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INFLUENCE OF COARSE RECYCLED CONCRETE AGGREGATE ON THE INDIRECT TENSILE STRENGTH OF HOT MIX ASPHALT

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Abstract: In terms of natural resources, natural aggregates (NAs) are quickly becoming exhausted worldwide due to an overwhelming demand for raw materials. Simultaneously, tremendous amounts of construction and demolition (C&D) waste are generated from various human activities including but not limited to construction, renovation and the demolition of aged buildings and civil engineering structures. To solve various problems including lowering the consumption of virgin materials, decreasing waste materials in landfills and reducing environmental problems, the utilization of recyclable waste materials, especially recycled concrete, has become a highly required and an urgent priority in the asphalt industry. This research is conducted to investigate the possibility of using coarse recycled concrete aggregate (CRCA) in asphalt mixtures by evaluating indirect tensile strength. Mix design of HMA mixtures is performed with the addition of CRCA at various percentages 0%, 15%, 30%, and 60%. After evaluation of the optimum asphalt content (OAC) of different mixtures, the indirect tensile strength of Ontario Superpave asphalt mixtures is examined. The obtained results also are statistically analyzed. The obtained results indicated that there is a considerable improvement in the tensile strength of HMA mixtures that included different CRCA proportions in both of conditioned and unconditioned status, which registered tensile strength values higher than the control mix. Additionally, differences among the results are statistically significant, indicating an increase in the CRCA proportion has a significant effect on the tensile strength of the mixture. The findings revealed that the utilization of CRCA in the asphalt mixtures appears to be highly successful.

1. INTRODUCTION

Construction waste materials are increasing due to the rising demand for new highways, commercial buildings, housing developments, and infrastructure projects. Unless recycled properly, these large amounts of waste end up in landfills every year, and natural resources are being depleted rapidly because of the tremendous demand for raw materials (Bolden, 2013). Nowadays, recycled concrete aggregate (RCA) obtained from C&D waste has become a valuable resource as an alternative solution to natural aggregate (NAs) (da Conceição Leite et al., 2011). Due to the lack of NA resources, the use of recycled concrete in different civil construction works has become widespread in Europe and countries such as Singapore, Japan, and Australia for more than 20 years (Paranavithana & Mohajerani, 2006).

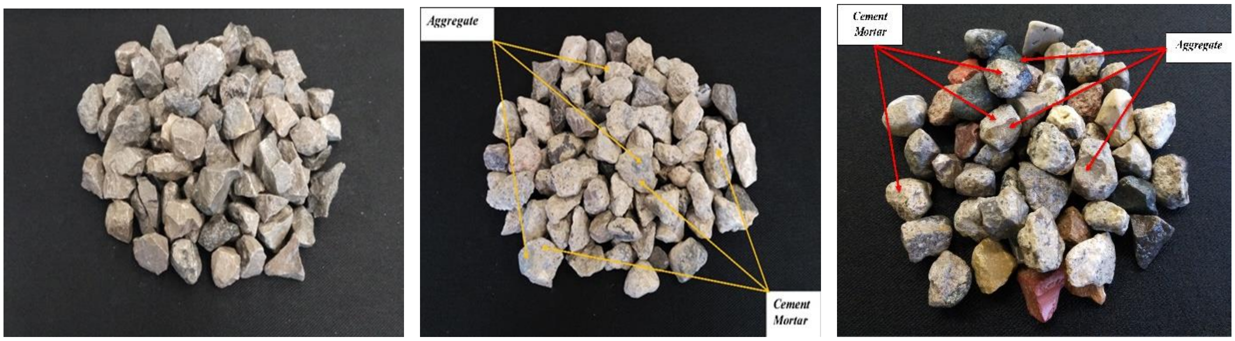
In the Province of Ontario, the MTO has used recycled materials in highway construction since the 1970s due to many different economic, environmental, and engineering factors (Senior et al., 2008). The establishment of Aggregate Recycling Ontario (ARO) in 2011 is one of the main steps which aims to provide a united program for stakeholders which are responsible for generating, operating and consuming recycled aggregate in order to achieve the optimal solution for increasing stockpiles and opportunities for recycling old concrete (ARO, 2014). The use of recycled materials in road construction has increased significantly from approximately 6 million tonnes to 13 million tonnes annually during the period between 1991 and 2006 (MONRO, 2009).

Very recently, the use of RCA has become an attractive topic for many researchers all over the world. The successful use of RCA in the base and sub-base applications is one of the main reasons to examine the feasibility of using RCA in HMA. Various studies have been conducted to investigate the use of RCA in hot mix asphalt (HMA) mixtures. One of the first efforts to use RCA in asphalt mixtures was made in a study by Wong et al., (2007). The research examined the use of a fine aggregate of RCA as a partial substitution for NA (granite type) in HMA. Three hybrid mixtures that contain added RCA were prepared to include 6% and 45% untreated RCA, and 45% heat treated RCA. The obtained results indicated that the mixture that included 6% RCA fillers showed comparable results to NA in terms of resilient modulus and creep resistance while the use of a high percentage of RCA in the two other mixtures achieved better performance. The resilient modulus test was conducted at two different temperatures (25 ºC and 40 ºC); the addition of RCA increased resilient modulus for both temperatures. It was concluded that the use of RCA as a partial percentage of aggregate is possible in HMA. Cho et al., (2011) examined the effect of RCA on the performance of an asphalt mixture. The RCA used was divided into two different sized coarse recycled concrete aggregate (CRCA) and fine recycled concrete aggregate (FRCA). Three different asphalt mixtures were prepared: the first consisted of 100% CRCA and 100% FRCA; the second consisted of 100% CRCA+100% natural fine aggregate (NFA), and the third mixture consisted of 100% FRCA+100% natural coarse aggregate (NCA). The obtained results demonstrated that mixtures with (100% CRCA and 100% FNA) and (100% FRCA+100% NCA) showed good performance compared to the mixture with NA only in terms of indirect tensile strength ratio, deformation strength, permanent deformation, and ITS. Whereas, the mixture with RCA (100% coarse and 100% fine) showed that it has not a good performance. Wu et al., (2013) investigated the effect of RCA on the performance of an asphalt mixture. The RCA used was divided into two different sized coarse and fine recycled aggregate. Three different asphalt mixtures were prepared: the first consisted of CRCA and natural limestone fine aggregate; the second consisted of FRCA and natural limestone coarse aggregate, and the third mixture consisted of natural limestone coarse and fine aggregate. Many laboratory tests were conducted to evaluate the performance of asphalt mixture including the Marshall test, freeze-thaw split test, bending test at low temperature and rutting test at high temperature. The obtained results demonstrated that the CRCA asphalt mixture has higher rutting resistance than the other two types and higher OAC. In terms of water damage resistance, the results showed that the FRCA asphalt mixture is better than CRCA, which has better cracking resistance at low temperature compared to FRCA. It was concluded that all the results meet the specification requirements in China. From the above discussion, it can be stated that the previous research studies were mainly focused on the effect of RCA on the mechanical properties of HMA mixtures such as stability, stiffness, moisture resistance, and dynamic modulus. A few studies were conducted for evaluating the tensile strength in the HMA mixes; therefore, the main objective of this research is to evaluate the possible application of various types and proportions of coarse recycled concrete aggregate (CRCA) in typical Ontario HMA mixtures in terms of tensile strength.

2. MATERIALS AND METHODS

2.1 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

2.2 Methods

2.2.1 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. The RCA was dried in an oven at 105±5°C for 24 hr. The samples were sieved with a 4.75 mm sieve to ensure that only the coarse aggregate was retained. The CRCA tests were performed at room temperature (20 °C).

2.2.2 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. The Superpave mixture design procedure was carried out based on the nominal maximum aggregate size (NMAS), 19 mm. For the included CRCA mixtures, four proportions (0%, 15%, 30, and 60%) were added as a partial substitute for coarse NA. The particle size gradation of virgin aggregate and various percentages of CRCA, targeted the mix design of the Miller group (Taregt), and Ministry Transportation Ontario (MTO) specifications are graphically plotted in Figure 2. Table 1 demonstrates the volumetric properties of different HMA mixtures that were prepared in this study. All experimental tests were conducted in the Centre for Pavement and Transportation Technology (CPATT) at the University of Waterloo.

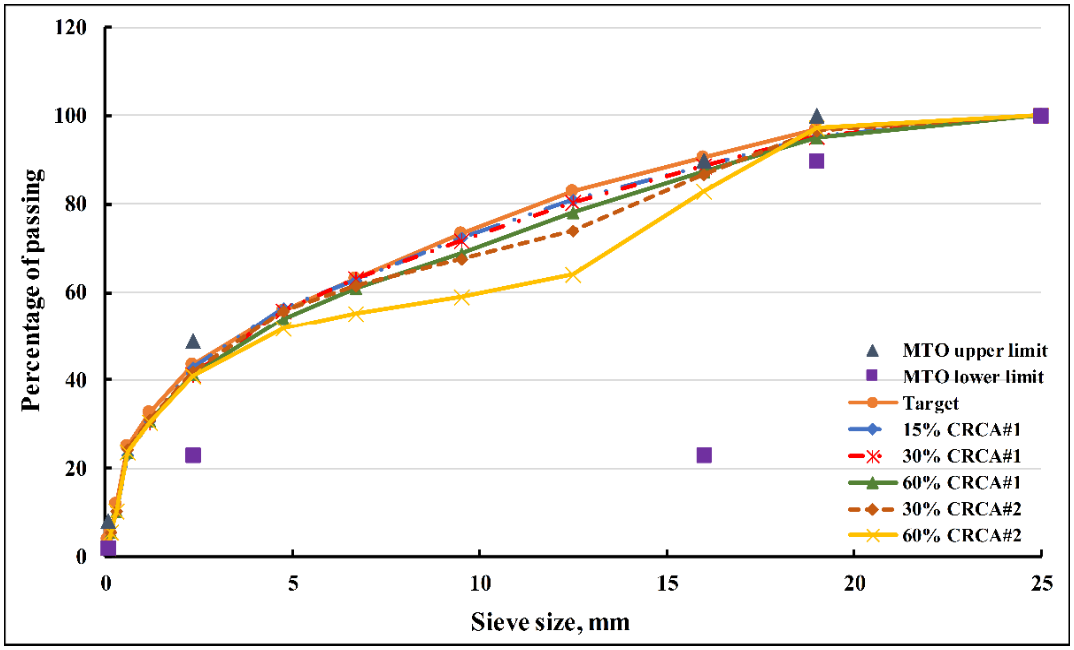


Figure 2: Particle size gradations with different percentages of CRCA

Table 1: Mix design volumetric properties for control and CRCA Mixtures

Property/ Aggregate Mix type	OAC (%)	VMA (%)	VFA (%)	Vv (%)	Dp	G_{mb}
Control mix (0 % CRCA)	4.83	14.50	72.5	4.0	0.60	2.400
15% Untreated CRCA#1	4.90	13.60	70.8	4.0	0.63	2.395
30% Untreated CRCA#1	5.31	13.66	70.7	4.0	0.74	2.373
60% Untreated CRCA#1	5.71	16.18	74.8	4.0	0.60	2.351
30% Untreated CRCA#2	5.12	14.00	71.4	4.0	0.70	2.384
60% Untreated CRCA#2	5.20	13.27	70.0	4.0	0.80	2.367
Acceptable Limitations of MTO specification	-	13 min.	65-75	4.0	0.6-1.2	-

2.2.3 Indirect tensile strength (ITS) test

The ITS was determined for mixtures that included both types of CRCA: untreated and treated with various treatment methods in accordance with the AASHTO T-283 method. The compacted samples were divided into two main groups in which three specimens for each group; namely, unconditioned (control) strengths and conditioned strengths. The conditioning firstly includes achieving a saturation between 70% and 80% for the samples. At a minimum period of 16 hrs, the samples then were placed in a freezer at a temperature of -18 ± 3°C. After that, the specimens were placed in a hot water bath at 60 ±1°C for 24 ±1 hrs. After the hot water bath, the samples were kept in a water bath at a temperature of 25 ±0.5°C for 2 hrs ±10 mins before the specimens were prepared for testing. The ITS is calculated using the following equation:

$$ITS = (2000 * P) / (\pi * t * D) \qquad (1)$$

Where: ITS = indirect tensile strength, kPa; P = maximum load, N; t = sample thickness before test, mm; D = sample diameter, mm.

3. RESULTS AND DISCUSSION

3.1 Physical and Mechanical Properties of NA and CRCA

The obtained results of the physical and mechanical properties of NA and untreated CRCA for both different CRCA types are presented in Table 2. In terms of physical properties, namely, bulk relative density (BRD) and water absorption, a considerable difference is registered between NA and untreated CRCA#1& 2. In addition, 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 significantly higher than NA (Wu et al., 2013; Pasandín & Pérez, 2014; Butler et al., 2013). Adhered mortar, which has a higher porosity than NA, results in the RCA being more susceptible to absorbing more water compared to NA (Al-Bayati et al., 2016). Hence, the presence of adhered mortar leads to increased water absorption, lowered density, and weaker bond strength (Wong et al., 2007).

From the perspective of mechanical properties, abrasion loss, adhered mortar loss, and aggregate crushing value, various 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 are consistent with the abrasion loss results. It is known that aggregate strength is an important factor in high-strength concrete and high-use pavements. Hence, the strength of Portland cement concrete aggregate and asphalt mixtures is influenced by 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 used 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)	Aggregate 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

3.2 Influence of CRCA on the tensile strength

ITS is usually used to measure the tensile strength of asphalt mixtures, which could be further used for evaluating different relevant behaviours such as road surface cracking, permanent deformation, and stripping (Lee et al., 2012).

3.2.1 Influence of CRCA proportion

Figure 3 reveals the behaviour of ITS values of both unconditioned and conditioned HMA samples which were carried out at the optimum asphalt content with various proportions of CRCA#1 (0%,15%, 30%, and 60%). The obtained results demonstrated that ITS values of both sample states are generally higher than the control mix (0% untreated CRCA), resulted in a successful behaviour for various untreated CRCA percentages, even the high proportion of 60%. Due to the crushing process of the old concrete and existence of mortar, which is a rough surface, the texture of the RCA surface consists of shaped particles with sharp edges. This leads to better interaction and higher friction between the surface particles (better adhesive bond) (Radević et al., 2017). It is interesting to note that the maximum ITS values recorded for the mixtures that included 15% untreated CRCA#1 for unconditioned and conditioned samples are 909.2 kPa and 830.3 kPa with an increase of 79.3% and 81%, respectively. This is followed by the ITS values of the mixtures that included 30% untreated CRCA#1 addition for both unconditioned and conditioned samples with an increase of 68% and 70%, respectively. This was then followed by the mixtures that included 60% untreated CRCA with an increase of 41.4% and 49% for both unconditioned and conditioned samples, respectively. An increase in the CRCA proportion can contribute to reducing the tensile strength of asphalt mixtures due to an increase in the dust proportion that results from the fragmentation of adhered mortar under the effect of compaction. This confirms the fact that the moisture and dust could considerably lead to a significant reduction in the bond strength between the aggregate particles and asphalt binder. Dust coating for an aggregate can work to prevent its surface from complete wetting by the asphalt binder due to an adhesion created between the asphalt binder and dust particles instead of aggregate particles (Moraes et al., 2011). This behaviour is confirmed by previous studies (Ríos et al., 2009; Zhu et al., 2012). In contrast, other investigations have reported that ITS increased as the proportion of RCA increases (Lee et al., 2012). However, due to a significant improvement in the tensile strength, the use of untreated CRCA in various percentages results in its successful utilization in HMA mixtures compared to the mixtures that included NA.

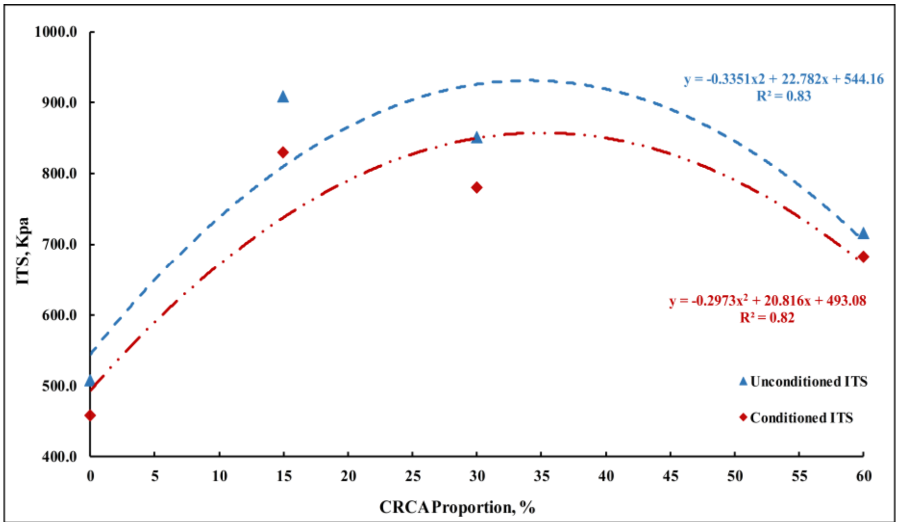


Figure 3.2: ITS for mixtures including untreated CRCA#1 with different proportions

3.2.2 Influence of the CRCA Types on ITS

To evaluate the effect of CRCA types on tensile strength, Figure 4 demonstrates the average of the laboratory outcomes of conditioned and unconditioned ITS samples of the mixtures that included untreated CRCA#1 and CRCA#2 with various proportions. For all cases, it is important to mention that the worst tensile strength is recorded for the control mixture (0% CRCA) among various tensile strength values, indicating a successful behaviour for the addition of various untreated CRCA types with different proportions. It is observed that the mixtures that included untreated CRCA#1 & 2 had the same behavior trend in terms of tensile strength. Generally, an increase in the CRCA percentages leads to a decrease in the ITS values. Additionally, the mixtures that included untreated CRCA#2 up to 60% exhibited better tensile strength in both ITS conditioned and unconditioned state, indicating a higher tensile strength than the mixtures that included the same proportion of untreated CRCA#1. It is interesting to note that the maximum

ITS values recorded for 30% untreated CRCA#2 for unconditioned and conditioned samples are 941.5 kPa and 856.5 kPa with an increase of 85.6% and 86.7%, respectively. This is followed by the ITS values of 60% untreated CRCA#2 addition for both unconditioned and conditioned samples with an increase of 71.5% and 56.8%, respectively. This could be explained by the existence of a high proportion of adhered mortar attached to the CRCA#1 surface, which is more brittle under the impact of the compaction of wheel loads, resulting in poor adhesion between the CRCA particles and asphalt binder. Hence, it can be stated that the type of CRCA has a considerable effect on the tensile strength of the mixture. In conclusion, the HMA mixtures that include CRCA with different types can tolerate higher strains before their failure, which means they are more likely to resist cracking compared to asphalt mixtures that include NA with a low tensile strain at failure.

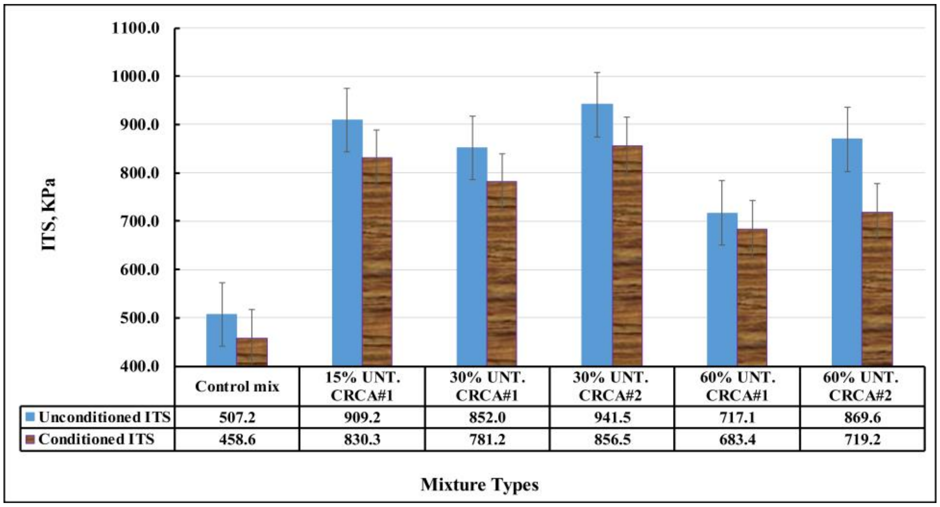


Figure 3.2: ITS for mixtures including different CRCA types with various proportions

3.3 Statistical Analysis of ITS Results

A two-way ANOVA analysis was carried out on the results of different mixtures which represent three replicate specimens of different HMA mixtures to evaluate the influence of many parameters on the ITS value. The mentioned parameters include various CRCA percentages (0%, 15%, 30%, and 60%); different CRCA types; and the state of the sample: conditioned or unconditioned sample. The ANOVA analysis was carried out with a probability of 95% (P=0.05). In the analysis of two-way ANOVA, the main impact could be defined from variables as well as their significance. A higher value of the sum of the squares generally refers to which of the variables has a major impact. When there is a significant interaction between two variables, the major impact cannot be determined.

The obtained results of a two-way ANOVA analysis are tabulated in Table 3. The findings showed that the type of CRCA has a significant effect on the ITS of the unconditioned sample, with Factual (6.41) > Fcritical (5.32) and a p-value of (0.0352). Thus, a variation in the CRCA type will impact the ITS of the unconditioned sample. Additionally, the results demonstrated that there is a statistically insignificant effect of CRCA percentage on the unconditioned ITS, with Factual (4.684) < Fcritical (5.318) and a p-value of (0.0624) for the HMA mixtures in the dry state. However, the effects of CRCA type and proportion act independently due to an insignificant interaction between the mentioned variables, with Factual (0.434) < Fcritical (5.318) and a p-value of (p= 0.53). Interestingly, the type of CRCA has a higher impact on the results of unconditioned ITS of asphalt mixtures than the CRCA proportion.

In terms of the influence of CRCA type and proportion on the conditioned ITS, the statistical analysis shows that there is a statistically insignificant effect of CRCA type on the conditioned ITS, with Factual (3.923) <

Fcritical (5.318) and a p-value of (0.0829) for the HMA mixtures. Meanwhile, the findings indicated that there is a statistically significant effect of CRC

A percentage on the conditioned ITS, with a p-value of (0.0031) and Factual (17.468) > Fcritical (5.318). However, the effects of CRCA type and proportion act independently due to an insignificant interaction between the mentioned variables, with a p-value of (0.497) and Factual (0.506) < Fcritical (5.318). Surprisingly, the type of CRCA has a greater effect on the results of the conditioned ITS of HMA mixtures than the CRCA percentage depending on the sum of the squares (SS) value.

Table 3: Results of Two-Way ANOVA analysis: P-Value and sum of squares of ITS

Source of Variation		Unconditioned ITS	Conditioned ITS
CRCA type	P-value	<0.035168	0.082964
	SS	43907.51	9333.15
	F	6.408942	3.923027
	F- critical	5.317655	5.317655
CRCA%	P-value	0.06238	<0.003082
	SS	32088.33	41558
	F	4.68376	17.46818
	F- critical	5.317655	5.317655
Interaction	P-value	0.528409	0.497284
	SS	2975.178	1202.687
	F	0.434271	0.505528
	F- critical	5.317655	5.317655

4. CONCLUSION

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

- The mixtures that included untreated CRCA#1 or CRCA#2 had the same behavior trend in terms of tensile strength. Generally, an increase in the CRCA percentages leads to a decrease in the ITS values; however, the reduced values were higher than the control mix value.
- The laboratory results showed that the ITS of unconditioned and conditioned samples that included different untreated CRCA types with various percentages have higher values than the control mix.
- The maximum ITS values recorded for 30% untreated CRCA#1 and CRCA#2 for both unconditioned and conditioned samples, registered increases of 68%, 70%, 85.6%, and 86.7%, respectively. This is followed by the ITS values of the mixtures that included 60% untreated CRCA1# and CRCA#2 for both unconditioned and conditioned samples with increases of 41.4%, 49.0% 71.5% and 56.8%, respectively.
- The results of an ANOVA analysis showed that the CRCA type is the main factor that influences the ITS value of asphalt mixtures for both conditioned and unconditioned samples.

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