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Mechanical properties of recycled concrete aggregates with superplasticizer

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ABSTRACT

Many dilapidated civil constructions have been demolished as a result of the necessity for rehabilitation and the effective use of the land that is available. The build-up of waste materials from destroyed concrete strains landfills and adds to the environmental load, making development initiatives unfeasible. Superplasticizers can be used to improve the mechanical characteristics of concrete, which is one way to address this problem. The objective of this work is to assess how a superplasticizer affects the mechanical characteristics of concrete made using recycled aggregate. In order to make concrete specimens, several replacement ratios of fresh natural aggregates with recycled stone and brick aggregates were tested, ranging from 0% to 100%. After applying the superplasticizer to 50% of the concrete specimens, the water content of the concrete mixtures decreased by 15%. The outcomes of the tests show that adding superplasticizers to recycled aggregate concrete improves its mechanical qualities. The mechanical performance of the concrete was found to be unaffected by the addition of superplasticizer, even when recovered stone and brick aggregates replace 50% and 25% of the fresh, natural coarse aggregates, respectively.

Keywords: Superplasticizer; Recycled stones and bricks; Mechanical properties; Fresh and Harden concrete tests; Microstructural Analysis.

1. INTRODUCTION

The unexpected rise in demand for concrete is being caused by the accelerated rate of urbanization. Concrete is used extensively in building in many developing nations because it is inexpensive and can be shaped into a variety of shapes. Concrete debris weighing millions of tons has been produced during the demolition of old and abandoned structures. A large amount of the debris from demolition is being dumped in landfills, which presents serious environmental issues and makes the area unusable for farming. The demolished debris is producing fine dust, which aggravates health problems by adding to air pollution. Furthermore, natural resources—which are necessary components in the production of fresh concrete—are in short supply. Globally, about the annual usage of concrete is 30 billion tons [1]. Over 26.8 billion tons of construction aggregates are required annually on a global basis. Due to both the need for substantial civil infrastructure and the country's fast expansion, aggregate demand has increased. The recycling and reuse of concrete waste have become vital techniques to support sustained growth and lessen the need for fresh natural aggregates (NA). Recycling and cutting down on pollutants in the environment are two benefits of using RAC [2]. The recycling and repurposing of destroyed concrete waste is nevertheless hampered by the Recycled aggregate concrete's (RAC) poor mechanical performance. Several studies have demonstrated that the service life of recycled aggregate concrete (RAC) decreases with an increasing replacement ratio of RAC with natural aggregates (NA). Three different treatment methods applied to RAC produced notable increases in compressive strength and a 15%–35% improvement in concrete slump Sodium silicate solution, cement-silica fume slurry, and Los Angeles (LA) abrasion treatment. Recycled aggregate concrete (RAC only) can have its mechanical qualities improved by chemically treating the recycled aggregate. Concrete's uniaxial compressive strength significantly decreases with increasing temperature [3]. That being said, this negative impact can be mitigated with the addition of rubber particles and recycled aggregate. It has been shown that the adhering mortar around the natural aggregate surface governs the properties of RCA.

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To differentiate itself from fresh Natural Aggregate (NA), RCA is mechanically superior to fresh NA because of the quantity and quality of attached mortar. RCA's attached mortar has a significant impact on its mechanical capabilities. Crushing is a step in the preparation process that affects adherent mortar quality in RCA. Several studies have demonstrated a decrease in the amount of adhering mortar as the size of the RCA rises. According to statistical studies, the volume of attached mortar in crushed demolished concrete used in RCA is more than one-third that of the parent concrete [4]. Recycled concrete aggregate's (RCA) increased porosity, high water absorption, and low relative density are all explained by adhering mortar. RAC with a high percentage of attached mortar has been shown to have high water absorption and poor mechanical performance. If the adhering mortar content in structural concrete is more than 44%, RCA cannot be employed. There is a positive correlation between aggregate sizes and the mechanical strength of Recycled Aggregate Concrete (RAC). This was observed as the size of the RCA rose. Early studies found that adding recycled concrete aggregates (RCA) in different ratios to natural aggregates (NA) significantly reduced the mechanical performance of the concrete [5]. Moreover, findings showed that RAC's mechanical qualities are influenced by the recycled aggregates' service life.

Based on studies [6–8], several researchers have found that replacing 50% of the natural aggregates (NA) in RAC with RCA can reduce the RAC's compressive strength by up to 25%. Following a similar pattern to the drop in compressive strength, as reported in different studies, tensile strength splitting was seen to fall by as much as 39% with a total replacement of natural aggregates (NA) with RCA. Compared to natural aggregate concrete (NAC), the elasticity modulus of RAC might be as low as 60%. Several studies have demonstrated that substituting up to 30% of Natural Aggregate (NA) with RCA does not significantly impair concrete's mechanical performance, as references demonstrate [9]. ZHANG *et al.* [10] reviewed the collective study on RAC carried out by different scholars in their review. They suggested that a number of criteria, including the properties of RCA, the presence of fines in RCA, and the required workability in mix design, are important in figuring out the best proportions for the replacement of Natural Aggregate (NA) by RCA. Concrete becomes more mechanically strong as the water-to-cement ratio is lowered, but it also becomes less workable [11]. Additionally, the workability of RAC is reduced by RCA's enhanced water absorption. To achieve the appropriate workability or slump value in concrete while lowering the water-to-cement ratio, superplasticizers are used. A small increase in mechanical strength and a reduction in the amount of water in the mixtures are the results of adding superplasticizers. PATOWARY and SIDDIQUE [8] claimed that a responsive superplasticizer may be used to control the rheology of newly manufactured cement-based products. The results of their study demonstrated that superplasticizers based on polycarboxylic ether (PCE) can be given other functions by adding certain chemical groups [12]. Superplasticizers based on PCE are utilized improved cementitious mixture workability and was linked to the mechanical restrictions involved. Nonetheless, they discovered that the use of superplasticizer reduced the compressive strength of alkali-activated cementitious mixes by an average of 17%. Using PCE-based superplasticizers with shorter side chain lengths has a negative impact on the concrete's performance in both the short and long term [13]. Concrete's compressive strength rises when a superplasticizer is added [14]. On the other hand, concrete segregates and loses compressive strength when superplasticizer is used excessively. Although the effects of superplasticizer on natural aggregate concrete (NAC) are well known, little research has been done on how superplasticizer affects recycled brick and stone aggregate concrete (RSAC & RBAC). Research has been conducted in the previously indicated context about the impact of superplasticizer on the mechanical characteristics of Recycled Aggregate Concrete (RAC), which is composed of two distinct types of recycled aggregates [15]. This paper shows experimental data to urge the building sector to use leftover concrete from demolition.

2. MATERIALS USED AND METHODOLOGY

The properties of fine aggregates, recycled brick and stone aggregates were found by laboratory research works. The following subsections contain a full description of the test results. Additionally, a variety of concrete mixtures procured from the nearby marketplace were blended utilizing commercially accessible cement and super plasticizers.

2.1. Cement and water

The binding material used in this study has been Portland Composite Cement (PCC), also known as BDS EN 197-1:2003 CEM II/B-M (S-V-L) 42.5 N. Drinkable freshwater has been utilized as the mixing water to prepare different mixes of concrete.

2.2. Coarse and fine aggregates

The study used fine aggregate that was obtained locally and was identified as "Sylhet sand," which is distinguished by its yellowish type. Either significantly larger or slightly coarser fine aggregate granules were present.

Three different kinds of coarse aggregate were employed, as shown in Figure 1. The three types of coarse aggregate that are utilized are recycled brick, stone aggregates and natural aggregate (black Indian stone). Whereas RBA came from the debris left behind after an old residential building was demolished, RSA was derived from concrete waste from laboratories. The aggregates' different physical characteristics were investigated, and their gradation was ascertained using sieve analysis. Figure 2 shows the aggregate gradation, while Table 1 provides a full explanation of the individual physical characteristics.

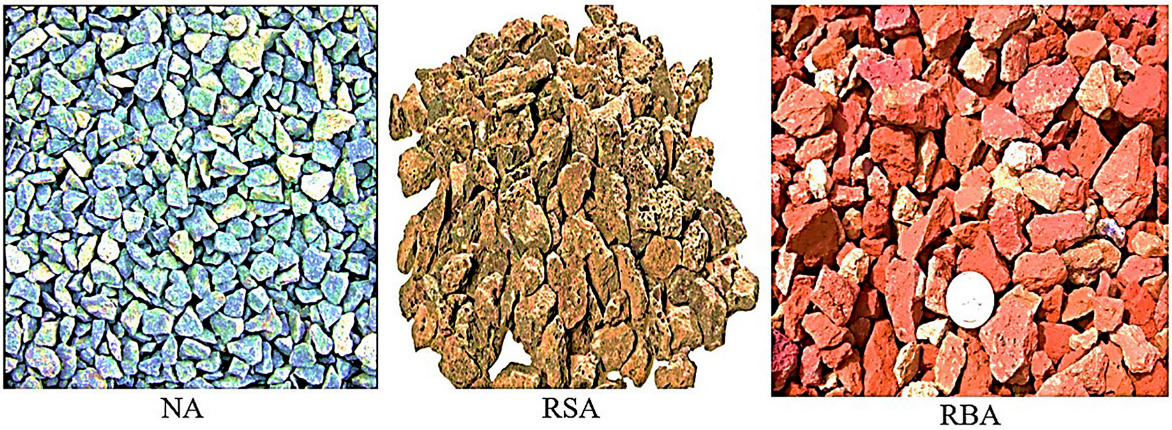


Figure 1: Types of coarse aggregates used for concrete mixes.

Table 1: Properties of coarse aggregates used for experimental work.

AGGREGATE TYPE	FM	UNIT WEIGHT (kg/m^3)	SPECIFIC GRAVITY	CAPACITY OF ABSORPTION (%)
NA	6.85	1531	2.71	1.79
RSA	6.28	1248	2.18	7.28
RBA	7.41	1024	1.76	11.15
FA	2.82	1527	2.61	0.71

*FA – Fine Aggregate, RSA – Recycled Stone Aggregate, RBA – Recycled Brick Aggregate & NA – Normal Aggregate.

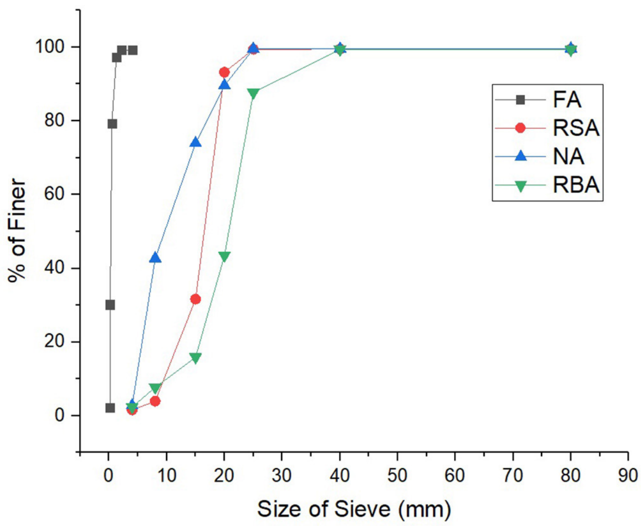


Figure 2: Aggregate types and its size distribution.

2.3. Superplasticizer

The concrete compositions were supplemented with La Hypercrete, a third-generation superplasticizer derived from PCE. Conforms to IS: 9103-1999 (reaffirmed 2004), ASTM C494, Type F&G.5, Edition 2.2 (2007–2008). 15% less mixing water was required for all concrete mixes, and a consistent dose of 0.7% of the dry cement weight had to be applied.

2.4. Concrete mix proportion

The normal mix in this study was a concrete mix design that included fresh stone chip aggregates and was intended to reach strength of 20.7 MPa. In the neighborhood, this particular mix is frequently used as the specified concrete strength. Using different types and amounts of coarse particles, fourteen different concrete mixes were produced. Natural Aggregate (NA) replacement ratios of 0%, 25%, 50%, and 100% were used by RCA in the formulation of RAC. Every concrete mixture maintained a consistent ratio of cement to water. These particular concrete mixtures had 15% lower water content when superplasticizer was added to half of the mixes. Superplasticizer was added to the concrete mixes at a rate of 0.7% of the total weight of cement. Tables 2 and 3 display the quantities of the primary component components in the concrete mix design.

Table 2: Types of concrete mixes used for experimental study.

SPECIMEN ID	MIX NO.	WATER (kg/m^3)	CEMENT (kg/m^3)	FA (kg/m^3)	NA	CA (kg/m^3) – RECYCLED	BRICK – RECYCLED	SUPERPLASTICIZER (kg/m^3)
NAC	1	179	345	732	1190	0	0	0
RSAC–25	2	179	345	732	895	295	0	0
RSAC–50	3	179	345	732	595	595	0	0
RASC–100	4	179	345	732	0	1190	0	0
RBAC–25	5	179	345	732	895	0	295	0
RBAC–50	6	179	345	732	595	0	595	0
RBAC–100	7	179	345	732	0	0	1190	0
NACA	8	152	345	732	1190	0	0	2.4
RSACA–25	9	152	345	732	895	295	0	2.4
RSACA–50	10	152	345	732	595	595	0	2.4
RSACA–100	11	152	345	732	0	1190	0	2.4
RBACA–25	12	152	345	732	895	0	295	2.4
RBACA–50	13	152	345	732	595	0	595	2.4
RBACA–100	14	152	345	732	0	0	1190	2.4

Table 3: Quantity of aggregates used for experimental study.

Specimen ID	NA	RSA	RBA
NAC	100	–	–
RSAC–25	75	25	–
RSAC–50	50	50	–
RASC–100	–	100	–
RBAC–25	75	–	25
RBAC–50	50	–	50
RBAC–100	–	–	100
NACA	100	–	–
RSACA–25	75	25	–
RSACA–50	50	50	–
RSACA–100	–	100	–
RBACA–25	75	–	25
RBACA–50	50	–	50
RBACA–100	–	–	100

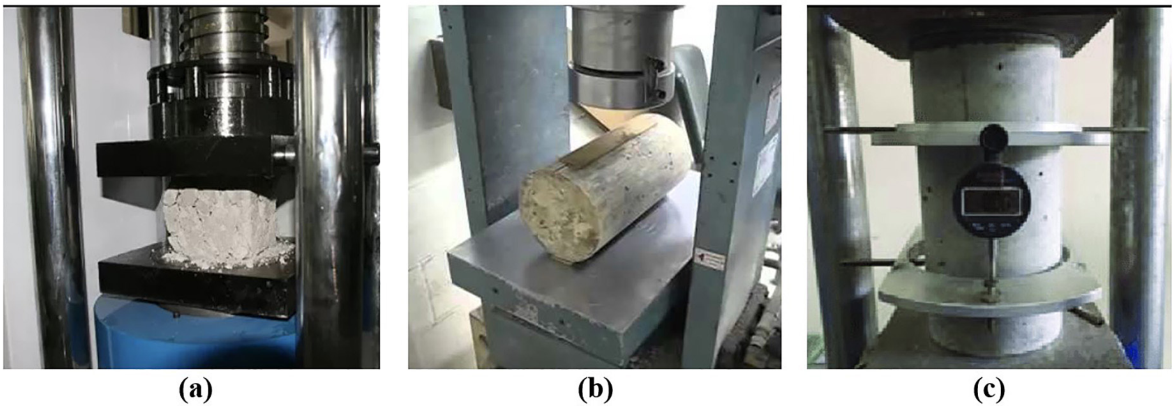


Figure 3: Laboratory setup of (a) compression, (b) split tensile and (c) elasticity modulus for concrete mixes.

2.5. Testing methods

In order to execute the compressive strength test, ASTM C39 procedures were followed. The curing period was varied at 7, 28 and 90 days and after that the testing procedure was done for prepared concrete cylinders. After 28 days curing period, the split tensile strength test was carried out using the ASTM C496 criteria. First, the concrete cylindrical specimen's stress–strain diagram was created. Using ASTM C469 criteria, the modulus of elasticity was calculated following a 28-day curing period. The experimental setup to find out the various strength of concrete mixes was shown in Figure 3.

2.6. Microstructural analysis of concrete aggregates

The surface behavior of various aggregates (NA, RSA & RBA) was analyzed using Scanning Electron Microscopy (SEM) with Energy-Dispersive X-ray Spectroscopy (EDX), X-ray Diffraction (XRD), and Fourier Transform Infrared Radiation (FT-IR) under various operating conditions. These analyses were performed to investigate the performance of the applied superplasticizer and its interactions with concrete particles to improve the mechanical strength of concrete mixes. In this study, the micro-structural analysis was examined for optimal mixes based on the results obtained from the mechanical strength of each concrete mix.

3. RESULTS AND DISCUSSION

The purpose of adding superplasticizer to RAC was to rectify a few of its particular flaws; the main goal of the investigation was to see how this would affect RAC's mechanical characteristics. The next sections contain the experimental results as well as a detailed explanation of how the superplasticizer impacts the properties of concrete, both while it's fresh and when it's hardened.

3.1. Impact of superplasticizer in fresh concrete

The workability of new concrete for both superplasticizer-containing and non-superplasticizer-containing concrete mixtures was assessed using the slump test. The procedure was followed in accordance with ASTM C143/C143M requirements. Table 4 lists the outcomes of the several kinds of concrete mixtures that were used in the study. The results indicate that the mixtures that included superplasticizer had greater slump values. Out of all the mixes, Mix-08 had the highest reported slump value. Superplasticizer was used in its study, and the coarse aggregate was used from the natural stone aggregates. Slump values were found to be greater in mixes with larger percentages of natural stone aggregates. However, the slump values of combinations with higher proportions of reclaimed brick aggregates were lower [16].

3.2. Impact of superplasticizer in harden concrete

This investigation used three different test kinds to measure the properties of the hardened concrete and the impact of the superplasticizer. The measures that were carried out included the evaluation of the concrete's modulus of elasticity (E), split tensile strength (f_{st}), and compressive strength (f'_c). The findings from this experimental study are presented in detail in the following sections.

3.2.1. Impact of superplasticizer in compressive strength

Recycled Brick Aggregate Concrete (RBAC) and Recycled Stone Aggregate Concrete (RSAC) compressive strengths at different curing ages, with and without superplasticizer added and provided graphic representations

Table 4: Workability (slump) of concrete mixes.

SPECIMEN ID	MIX NO.	WITH/WITHOUT SUPERPLASTICIZER	SLUMP VALUE IN mm
NAC	1	Without Superplasticizer	84
RSAC–25	2		81
RSAC–50	3		72
RASC–100	4		70
RBAC–25	5		81
RBAC–50	6		76
RBAC–100	7		72
NACA	8	With Superplasticizer	127
RSACA–25	9		119
RSACA–50	10		101
RSACA–100	11		101
RBACA–25	12		85
RBACA–50	13		101
RBACA–100	14		114

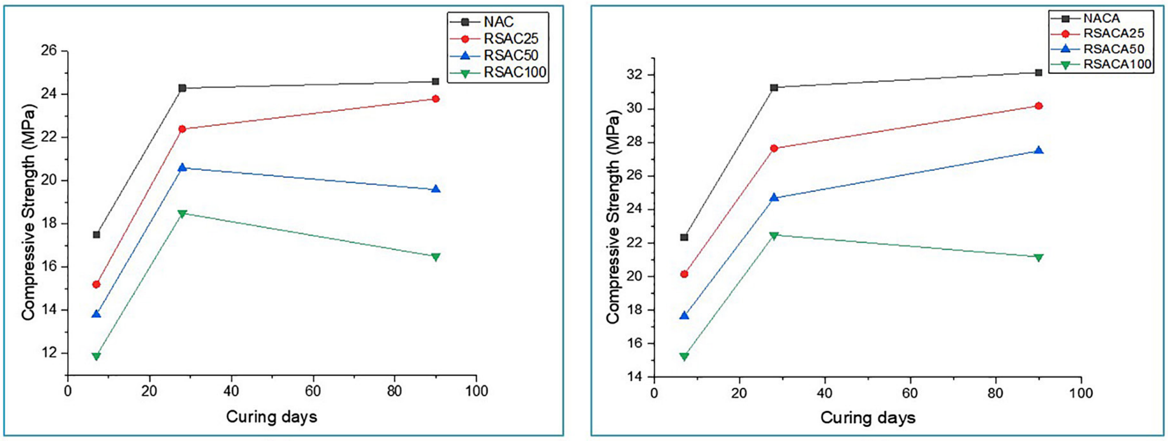


Figure 4: RSAC – compressive strength of cylinder specimens at different curing periods (a) without and (b) with superplasticizer.

in Figure 4 and Figure 5 respectively. Based on Recycled Aggregate Concrete (RAC), the results show that the superplasticizer makes a difference. Exhibiting the highest levels of compressive strength were control specimens made entirely of natural stone aggregate, both with and without the superplasticizer (NAC and NACA). When 25%, 50%, and 100% of the NA in the RSAC sample was replaced with RSA, 9.1%, 20.4%, and 25.6% decreases in compressive strength were observed, respectively in the absence of a superplasticizer after 28 days [17]. The compressive strength data for RBAC and RSAC at varying curing ages, both with and without the superplasticizer, are displayed in Figure 4 and Figure 5 respectively. The outcomes demonstrate how Recycled Aggregate Concrete (RAC) is enhanced by the superplasticizer. The specimens with the highest compressive strength were control samples made up completely of natural stone aggregate, both with and without the superplasticizer (NAC and NACA) [18]. The increase in compressive strength of 11.1%, 22.3% and 27.4% after 28 days was noticed when RSAC was employed in place of a superplasticizer, with RSA replacing 25%, 50%, and 100% of NA, respectively. When 25%, 50%, and 100% of NA were substituted with RBAC at day 28, the compressive strength of RBAC decreased by 19.2%, 26.57%, and 34.18% in the absence of superplasticizer. Compressive strength for RSAC with superplasticizer dropped by 10.2%, 23.5%, and 29.4% after 28 days; these percentages indicate that RSAC replaced 25%, 50%, and 100% of NA. The compression strength for RBAC with superplasticizer decreased by 21.8%, 29.5%, and 37.5% after 28 days, or by 25%, 50%, and 100% when

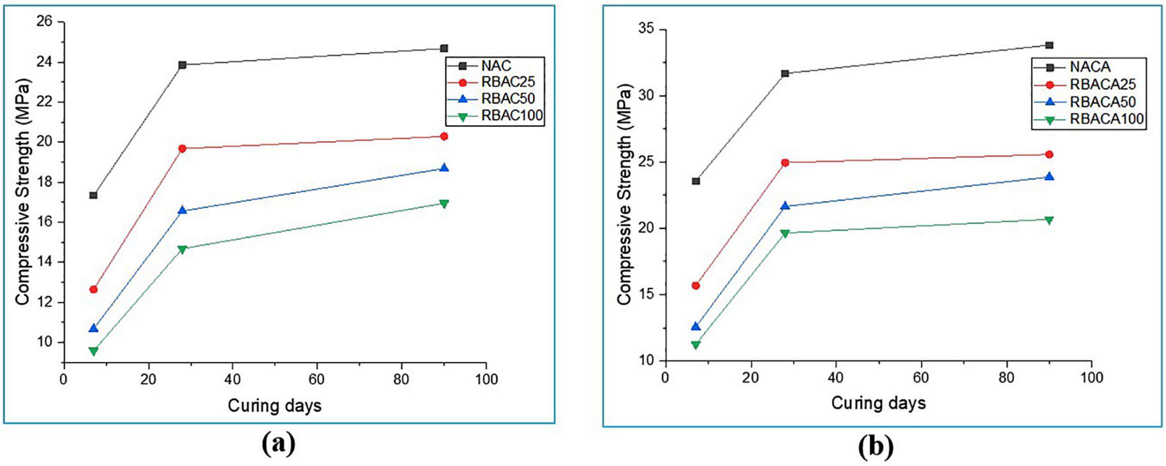


Figure 5: RBAC – compressive strength of cylinder specimens at different curing periods (a) without and (b) with superplasticizer.

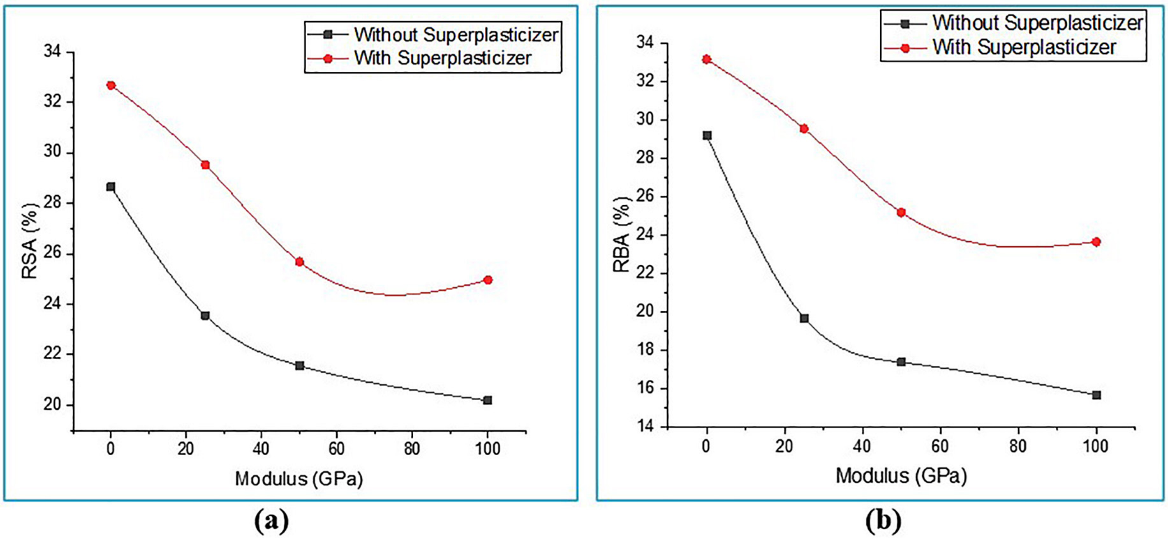


Figure 6: (a) RSAC and (b) RBAC – compressive strength with/without superplasticizer after 28 days of curing period.

RBA replaced NA. After the curing period (7 & 90 days), a regular pattern is also observed. RAC showed a progressive decline in compressive strength as the percentage of RCA (recycled concrete aggregate) rise [19]. When recycled aggregates are used in concrete production, the presence of old mortar attached to these aggregates can indeed affect the performance of the concrete [20].

Recycled Brick Aggregate Concrete (RBAC) and Recycled Stone Aggregate Concrete (RSAC) at 28 days of curing are shown graphically in Figure 6(a) and (b), respectively, to show how superplasticizer affects their compressive strengths. The application of superplasticizer increased the compressive strength of NAC, which is made entirely of natural stone chips, by 32.5% to 36.9% at different curing times. The equivalent compressive strength in RSAC containing 25%, 50%, and 100% recycled stone chips increased by 33.1% to 34.9%, 29.4% to 34.5%, and 28.3% to 33.9%, respectively, as a result of superplasticizer being added at varied curing periods. Adding superplasticizer to concrete has been shown to improve compaction, which makes the concrete denser and increases its compressive strength [21]. This impact can be shown in RBAC compositions, where different recycled brick chip percentages (from 25.2% to 30.5%) result in higher compressive strength. Because of its ultra-long side chains; Superplasticizer has a potent anti-steric action [22]. By increasing the area of contact between cement particles and water, this impact speeds up cement hydration and makes it easier for a compact C-S-H gel structure to develop. This C-S-H gel then fills the gaps in the cement paste, creating a denser structure with increased durability and mechanical strength [23].

3.2.2. Impact of superplasticizer in tensile strength

Figure 7(a) and (b) shows the graphical representation of split tensile strength for RSAC and RBAC with superplasticizer. The splitting tensile strength of NAC made entirely of natural stone chips increased by 15.38% when superplasticizer was added. The use of superplasticizer resulted in increases in split tensile strength of 11.7%, 12.4%, and 4.7% in RSAC at different percentages of recycled stone chips: 25%, 50%, and 100%. After 28 days of curing, the split tensile strength of RBAC consisting of 25%, 50%, and 100% recycled brick chips increased by 10.2%, 11.8%, and 6.2%, respectively, due to the use of superplasticizer. As a result of the superplasticizer's action, a superior quality cement paste with increased density is produced, which helps to improve splitting tensile strength [24]. Similar to the behavior seen in compressive strength, the splitting tensile strength exhibits a decreasing trend when the amount of RCA replaces natural aggregate (NA). Figure 8 and Figure 9 visually display the experimental data illustrating the link between the splitting tensile strength and compressive strength of Recycled Aggregate Concrete (RAC), together with the correlation suggested by ACI 318-14. This shows that there is a linear relationship between the two variables. The graphical representations demonstrate that, in comparison to the suggested values of ACI 318-14, the measured split tensile strength readings are lower. The reason for this discrepancy is that the mix contains RCA. According to the developed formulas; the splitting tensile strength of concrete is highly dependent on its compressive strength [25]. The effect of modulus of elasticity with superplasticizer equations and their accompanying coefficient of determination values in the relevant

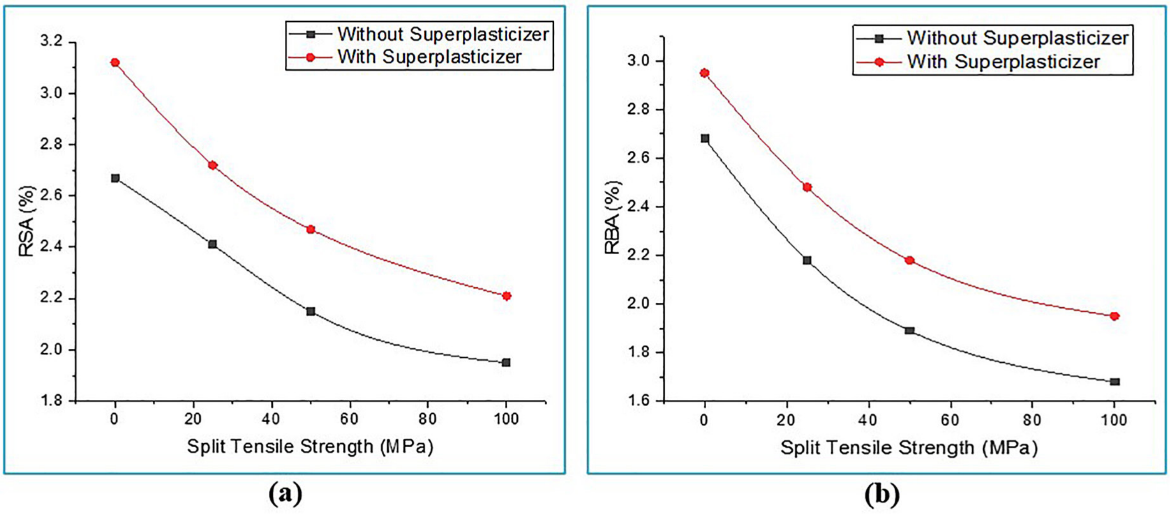


Figure 7: (a) RSAC and (b) RBAC – split tensile strength with/without superplasticizer after 28 days curing period.

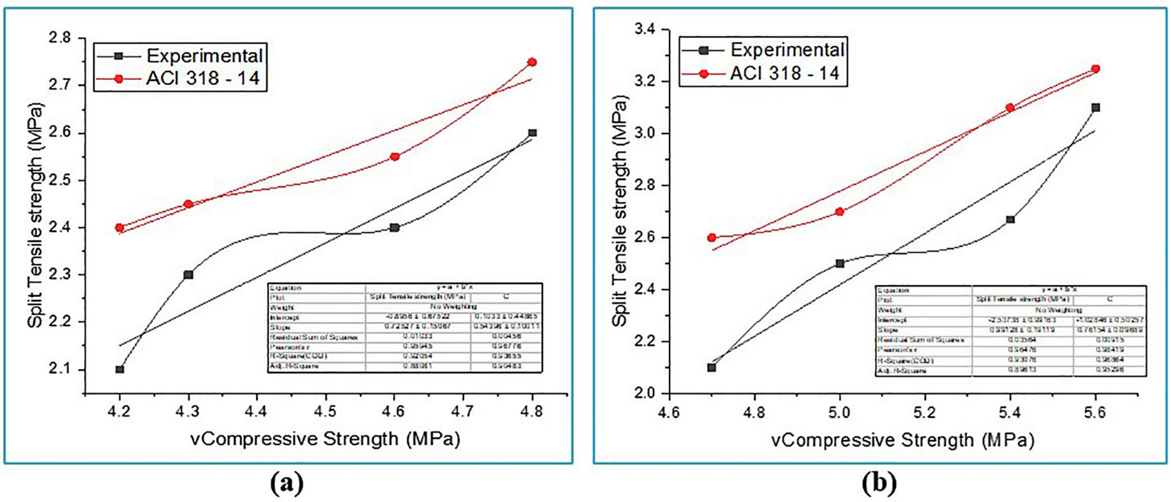


Figure 8: Comparison of the RSAC's split and compression tensile values after 28 days, (a) with and (b) with superplasticizer.

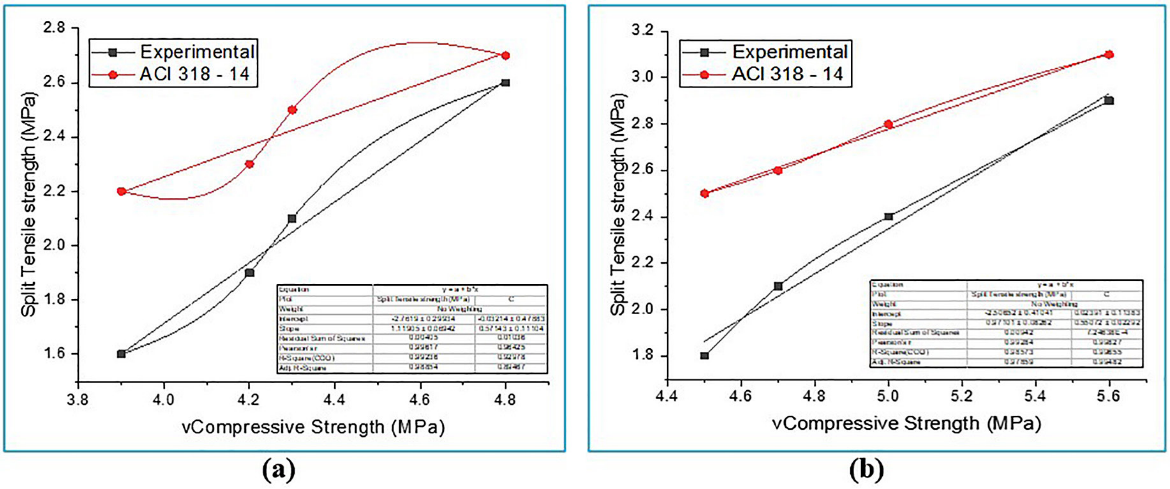


Figure 9: Comparison of the RBAC's split and compression tensile values after 28 days, (a) with and (b) with superplasticizer.

figures for both RAC with and without superplasticizer. The elasticity modulus of concrete is impacted by the presence of superplasticizer. Increased compressive strength in concrete indicates better elastic properties [26].

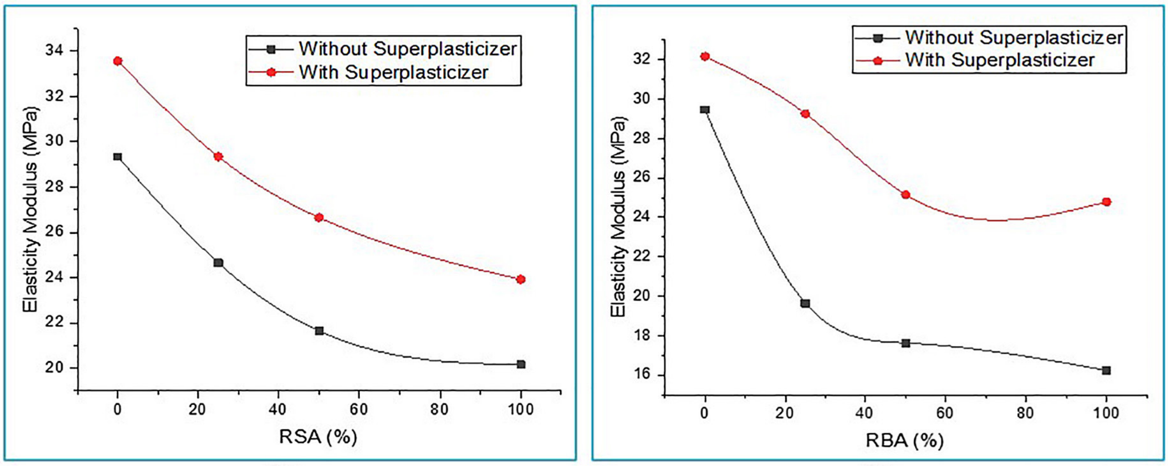
3.2.3. Impact of superplasticizer in elasticity modulus

The superplasticizer's effect on NAC, RSAC, and RBAC's static modulus of elasticity is graphically depicted in Figure 10(a) and (b). The elasticity modulus of NAC, which is composed solely of natural stone chips, rose by 10.4% upon by adding of superplasticizer. In RSAC compositions containing 25%, 50%, and 100% recycled stone chips, the addition of the superplasticizer raised the elasticity modulus by 22.1%, 21.3%, and 21.1%, respectively. The increases in modulus of elasticity seen in RBAC formulations including 25%, 50%, and 100% recycled brick chips - 36.2%, 28.5%, and 22.0%, respectively, were caused by the application of superplasticizer. Concrete's elastic modulus and density are closely related. Additionally, when the amount of recycled aggregate in the concrete sample rises, the static modulus of elasticity drops [27]. Figure 11 and Figure 12 visually depict the linear connection between the compressive strength of concrete and its static modulus of elasticity, which was discovered via experiments. The figures show that, while being greater than RSAC, the experimental elasticity modulus for RBAC is still lower than the recommended values of ACI 318-14. The RAC's co-efficient was calculated by referring the following figures.

3.3. Microstructural analysis

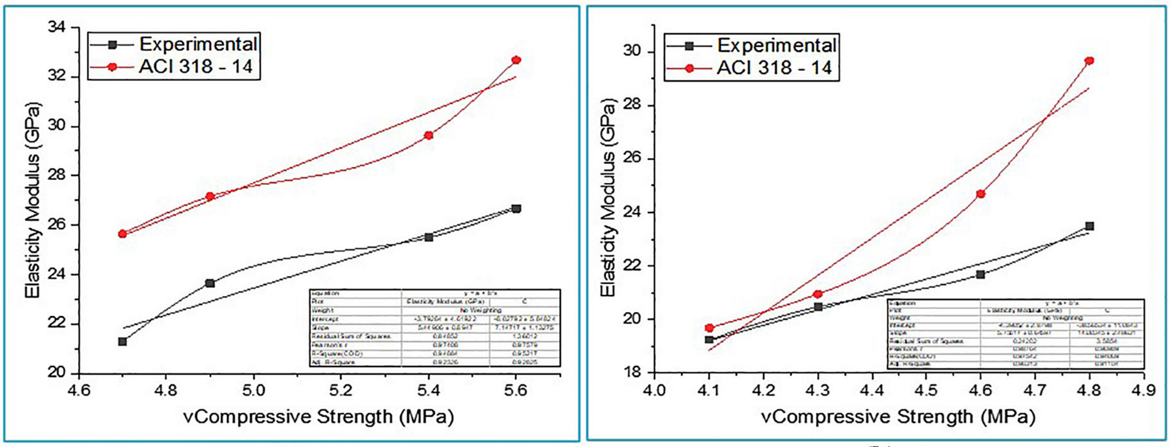
The hardened properties of concrete are largely dependent on the microstructure features of cement-based materials. The matrix morphology and concrete microstructure have been studied via SEM examination. Two SEM micrographs of the RSAC and RBAC mixtures were acquired after 28 days. The micrograph of mix RBAC is presented in Figure 13(a), which shows a denser and more homogeneous microstructure than the mix RSAC micrograph in Figure 13(b). The hydration mechanism aids in the refining of the pore structure, and the smaller RBAC grains greatly lower the size of the pores [28]. According to the experimental results pertaining to mechanical qualities, the mixture that included 50% RBAC performed well in terms of compressive strength. The presence of C-S-H gel in this mixture adds to its improved strength. In comparison to the control mix, the CH area rose by 0.340%, 8.214%, and 3.210%, respectively, for the RBAC mix containing 25%, 50%, and 100% of superplasticizer. The CH (Calcium Hydroxide) area of RBAC lowers when RSAC with 50% superplasticizer is compared to RBAC with 50% superplasticizer [29].

The EDX results, which show that the amount of calcium hydrate in RSAC with 50% superplasticizer was less than that in RBAC with 50% superplasticizer, corroborate this conclusion (Figure 14(a) and (b)). The C-S-H content was reduced as a result of the rise in the superplasticizer ratio, which was caused by the decrease in silicate hydrate (S_i) and the increase in CH content [30]. The increase in porosity was made possible by the decrease in C-S-H. Prior research studies [31–33] also concluded the same C-S-H bond decrement by using the recycled aggregates. Lastly, the compressive strength and porosity test findings utilizing the methanol exchange technique are confirmed by the results of the EDX and SEM analyses.



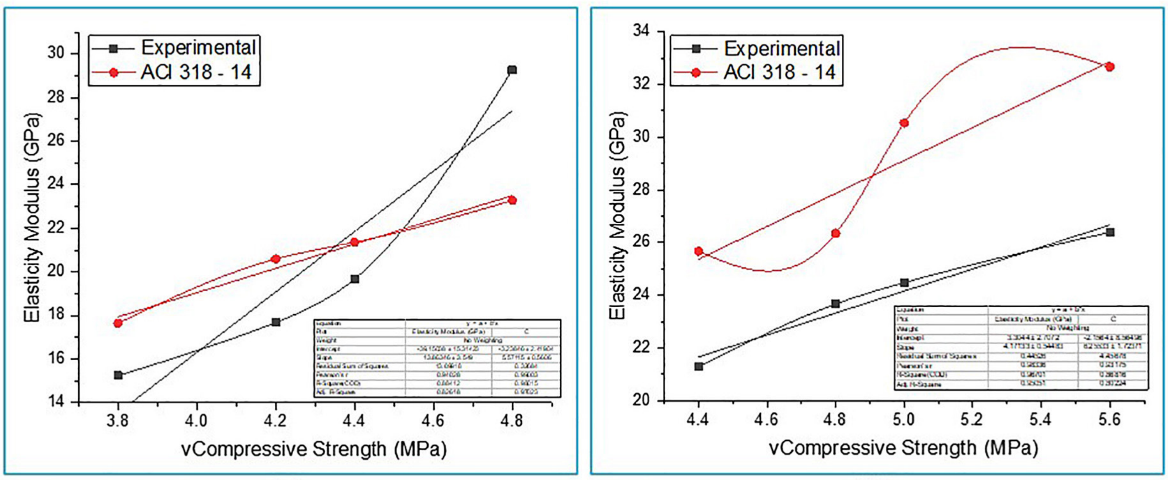
(a) (b)

Figure 10: (a) RSAC and (b) RBAC – changes in elasticity modulus and its impact after 28 days of curing time.



(a) (b)

Figure 11: RSAC mixes – elasticity modulus and its relationship with/without superplasticizers.



(a) (b)

Figure 12: RBAC mixes – elasticity modulus and its relationship with/without superplasticizers.

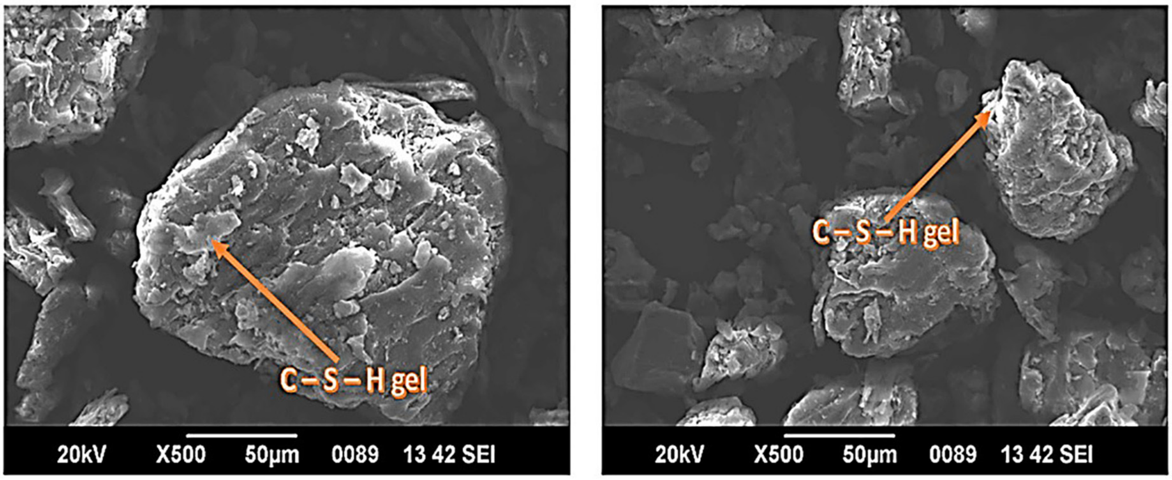


Figure 13: SEM images of (a) RBAC and (b) RSAC concrete mix with superplasticizer.

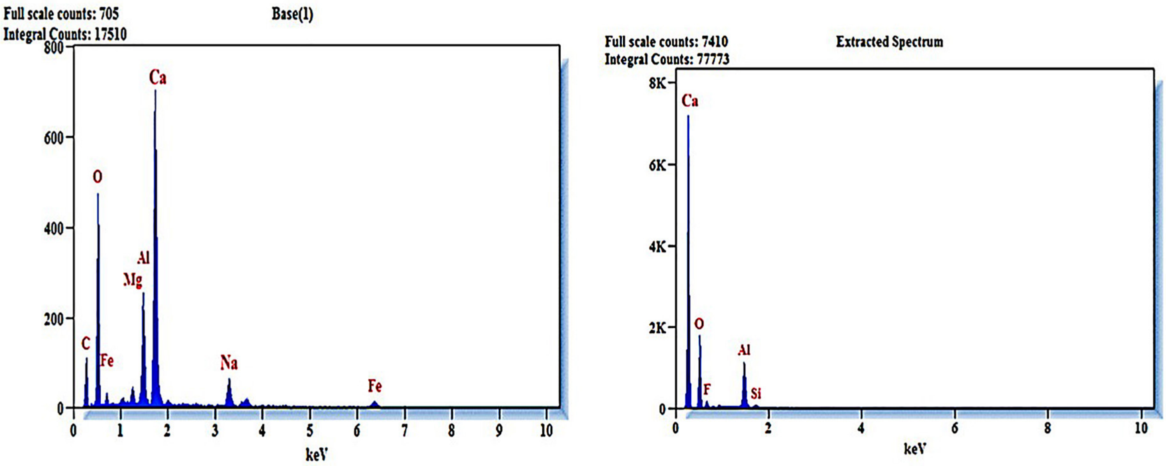


Figure 14: EDX images of (a) RBAC and (b) RSAC concrete mix with superplasticizer.

The X-ray diffraction investigation was carried out for the RBAC and RSAC mixes with superplasticizers in order to investigate the corrosive products in the concrete brought on by the sulphate attack. In Figure 15, the XRD diffractograms are displayed. Figure 15(a) shows that the C-S-H and portlandite intensity peaks in the RBAC sample, which was exposed to 200 cycles, were comparatively lower than those in the RSAC sample (Figure 15(b)). In Figure 15(a), trace quantities of gypsum and thenardite were also found. The material peaks became more intense following exposure. This shows that during cyclic sulphate exposure, gypsum, thenardite, and the material are formed and C-S-H and portlandite are consumed [34]. The crystalline structures of RBAC mix are very high when compared to the RSAC mix by referring the XRD figures. The peaks of RBAC mix were good at 140, 210, 260, 291, 370 and 450 at 20 matches with 80, 110, 60, 40, 30 and 20 hkl planes. This confirms the very high intensity pitching of RBAC mix compared to RSAC mix.

In Figure 16(a), the FTIR spectrum of RBAC is shown. The –OH group is responsible for the asymmetric absorption peak in the region of 3235 to 3730 cm^{-1}, indicating that the stretching vibration of the hydroxyl (–OH) and carboxyl (–COOH) groups in RBAC may be represented by the peak at 3481 cm^{-1}. The methyl and methylene group characteristic absorption were identified at various peaks at 2754, 1391, and 1317 cm^{-1} line up [35]. The ester group also identified due to the stretching vibration of –C=O– at the peak of 1692 cm^{-1}. Moreover, the polyether –C–O–C– stretching vibration in RBAC is responsible for the distinctive absorption peak at 1107 cm^{-1}. The FTIR spectra of RSAC is shown in Figure 16(b), where an asymmetric peak in the 3115–3655 cm^{-1} region is linked to the hydroxyl (–OH) stretching vibration [36]. An indication of carboxyl (–COOH) and hydroxyl (–OH) groups is the absorption peak at 3448 cm^{-1}. The characteristic absorption of methylene groups

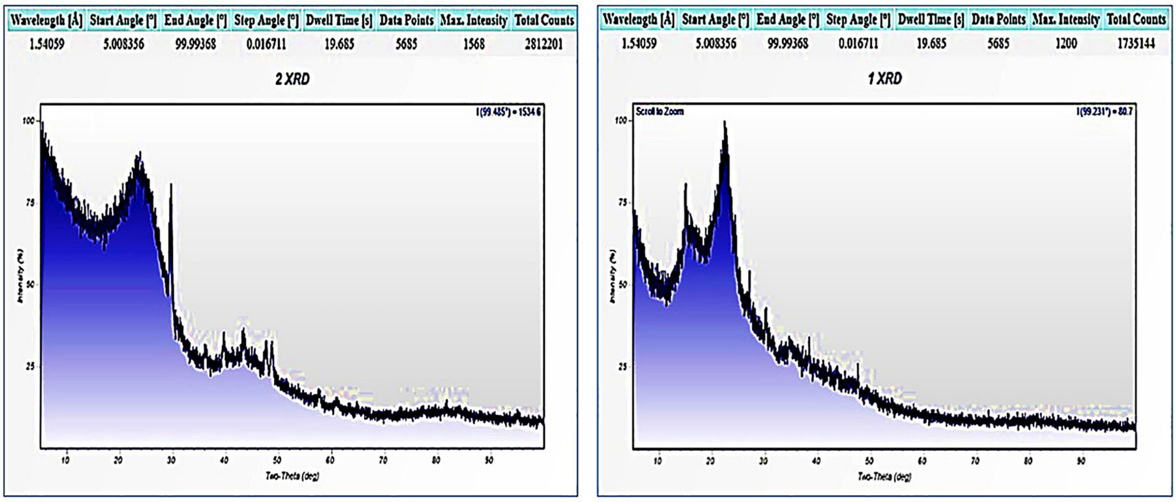


Figure 15: XRD images of (a) RBAC and (b) RSAC concrete mix with superplasticizer.

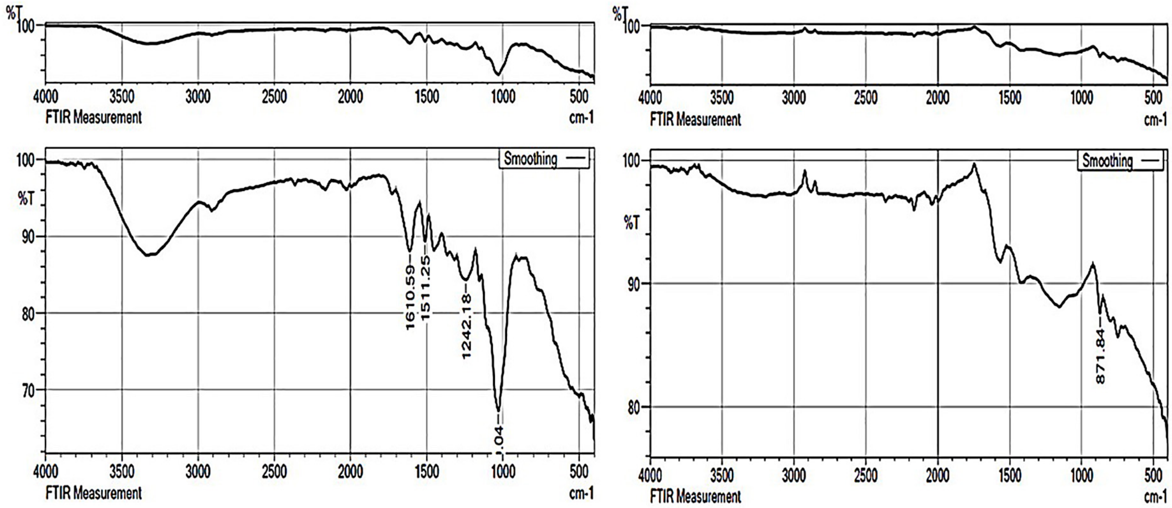


Figure 16: FTIR peaks of (a) RBAC and (b) RSAC concrete mix with superplasticizer.

was shown at 2720, 1385, and 1257 cm^{-1} peak. Also, the ester group was identified at 1729 cm^{-1} due to stretching of –C=O– groups. Moreover, the polyether –C–O–C– stretching vibration in RSAC is also responsible for the distinctive absorption peak at 1107 cm^{-1} [37]. From the above experimental study, it was observed that the RBAC mix has many functional groups compared to the RSAC mix.

4. CONCLUSION

The impact of the superplasticizer on RAC's mechanical properties is assessed through an experimental investigation. The two varieties of RCA in the experimental program, RSA and RBA, were analyzed and contrasted with Natural Aggregate (NA). Four replacement percentages for coarse aggregate were used: 0%, 25%, 50%, and 100%. Furthermore, in order to assess the effect of locally obtained superplasticizer on the mechanical performance of the concrete, it was added to half of the specimens. Experiments were carried out on the hardened properties (modulus of elasticity, split tensile strength, and compressive strength) at the 28-day point, as well as the fresh characteristics (measured by slump value). The following are the main conclusions drawn from the experimental investigation:

- Adding superplasticizer to RAC resulted in a significant increase in compressive strength.
- The addition of superplasticizer also had a good effect on the splitting tensile strength of RAC. Nevertheless, it was discovered that the experimental splitting tensile strength fell short of the standard value specified by ACI 318-14.

- Over a variety of aggregate replacement ratios, the static modulus of elasticity for RBAC and RSAC improved as a result of the superplasticizer's application. Elasticity for RASC generally exceeds the value given in ACI 318-14 or above. The similar steady trend is not shown by RBAC, though.
- As RCA supplanted natural aggregate (NA) in RAC, the mechanical performance of the former declined.
- The addition of the superplasticizer resulted in a significant increase in the splitting tensile strength and modulus of elasticity for both RBAC and RSAC.
- The results show that adding the superplasticizer to a concrete mixture allows for the effective replacement of natural aggregate (NA) for 25% of the recycled brick aggregate (RBA) and 50% of the recycled stone aggregate (RSA) without compromising the mixture's mechanical qualities. This highlights the positive impact of the superplasticizer on the mechanical characteristics of RAC.

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