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The Effects of Soft Reclaimed Asphalt Pavement on the Characteristics of Roller-Compacted Concrete

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Abstract: Increased the amounts of soft reclaimed asphalt pavement (S-RAP) are due to the increased maintenance and rehabilitation actions. Also, a restricted quantity of research has been conducted on the impact of soft Reclaimed Asphalt Pavement (S-RAP) on the performance of Roller Compacted Concrete Pavement (RCCP). In addition, use of soft Reclaimed Asphalt Pavement in roller-compacted concrete pavements (RCCP) offers both benefits and drawbacks. The substantial advantages of employing S-RAP aggregates include addressing S-RAP disposal issues, mitigating greenhouse gas emissions, reducing reliance on natural aggregates, and lowering transportation expenses. Furthermore, employing soft reclaimed asphalt pavement (S-RAP) as a substitute for aggregate in Roller-Compacted Concrete (RCC) may reduce the amount of natural aggregate necessary in RCC. So, this study examined the effects of substituting 25%, 50%, 75%, and 100% of the coarse aggregate weight in roller-compacted concrete (RCC) with soft reclaimed asphalt pavement (S-RAP) on compressive strength, splitting tensile strength, flexural strength, modulus of elasticity, and drying shrinkage. The substitution of 25%, 50%, 75%, and 100% soft Reclaimed Asphalt Pavement (RAP) by weight of natural coarse aggregate adversely affected the characteristics of Roller Compacted Concrete (RCC), leading to reductions in compressive, splitting tensile, and flexural strengths, along with the modulus of elasticity following a 28-day curing period.

Keywords: Reclaimed asphalt pavement, Roller compacted concrete, Less-aged RAP, Soft RAP, Optimum moisture content and maximum dry density

Introduction

In recent years, academics and various industries have placed a high priority on sustainable infrastructure. The realization of this sustainability idea depends on the infrastructure meeting the necessary criteria related to economic and environmental considerations. Manufacturing and destroying concrete, the most often used building material, has the most negative environmental effects (Debbarma et al., 2019a). The worldwide generation of construction and demolition waste (CDW) has shown a notable rise in recent decades, which represents 25–30% of the total material waste generated on Earth, and a substantial amount of waste is associated with it. The continuous and rapid construction of roads worldwide has resulted in a progressive decline of traditional natural aggregates in the road sector industry (Pavlů et al., 2018).

A type of stiff concrete called Roller Compacted Concrete (RCCP or RCC pavements) is compacted using vibratory rollers after it is placed with asphalt pavers. Designers are showing a renewed interest in RCC pavements as a sustainable pavement option, as they may incorporate recycled aggregates, reduce the overall amount of cement used, shorten the duration of road closures, and lower total project costs (Ferrebee et al., 2014).

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Traditionally, RCC pavements have utilized virgin aggregates; however, researchers have experimented with recycled materials in the production of RCC.

Using RAP aggregates in low-cost paving technologies, such as RCCP, would fulfill the concept of a sustainable-built road (Debbarma et al., 2019a). Generally, reclaimed asphalt pavement (RAP) is the substance that is obtained after an existing asphalt pavement is milled off for maintenance, repair, and rehabilitation activities (Huang et al., 2005; Kumari et al., 2019). As a result, RAP aggregate utilization may benefit the environment and the economy in new pavement applications, including reduced aggregate costs and transportation costs because of on-site use (reduced carbon footprint) (Singh et al., 2017; Shi et al., 2018).

The primary obstacle for the transportation sector in utilizing RAP for cement concrete pavements is the lack of suitable documentation and specifications (Singh et al., 2017). The creation of a deficient interfacial transition zone between the reclaimed asphalt pavement surface and the cementitious mortar matrix presents another obstacle associated with the incorporation of reclaimed asphalt pavement in cement concrete pavements (Brand & Roesler, 2015, 2017; Delwar et al., 1997; El Euch Ben Said et al., 2018; Huang et al., 2006; Shi et al., 2017, 2018; Singh et al., 2017, 2018). In addition to the asphalt coating, agglomerated particles in soft RAP have been documented to decrease strength properties by as much as 70% relative to the control mix (Huang et al. 2005, 2006). Most publications advised utilizing just the coarser fraction of RAP, with a maximum limit of 50%, (Brand and Roesler (2015), El Euch Ben Said et al. (2018), Euch Khay et al. (2014), Shi et al. (2017) and Singh et al. (2017, 2018).

Furthermore, only a limited number of studies have been conducted on soft RAP-inclusive RCCP mixtures to date. Just as with cement concrete pavements, the incorporation of soft RAP into the production of RCC pavements is limited to a maximum of 50% (Fakhri & Amoosoltani, 2017a; Settari et al., 2015). As soft RAP aggregates have a lower specific gravity and density, their incorporation in RCCP mixes significantly reduces the compactness and density of fresh mixes, which, in turn, has a substantial negative impact on the hardened properties (Settari et al., 2015). All of the aforementioned factors (asphalt, agglomerated particles, weak ITZ, lower specific gravity, and density) significantly reduced the possibilities of soft RAP in RCCP mixtures. Additionally, due to the presence of a low-density asphalt coating, the specific gravity of soft RAP aggregates is typically lower than that of natural aggregates. Moreover, due to the hydrophobic nature of asphalt, the soft-RAP aggregates demonstrated lower water absorption values relative to that of the natural aggregates (Debbarma et al., 2019a). A limited number of studies addressed the suitability of soft RAP for RCCP mixtures and the optimal replacement ratio of natural coarse aggregate with coarse soft RAP.

Additionally, there is a difference among researchers regarding the effect of soft RAP on the properties of RCC due to variations in the results of water absorption rates and specific gravity, which in turn affect the rates of decrease in the properties of RCC containing soft RAP. Therefore, this research addresses several issues related to the effect of (less-aged RAP) soft RAP that is generated in a much cleaner way, usually having a soft-asphalt coating, on the mechanical performances (compressive strength, splitting tensile strength, flexural strength, drying shrinkage, and elastic modulus) of RCC mixtures. To achieve these objectives, investigate the physical properties of soft RAP aggregate (i.e., specific gravity, density, water absorption, and asphalt content). Then, the mixtures were designed and produced with various percentages of coarse soft RAP aggregate (0%, 25%, 50%, 75%, and 100%) to use in RCCP.

Research Program

Materials and Tests

Fine Aggregate

This study utilized fine aggregate, specifically normal-weight natural sand sourced from the Al-Najaf quarry. The sand was sieved through a 4.75 mm sieve before being incorporated into the RCC mix. Figure 1 illustrates the grading of sand. The findings from the physical and chemical analysis of the sand utilized in this study are displayed in Table 1.

Coarse Aggregate: Natural Coarse Aggregate

Natural crushed gravel with a maximum size of 19.5 mm from the Al–Nibaey region was used in this work. The absorption, specific gravity, and sulfate content (as SO_3) of the used gravel are (0.5%), (2.63), and (%0.058), respectively. Figure 2. shows the grading of this aggregate and the limits specified by ASTM C33-18.

Table 1. The physical and chemical properties of sand

Property	Speciefication	Result	Limit of I.O.S N0. 45/1984
Bulk Specific gravity	ASTM C128-2003	2.6	
Absorption, %	ASTM C128-2003	1.1	
Dry loose unit weight, kg/m^3	ASTM C29-2003	1580	
Sulfate content (as SO_3),%	I.O.S No.45-84	0.36	0.5 (Max.)
Materials finer than 0.075 mm sieve, %	ASTM C117-17	4.1	5.0 (Max.)

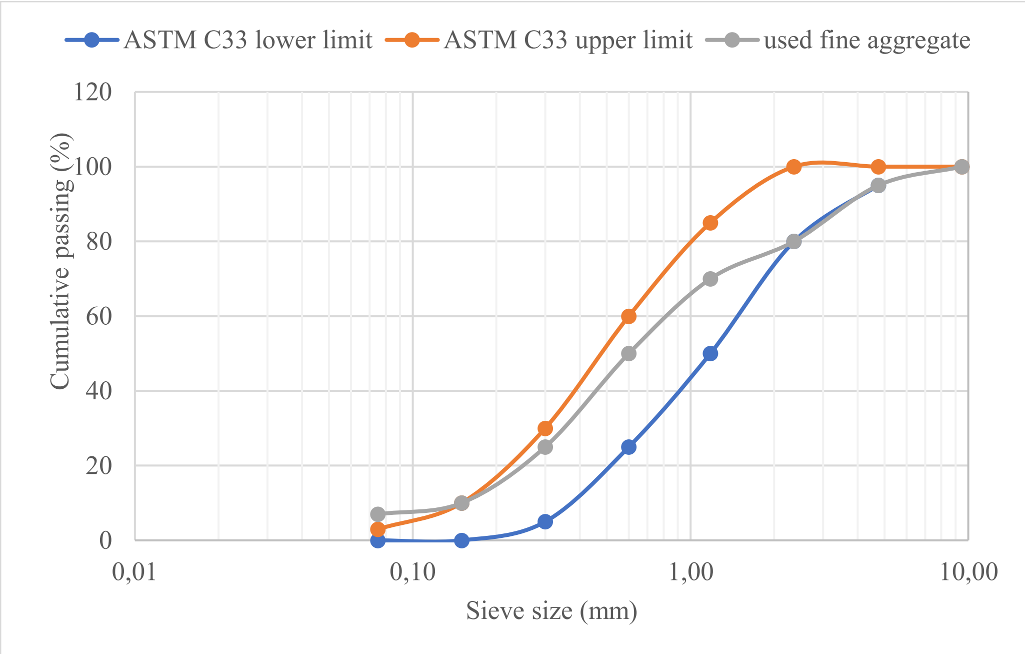


Figure 1. Grading of fine aggregate

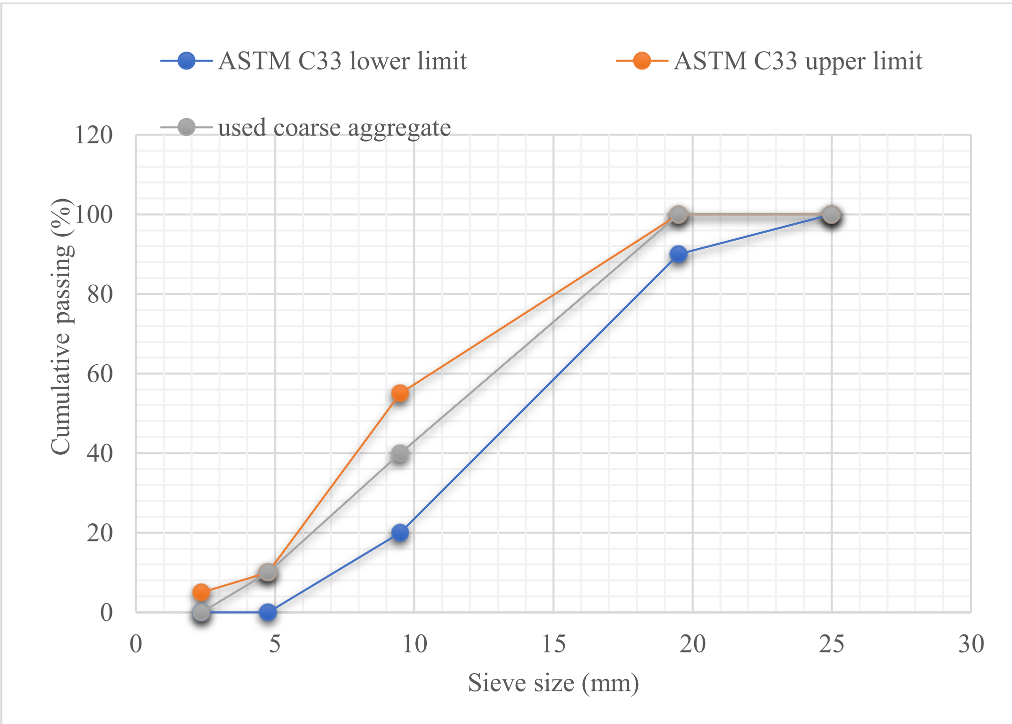


Figure 2. Grading of natural coarse aggregate

Coarse Aggregate: Soft Reclaimed Asphalt Pavement (soft RAP)

There are only a limited number of research that address soft RAP-inclusive RCCP mixes. In this research, the soft RAP material was obtained from the demolished full-depth pavement, which was generated in a more environmentally friendly manner. Typically, it usually has a soft asphalt coating, which is disposed of near the University of Babylon Road, reportedly having been lying on that site for less than a year. Table 2 lists the properties of soft RAP, along with their corresponding proper specifications.

Table 2. Properties of soft RAP

Property	Specification	Test result (soft RAP)
Specific gravity	ASTM C127-2003	2.32
Absorption, %	ASTM C127-2003	1.6
Asphalt content ,%	ASTM D2172-2003	4.88

Cement

Sulfate Resisting Cement (Type V) produced by Karbala Cement Factory (Lafarge Al Jiser) was used in every mixture throughout this study.

Mix Design

Five different RCC mixes were used in this study, identified as:

- M-0%soft-RAP: 0% soft RAP, 100% natural coarse aggregate (control mix).
- M-25%soft-RAP: 25% soft RAP, 75% natural coarse aggregate.
- M-50%soft-RAP: 50% soft RAP, 50% natural coarse aggregate.
- M-75%soft-RAP: 75% soft RAP, 25% natural coarse aggregate.

Figure 3. the modified proctor

Due to the rigid character of roller-compact concrete, the modified Proctor method (see Figure 3) is the most commonly used soil compaction method for designing RCCP mixes. This approach is based on ASTM D1557-12. The results of the modified Proctor method are represented by a curve showing a definite γ dry density (g/cm³) and MC (moisture content) (%). See Figure 4. It can be observed that the maximum dry density (MDD) decreased as the soft RAP replacement increased for the mixes (M-25% soft RAP, M-50% soft RAP, M-75% soft RAP, and M-100% soft RAP), and the optimum moisture content (OMC) increased.

Preparation, Casting, Compaction, and Curing of RCC samples

For all the tests carried out during this study, cylindrical steel mold size (150 x 300) mm and prism size (100 x 100 x 400) mm are used for preparing the RCC specimens. The molds are cleaned, rigidly tightened, and lightly oiled before casting to keep concrete from sticking to them. The materials are placed on the molds by filling the prisms into two layers and the cylinders into three layers, then compacting the mixture with a hammer and tamping plate. After that, compaction of the concrete under the tamping plate begins when the hammer vibrates. The concrete in the annular space, the area between the tamping plate edge and the molds inside wall, should be observed.

When the concrete consolidates, the annular gap that exists between the interior mold wall and the outer surround of the tamping plate should be filled with mortar. This mortar must be watched until it creates a ring around the entire tamping plate. The vibrating hammer should be stopped when the mortar ring completes the tamping plate. The vibrating hammer must be stopped after 20 seconds if a significant amount of the mortar ring has not formed; the next layer of concrete must then be applied (ASTM C1435–99). Figure 5. shows the vibrating compaction hammer with a minimum mass of 10 ± 0.2 kg (without a tamping plate). It can also produce at least 2000 impacts per minute and requires a minimum power input of 900 watts.

Tamping plate: For prism and cylindrical molds, a (390 ×90) mm rectangle steel plate and a (140) mm circular steel plate, respectively. A metal shaft with a steel plate attached is placed into the vibrating hammer chuck (ASTM C 1435–99). After that, all concrete test specimens were demolded after 24 hours and stored in a water tank for 7, 28, and 91 days, except for those related to drying shrinkage, which were cured according to ASTM C157 (2005). Table 3 shows a summary of the various tests conducted on concrete.

Table 3. Different tests realized on concrete

Tests	Speciemen (mm)	Standard
Compressive strength	Cylinder (150*300)	ASTM C39 (2003)
Splitting tensile strength	Cylinder (150*300)	ASTM C496 (2003)
Flexural strength	Prism (100*100*400)	ASTM C78 (2005)
Modulus of elasticity	Cylinder (150*300)	ASTM C469 (2003)
Drying shrinkage	Prism (100*100*400)	ASTM C157 (2005)

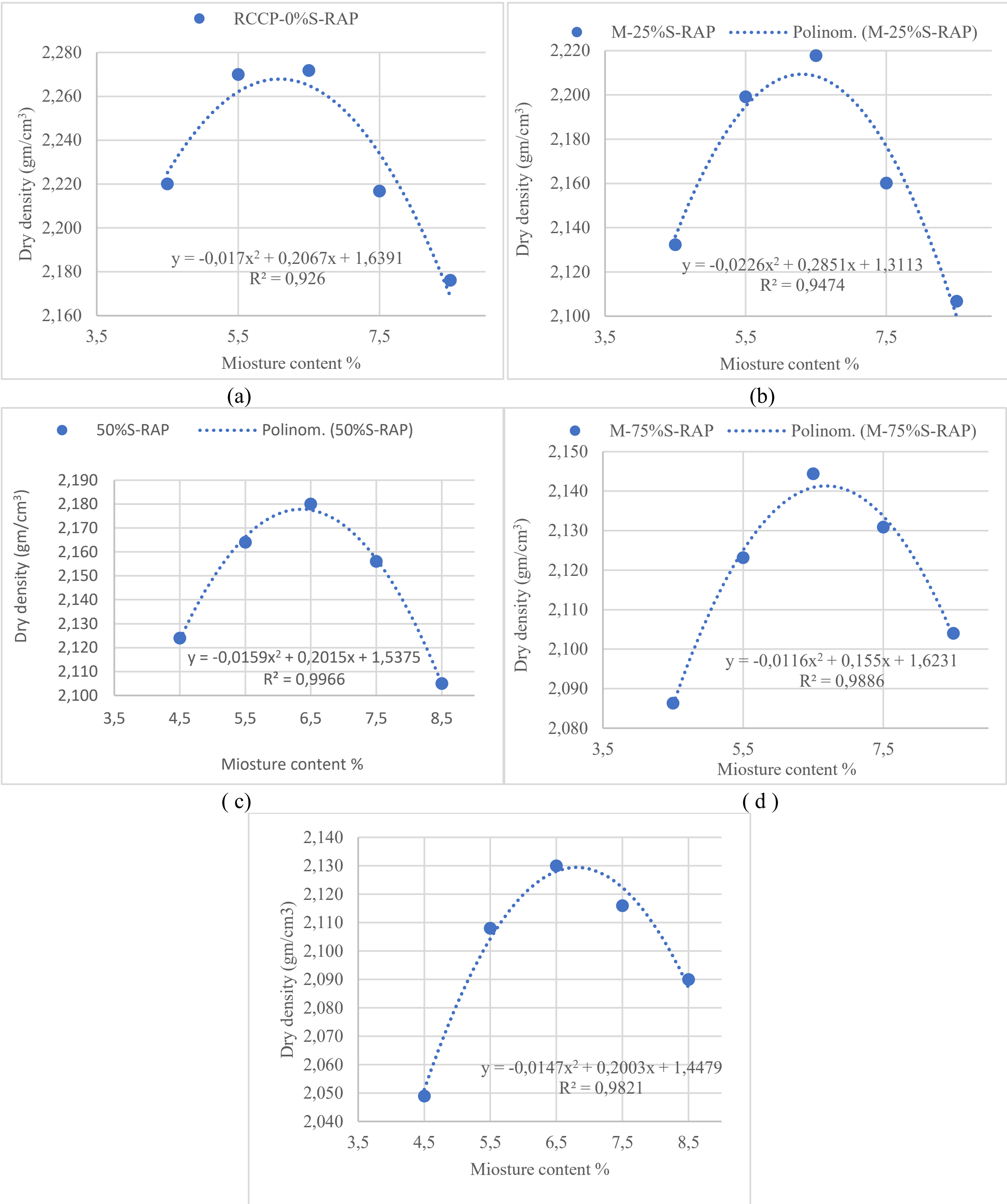
Results and Discussions

Compressive Strength

The results of the compressive strength of the hardened RCCP mixes with soft RAP at 28 days of curing are summarized in Figure 5. It is evident the compressive strength decreases linearly as the percentage of coarse soft RAP fraction increases. For instance, the decrease in compressive strength of mixtures (M-25%S-RAP, M-50%S-RAP, M-75%S-RAP, and M-100%S-RAP) were (20%, 35%, 46%, and 60%) consecutively, at 28 days of curing. The reason for this decrease in strength is the asphalt coating that surrounds the aggregates, which hindered the bond between the soft RAP aggregate and the cementitious mortar matrix. Also, Debbarma et al. (2019a, 2019b), investigated reduction in compressive strength. Where, Debbarma et al. (2019b), discovered that the compressive strength was reduced by 26 to 67% when less-aged RAP (soft RAP) was incorporated into the RCC mix. The minimum recommended strength of 27.6 MPa at 28 days of curing for the construction of RCC pavements (as a surface layer) as specified by ACI 327 (ACI, 2014), so, in this study, the minimum recommended strength was achieved only by a 25% soft RAP mix, which is 30.56 MPa.

Splitting Tensile Strength

Consistent with the compressive strength results, inclusion of coarse soft RAP fraction resulted in lowering the split tensile strength of RCCP mixes. The impact of varying proportions of soft RAP aggregates on the splitting tensile strength of the investigated RCCP mixtures after 28 days of typical curing is illustrated in Figure 7. It was observed that a reduction in the splitting tensile strength at 28 days of curing, of 18.4%, 37.6%, 42.4%, and 45.6% for mixtures (M-25%S-RAP, M-50%S-RAP, M-75%S-RAP, and M-100%S-RAP), respectively. However, Debbarma, 2021, found that, the splitting tensile strength was reduced about 41.7% and 52.8% when 50%S-RAP and 100%S-RAP was added, respectively.



(e)

Figure 4. Proctor test results for the samples: a) M-0%soft RAP, b) M-25%soft-RAP, c) M-50%soft RAP, d) M-75%soft RAP, and e) M-100%soft RAP.

Figure 5. The vibrating hammer with a tamping plate

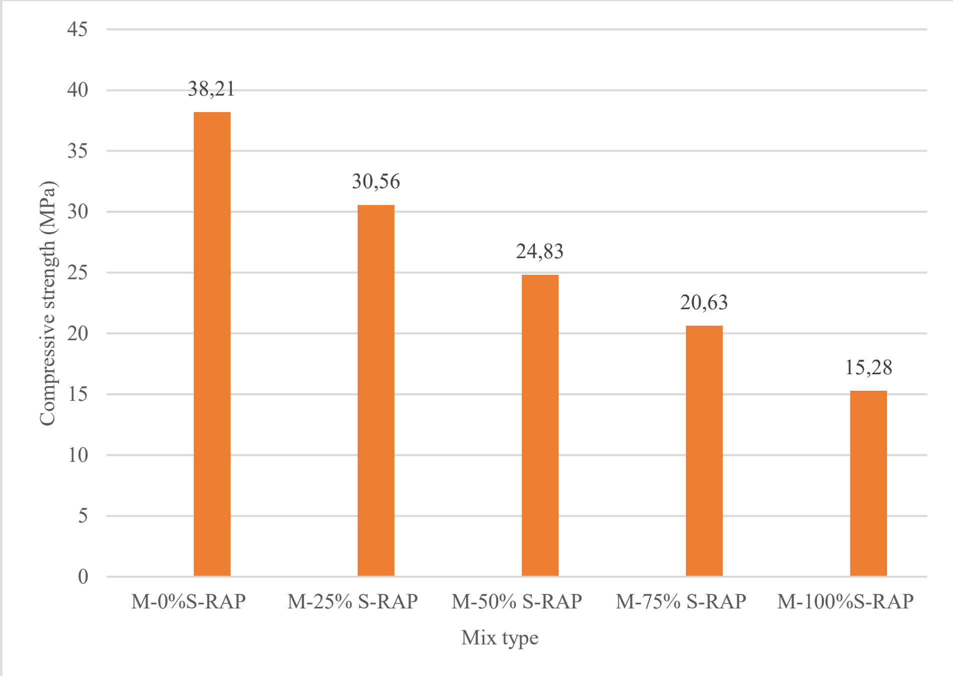


Figure 6. Effect of soft RAP on compressive strength of RCCP

Flexural Strength

The flexural strength of RCCP mixtures was found to be less negatively impacted by the incorporation of coarse soft RAP, as shown in Figure 8. Nevertheless, it was observed that the percentage reduction compared to the control mix was significantly lower. For example, a reduction of 15%, 25%, 30%, and 38% in the flexural strength at 28 dats of curing for mixes (M-25%S-RAP, M-50%S-RAP, M-75%S-RAP, and M-100%S-RAP), respectively. The finding is of utmost significance to pavement engineers, as RCC pavements are typically evaluated based on the flexural strength results obtained after 28 days rather than the compressive strength. The minimum recommended flexural strength of 3.5 MPa at 28 days of curing for the construction of RCC pavements (as a surface layer) as specified by ACI 327 (ACI, 2014), so, in this study, the minimum recommended strength was achieved at all S-RAP percentages except M-100%-RAP mixture, which is 3.47 MPa.

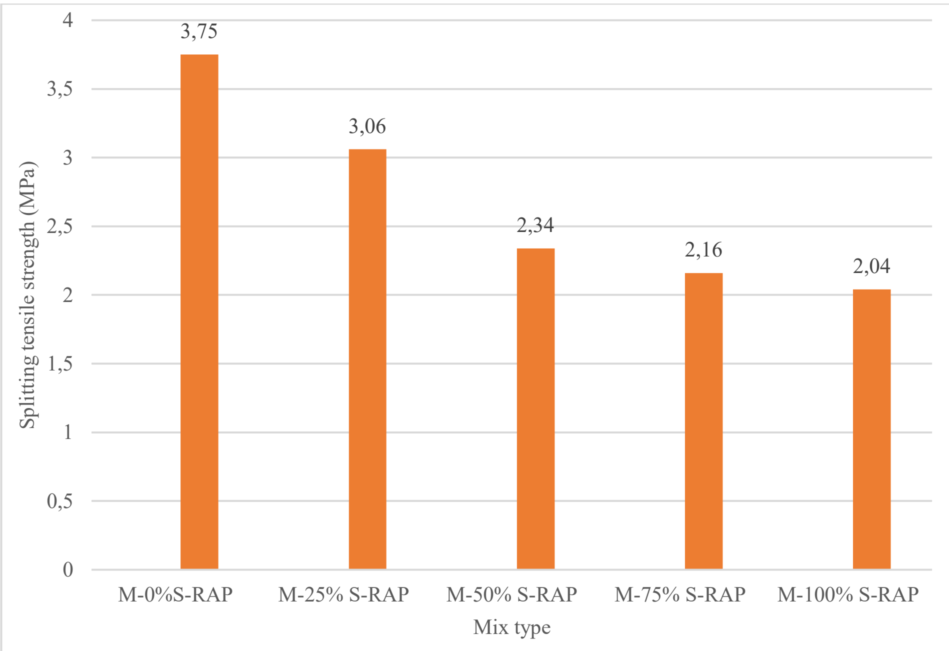


Figure 7. Effect of soft-RAP on the splitting tensile strength of RCCP

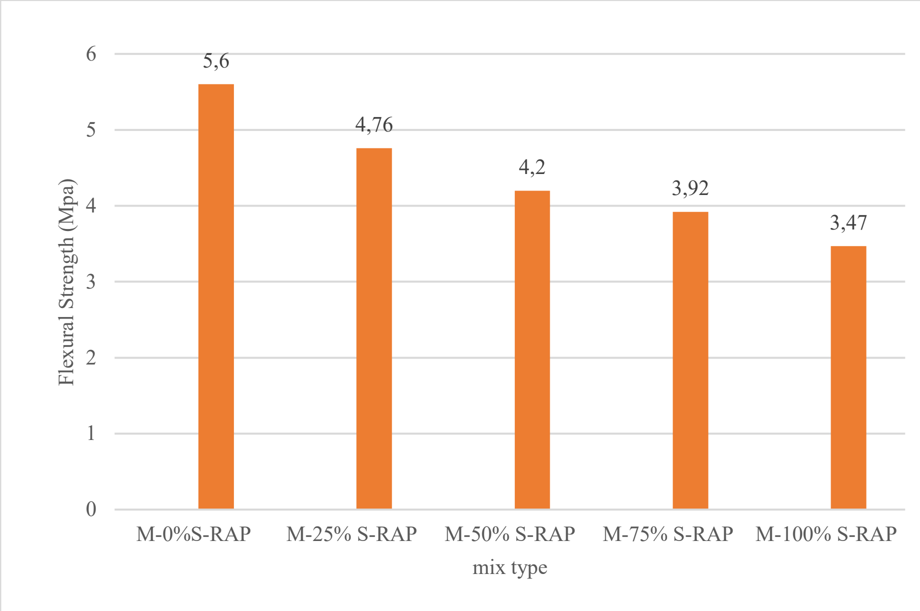


Figure 8. the impact of soft-RAP on the flexural strength of RCCP

Modulus of Elasticity

The modulus of elasticity is a measure of the ratio between the applied stress and strain in a linear manner. When the cement contents of the mixes are similar, the modulus of elasticity of RCC is either slightly higher or similar to that of conventional concrete. The modulus of elasticity of RCC decreases when adding soft RAP, as illustrated in Figure 9. As a result, the quantity of soft RAP materials significantly impacts the decrease in the modulus of elasticity of RCC, which is approximately 29.4%, 44.5%, 57.6%, and 69.7% at mixtures of M-25%S-RAP, M-50%S-RAP, M-75%S-RAP, and M-100%S-RAP, respectively with respect of control mix and at 28 days of curing. Also, Debbarma et al., 2020b noted that the incorporation of soft RAP reduces the modulus of elasticity of RCCP mixtures.

Drying Shrinkage

It is anticipated that the drying shrinkage of RCC mixtures will be significantly lower than that of conventional concrete pavements due to the relatively low water content of RCC pavements. Additionally, the drying shrinkage of RCC with soft RAP is expected to be higher than that of RCC with natural aggregate (Pittman & Ragan, 1998).

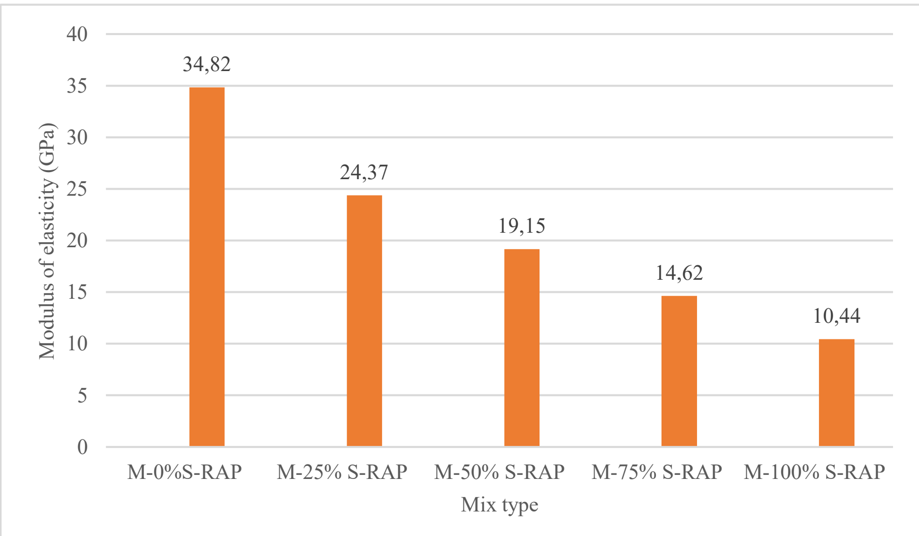


Figure 9. Effect of soft-RAP on modulus of elasticity strength of RCCP

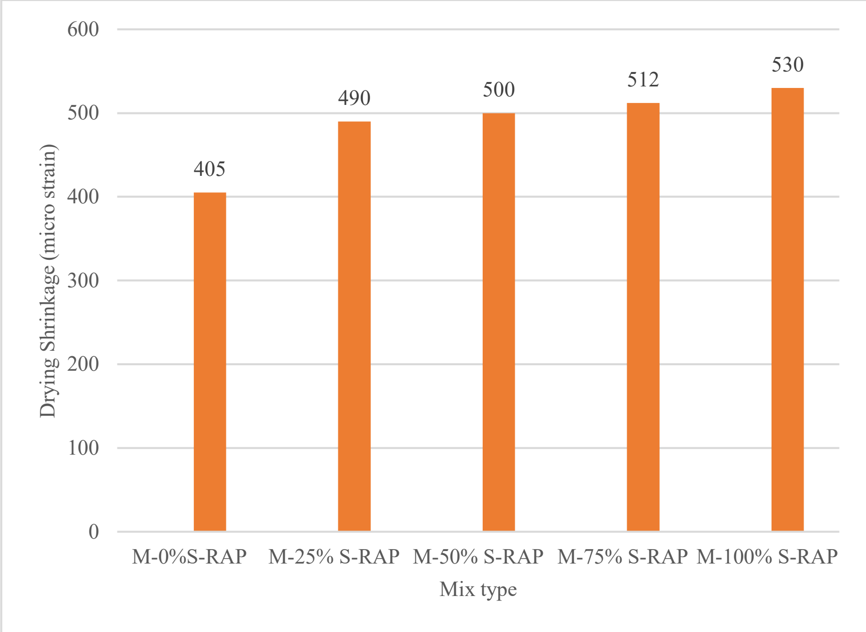


Figure 10. Drying shrinkage strains of RCCP mixes after 28 days

Very few researchers have examined the impact of soft RAP on the mechanical properties of RCC, such as drying shrinkage. The replacement of coarse aggregate with soft RAP significantly increases the drying shrinkage, as demonstrated in Figure 10. It was observed for this study, the increased rate of drying shrinkage for mixtures (M-25%S-RAP, M-50%S-RAP, M-75%S-RAP, and M-100%S-RAP) about 20%, 23%, 26%, and 30.8%, respectively, with respect to the control mix, on the 28th day of curing.

Conclusion

The characteristics of RCC were examined in this study through laboratory tests to investigate the impact of less-aged RAP (soft RAP) materials. The test results indicate that the particles have a lesser density and a greater capacity for water absorption due to the association of some bitumen with them. Soft-RAP materials are different than natural aggregate. Additionally, the quantity of soft RAP materials significantly affects the density and compactness of RCC. It was observed that the optimal moisture content (OMC) values increased when coarse soft RAP was partially and fully replaced by natural coarse aggregates in the RCCP mixes under investigation. So, OMC for M-0%S-RAP, M-25%S-RAP, M-50%S-RAP, M-75%S-RAP, and M-100%S-RAP were 6%, 6.3%, 6.4%, 6.7%, 6.8%, respectively.

Furthermore, the maximum dry density (MDD) decreases with the addition of soft RAP in RCCP, with reduction percentages reaching 2.5%, 4%, 5%, and 6% for M-25%S-RAP, M-50%S-RAP, M-75%S-RAP, and M-100%S-RAP, respectively. The incorporation of coarse soft-RAP may lead to a significant decrease in the compressive strength, split tensile strength, flexural strength, and modulus of elasticity of the RCCP mixtures at the 28-day curing age. For instance, the compressive strength of (M-0%S-RAP, M-25%S-RAP, M-50%S-RAP, M-75%S-RAP, and M-100%S-RAP) at 28 days of curing were (38.21 MPa, 30.56 MPa, 24.83 MPa, 20.63 MPa, 15.28 MPa), respectively.

Additionally, the split tensile strength decreases when soft RAP is used in RCCP, where the split tensile strength of (M-0%S-RAP, M-25%S-RAP, M-50%S-RAP, M-75%S-RAP, and M-100%S-RAP) at 28 days of curing were (3.75 MPa, 3.06 MPa, 2.34 MPa, 2.16 MPa, 2.04 MPa), respectively. Flexural strength is less affected by the incorporation of soft RAP in roller-compacted concrete pavement. For instance, the flexural strength of this study for (M-25%S-RAP, M-50%S-RAP, M-75%S-RAP, and M-100%S-RAP) was (4.76 MPa, 4.2 MPa, 3.92 MPa, 3.47 MPa), respectively, at 28 days of curing. Finally, the modulus of elasticity is reduced when using soft reclaimed asphalt pavement as a substitute for natural coarse aggregate. As well as an increase in drying shrinkage was observed when incorporating soft reclaimed asphalt pavement to produce roller compacted concrete mixtures, where percentages of increase are (20%, 23%, 26%, and 30.8%) for (M-25%S-RAP, M-50%S-RAP, M-75%S-RAP, and M-100%S-RAP), respectively.

Recommendations

Extensive experimental studies are necessary to determine the optimal type and percentage of pozzolanic materials that enhance the mechanical properties of RCCP containing soft RAP.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

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