded that the addition of RCA leads to an increase in the stiffness of a HMA mixture even if a large amount of bitumen is used. Zhu et al. (2012) concluded that the addition of CRCA without treatment causes poor moisture resistance and low temperature flexibility. The addition of treated CRCA, using pre-coating method by using liquid silicone resin, works to improve these properties. The addition of treated CRCA improves strength, absorption and adhesion with asphalt while it has a negative effect on permanent deformation at high temperature. However, mixture properties at high temperatures are still acceptable.

From the literature study, it can be stated that most of the previous research was mainly focused on the effect of untreated RCA on the mechanical properties of HMA mixtures such as stability, stiffness, moisture resistance, and dynamic modulus. Though a few studies were conducted for evaluating the thermal cracks in the HMA mixes, none of the above-mentioned investigations considered the effect of treated RCA on the thermal cracking resistance of asphalt mixes. In this study, experiments were set up to investigate the thermal crack susceptibility of the asphalt mixture samples containing CRCA using a thermal stress restrained specimen test (TSRST). The main objectives of this investigation are carried out in two phases. In the first phase, the effects of different untreated CRCA types with various proportions on the fracture stress and the fracture temperature of the typical Ontario HMA mixtures are investigated. Heat treatment at 300°C followed by a short mechanical treatment were performed to enhance the physical and mechanical properties of CRCA, then the influence of treated CRCA on the fractural temperature and the fractural stress of asphalt mixtures is examined in the second phase. A complementary objective for the second phase is that the impact of the combination of various treatment methods on the main RCA properties is further evaluated.

## 3 MATERIALS AND METHODS

### 3.1 Material

NA and one filler type that is commonly utilized for preparing asphalt mixtures; namely, dust plant, were obtained from the Miller Group and one type of asphalt binder, namely, PG 64-28 was used. In this research, two different RCA types were utilized, RCA#1 was provided from a ready-mix concrete plant through the crushing process of concrete that has unsatisfactory properties, performance, and age. Hence, RCA#1 can be categorized as fresh concrete that has not been used in civil engineering works. The second type, RCA#2, is classified as a granular A according to the Ontario provincial standard specifications (OPSS.MUNI 1010). RCA#2 was produced by Steed and Evans Limited in St. Jacobs, Ontario. In this study, CRCA is defined as the sieve fraction retained between 4.75 and 19 mm. The optical images of NA, RCA#1 & RCA#2 are shown in Figure 1-a, b, and c, respectively.




1-a. NA 1-b. RCA#1 1-c. RCA#2

Figure 1: Optical images of NA & RCA types

### 3.2 Methods

#### 3.2.1 Preparation of treated and untreated CRCA

All CRCA types were washed thoroughly so that all noticeable impurities such as wood chips and others were removed. Then, the CRCA was dried in an oven at 105±5°C for 24 hr before undergoing various types of treatments and tests. The untreated CRCA tests were performed at room temperature (20°C), whereas the CRCA was heated at 300 °C for 1 hr to achieve the heat treatment. For the short mechanical treatment, the CRCA samples were placed in a Micro-Deval device for 15 minutes under the effect of metal balls. Then the samples were sieved with a 4.75 mm sieve to ensure that only the coarse aggregate was retained.

#### 3.2.2 Superpave mix design

The Superpave mix design was performed according to AASHTO R 30-02 (2006). The design is equivalent to a single-axle load ranging between 10 and 30 million. Superpave mixture design procedure was carried out based on the nominal maximum aggregate size (NMAS), 19 mm. For the included untreated CRCA#1 and CRCA#2 mixtures, three proportions (0%, 15%, and 30%) and one percentage (30%), respectively, were added as a partial substitute for coarse NA. For the included treated CRCA, one portion of CRCA#1, (30%) was used. The gradation of virgin aggregate and various percentages of CRCA, targeted the mix design of Miller group, and ministry transportation Ontario (MTO) specifications are numerically tabulated in Table 1.

Table 1. Gradations with various CRCA proportions, targeted mix design, and MTO Specifications

| Sieve Size | Passing (%) for Different CRCA Percentages | | | | Target of | MTO |
|---|---|---|---|---|---|---|
| mm | 0.0 | 15%CRCA#1 | 30%CRCA#1 | 30%CRCA#2 | Mix Design | Limitation |
| 25 | 100 | 100 | 100.0 | 100 | 100 | 100 |

| Sieve Size | Passing (%) for Different CRCA Percentages | | | | Target of | MTO |
|---|---|---|---|---|---|---|
| mm | 0.0 | 15%CRCA#1 | 30%CRCA#1 | 30%CRCA#2 | Mix Design | Limitation |
| 19 | 95.2 | 95.2 | 95.3 | 96.6 | 96.8 | 100 - 90 |
| 16 | 89.0 | 88.7 | 88.5 | 86.6 | 90.6 | 90 - 23 |
| 12.5 | 81.8 | 81.1 | 80.5 | 73.9 | 83 | |
| 9.5 | 73.2 | 72.3 | 71.8 | 67.8 | 73.3 | |
| 6.7 | 63.3 | 63.0 | 63.1 | 61.5 | 63.3 | |
| 4.75 | 57.1 | 56.7 | 55.9 | 56.0 | 55.9 | |
| 2.36 | 42.8 | 42.8 | 41.3 | 41.8 | 43.5 | 49 - 23 |
| 1.18 | 30.7 | 30.7 | 30.5 | 31.2 | 32.5 | |
| 0.6 | 22.9 | 23.0 | 23.6 | 24.3 | 25.1 | |
| 0.3 | 10.2 | 10.3 | 10.3 | 10.3 | 11.8 | |
| 0.15 | 5.4 | 5.5 | 5.6 | 5.5 | 5.5 | |
| 0.075 | 2.1 | 2.2 | 2.2 | 2.1 | 3.8 | 8 - 2 |

### 3.2.3 Preparation of TSRST Specimens

Based on AASHTO R 30-02 (2006), the loose HMA mixtures were exposed to a short-term condition at 135°C for a period of four hrs before compaction to simulate the plant mixing and placement effects. An asphalt shearbox compactor (PReSBOX) was used to compact the beam specimens that were approximately 390mm x150mm x130mm in length, height, and width, respectively. Then, the beams were saw-cut into TSRST specimens with approximate dimensions 250mm× 50mm × 50mm at air voids of 7±1% that represent the typical values for compaction (AASHTO TP 10-93 1993, NCHRP 2007). The TSRST test was performed in accordance with AASHTO TP 10-93 (1993). The test specimens were conditioned at 5°C in an environmental test chamber for six hrs before starting the test. An initial tensile load is applied to the compacted beam specimens. Simultaneously, the specimen is exposed to a constant cooling rate of -10ºC/hr and is restrained from the contraction by re-establishing the initial length of the specimen.

## 4 RESULTS AND DISCUSSION

### 4.1 Physical properties of NA and untreated CRCA

Table 2 reveals the obtained results of the physical and mechanical properties of NA and two different CRCA types. Generally, there is a considerable difference in the properties between the NA and both types of untreated CRCA. In terms of physical properties, namely, bulk relative density (BRD) and water absorption, a significant difference is registered between NA and untreated CRCA#1& 2. It is also indicated that a relative variation is observed in the physical properties between CRCA#1 and CRCA#2. It is also indicated that a relative variation is observed in the physical properties between CRCA#1 and CRCA#2. These findings confirm the outcomes of previous investigations which demonstrated that the absorption capacity of RCA is higher than NA (Ektas and Karacasu 2012, Butler et al. 2013a, Wu et al. 2013, Younis and Pilakoutas 2013, Pasandín and Pérez 2014, Singh et al. 2014). Adhered mortar, which has a higher porosity than NA, results in RCA being more susceptible to absorbing more water compared to NA (Tam et al. 2007). Hence, the presence of adhered mortar leads to increased water absorption, lowered density, and weaker bond strength (Wong et al. 2007). In the perspective of the mechanical properties, abrasion loss, adhered mortar loss, and aggregate crushing value, different observations can be indicated. Compared to CRCA#1, the outcomes indicate that the abrasion loss of CRCA#2 is significantly lower and closer to the NA value, indicating a strong type of CRCA. Such a strong type of CRCA has a lower quantity of attached mortar; therefore, the findings of the adhered mortar loss completely agree with the abrasion loss results. It is known that aggregate strength is an important factor in high-strength concrete and highly used pavements. Hence, the strength of Portland cement concrete aggregate and asphalt mixtures consider the importance of the influence of aggregate strength. According to British standards (BS) (882:1992), the aggregates could be possibly utilized in various applications depending on the maximum crushing values as in the following classifications: for a type with an aggregate crushing value (ACV) of less than 25%, this aggregate could be used in the production of heavy-duty concrete floor finishes. When the ACV value ranges between 25%-30%, this aggregate type could be utilized in the concrete used for pavement wearing surfaces. If the ACV value ranges between 30%-45%, this aggregate could be utilized in concrete used for other applications. Depending on the previous categories, the obtained findings indicate that NA and CRCA#2 can be used for heavy-duty concrete applications, whereas CRCA#1 can be utilized for pavement wearing layers.

Table 2: Physical and mechanical properties of NA and untreated CRCA types

| Aggregate Type | Bulk Relative Density (BRD) ASTM (C 127) | Absorption, % ASTM (C 127) | Adhered Mortar, % Without Steel Ball | Micro-Deval Abrasion Loss, % ASTM (D6928) | Fractured Particles, % ASTM (D5821) | Agg. Crushing Value Test (ACV) (BS 812-110) |
|---|---|---|---|---|---|---|
| NA | 2.658 | 0.8 | - | 15.89 | 95.5 | 19.48 |
| CRCA#1 | 2.295 | 5.91 | 3.02 | 23.57 | 89.9 | 27.42 |
| CRCA#2 | 2.421 | 3.74 | 1.08 | 16.03 | 95.72 | 23.28 |

## 4.2 Characteristics of treated CRCA

After applying the combination of heat treatment and short mechanical treatment, the main physical characteristics of CRCA are presented in Table 3. In general, it is obvious that a considerable improvement is registered for CRCA characteristics due to the application of a combination of different treatment methods. It is noted that the water absorption of CRCA significantly decreases from 5.91% to 4.13% due to the integration of heat treatment at 300 °C and mechanical method, indicating a successful treatment approach and recording a reduction of 30.12%. Simultaneously, a notable enhancement to the BRD characteristic is obtained. In terms of porosity, the laboratory results indicate that a significant reduction in the porosity is registered with an approximate reduction of 25.59%.

Table 3: Characteristics of treated and untreated CRCA

| Type of Property | Untreated CRCA | CRCA after Heat & Sh.M.T.* |
|---|---|---|
| Bulk Relative Density (BRD) | 2.295 | 2.447 |
| Absorption, % | 5.91 | 4.13 |
| Porosity, % | 13.56 | 10.092 |

Sh.M.T.* = Short mechanical treatment

## 4.3 Volumetric properties of asphalt mixture with CRCA addition

Table 4 shows the volumetric properties of different HMA mixtures that are prepared in this study. The laboratory results indicate that the mix design for various untreated CRCA#1 proportions (0%, 15%, 30%), untreated CRCA#2 (30%), and treated CRCA#1 (30%) successfully meet all the MTO requirements. As shown in Table 4 the optimum asphalt content (OAC) gradually increases with increasing untreated CRCA percentage. This is explained by untreated CRCA having a higher absorption capacity than NA due to the presence of adhered mortar. In contrast, there is a slight reduction in the bulk specific gravity (Gmb), voids in mineral aggregates (VMA), and voids filled with asphalt (VFA) of the mixes when increasing the CRCA proportion. In terms of the effect of the type of RCA on the volumetric properties of the asphalt mixtures, a considerable effect is registered for the type of RCA on these properties. For the same percentage of untreated CRCA addition, 30%, the asphalt mixture included CRCA#2 has a lower OAC than the mixture that included CRCA#1. In contrast, the asphalt mixture that included CRCA#2 has higher VMA and VFA values than the mixture that included CRCA#1. As a result, the volumetric properties of the asphalt mixture that included CRCA#2 are slightly better than the mixture that included CRCA#1. These outcomes correspond to the physical and mechanical property results. As previously shown in Table 2, CRCA#2 has a lower water absorption, higher BRD, and lower adhered mortar loss than CRCA#1. These findings have been confirmed by other researchers (Anderson & Bahia1997, Mills-Beale and You 2010, Bhusal & Wen 2011, Al-Bayati et al. 2018). The outcomes also demonstrate that there is an important decrease in the OAC for mixtures that included 30% treated CRCA compared to the mixture that included the same percentage of untreated CRCA. Additionally, a slight improvement is recorded for volumetric properties, VMA, VFA, and Gmb properties under the influence of the treatment approach for CRCA.

Table 4: Mix design volumetric properties for different CRCA percentages

| Aggregate Type / Property | 0 % CRCA | 15% Untreated CRCA#1 | 30% Untreated CRCA#1 | 30% CRCA#1 with Heating+ Sh.M.T.* | 30% Untreated CRCA#2 | Acceptable Limitations of MTO Specification |
|---|---|---|---|---|---|---|
| OAC AC (%) | 4.83 | 4.9 | 5.31 | 5.21 | 5.12 | - |
| VMA (%) | 14.5 | 13.6 | 13.66 | 13.88 | 14.0 | 13 min. |
| VFA (%) | 72.5 | 70.8 | 70.7 | 70.9 | 71.4 | 65-75 |
| Vv (%) | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 |
| $G_{mb}$ | 2.4 | 2.395 | 2.373 | 2.393 | 2.384 | - |

Sh.M.T.* = Short mechanical treatment

### 4.4 TSRST of asphalt mixtures with various CRCA proportions

The TSRST results reveal a considerable reduction (i.e. more negative) in the fracture temperature, indicating a greater resistance of the mixture to low-temperature thermal cracks. In Table 5, the tabulated outcomes illustrate that the variation in the CRCA proportions has an impact on the fracture thermal stress and the failure temperature. The average values of fracture temperature are plotted in Figure 2. Compared to the control mix, 0% CRCA, it is noted that the average fracture temperature is reduced due to the CRCA addition. The reason behind this can be explained by the fact that RCA has more microcracks than NA. Due to the presence of microcracks, the strength of RCA is lower than NA. In addition, the cement mortar particles may become brittle under the impact of low temperatures, which leads to a higher probability of failure (Wu et al. 2013). The maximum reduction of the fracture temperature was up to -2.6 °C more than the corresponding low-temperature performance grade of the respective asphalt binder used. It is important to note that there is no significant impact for the RCA type on the thermal cracks at low temperatures. While the average fracture temperature of the mixture that included 30% CRCA#1 is -25.6 °C, the average fracture temperature of the mixture that included the same percentage of CRCA#2 is -25.4 °C.

To evaluate the influence of RCA treatment on the thermal cracks, the average fracture temperatures of the mixtures that included untreated and treated CRCA#1 with the same proportion are presented in Figure 3. It is interesting to note that the combination of the heat treatment at 300 °C and short mechanical treatment leads to a considerable decrease in the average fracture temperature. The average fracture temperatures are -25.6 °C and -28.2 °C for the mixtures that included 30% untreated CRCA#1 and treated CRCA#1 at the same percentage, respectively. Interestingly, this obtained result meets the corresponding low-temperature performance grade, -28.0 °C, of the respective asphalt binder used. Hence, this treatment type appears to be highly successful in the low- temperature regions.

Table 4: Results of TSRST for different asphalt mixtures including CRCA

| Properties/Mixture Types | Control Mix, 0% CRCA | 15% CRCA#1 Untreated | 30% CRCA#1 Untreated | 30% CRCA#2 Untreated | 30% CRCA#1 with Heat Treatment |
|---|---|---|---|---|---|
| Binder PG | 64-28 | 64-28 | 64-28 | 64-28 | 64-28 |
| Fracture | -31.5 | -26.21 | -25.76 | -25.95 | -28.37 |
| Temperature, °C | -31.1 | -25.14 | -25.70 | -24.43 | -27.95 |
| | -28.1 | -24.80 | -25.41 | -25.86 | -28.27 |
| Average | **-30.2** | **-25.4** | **-25.6** | **-25.4** | **-28.2** |
| Fracture Stress, | 2.94 | 2.02 | 2.70 | 2.52 | 2.36 |
| MPa | 3.10 | 1.88 | 3.08 | 2.57 | 2.79 |
| | 1.57 | 1.65 | 2.76 | 2.63 | 3.18 |
| Average | **2.54** | **1.85** | **2.85** | **2.58** | **2.78** |

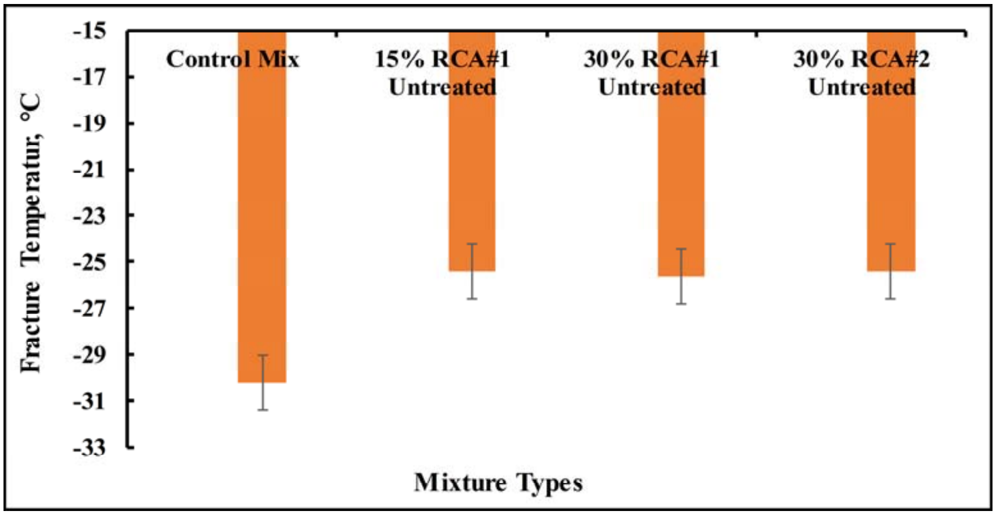



Figure 2: Fracture temperature of mixtures with different CRCA proportions and types

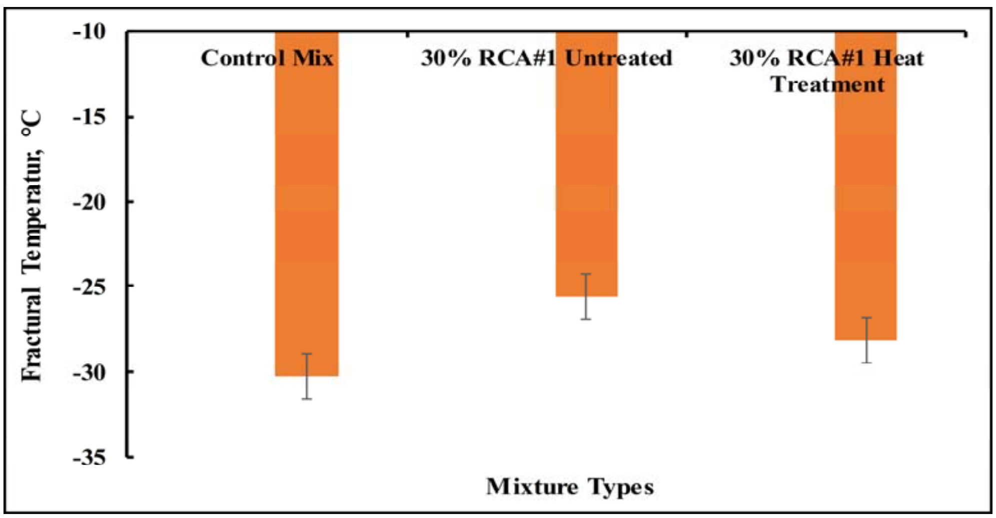



Figure 3: Fracture temperature of mixtures with treated and untreated CRCA#1

Figure 4 demonstrates the mean of the fracture stress for different asphalt mixtures. It is known that the higher value of the fracture stress refers to the largest resistance to the thermal cracks. The obtained results indicate that the fracture stress levels of the mixtures that included 30% untreated CRCA#1 & 2 are slightly higher than the fracture stress of the control mix. It is important to mention that the mixture that included 15% untreated CRCA#1 has a lower fracture stress compared to the control mix. Surprisingly, the values of the fracture stress for the mixtures that included treated and untreated CRCA#1 in the same proportions are approximately equal, indicating there is no impact of the RCA treatment technique on fracture stress. This obtained result is completely different than the average fracture temperature for the same mixture that included the same RCA type as earlier discussed. As a result, it can be concluded that the treatment approach for RCA has a significant effect on the average fracture temperature, whereas it has no impact on the fracture stress.

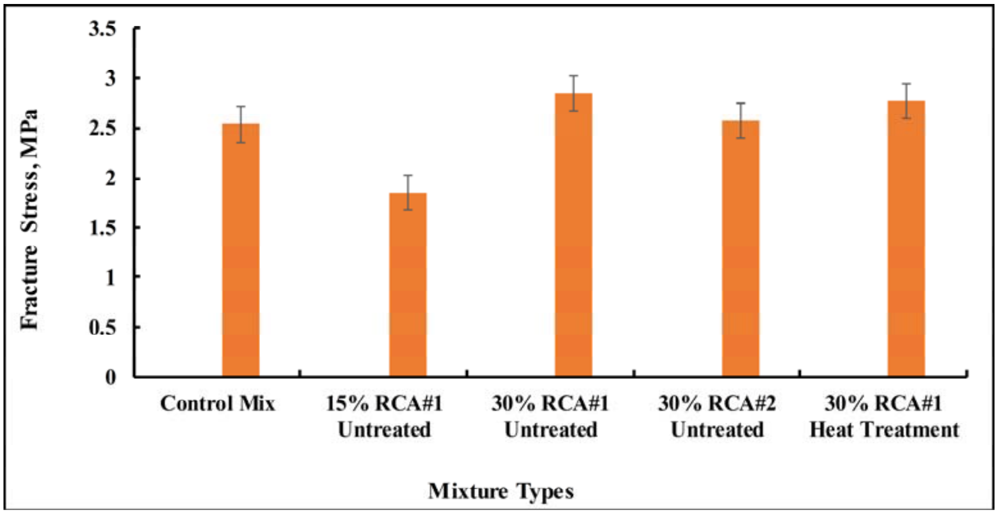



Figure 4: Fracture stress of mixtures with different CRCA types and proportions

## 5 CONCLUSION

Based on the obtained laboratory results, the following conclusions can be drawn:

- The Physical and mechanical characteristics of both CRCA#1 and CRCA#2 are inferior compared to NA. However, the properties of CRCA#2 appear to be better than those of CRCA#1, and closer to NA characteristics.
- The use of a combination technique of heat treatment at 300 °C and short mechanical treatment method is a highly successful method for improving various physical properties including water absorption, specific gravity, and porosity.
- The obtained results of volumetric properties demonstrate that the addition of both CRCA types into the asphalt mixtures at different percentages is very successful, evidenced by achieving all MTO requirements for asphalt mixtures.
- The findings indicate that the average fracture temperature is reduced due to CRCA addition compared to the control mix. However, there is no significant influence for the RCA type on thermal cracks at low temperatures. The application of the combination of various treatments results in a considerable reduction of the average fracture temperature.
- It is concluded that fracture stress of the mixtures that included CRCA at various proportions is generally higher, except for 30%, than the fracture stress of the control mix. In contrast to the average fracture temperature of the asphalt mixtures, there is no influence of the treatment technique of RCA on the fracture stress of the asphalt mixtures.

**Acknowledgements**

The authors would like to gratefully acknowledge the funding provided by Ministry of Higher Education and Scientific Research/Iraq through Iraqi Scholarship/Doctoral Program. The authors are also grateful to Steed and Evans Limited in St. Jacobs, Ontario for providing recycled concrete aggregate material. The authors would like to thank Miller Group in Toronto, Ontario for supplying natural aggregate.

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