Effect of Coarse Recycled Aggregates and Supplementary Cementitious Materials for Interlocking Concrete Pavers Performance

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Abstract

Reducing waste and conserving natural resources are the main reasons for using recycled concrete aggregate (RCA) in concrete pavement. Concrete reuse helps the construction sector reduce its need for virgin aggregate, thereby lessening quarrying operations and the related environmental impacts, such as dust production and habitat destruction. Supplementary cementitious materials (SCMs) significantly reduce CO2 emissions and cement usage in concrete mixes. Substituting crushed RCA for natural aggregates (Nag) and SCMs for conventional cement can achieve a more sustainable concrete production method. This method is a greener option because it reduces the environmental impact of concrete and

helps protect natural resources. This study aims to examine the durability and mechanical characteristics of concrete mixes designed for interlocking concrete pavers that contain SCMs and coarse recycled concrete aggregates (CRCA). The research evaluates the feasibility of incorporating environmentally sustainable materials into traditional concrete production, focusing on shear strength and splitting tensile strength. Three concrete mixes with different proportions of CRCA and SCMs (0%, 20%, and 40%) and (0%, 20%, and 30%) are evaluated against the control mix. Ground glass pozzolans (GP), limestone cement (GUL), and slag were used as SCMs in this study. The specimens were tested after 28 days of curing.
The outcome indicated that the control mix (CM) had the highest shear strength value compared to the other mixes. As the percentage of CRCA in mixtures increased, the shear strength value dropped by as much as 20.27%. However, when the replacement percentage of CRCA was 20%, there was a slight variation in the shear strength value of less than 1 In addition, the splitting tensile strength value was highest for CM. The splitting tensile strength value dropped by 14.5% as the CRCA replacement percentage up to 40%. The mixes with the lowest value were RC 40/S 20/G10. The difference in tensile strength was less than 1% when the CRCA replacement percentage was 20%. Furthermore, the results demonstrate that adding SCMs has no discernible impact on the concrete's shear and splitting tensile strengths. Consequently, the results support using CRCA up to 20% as a partial substitute for NAg in interlocking concrete paving (ICPs) to reduce Nag consumption and serve as a step toward more sustainable concrete construction.
Keywords: Coarse recycled concrete aggregate (CRCA), Supplementary cementitious materials (SCMs), Slag, Ground Glass Pozzolans (GP), Limestone Cement (GUL), Sustainable concrete, Shear and tensile strength.

Introduction

The growth of the construction industry necessitates vast quantities of cement and natural aggregates (Nag), leading to significant carbon emissions and the depletion of natural resources. Achieving sustainability in construction is essential, requiring not only a reduction in carbon footprint but also the preservation of these resources (Akhtar and Sarmah, 2018). Thus, reusing recycled concrete aggregates (RCA) as aggregates is a critical topic in achieving sustainable development (Oikonomou, 2005). However, the RCA created by crushing old concrete is more porous because of the mortar attached to its surface, which adversely affects the mechanical properties and durability of concrete made with recycled aggregate (RA) (Al-Bayati et al., 2016, Alexandridou et al., 2018, Al-Bayati, 2019). Traditional supplementary cementitious materials (SCMs) such as fly ash (FA), ground granulated blast-furnace slag (GGBFS), and silica fume address this issue, but their growing commercialization diminishes economic advantages (Akhtar and Sarmah, 2018; Vieira et al., 2020; Xie et al., 2020). Therefore, research into alternative and unconventional SCMs for RCA is essential to achieve sustainability and economic viability (Akhtar and Sarmah, 2018). The escalating issue of solid waste pollution poses significant threats to the environment, public health, and the global economy. Consequently, recycling and repurposing solid waste into building materials is crucial (Gharieb and Rashed, 2020, Sadek and El-Attar, 2012). Given the projected increase in cement usage, a major contributor to carbon emissions, researchers are exploring alternative cementitious materials derived from industrial waste and byproducts to mitigate environmental impact (Yadav et al., 2020, Yousef et al., 2022).
Previous research indicates that incorporating industrial byproducts such as slag, aluminum, and granite into concrete not only lowers production costs and carbon footprint but also enhances its mechanical strength and durability. Furthermore, admixtures, particularly nanosilica, refine the microstructure of concrete and reduce calcium hydroxide (CH) content through pozzolanic reactions. Nanosilica, in comparison to microsilica, more effectively improves compressive strength by promoting the formation

of denser silicon chains, filling voids with nanoscale particles, and enhancing the microstructure of the interfacial transition zone (ITZ), resulting in improved impermeability (Sun et al., 2021, Al-Bayati et al., 2024). This method promotes a more uniform concrete structure. This homogeneity arises from the pozzolanic material's amorphous silica reacting with the calcium hydroxide produced during cement hydration. Furthermore, the fine particles contribute to denser packing within the concrete and minimize the "wall effect" at the interface between the cement paste and aggregate (fine and coarse aggregate) (Guo et al., 2014; Page and Fanourakis, 2021).

Research explored the use of FA and slag (GBFS), along with RA, in concrete production (Tam et al., 2019, Vesmawala et al., 2018). An experimental study assessed the concrete's compressive strength, rupture modulus, and shrinkage by varying the proportions of recycled coarse aggregate (0%, 50%, 100%), slag (0%, 50%), and FA (0%, 50%). The findings indicated that increasing the RA content improved concrete strength, potentially due to material quality and mixing methods. The study suggests that high-quality recycled concrete can be produced by combining RCA with FA and slag (Ferraro et al. 2019, Sandanayake et al. 2020).

Numerous studies have explored the use of RA and various waste materials to create sustainable concrete (Memon et al., 2020; Rashad and Gharieb,2021; Colangelo et al., 2021). Recently, Chhetri et al., (2024) investigated the properties of concrete mixes for interlocking concrete pavers (ICP), using coarse recycled concrete aggregates (CRCA) and SCMs. The study compared mixes with varying CRCA and SCM percentages to a control mix, which utilized ground glass pozzolans, limestone cement, and slag as SCMs. Their research revealed that while CRCA increased the water-cement ratio, combining CRCA with SCMs maintained a similar ratio to the control. Notably, SCMs improved water absorption resistance, and although CRCA slightly reduced compressive strength, the mixes with both CRCA and SCMs demonstrated significantly improved freeze-thaw resistance, with mass loss reduced by 57-77%. These findings strongly support the partial replacement of natural aggregates and conventional cement with CRCA and SCMs for more sustainable concrete construction.

The internal curing potential of RCA was examined by Pickel (2014). This study varied RCA saturation and replacement levels in concrete. The research revealed that fully saturated RCA boosted early compressive strength compared to Nag mixes. At a 30% replacement level, RCA didn't significantly alter tensile strength, elastic modulus, or permeable porosity. However, when compared to Nag concrete, RCA concrete generally exhibited higher permeable porosity and reduced tensile strength and elastic modulus.

The concrete industry can contribute to sustainability by recycling construction waste, which minimizes landfill space, saves energy, reduces pollution, and conserves resources (Seara et al., 2016; Rashad and Gharieb, 2021). Studies have demonstrated that concrete made with fully replaced RAs, when combined with mineral admixtures such as FA, slag, and silica fume, can meet specific performance requirements (Corinaldesi et al., 2010; Corinaldesi et al., 2011). Additionally, the use of nanomaterials to enhance the physical and mechanical properties of concrete is a growing area of research, with various nanoparticles being effectively incorporated to improve durability (Han et al., 2017; Ahmad et al., 2022). The study explored the effects of incorporating RAs and mineral admixtures (nanosilica fume, granite, slag, and aluminum waste) on concrete's physical and mechanical properties. By replacing cement with 15% slag, 10% granite, 1.5% aluminum waste, and 1% nanosilica, and substituting coarse aggregate with recycled concrete, the research sought to develop a sustainable concrete mix using readily available waste materials in Egypt.

In contrast, ICP has been utilized since the 19th century and has undergone remarkable advancements over the years. Extensive research continues to be conducted on ICP, which is applied in numerous settings, including driveways, crosswalks, sidewalks, parking lots, ports, and airports (Garilli et al., 2020). ICP effectively tackles many urban pavement challenges, particularly the rapid deterioration of surfaces due to heavy traffic in city environments. Urban traffic demands frequent pavement repairs, but closures hurt the economy. Industrially produced ICPs avoid on-site defects, offering superior quality and durability over conventional options (Vaitkus et al., 2019). They can be installed year-round, transported, and opened to traffic immediately, unlike traditional concrete, which needs curing (Delatte, 2014). These advantages position ICPs as the better option for urban pavement.

To address the issues of urban traffic, natural resource depletion, and the disposal of concrete waste in landfills, this paper aims to utilize CRCA and SCMs in ICPs and evaluate their mechanical performance. The performance of concrete mixtures with varying percentages of CRCA and SCMs is compared with that of the control mix. This paper examines the mechanical characteristics of concrete mixes through shear strength and splitting tensile strength tests.

Experimental program

Materials

This study utilizes General Use Limestone Cement (GUL), containing 11.3% limestone powder, that complies with the CAN/CSA-A3001 standard. The concrete mixtures partially replace cement with GGBFS and ground glass pozzolan (GP) as SCMs. Table 1 outlines the properties of cement and SCM. The micro synthetic fiber utilized in this research complies with ASTM C 1116 standards and acts as reinforcement in the concrete mixtures. The physical characteristics of this micro synthetic fiber are detailed in Table 2.

This study utilizes CRCA and Nag not exceeding 20 mm in size. The particles of Nag exhibit either a smooth or rough surface texture and can be irregular or spherical in shape. The CRCA used in this investigation was produced by crushing concrete deemed unsuitable due to age, performance, and characteristics at a ready-mix concrete facility. The CRCA in the research was the portion of RCA that was kept after sifting, varying from 4.75 mm to 19 mm. The kept materials were graded using a mechanical shaker and oven-dried at 110° ± 5° C after being properly washed to remove as much mortar as had attached. Figure 1 (a and b) presents the optical images of Nag and RCA. Table 3 presents the characteristics of CRCA and Nag utilized in this study. BASF Micro-Air served as the air-entraining admixture (AEA) for all mixtures, while BASF Pozzolith 100 XR functioned as the water-reducing admixture (WRA).

This research developed three concrete mixtures incorporating CRCA and SCM replacements, alongside a control mix. Various percentages of CRCA (0%, 20%, and 40%) and SCMs (0%, 20%, and 30%) were utilized to substitute for the Nag and cement in the concrete formulations. The degree of CRCA and SCM replacement differentiated the sample sets. A naming system was created for the different concrete types to facilitate tracking of these variables, as outlined in Table 4. Every concrete type received a name derived from three specific components. The mixtures are designated as RCx/Sy/Gz, where RC represents CRCA, and "x" indicates the replacement percentage. The letter S denotes the inclusion of GGBFS in the concrete mix, with "y" showing the proportion of cement substituted by GGBFS. Meanwhile, G stands for GP in the mixtures, and "z" specifies the percentage of cement substituted by GP.

The two-stage mixing approach (TSMA) was employed during the batching process (Tam et al., 2006). Initially, fine aggregates were placed into the concrete mixer's drum, followed by a manual mixing of all cementitious materials, including SCMs. Next, coarse aggregates were added, along with half of the mixing water, to initiate the coating of the aggregates. Simultaneously, the AE and WR admixtures were introduced. Finally, the remaining water was added and mixed until the fresh concrete achieved a homogeneous consistency.

Test Methods

Slump and Air Content tests

The slump of the fresh concrete and its air content were measured according to the methods specified in CSA A23.2-5C and CSA A23.2-4C, respectively (Canadian Standards Association, 2019). A standard cone with a top diameter of 100 mm, a bottom diameter of 200 mm, and a height of 300 mm was used to assess the slump values. Three equal volumes of fresh concrete were then carefully introduced into the damp mold. Additionally, this experiment employed a steel tamping rod with a diameter of 16 mm and a rounded end. Each concrete layer was struck 25 times on the surface. After placing and rodding the third layer of concrete, the surface was leveled. Once the surface layer was leveled, the cone was lifted vertically for approximately 5 seconds. The cone was inverted and positioned next to the concrete to measure the vertical displacement of its top level. The average of the three data points was used to assess the differential settling of this layer.
To measure the air content in the concrete mixtures, the concrete was consolidated in a cylindrical pressure vessel with an internal diameter of 206 mm and a height of approximately 212 mm. Three equal layers of concrete were applied and compacted firmly with a rod. Afterward, each layer was further consolidated with a rubber mallet to remove any air bubbles trapped in the mixture. The vessel was then filled and leveled off. The pressure cylinder's lid was securely sealed to the vessel. Gaps between the lid and the concrete surface were filled with water, and air was introduced to pressurize the vessel. The degree of air infiltration into the concrete indicated its air content, and the measured values of air content were subsequently documented (Chhetri et al., 2024).

Shear Strength Test

Two specimens, each measuring 150 mm x 150 mm x 450 mm and featuring notches on opposite sides, were prepared to assess the shear strength of concrete mixtures. The test specimens were created using a mold assembled at the University of Waterloo, as shown in Figure 2. A shear test was conducted on the specimens 28 days post-curing. The universal testing machine applies a constant shear load of 0.25 ± 0.05 kN/sec, as illustrated in Figure 3. The specimen was designed to ensure that shear failure occurs at a known plane. The method described above is referred to as the single shear test because failure occurs at only one plane (Omidi 2021).
The concrete's shear strength is calculated using the formula in equation 1.

$$\tau_s = \frac{p_s}{bh} \tag{1}$$

Where:
τ_s = Shear strength of the sample, MPa,
p_s = Maximum shear load, KN,
b = Widht of sample, mm,
h = Height of shear failure plane, mm.

Splitting Tensile Strength Testing

The splitting tensile tests were conducted in accordance with CSA A23.2-13C (CSA, 2009) using concrete cylinders measuring 100 x 200 mm. Testing occurred after a curing period of 28 days. All results were documented and presented as an average of three test samples. Specimens were placed beneath the bearing block, as shown in Figure 4. Each specimen was carefully aligned with the center of the bearing block in the testing area. A continuous load was applied to each specimen, varying from 0.7 to 1.4 MPa/min. The testing equipment measured the load applied, recording the ultimate load at the point of sample failure. This maximum load, expressed in kN, was logged, and Equation 2 was utilized to calculate the splitting tensile strength.

$$T = \frac{2p}{\pi . l . d} \quad (2)$$

Where:
T = Splitting tensile strength, MPa
P = Maximum applied load indicated by the testing machine
l = Length of the, mm
d = Diameter of the specimens, mm.

Results and Discussion

Table 5 presents a summary of the study's findings, displaying the averages derived from three measurements for each test.

Slump and Air void

The slump value of 55 ± 5 mm was consistently observed across all mixtures. These measurements suggest that the mixtures are moderately workable. Nonetheless, the water-cement (w/c) ratio varied for each mixture to reach the target slump of 55 ± 5 mm. All mixtures examined, including CM, featured water-to-cement (w/c) ratios of less than 0.5, as shown in Table 5. Notably, the RC 20 mixture has the highest w/c ratio. This rise in w/c ratios is attributed to the greater amounts of CRCA present in this mixture. The characteristics of CRCA are influenced by the residual mortar that adheres to the aggregates; an increase in mortar content results in higher porosity of the CRCA, thereby increasing its water absorption capacity demand (Cahyani and Rusdianto 2021; Yehia et al., 2015). Even with CRCA in the mixtures, the water-to-cement ratios for RC 20/S 20 and RC 40/S 20/G 10 are equal to or lower than that of CM. This reduction can be credited to the inclusion of SCM, which diminishes water needs in these blends. The smooth and dense nature of SCM particles means they absorb less water than Portland cement particles, which enhances the workability of concrete that contains SCM (Cahyani and Rusdianto 2021).
The results indicate that all of the combinations satisfied the 5-8 percent air content requirements as stated in the CSA A23.1 regulation. The findings demonstrate that the air void content of each combination was similar to that of the CM. To make sure all mixes complied with the requirements, the air content was tested as soon as the mixture was mixed. All of the combinations contained an air-entraining agent (AEA) in order to comply with the specifications.

Shear Strength Test

Table 5 presents the maximum shear load (Ps) and shear strength (τs) results for all mixtures, depicted in Figure 5. The shear strength findings correlate by the percentage of Nag replaced by CRCA and the cement replaced by SCMs.
It is clear that CM, with 0% CRCA and SCM, exhibits the greatest shear strength. When the CRCA percentage rises to 20%, the reduction in shear strength is minimal, registering at less than 1% in the RC 20 mix. Meanwhile, the mixed RC 20/S 20 demonstrates shear strength closest to CM. In contrast, the mix RC 40/S 20/G 10 displays the lowest shear strength, with a decrease of approximately 20.27%. It is evident that the percentage replacement of CRCA significantly affects the shear strength properties of concrete. However, it is also noted that adding SCM does not substantially enhance shear strength. The RC 20/S 20 mix, which contains 20% SCM compared to 0% SCM in the RC 20 mix, shows a slight increase. The shear strength of RC 20/S 20 is about 1% higher than that of RC 20.

The highest shear stress that ICPs encounter under heavy loading is 1.42 MPa, according to the finite element modeling results (Omidi, 2021). When the shear stress exceeds the material's shear strength, it causes the pavement to break. Given that the shear strength values for all mixtures range from 4.5 to 5.7 MPa, they provide adequate shear strength.

The shear strength of Mix RC 20/S 20 is comparable to that of CM. These results are highly promising for increasing the application of CRCA and SCM in concrete pavements, which could help lower Nag consumption and CO_2 emissions.

Splitting Tensile Strength

After 28 days, splitting tensile strength tests were conducted on each specimen. Table 5 and Figure 4 present the results, which include the splitting tensile strength (T) and maximum applied load (P) for each mixture.

The findings of the splitting tensile strength analysis have been examined in connection with substituting cement with SCM and Nag with CRCA. Out of all the studied mixes, the CM showed the highest tensile strength. Also, the outcomes reveal that tensile strength decreased by just around 1% when CRCA was added to the RC 20 mix at a 20% replacement level, suggesting a minor effect. On the other hand, the RC 20/S 20 mix, which contains 20% CRCA and 20% SCM, showed a slightly lower drop in tensile strength (approximately 2.5%) compared to the CM. With a notable 14.5% loss in tensile strength, the RC 40/S 20/G10 mix, which contains 40% CRCA, 20% SCM, and 10% glass, exhibited the most significant impact on tensile performance, underscoring the negative effects of increased replacement levels.

Generally, as the content of RCA increases, the splitting tensile strength typically decreases. This reduction is primarily attributed to the higher porosity, lower density, and weaker bonding of the mortar in RCA. Similar to the findings regarding shear strength, the inclusion of supplementary cementitious materials (SCM) results in only slight enhancements in tensile strength.

The results regarding splitting tensile strength align with findings from other studies, indicating that the splitting tensile strength of RCA concrete is lower compared to that of Nag concrete (Çakir 2014; Maruyama 2014; Mcneil and Kang 2013; Padmini et al., 2009). Furthermore, research shows that utilizing SCM has a limited effect on enhancing the tensile strength of the specimen (Ann et al., 2008).

Statistical Analysis of the Obtained Results

To determine whether significant differences exist between the mean values from the various tests, a one-way analysis of variance (ANOVA) was conducted. Shear strength and tensile strength were considered dependent factors in this study, while the different proportions of CRCA and SCM in the mixes were treated as independent variables. Since a significance criterion of 0.05 was used, any p-value below this threshold would indicate a statistically significant impact.

Table 6 presents the findings from the one-way ANOVA analysis. This analysis aimed to determine the statistical significance of CRCA in the concrete mixtures by comparing the results from the CM and RC 20 mix. A comparison was conducted between the results of RC 20 and RC 20/S 20 mixes to determine the statistical significance of GGBFS as an SCM in the concrete mix. The obtained results indicate that the impact of 20% CRCA and 20% SCM on the shear and tensile strength of concrete mixtures seems statistically insignificant.

It is reasonable to conclude that the differences in the results are statistically insignificant, indicating that the incorporation of SCM along with CRCA has an insignificant effect on the shear and tensile strength of concrete.

The experimental findings strongly support the adoption of CRCA and SCM in concrete mixes, applicable not only in ICP but also in structural concrete and more sustainable concrete practices.

Conclusion

This study primarily aimed to assess the mechanical performance of ICPs that incorporate CRCA and SCMs in typical high-traffic urban environments. To achieve this aim, three concrete mixtures were examined, featuring different percentages of CRCA and SCMs as partial substitutes for cement and GUL cement, along with a CM.

- Concrete mixtures incorporating CRCA and SCMS produced workable mixes. All mixtures exhibited a slump value of 55 ± 5 mm, and the w/c ratio was adjusted in each mix to attain these slump measurements.
- The shear strength of CM was the highest among all mixes. As the percentage of CRCA in the mixtures increased, the shear strength value decreased by as much as 20.27 %. The findings indicated that adding SCMs did not significantly impact the concrete's shear strength. Nevertheless, a minimal difference of less than 1% in shear strength was observed when 20% of CRCA was replaced. Hence, the results suggest that using CRCA as a replacement for Nag in ICPS up to 20% can help reduce the consumption of natural aggregates.
- CM exhibited the highest splitting tensile strength. As the CRCA replacement percentage increased to 40%, the splitting tensile strength dropped by up to 14.5%. The mix of RC 40/S 20/G 10 recorded the lowest tensile strength. Nevertheless, at a 20% CRCA replacement level, the tensile strength varied minimally, with differences of less than 1%. Additionally, the results indicate that incorporating SCMs did not significantly affect the concrete's tensile strength. Hence, the findings promote using CRCA as a partial substitute for Nag in ICPs, up to 20%, to reduce the consumption of natural aggregates.
- According to the findings of a single-factor ANOVA analysis, incorporating SCM along with CRCA has an insignificant effect on the results of tensile and shear tests.

The findings from this study strongly support the use of CRCA and SCMS in ICPS and concrete overall, as they can partially replace Nag and traditional cement by reducing CO_2 emissions, facilitating the transition to more sustainable concrete practices.

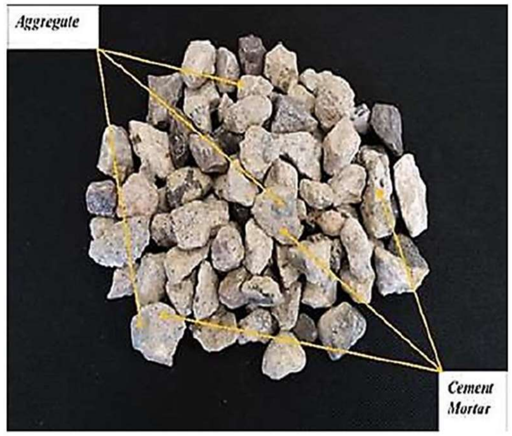

Figure 1: Optical images of Nag & RCA.

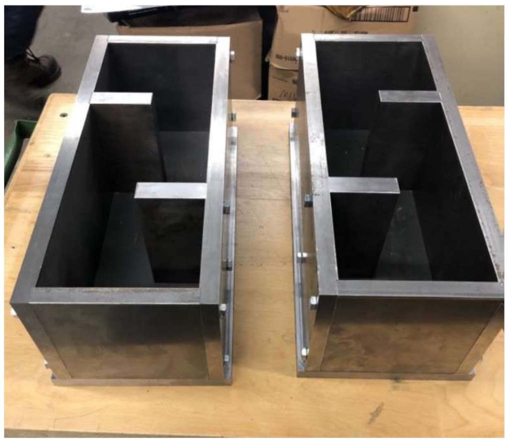

Figure 2: Shear mold for double shear test (Omidi 2021).

Figure 3: Shear strength test setup

Figure 4: Splitting tensile strength setup

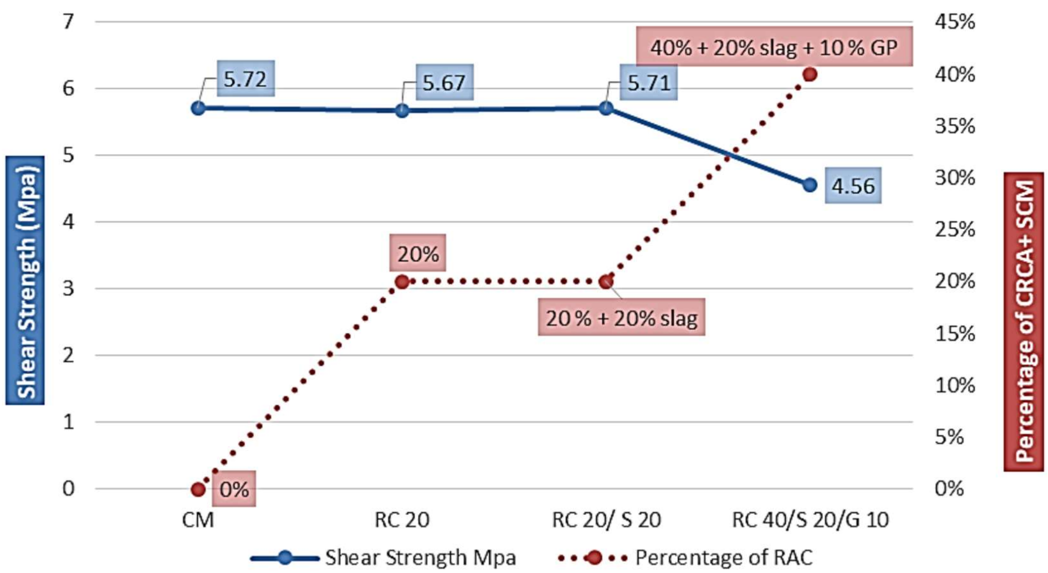

Figure 5: Results of shear strength in relation to the percentage of RCA and SCMs substituted in all mixes.

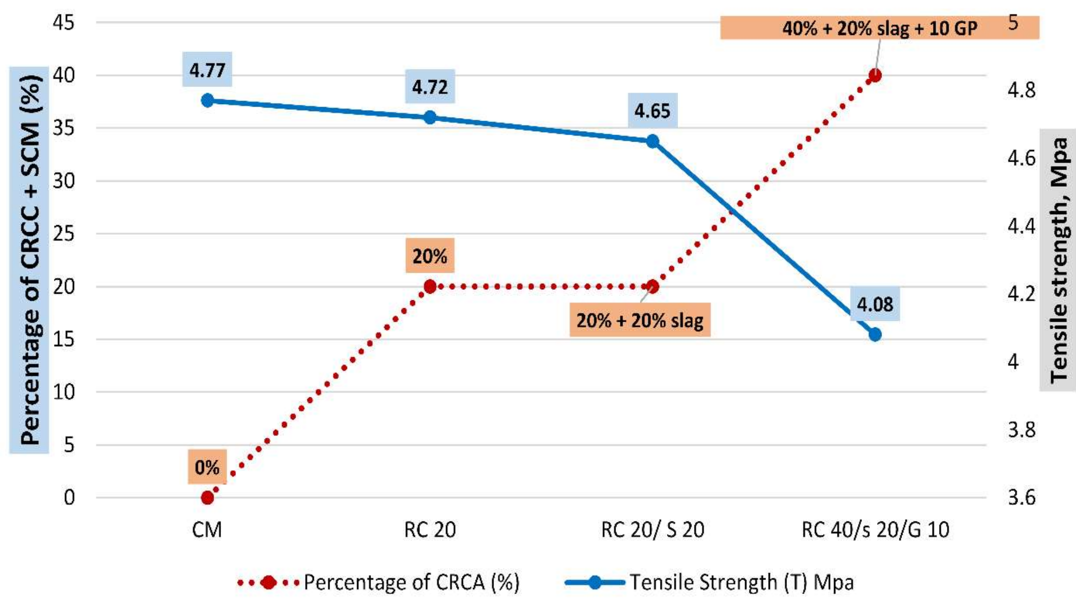

Figure 6: Results of splitting tensile strength with various percentages of RCA and SCM replacements for all mixtures.

Table 1. Cementing materials' properties

Cementing Material	General Use Limestone Cement (GUL)	GGBFS	GP
CaO (%)	63.4	38.5	10.9
SiO_2 (%)	18.9	40.1	71.0
Al_2O_3 (%)	4.4	7.8	1.82
Fe_2O_3 (%)	3.2	0.74	0.61
MgO (%)	0.7	9.7	0.94
SO_3 (%)	2.7	2.21	< 0.1
Na2O (%)	0.12	0.38	13.0
K_2O (%)	-	0.53	0.52

Table 2. Properties of micro-synthetic fibres

Properties	Value
Specific gravity	0.91
Melting point	160°C
Ignition Point	590 °C
Absorption	_
Alkali Resistance	Excellent
Electrical Conductivity	Low
Thermal Conductivity	Low
Tensile Strength	415 MPa
Modulus of Elasticity	5.52 Gpa
Length	19 mm

Table 3. Properties of Nag and CRCA

Aggregate Properties	Nag	CRCA
Apparent Specific Gravity	2.7	2.638
Absorption (%)	0.66	5.91
Micro-Deval Abrasion Loss (%)	12.58	23.57
Adhered Mortar (%)	_	3.02

Table 4. Concrete mix designation

Sl No.	CRCA Content (%)	GGBFS content (%)	GP Content (%)	Mix-Designation
1	0	0	0	CM
2	20	0	0	RC 20
3	20	20	0	RC 20/S 20
4	40	20	10	RC 40/S 20/ G 10

Table 5. Summary of testing outcomes

Mix	slump		Air Void Content (%) (Chhetri et. al., 2024)	Shear Strength (MPa)			Splitting Tensile Strength		
	Slump (mm)	w/c ratio		Maximum Shear Load (PS) kN	Shear Strength (τs) MPa	Percentage Decrease in Shear Strength over Control Mix	Maximum Shear Load (PS) kN	Tensile Strength (T) Mpa	Loss of mass 28 cycles g/m2)
CM	55	0.461	5.1	128.8	5.72	NA	149.8	4.77	NA
RC 20	52.9	0.48	5.2	127.7	5.67	< 1%	148.3	4.72	1.00%
RC 20/S 20	55.8	0.46	5	128.5	5.71	< 1%	146	4.65	2.5%
RC 40/s 20/G 10	54.61	0.44	5.3	102.7	4.56	20.27%	128	4.08	14.50%

Table 6. Outcomes of One-Way ANOVA Analysis

Test	P-value	F actual	F critical	Significance
Shear strength				
20% CRCA	0.36	1.35	18.51	Insignificant
20% CRCA with 20% GGBFS	0.57	0.46	18.51	Insignificant
Tensile strength				
20% CRCA	0.17	2.65	7.7	Insignificant
20% CRCA with 20% GGBFS	0.31	1.29	7.7	Insignificant

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