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River Sand Replacement with Sustainable Sand in Design Mix Concrete for the Construction Industry

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Abstract

The present study prepared four sustainable design mixes of concrete using desert sand, modified recycled sand, and supplementary cementitious material silica fume to replace cement. The design mix concrete was prepared using the absolute volume method of a design strength ($f'c$) and target strength (f'_{cr}) of 30 MPa and 38 MPa, respectively. The analysis of results showed that the four sustainable design mix concrete successfully passed the strength criterion set by the ACI 318-19 building code. The resulting pattern shows an increment in the mechanical and durability properties compared to the reference mix when (50% desert sand + 50% recycled crushed sand) is combined with 5-12.5% silica fume. The optimum result was achieved when the optimized, sustainable sand ratio (50% desert sand + 50% recycled crushed sand) was combined with 10% silica fume. It can be concluded that the prepared concrete has excellent results in terms of concrete strength and durability properties. Furthermore, this study shows that 100% of natural sand and 10% of cement can be saved using the optimal proposed concrete design mix. This study would have explored sustainability in the Saudi region by utilizing a vast percentage of vacant desert sand in concrete manufacturing.

Keywords: Silica Fume; Desert Sand; Recycled Sand; Sustainable Concrete; Absolute Volume Method.

1. Introduction

Most of the sand used in the construction industry in the past came from regional quarries and rivers. River sand is an essential constituent of concrete and is becoming the most demanded sand for construction activities. The ecology and ecosystem were impacted by the construction sector's misuse of natural river sand. For example, sand extraction has dramatically affected the rivers in the last decade. The floods India, Bangladesh, and China have witnessed in the last few decades can be related to extensive sand mining. It can cause the river bed and banks to have accelerated scouring, widen channel area, and weaken any close bridge foundations [1-5]. Every year, the amount of solid waste generated globally increases exponentially. China alone produces about 1.5 billion tons of demolished concrete. The EU established a goal of recycling 70% of demolished concrete to address this problem [6, 7]. Therefore, there is an intense need to find alternative sources of natural sand for the construction industry to save the environment and the ecosystem.

Several research studies have been done to utilize solid waste in concrete manufacturing to replace natural materials. The recycled coarse and fine aggregate from demolished concrete to replace the natural coarse and fine aggregate in new concrete was studied in several studies [8-11]. A study done by Monish et al. [12] revealed that the strength of the design mix concrete was 30% higher when recycled coarse aggregate (RCA) was replaced with natural coarse aggregate

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(NCA). Another study by Ju et al. [13] studied the higher replacement ratio of (50-100%) RCA with NCA. The study results showed that the newly prepared concrete with higher RCA replacement decelerated the early gain of strength. It has also been noted that longer curing periods were necessary to achieve the required design strength when substituting more than 50% of RCA in new concrete. For this reason, many published studies do not advise using more than 50% of RCA instead of NCA in structural concrete. It has also been reported that compressive and tensile strength reduction was noted at higher replacement rates of more than 50% of RCA. Most recent studies [4, 13-18] have introduced the utilization of recycled fine aggregate (RFA) in place of natural fine aggregate (NFA), such as river sand, in design mix concrete. The replacement ratio of RFA with NFA was incorporated by 30%, 50%, and 100%, respectively. It has been reported from the results of the studies that a replacement ratio of up to 30% did not affect the strength of newly developed concrete with 30% RFA in new concrete. At 50% replacement, satisfactory results were observed, and at 100%, a significant reduction was reported. Newly published studies [14, 19-25] suggested using vacant desert sand in the design mix concrete as a suitable replacement for natural river sand in the concrete industry. However, no published study has recommended the full replacement of desert sand in concrete manufacturing. The desert sand's physical properties do not fulfill the standard design mix concrete requirements. The studies showed that the physical properties could be modified by adding other waste materials as a sand replacement in concrete, such as recycled crushed sand, recycled PET, recycled crumb rubber, and waste foundry sand. The results of the studies reported that (20-50%) of replacements are acceptable without affecting the mechanical properties of newly prepared concrete compared to their control mixes. It is concluded from this discussion that sustainable sand could replace the natural river sand in the concrete industry. Still, studies in this area are limited, and long-term durability has not yet been studied on sustainable sand concrete.

Ordinary Portland cement (OPC) can be replaced with supplementary cementitious materials (SCMs), such as fly ash (FA), copper slag (CS), granulated blast furnace slag (GBFS), and silica fume (SF), to preserve limestone and carbon footprint from the concrete industry, as validated by [26-28]. Incorporating SCMs such as FA, CS, GBFS, and SF reduced OPC requirements for the concrete industry. In addition, including FA, CS, GBFS, and SF in concrete manufacturing enhanced concrete strength and durability characteristics [29-33]. Recent studies [14, 20, 28, 34, 35] examined the design mix concrete performance by incorporating SF content. The results of the studies discovered that the optimum 10% replacement of OPC with SF showed an increment in strength and durability characteristics for newly prepared concrete samples. Other studies [36-39] also discovered similar findings of improving strength characteristics when the optimum percentage of OPC was replaced with SF. In line with similar studies, a recently published study by Ji et al. [21] found that the SCMs SF addition with marble powder significantly improves strength properties. It has been concluded that SCMs SF is compelling when added with other waste materials in optimized amounts.

It can be seen from the literature review that recycled crushed and desert sand can replace river sand. Further, adding the silica fume can improve concrete's strength and durability characteristics. A literature assessment indicates that studies on recycled crushed and desert sand combinations are scanty. However, it has been discovered that replacing the combined recycled crushed sand with desert sand, as fine aggregate in a design mix of concrete manufacturing, can replace river sand. The collective usage of waste materials could help recycle, reuse, and recover (RRR) goals to preserve our environment. The present study aims to discover the relationship between the combined effect of recycled crushed sand with desert sand and optimized silica fume content to replace it with natural sand such as river sand and OPC.

2. Experimental Program

2.1. Materials

The ordinary Portland cement (OPC) was partially replaced with solid waste binding materials silica fume (SF), as shown in Figure 1-a. In the present study, SF was procured from Abdin Construction Company (ACC), Tabuk, Saudi Arabia. The SF does not meet the standards for hazardous classification. Crystalline quartz may be present in trace amounts, i.e., < 0.5% in silica fume. The product's reparable crystalline silica is below 0.1% and does not trigger a hazard classification. The present research utilized two types of fine aggregates to develop four types of modified concrete. The first fine aggregate, desert sand (DS), was obtained from the desert of Tabuk, Saudi Arabia. The second fine aggregate, the recycled crushed sand (RCS), was prepared through demolished concrete samples collected from different sites. The selected demolished concrete samples must satisfy the strength criterion set by ACI 318-08 [40]. Those demolished concrete samples that satisfied ACI 318-08 [40] criterion are collected and crushed at the aggregate crushing plant of Abdin Construction Company (ACC). Figures 1-b and 1-c show the DS and RCS, respectively.

Figure 1. (a) Silica fume, (b) desert sand, (c) recycled crushed sand

2.2. Methods

2.2.1 Preparation of Recycled Crushed Sand

The main composition of demolished concrete includes aggregate and cement dust. Such waste is ample because, in terms of consumption, concrete holds the second position among the most consumed materials worldwide [41]. Selective demolition of the building helps separate waste materials as per their properties, type, and composition; this is the first stage of processing aggregated from demolished concrete [42]. After dismantling other materials using machinery, the End-of-Life (EoL) concrete is undecided. Landfilling EoL concrete waste requires a vast amount of area. Hence, recycling/upcycling is supposed to be the most suitable option for such types of waste.

Crushing demolished concrete waste is the most widely used technique. This process generates different sizes of aggregates. The technique utilized the jaw and secondary impact crushers [43]. In the compression's central tension plane, jaw crushers fracture the material. Conversely, impact crushers continuously pound the concrete against an impact plate and take it into a rapidly rotating rotor until the required size fraction is reached. Secondary crushes were presented by impact and jaw crusher Ulsen et al. [43]. For this study, the physicochemical characteristics of samples of about 100 kg, representative portions from each sample, were taken from the primary stockpile for laboratory studies. Samples were screened in (≥ 12.5 mm) sieves in the laboratory. Any fraction greater than 12.5 mm was separated to utilize as a coarse aggregate, as shown in Figure. 2. The particles' crushing process was continued until 95% of particles passed by the 12.5 mm sieve (P_{95} = 95%). Advanced Dry Recovery (ADR) [44] discussed the ADR technology for a fraction of demolished concrete aggregate. ADR technology is a mechanical system for extracting fine fractions from moist crushed concrete aggregates. Figure 2 describes an outline for the entire process of recycling EoL concrete using ADR and HAS. For this study, the fine aggregate fraction was separated into three fraction sizes: coarse recycled sand (CRS) (passed by 4.75 mm), medium recycled sand (MRS) (passed by 4.75 mm and returned on 2.36 mm), and found recycled sand (FRS) (passed by 2.36 mm and returned on 1.18 mm).

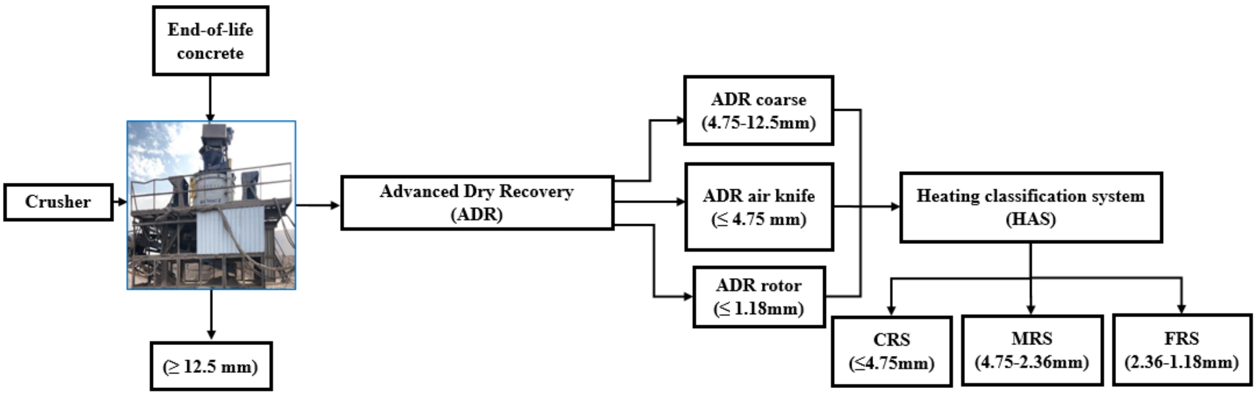

Figure 2. Preparation methodology of recycled crushed sand

2.2.2. Properties of Concrete Ingredient

All properties of the cement utilized in the design mix of the present research are well within the specified limits. The specific physical and chemical properties of OPC used in the present research work are shown in Table 1. The present study utilized partial replacement of OPC with SF. The specific gravity of SF is about 2.1 and 2.3 lower than ordinary Portland cement (OPC), as mentioned in Table 1.

Table 1. Chemical and physical properties of mixing ingredients

Properties	OPC	SF	RCS	DS	NCA	Mixing water
Specific gravity	3.15	2.20	2.52	2.65	2.81	-
Water absorption (%)	-	-	2.65	1.42	0.88	-
Sand equivalent values	-	-	92	95	-	-
Fineness modulus (FM)	-	-	2.6	3.3	7.0	-
pH	-	-	7.3	7.7		7.6
Sulfate (ppm)	-	-	979	258	153	23
TDS (ppm)	-	-				654
Chloride (ppm)	-	-	1060	140	84	52
Organic impurities	-	Nil	Nil	Nil	Nil	-
Salinity						498

The water absorption and specific gravity of RCS and DS were evaluated per standard ASTM-C128-88, 2001 [45]. The specific gravity of all developed modified RCS and DS was within the standard limits. The water absorption of RCS is significantly higher than that of DS in all the samples. RCS has absorbed more water than DS because of its porous characteristics. Table 1 displays the observed sand equivalent values for the RCS and DS samples, observed at 92% and 95% and within the permitted range. A sample is deemed suitable for use in the manufacturing of concrete if its sand equivalent value is more excellent than 75%.

Total dissolved solids (TDS), one of the primary contaminants in mixing water that can impact the strength and durability characteristics of the concrete, are restricted by codes and regulations because they may lower the quality of the concrete [46]. The water used to mix concrete materials shall be free of ingredients that significantly change the hydration reaction of ordinary Portland cement (OPC) or otherwise delay the phenomena anticipated to occur during concrete mixing, placing, and curing. Concrete ingredients can be mixed with water that is safe to drink. Because of resource and cost constraints, using drinking water all the time is not favorable. Researchers also suggested that if the water complies with the standard requirements, non-drinking water can still be used in concrete mixtures [47]. To prevent the harmful effects of water contamination on the fresh and hardened properties of concrete, the present research work on the water used in mixing analyzed for chemical properties such as pH, TDS, sulfate, and chloride by the maximum permissible limits of chemical substances specified by BS-3148 [48]. The chemical parameters like pH, TDS, sulfate, chloride, and salinity are listed in Table 1 for the strength and durability of hardened concrete. The results of all chemical parameters of mixing water are clearly within acceptable limits, as shown in Table 1.

2.2.3 Optimization, Design Mix, and Research Methodology

2.2.3.1 Optimization of Silica Fume

The different percentages of SF dosages were added to replace OPC in the reference mix to decide the optimum SF content value in the design mix concrete. By observing different past studies, the dosages were decided to be 5%, 7.5%, 10%, and 12.5%, respectively. Compressive strength increased when the selected dosages were added; finally, a 10% replacement ratio of SF with OPC threshold was achieved. It has been decided to add a 10% SF in the prepared mixes of the present study.

2.2.3.2 Optimization of Sustainable Sand

Desert sand (DS) received fine particles, significantly affecting the fineness modulus (FM). For this reason, recycled crushed sand (RCS) was taken to optimize the DS to satisfy the FM as per the requirement of the design mix by the absolute volume method ACI-211.1-91 [49].

The four proportions of DS and RCS were taken to optimize the combination of combined sand in the concrete design mix. Different proportions of DS and RCS are taken to understand the FM of the composite sand (DS + RCS). By the standard ASTM-C136-06 [50], the sieve analysis test was performed to evaluate the FM of the selected sand combination. The RCS was replaced with 20, 30, 40, and 50% of DS, as reported in Table 2. The continuous improvement in the FM values was seen with the addition of 20, 30, 40, and 50% of RCS, and the optimum value was obtained by combining (50% DS + 50% RCS).

Table 2. Optimization of R-sand by M-sand

Proportions of (R-Sand+M-Sand)	Fineness modulus (FM)
(20% DS + 80% RCS)	2.2
(30% DS + 70% RCS)	2.4
(40% DS + 60% RCS)	2.6
(50% DS + 50% RCS)	2.8

2.2.3.3. Design Mix

In the present research study, several trail mixes were prepared to evaluate modified sustainable concrete's strength and durability characteristics. The control mix was prepared with natural aggregate concrete (NAC*) with all-natural ingredients with 100% OPC to compare the results with this study's developed sustainable sand concrete. Four silica fume recycled crushed sand concrete (SFRCSC) mixes, with different proportions of (5-12.5% of silica fume) with (50% DS + 50% RCS), were designated as 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC, respectively. The present study included up to 100% replacing natural sand (NS) with (50% DS + 50% RCS), respectively. The sustainable design mix concrete designations and quantities for each mix are presented in Table 3. The fresh properties of each trail mix were measured to identify whether the prepared mixes passed the design mix condition of the absolute volume method (AVM). The absolute volume method set the slump value of 100 mm for structural concrete [49, 51] for all design mixes, including the reference mix. The SP dosage was added to each design mix, as shown in Table 3. The purpose of adding SP dosages is to keep the slump value at 100 mm in each design mix. The temperature and the air content of the freshly mixed concrete were also recorded in Table 3.

Table 3. Design mix data and mix properties

Mix Designation	Cementitious materials %			Fine aggregate %			NCA %	Admixture by weight of cement (%)	Mix temperature (°C)	Mix Air temperature (°C)	Mix Air content (%)
	OPC	SF	Total	NS	DS	RCS					
NAC*	100	0	100	100	0	0	100	0.0	26	20	2.4
5SFRCSC	95	5	100	0	50	50	100	0.9	26	20	2.4
7.5SFRCSC	92.5	7.5	100	0	50	50	100	1.4	25	20	2.5
10SFRCSC	90	10	100	0	50	50	100	1.8	25	20	2.6
12.5SFRCSC	87.5	12.5	100	0	50	50	100	2.2	25	20	2.7

NAC* = Natural aggregates concrete (Control mix*); 5SFRCSC = (5%SF + 50%DS + 50%RCS); 7.5SFRCSC = (7.5%SF + 50%DS + 50%RCS); 10SFRCSC = (10%SF + 50%DS + 50%RCS); 12.5SFRCSC = (12.5%SF + 50%DS + 50%RCS).

OPC = Ordinary Portland cement; SF = Silica fume; DS = Desert sand; RCS = Recycled crushed sand; NS = Natural sand; NCA = Natural coarse aggregate.

2.2.3.4. Research Methodology

The detailed methodology of the present research study is reported through a flow chart, as shown in Figure 3. The absolute volume method ACI-211.1-91 [49] was selected to decide the mixing ingredients mentioned in Table 3. The samples were prepared using the standard ASTM-C31/C31M-19a [52]. The flow chart of the present research methodology is shown in Figure 3. Cylindrical samples' compressive and tensile strength were measured using a 2000 kN compression machine and a 100 kN universal tensile testing machine capacity.

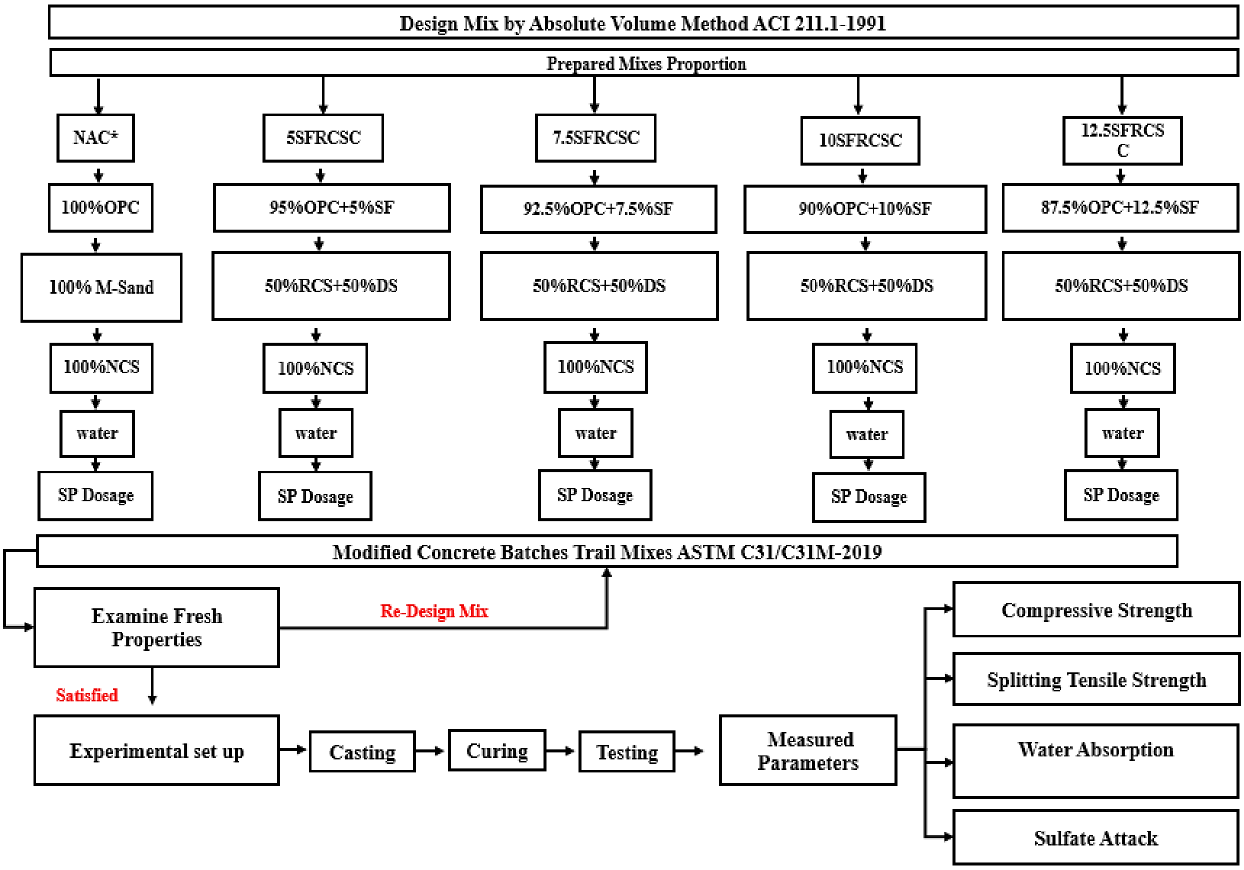

Figure 3. Design mix concrete manufacturing process

3. Results and Discussion

3.1. Strength Characteristics

3.1.1. Compressive Strength Evaluation

The 28-day concrete strength is a standard reference for evaluating the compressive strength by any standard code of practice. The compressive strength of this study was evaluated at the ages of 28, 56, and 91 days after casting. As revealed by past studies, the SF and RCS gain strength with time [4, 30, 53, 54]. In the mix, NAC*, containing 100% manufactured sand along with prepared mixes 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC, with varying percentages of (5-12.5% of silica fume) and (50% DS + 50% RCS), compressive strength was evaluated and presented in Figure 4. After several trial mixes, thresholds in compressive strength were observed when up to 50% DS + 50% RCS replaced 100% river sand, and 10% of OPC was substituted by combining 90% OPC + 10% SF.

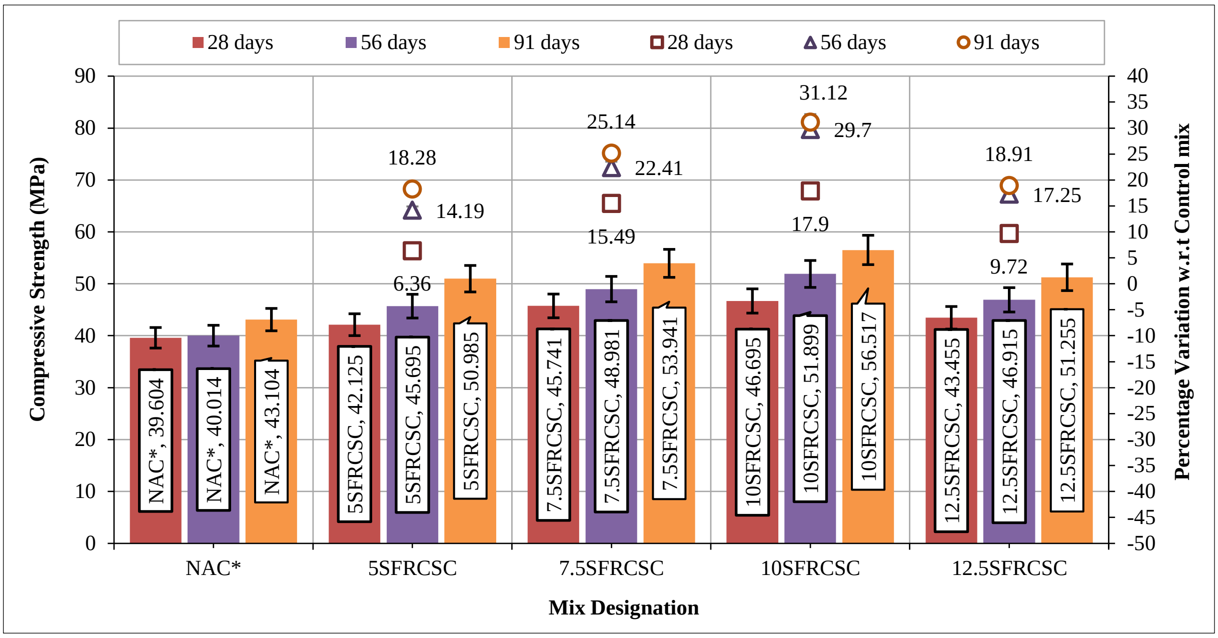

Figure 4. Evaluation of compressive strength

In the mixes, NAC*, 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC were 39.604, 42.125, 45.741, 46,695, and 43.455 MPa. The increment in compressive strength after 28 days of curing in the mixes 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC with respect to the control mix NAC* was found to be 6.36%, 15.49%, 17.90%, and 9.72%, shown in Figure 4. The prepared mixes 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC fulfill the strength condition of design and target strength ($f'c$) (30MPa) and (f'_{cr}) (38 MPa) set as per [40, 55]. At 28 days of curing, the result shows that the silica fume recycled crushed sand concrete combinations performed well and fulfilled the design strength criteria [40, 55]. The prepared mixes 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC achieved all standard criteria design, and the target strength for this study was 28 days of curing.

In the mixes NAC*, 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC at 56 days of curing were found to be 40.014, 45.695, 48.981, 51.899 and 46.915 MPa. All mixes surpassed the target strength (f'_{cr}) (38 MPa) at 56 days. Figure 4 also reported the increments in the mixes 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC than mix NAC* at 56 days. The mixes 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC was found to be 14.19%, 22.41%, 29.7%, and 17.25%, percentage increment at 56days of curing. The highest percentage increase at 56 days was found in the mix 10SFRCSC, about 29.7%, compared to the control mix NAC*. It shows that the (50%DS+50%RCS) combination with 10% SF in the mix 10SFRCSC performs well up to 56 days of curing.

In the mixes 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC, the compressive strength was obtained at 43.104, 50.985, 53.941, 56.517, and 51.255 MPa, respectively. The results showed a continuous increase in strength with curing time. Figure 4 shows percentage increases of compressive strength in the mixes 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC at 91 days with respect to the reference mix NAC*. The percentage increase in the mixes 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC was found to be 18.28%, 25.14%, 31.12%, and 18.91% respectively. At 91 days, the percentage increase in the mixes 7.5SFRCSC and 10SFRCSC was higher than the mixes 5SFRCSC and 12.5SFRCSC. It shows that the optimum percentage of SF and RCS at later ages shows a rise in compressive strength.

It is visible from Figure 4 that replacing OPC with the SF combination enhanced the compressive strength of the mixes. The SF variation at 5%, 7.5%, 10%, and 12.5% were replaced with OPC in each mix. It has been observed from the results of the study that the mixes 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC showed a continuous increment in compressive strength. The optimal compressive strength was recorded in a mix of 10SFRCSC with the fine aggregate combination of (50%DS+50%RCS). When the combination reached 12.5%SF, a slight decrease in the compressive strength value was reported.

The results of the mixes are in line with published studies [19, 20, 56-58] when sustainable sand was replaced with natural river sand. The published study [4, 20, 30, 57] recommended that up to 50% of desert sand can be incorporated into concrete manufacturing. A large surface area is created when the precise percentage is applied since the SF and DS particles are finely ground. A sturdy cement bond is the result. The mixtures' compressive strength increased as a result.

Furthermore, the strength gain rate in the mix could be the secondary hydration of the left-over cement in the RCS. The modified (50%DS+50%RCS) in the mixes around the aggregates remains weak in the initial days. It also depends on the portion of RCS that still has the old concrete's visible cement matrix. Over time, the gel reacts with the prior layer's unhydrated cement. This secondary hydration of RCS may occur because of SF combination with RCS. Finally, it can be concluded that the mix 10SFRCSC with the combination of 10%SF with the 100% natural sand replaced by (50%DS+50%RCS) was found to be highest at all curing stages compared to the control mix NCA*.

3.1.2. Splitting Tensile Strength

The capacity of concrete to resist crashing or cracking under tension is known as tensile strength. The resulting "pulling" forces essentially act to force open the concrete transition zones (comprising the binder that prevents aggregate diffusion). When tensile forces are more significant than the tensile strength, cracks form. Traditional concrete has a compressive strength far higher than its tensile strength. Since it is challenging to test concrete directly for tensile strength, indirect tests are employed. The present research study used the standard test method's splitting tensile strength (STS) ASTM-C496/C496M-11 [59].

This research study evaluated the STS of mixes designated as NAC*, 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC at 28, 56, and 91 days of curing. The STS of modified concrete with DS and RCS combination with SF was evaluated by ASTM-C496/C496M-11 [59]. The requirement of ASTM-C496/C496M-11 [59] is that the average STS value lies in between (10-15%) design strength *(f´c)* concrete mix design. The present research study selects the design strength (*f´c*) (30 MPa) at 28 days of curing. According to the criterion ASTM-C496/C496M-11 [59], (10 to 15%) of (*f´c*) retains the value of (3 to 4.5 MPa). The average STS of the developed sustainable concrete should be in the range of (3-4.5 MPa).

Each sample's peak load (P) was determined to evaluate the average STS value from each designated mix NAC*, 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC respectively. As shown in Figure 5, samples are being tested to record each sample's peak load (P). The STS value of each mix was calculated by peak load (P) from Equation 1. The STS results in (MPa), Peak Load (P) in (Newton), Length (l) in (mm), and diameter (d) in (mm), as stated in Equation 1.

$$STS = \frac{2P}{\pi l d} \tag{1}$$

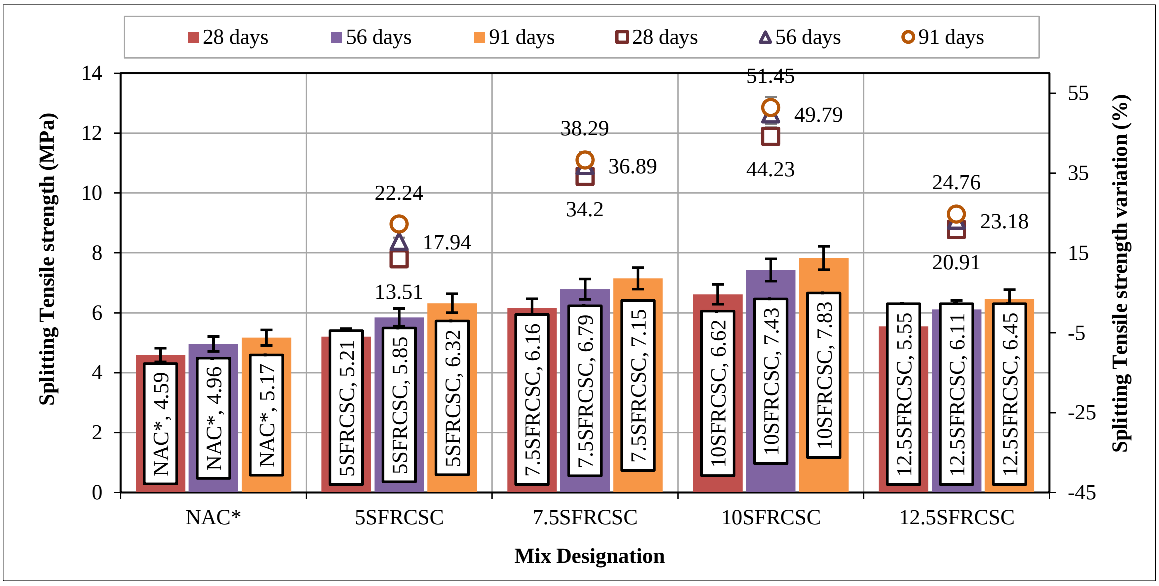

Figure 5. Evaluation of splitting tensile strength

At 28 days of curing, the STS results of prepared mixes NAC*, 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC were 4.59, 5.21, 6.16, 6.62, and 5.55 MPa, as shown in Figure 5. In the mixes NAC*, 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC STS values were recorded at 15.3%, 17.4%, 20.53%, 20.2%, and 18.5% of the design strength *(f´c)*. The increment in STS values of the prepared mixes 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC with respect to the reference mix NAC* was found to be 13.51%, 34.21%, 44.23%, and 20.91% respectively.

At 56 days of curing, the STS results of prepared mixes NAC*, 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC were 4.96, 5.85, 6.79, 7.43 and 6.11 MPa respectively. The STS of the mixes NAC*, 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC were recorded at 16.5%, 19.5%, 22.6%, 24.8%, and 20.4% of the *(f´c)* of the concrete. The increment in STS values after 56 days of curing in the mixes 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC with respect to the reference mix NAC* was found to be 17.94%, 36.89%, 49.79%, and 23.18% respectively.

At 91 days of curing, the STS results of prepared mixes NAC*, 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC were 5.17, 6.32, 7.15, 7.83 and 6.45 MPa. The mixes NAC*, 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC STS values were recorded at 17.2%, 21.1%, 23.8%, 26.1%, and 21.5% of the *(f´c)* of design mix concrete. The increment in STS values of the mixes 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC with respect to the reference mix NAC* at 91 days was found to be 22.24%, 38.29%, 51.45%, and 24.76% respectively.

In the mixes, NAC*, 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC, the STS increases with the addition of the SF combination. All mixes NAC*, 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC, including reference mix at all curing stages, successfully satisfied *(f´c)* criteria ASTM-C496/C496M-11 [59]. It indicates that SF combined with a sand combination (50%DS+50%RCS) has improved STS.

The STS variation in the mixes NAC*, 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC was found to be higher with respect to the control mix NAC* as shown in Figure 5. It shows that all mixes revealed a positive gain in STS values compared to the control mix of NAC*. It is because the mixes with SF showed continuous gain when combined with (50%DS+50%RCS). Incorporating SF combination with (50%DS+50%RCS) in the mixes 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC shows ductile behavior. The modified sand (50%DS+50%RCS) characteristics typically impact the paste quality and interfacial transition zone on which STS depends. The optimized modified sand combination (50%DS+50%RCS) with SF improved the paste quality of the prepared samples of the mixes 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC. Partial replacement of SF with optimized modified sand (50%DS+50%RCS) enhances the bond between aggregate pastes, ultimately improving the bond at the interface in the mixes. The optimized modified sand (50%DS+50%RCS) with SF developed elastic behavior in the 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC. For this reason, the cylindrical samples were observed to have strengthened the mixes. The optimized sand technique of the present study, with SF, effectively increases the cracking load and decreases the brittleness of the mixes 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC, respectively.

3.2. Durability Characteristics of Manufactured Concrete

3.2.1 Water Absorption Manufactured Concrete

The prepared mixes NAC*, 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC water absorption are given in Figure 6. The increment in water absorption was found higher in the mixes 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC when SF combined with (50%DS+50%RCS) combination compared to reference mix NAC*.

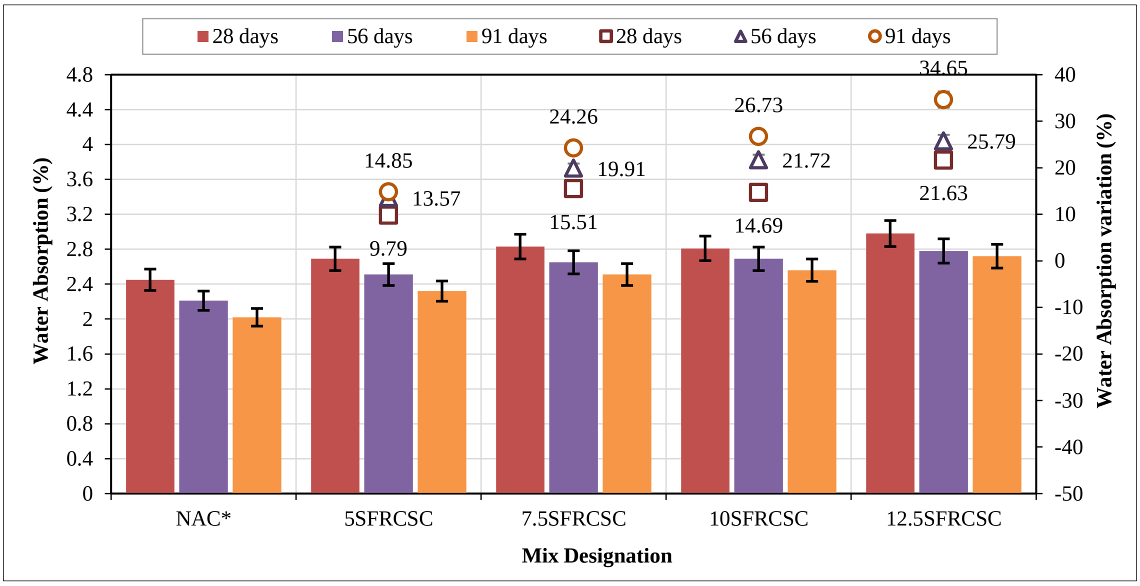

Figure 6. Water absorption of tested specimens

At 28 days of curing, the water absorption of mixes NAC*, 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC was obtained at 2.45%, 2.69%, 2.83%, 2.81%, and 2.98% respectively. When the samples reached 56 days of curing, the water absorption was found to be 2.21%, 2.51%, 2.65%, 2.69%, and 2.78%, respectively. Furthermore, the water absorption was also checked at the curing age of 91 days, and the values of 2.02%, 2.32%, 2.51%, 2.56%, and 2.72%

were found. The pattern of the results shows that as and when the curing age increased, the water absorption percentages decreased. The present silica in SF is active and reacts with hydration products of OPC, producing extra CSH gel at the later ages of curing. Thus, the concrete matrix formed a dense structure, preventing adding extra water. The products formed by the micro silica's Pozzolanic activity block the concrete's pores. Microsilica also reduces the pore size by filling them so that water does not penetrate easily, reducing water absorption and enhancing durability. The results of the present study were in line with those of recently published studies [9, 30, 54, 60].

The water absorption at 28, 56, and 91 days in the mix 10SFRCSC was observed to be decreased by 5.70%, 3.23%, and 5.88% compared to 12.5SFRCSC. It shows that the optimum SCMs were achieved at 10%SF addition to the mix with a modified sand combination (50%DS+50%RCS). Regarding water absorption durability, the best combination was found to be 10SFRCSC.

3.2.2. Effect of Sulfate Environment Manufactured Concrete

The concrete mixes NAC*, 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC were exposed in a solution of 5%Na_2SO_4 and 5%$MgSO_4$ for testing the durability against sulfate. The effect of the sulfate was assessed by determining the change in weight and compressive strength of the prepared mixes at 28, 56, and 91 days after it was cured in the sulfate solution.

3.2.2.1 Weight Change

In the mixes 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC, the increment was reduced compared to the reference mix NAC*, which decreased from 28 to 91 days, as shown in Figure 7. The weight increments in the reference mix were 0.69, 0.81, and 0.92% when exposed to sulfate solution for 28, 56, and 91 days, respectively. The weight increments in concrete mixes 5SFRCSC and 7.5SFRCSC were 0.67, 0.78, 0.89%, and 0.68, 0.79, 0.9% at 28, 56, and 91 days respectively. The mixes 5SFRCSC and 7.5SFRCSC show a decrease in the weight by 2.89%, 3.7%, 3.26% and 1.44%, 2.46, and 2.17% compared to NAC*.

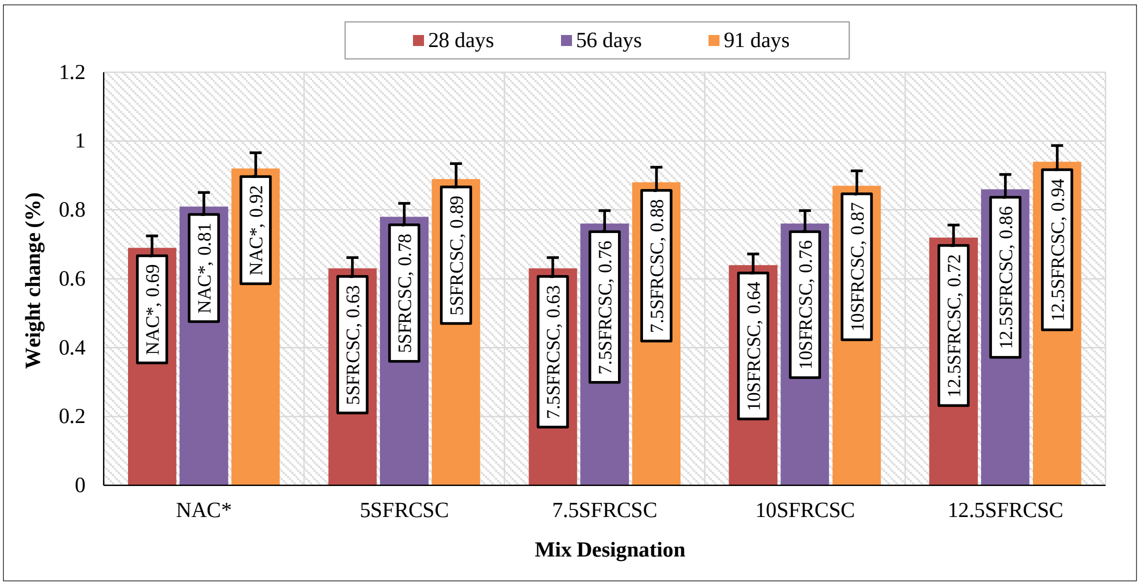

Figure 7. Sulfate weight change of tested specimens

The same trend of weight gain was found in 10SFRCSC and 12.5SFRCSC when exposed to sulfate solution by 0.7%, 0.82%, 0.93% and 0.71%, 0.83%, 0.94% at 28, 56, and 91 days. It was observed that the weight increased by 1.44%, 1.23%, 1.08% and, 2.89%, 2.47%, 2.17% in the mixes 10SFRCSC and 12.5SFRCSC as compared to reference mix NAC* at 28, 56, and 91 days respectively. When seep into the concrete, sulfate ions react with hydration products, including CH, C3A, and CSH. Their interaction results in the production of sulfate salts; this is the reason the weight of concrete increases [7, 8].

3.2.2.2. Performance of Compressive Strength in Sulfate Solution

When exposed to the sulfate solution, the compressive strength results of mixes NAC*, 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC are presented in Figure 8. The specimen cured for 28 to 91 days in a sulfate solution usually shows an initial increase in compressive strength during this time. It was also discovered that compressive strength decreased after 91 days of sulfate curing. The reference mix performance was evaluated in the sulfate solution at 28, 56, and 91 days. The compressive strength values were reported as 39.95, 40.75, and 40.25 MPa, respectively. In contrast to the compressive strength achieved after 28 days of curing in regular water, this indicated increases of 4.29%, 6.38%, and 5.08%.

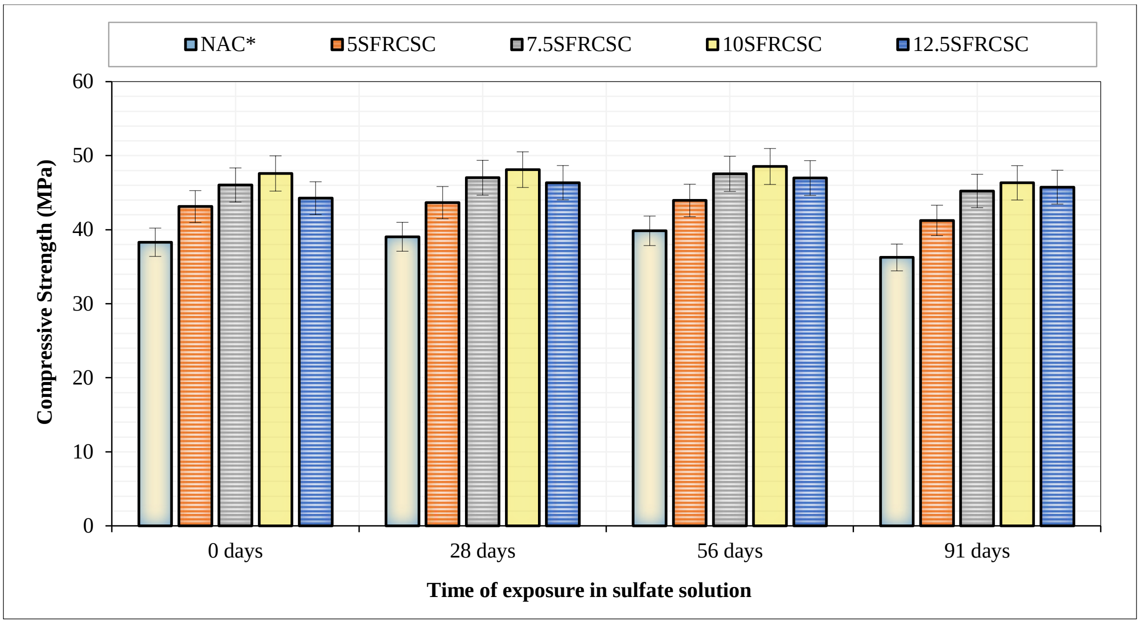

Figure 8. Variation in compressive strength against sulfate solution

At 28, 56, and 91 days, compressive strength after exposure to sulfate water compared to the 28 days results in normal water in the mixes 5SFRCSC and 7.5SFRCSC were 44.85, 44.95, 44.05 MPa and 47.72, 48.19, and 47.53 MPa increased by 4.0%, 4.23%, 2.14% and 3.65%, 4.66%, 3.23% respectively. Further, the mix of 10SFRCSC at 28, 56, and 91 days achieved the compressive strength of 49.91, 49.99, and 49.33 MPa. It shows the compressive strength gain of 4.86, 5.03, and 3.64%, respectively.

In the mix, 12.5SFRCSC, the compressive strength after exposure to sulfate water at 28, 56, and 91 days was 43.65, 43.21, and 42.75 MPa reduced by 1.37%, 2.36%, and 3.40%. The mix 10SFRCSC was more stable against sulfate exposure than the strength cured in the nominal mix. The optimized SCMs of 10% SF combination lead to densification in the concrete matrix, which the sulfate ions in the prepared concrete mix prevent.

The porous microstructure of recycled concrete allows sulfate ions to penetrate quickly, and they react with hydration products to produce sulfate salts like Ettringite and gypsum. The concrete initially densifies due to these sulfate salts, but internal expanding pressures in the pores are gradually caused by over-density. It leads to a reduction in the strength of the concrete matrix and a loss of particle cohesion. Because calcites fill in the gaps, there is very little sulfate ion penetration in mix 10SFRCSC. Thus, 10SFRCSC achieves better durability against sulfate attacks and lowers this sulfate attack.

3.3. Failure Mode

Figure 9 shows the cracking pattern of this study's prepared mixes NAC*, 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC respectively. It can be seen from Figure 9 that the concrete pieces were chipped off from the sample surface with an approximate 60 mm width and 70 mm depth of the reference mix NAC* with 100% OPC. A full-depth vertical cracks of 2-4 mm were also formed in the reference mix NAC*

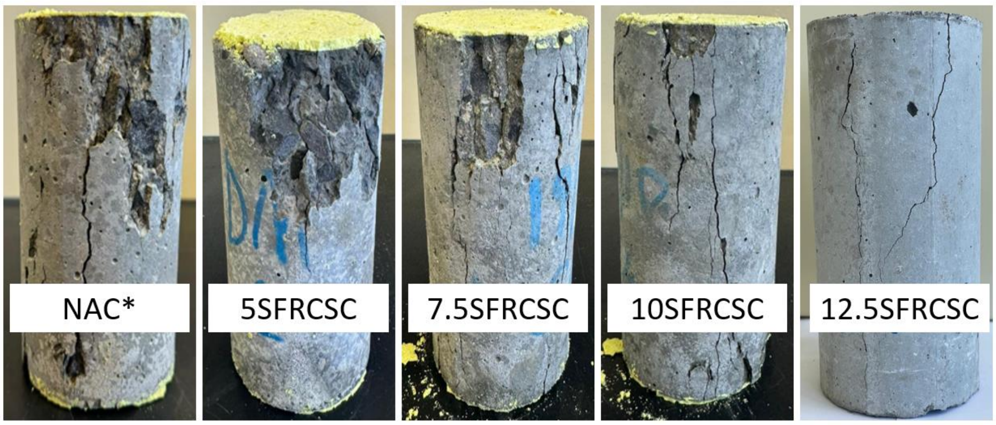

Figure 9. Crack pattern of prepared mixes of the study

Figure 9 also shows the failure mode of mix 5SFRCSC when 5% OPC was replaced with SF and 100% natural sand was replaced with the combination (50%DS+50%RCS). The samples of the mixes 5SFRCSC showed that the upper portion began breaking off concrete pieces. The edge failure was also observed in the samples of mix 5SFRCSC. However, no damage was found on the bottom of the sample, and chipped concrete surfaces were also lower than the reference mix NAC* with 100% OPC. Increasing SF percentages in the mixes allow for more stability in the samples. As seen in Figure 9, mix 7.5SFRCSC when 7.5% OPC was replaced with SF along with the same combination of sustainable sand (50%DS+50%RCS) shows a small portion of concrete pieces were chipped off from the top of the sample. Minor vertical cracks were also observed up to the full depth of the samples. Overall, more stability was observed in the samples than in the previously discussed mixes NAC* and 5SFRCSC, respectively.

The most critical finding was observed when SF percentages were increased by 10% and 12.5% in the mixes 10SFRCSC and 12.5SFRCSC. The sample of mix 10SFRCSC showed minor vertical cracks up to the full depth of the samples with minor damage at the upper edge of the sample when the loading was at its peak. No concrete crushing was seen in the mix 10SFRCSC at any loading stage. In the samples of mix 12.5SFRCSC, the crack formation started from the top with an approximate distance between two cracks of 40 mm, then started narrowing, and finally, a perfect cone shape was observed about 90 mm from the top of the sample. The cone shape, a standard concrete failure with no chipping and breaking of the concrete particles, was seen in the sample shown in Figure 9 of the mix 12.5SFRCSC. Some similarities in the failure mode were seen in the mixes 10SFRCSC and 12.5SFRCSC, with 10% and 12.5% SF incorporation in the mixes. The mix 10SFRCSC and 12.5SFRCSC showed an almost similar pattern of crushing the concrete surface. The mix of 12.5SFRCSC combined with 12.5% SF provides a standard failure mode such as cone failure. Hence, it can be concluded that the mix designations (10SFRCSC and 12.5SFRCSC) have almost the standard failure modes.

4. Conclusions

In this study, four silica fume recycled crushed sand concrete with different proportions of (5-12.5% silica fume) and (50% desert sand + 50% recycled crushed sand) have been studied. This study discloses the combination of waste in concrete to enhance sustainability without compromising the engineering properties. The study's main conclusions are as follows:

- The developed silica fume recycled crushed sand concrete revealed enhanced mechanical properties and satisfactory durability.
- The four tested sustainable silica fume recycled crushed sand concrete satisfied the criterion of specified and required compressive strength ($f'c$) and (f'_{cr}) 30 and 38 MPa set by ACI 318-19.
- The developed mixes 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC compressive strength was higher than the control mix at all curing ages of 28, 56, and 91 days. The results show that the recycled crushed sand with a combination of silica fume performs well and achieves higher compressive strength at later curing days.
- The STS of the mixes NAC*, 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC at 28 days of curing were recorded at 15.3%, 17.4%, 20.53%, 20.2%, and 18.5% of the (f'_c) of the concrete. The requirement of ASTM-C496/C496M-11 of (10-15%) ($f'c$) is satisfied.
- The increment in water absorption was found to be higher in the mixes 5SFRCSC, 7.5SFRCSC, 10SFRCSC, and 12.5SFRCSC when silica fume combined with optimized fine aggregate (50% desert sand + 50% recycled crushed sand) combination compared to reference mix NAC*.
- Better durability against sulfate attacks is achieved in the mix 10SFRCSC when the optimized fine aggregate (50% desert sand + 50% recycled crushed sand) is combined with the SCM of 10% SF.
- The mix of 10SFRCSC and 12.5SFRCSC combined with 10% and 12.5% SF showed a similar failure pattern, providing a standard failure mode such as cone failure.
- It is concluded that up to 10% SF and optimized fine aggregate (50% desert sand + 50% recycled crushed sand) could be replaced by 10% OPC and 100% natural sand in the design mix concrete manufacturing for the construction industry.

5. Declarations

5.1. Author Contributions

Conceptualization, M.N.A. and A.A.; methodology, M.N.A.; validation, N.I.S. and M.N.A.; formal analysis, N.I.S.; investigation, A.A.; resources, A.A.; data curation, M.N.A.; writing—original draft preparation, N.I.S.; writing—review and editing, A.A.; visualization, A.A.; supervision, M.N.A.; funding acquisition, N.I.S. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

Data presented in this study is available in the article.

5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

5.4. Conflicts of Interest

The authors declare no conflict of interest.

6. References

[1] Bendixen, M., Best, J., Hackney, C., & Iversen, L. L. (2019). Time is running out for sand. Nature, 571(7763), 29–31. doi:10.1038/d41586-019-02042-4.

[2] Zhang, T., Zhu, Q., Liu, H., & Gao, S. (2024). Utilization of coal gangue sand in structural concrete as fine aggregate towards sustainable production. Construction and Building Materials, 417, 135264. doi:10.1016/j.conbuildmat.2024.135264.

[3] Mehta, V. (2024). Sustainable approaches in concrete production: An in-depth review of waste foundry sand utilization and environmental considerations. Environmental Science and Pollution Research, 31(16), 23435–23461. doi:10.1007/s11356-024-32785-1.

[4] Akhtar, M. N., Bani-Hani, K. A., Malkawi, D. A. H., & Albatayneh, O. (2024). Suitability of sustainable sand for concrete manufacturing - A complete review of recycled and desert sand substitution. Results in Engineering, 23, 102478. doi:10.1016/j.rineng.2024.102478.

[5] Saini, A., Soni, H., & Yadav, J. S. (2024). Utilization of recycled construction and demolition waste to improve the bearing capacity of loose sand: an integrated experimental and numerical study. Geomechanics and Geoengineering, 19(4), 444–461. doi:10.1080/17486025.2023.2288925.

[6] Monier, V., Mudgal, S., Hestin, M., Trarieux, M., & Mimid, S. (2011). Service contract on management of construction and demolition waste–SR1. Final Report Task 2. European Commission DG ENV, Brussels, Belgium.

[7] Sáez, P. V., Merino, M. D. R., & Porras-Amores, C. (2011). Managing construction and demolition (C&D) waste–a European perspective. International Conference on Petroleum and Sustainable Development, 28-30 December, 2011, Dubai, United Arab Emirates.

[8] Mistri, A., Bhattacharyya, S. K., Dhami, N., Mukherjee, A., & Barai, S. V. (2020). A review on different treatment methods for enhancing the properties of recycled aggregates for sustainable construction materials. Construction and Building Materials, 233, 117894. doi:10.1016/j.conbuildmat.2019.117894.

[9] Akhtar, J. N., & Akhtar, M. N. (2014). Enhancement in properties of concrete with demolished waste aggregate. GE-International Journal of Engineering Research, 2(9), 73-83.

[10] Panghal, H., & Kumar, A. (2024). Recycled Coarse Aggregates in Concrete: A Comprehensive Study of Mechanical and Microstructural Properties. Iranian Journal of Science and Technology - Transactions of Civil Engineering, 1–17. doi:10.1007/s40996-024-01539-x.

[11] Luo, H., Aguiar, J., Wan, X., Wang, Y., Cunha, S., & Jia, Z. (2024). Application of Aggregates from Construction and Demolition Wastes in Concrete: Review. Sustainability (Switzerland), 16(10), 4277. doi:10.3390/su16104277.

[12] Monish, M., Srivastava, V., Agarwal, V. C., & Kumar, R. (2012). Utilization of demolished waste as fine aggregate in Concrete. Journal of Academia and Industrial Research, 1(7), 398-400.

[13] Ju, M., Jeong, J. G., Palou, M., & Park, K. (2020). Mechanical behavior of fine recycled concrete aggregate concrete with the mineral admixtures. Materials, 13(10), 2264. doi:10.3390/ma13102264.

[14] Akhtar, M. N., Jameel, M., Ibrahim, Z., & Muhamad Bunnori, N. (2024). Assessment of structural concrete made by sustainable sand at high temperatures: An experimental research. Ain Shams Engineering Journal, 103108. doi:10.1016/j.asej.2024.103108.

[15] Akhtar, M. N., Jameel, M., Ibrahim, Z., Muhamad Bunnori, N., & Bani-Hani, K. A. (2024). Development of sustainable modified sand concrete: An experimental study. Ain Shams Engineering Journal, 15(1), 102331. doi:10.1016/j.asej.2023.102331.

[16] Wang, C. Q., Cheng, L. X., Ying, Y., & Yang, F. H. (2024). Utilization of all components of waste concrete: Recycled aggregate strengthening, recycled fine powder activity, composite recycled concrete and life cycle assessment. Journal of Building Engineering, 82, 108255. doi:10.1016/j.jobe.2023.108255.

[17] Shah, M. M., Khalid, U., Mujtaba, H., Naqvi, S. A. Z., & Masood, S. (2024). Environmental impacts and performance assessment of recycled fine aggregate concrete. Environmental Science and Pollution Research, 31(25), 36938–36957. doi:10.1007/s11356-024-33590-6.

[18] Lu, D., Qu, F., Su, Y., & Cui, K. (2024). Nano-engineered the interfacial transition zone between recycled fine aggregates and paste with graphene oxide for sustainable cement composites. Cement and Concrete Composites, 154, 105762. doi:10.1016/j.cemconcomp.2024.105762.

[19] Akhtar, M. N., Ibrahim, Z., Bunnori, N. M., Jameel, M., Tarannum, N., & Akhtar, J. N. (2021). Performance of sustainable sand concrete at ambient and elevated temperature. Construction and Building Materials, 280, 122404. doi:10.1016/j.conbuildmat.2021.122404.

[20] Akhtar, M. N., Albatayneh, O., Bani-Hani, K. A., & Husein Malkawi, A. I. (2024). Performance of modified desert sand concrete: An experimental case study. Case Studies in Construction Materials, 21, 3465. doi:10.1016/j.cscm.2024.e03465.

[21] Ji, Y., Qasem, M. G. S., Xu, T., & Mohammed, A. O. Y. (2024). Mechanical properties investigation on recycled rubber desert sand concrete. Journal of CO2 Utilization, 88, 102939. doi:10.1016/j.jcou.2024.102939.

[22] Kazmi, S. M. S., Munir, M. J., & Wu, Y. F. (2025). Development of sustainable high-performance desert sand concrete: Engineering and environmental impacts of compression casting. Resources, Conservation and Recycling, 212, 108002. doi:10.1016/j.resconrec.2024.108002.

[23] Hou, M., Li, Z., & Li, V. C. (2024). Green and durable engineered cementitious composites (GD-ECC) with recycled PE fiber, desert sand, and carbonation curing: Mixture design, durability performance, and life-cycle analysis. Construction and Building Materials, 414, 134984. doi:10.1016/j.conbuildmat.2024.134984.

[24] Hamada, H. M., Abed, F., Al-Sadoon, Z. A., Elnassar, Z., & Hassan, A. (2023). The use of treated desert sand in sustainable concrete: A mechanical and microstructure study. Journal of Building Engineering, 79, 107843. doi:10.1016/j.jobe.2023.107843.

[25] Manjunatha, M., Suresh, N., Bindiganavile, V., Rao, V., & Shivaswamy, S. (2024). Effect of sustained elevated temperature on compression and split-tensile properties of concrete made with waste foundry sand. Journal of Structural Fire Engineering. doi:10.1108/JSFE-08-2024-0028.

[26] Williams, K. C., & Partheeban, P. (2018). An experimental and numerical approach in strength prediction of reclaimed rubber concrete. Advances in Concrete Construction, 6(1), 87–102. doi:10.12989/acc.2018.6.1.087.

[27] Wu, H., Chen, G., Liu, C., & Gao, J. (2024). Understanding the micro-macro properties of sustainable ultra-high performance concrete incorporating high-volume recycled brick powder as cement and silica fume replacement. Construction and Building Materials, 448, 138170. doi:10.1016/j.conbuildmat.2024.138170.

[28] Benemaran, R. S., Esmaeili-Falak, M., & Kordlar, M. S. (2024). Improvement of recycled aggregate concrete using glass fiber and silica fume. Multiscale and Multidisciplinary Modeling, Experiments and Design, 7(3), 1895–1914. doi:10.1007/s41939-023-00313-2.

[29] Nisar Akhtar, J., Ahmad Khan, R., Ahmad Khan, R., Nadeem Akhtar, M., & Thomas, B. S. (2023). A comparative study of strength and durability characteristics of concrete and mortar admixture by bacterial calcite precipitation: A review. Materials Today: Proceedings. doi:10.1016/j.matpr.2023.03.490.

[30] Akhtar, M. N., Jameel, M., Ibrahim, Z., & Bunnori, N. M. (2022). Incorporation of recycled aggregates and silica fume in concrete: an environmental savior-a systematic review. Journal of Materials Research and Technology, 20, 4525–4544. doi:10.1016/j.jmrt.2022.09.021.

[31] Alhajiri, A. M., & Akhtar, M. N. (2023). Enhancing Sustainability and Economics of Concrete Production through Silica Fume: A Systematic Review. Civil Engineering Journal (Iran), 9(10), 2612–2629. doi:10.28991/CEJ-2023-09-10-017.

[32] Uddin, M. A., Bashir, M. T., Khan, A. M., Alsharari, F., Farid, F., & Alrowais, R. (2024). Effect of Silica Fume on Compressive Strength and Water Absorption of the Portland Cement–Silica Fume Blended Mortar. Arabian Journal for Science and Engineering, 49(4), 4803–4811. doi:10.1007/s13369-023-08204-x.

[33] Kumar, A., Jail Singh, G., Chauhan, B. L., & Kumar, R. (2024). Strength and Durability Performance of Recycled Aggregate Structural Concrete with Silica Fume, Furnace Slag, and M-Fine. Journal of Materials in Civil Engineering, 36(7), 4024165. doi:10.1061/jmcee7.mteng-17547.

[34] Alkhrissat, T. (2024). Impact of adding waste polyethylene (PE) and silica fume (SF) on the engineering properties of cement mortar. Case Studies in Chemical and Environmental Engineering, 9, 100731. doi:10.1016/j.cscee.2024.100731.

[35] Etli, S. (2023). Evaluation of the effect of silica fume on the fresh, mechanical and durability properties of self-compacting concrete produced by using waste rubber as fine aggregate. Journal of Cleaner Production, 384, 135590. doi:10.1016/j.jclepro.2022.135590.

[36] Mehta, A., & Ashish, D. K. (2020). Silica fume and waste glass in cement concrete production: A review. Journal of Building Engineering, 29, 100888. doi:10.1016/j.jobe.2019.100888.

[37] Ashish, D. K., & Verma, S. K. (2019). An overview on mixture design of self-compacting concrete. Structural Concrete, 20(1), 371–395. doi:10.1002/suco.201700279.

[38] Akhtar, M. N., Hattamleh, O., & Akhtar, J. N. (2017). Feasibility of coal fly ash based bricks and roof tiles as construction materials: a review. MATEC Web of Conferences, 120, 03008. doi:10.1051/matecconf/201712003008.

[39] Long, W. J., Peng, J. K., Gu, Y. C., Li, J. L., Dong, B., Xing, F., & Fang, Y. (2021). Recycled use of municipal solid waste incinerator fly ash and ferronickel slag for eco-friendly mortar through geopolymer technology. Journal of Cleaner Production, 307, 127281. doi:10.1016/j.jclepro.2021.127281.

[40] ACI-318. (2008). Building code requirements for structural concrete (ACI 318-08) and commentary. American Concrete Institute (ACI), Michigan, United States.

[41] Klee, H., & Coles, E. (2004). The cement sustainability initiative – implementing change across a global industry. Corporate Social Responsibility and Environmental Management, 11(2), 114–120. doi:10.1002/csr.59.

[42] Coelho, A., & De Brito, J. (2011). Economic analysis of conventional versus selective demolition - A case study. Resources, Conservation and Recycling, 55(3), 382–392. doi:10.1016/j.resconrec.2010.11.003.

[43] Ulsen, C., Tseng, E., Angulo, S. C., Landmann, M., Contessotto, R., Balbo, J. T., & Kahn, H. (2019). Concrete aggregates properties crushed by jaw and impact secondary crushing. Journal of Materials Research and Technology, 8(1), 494–502. doi:10.1016/j.jmrt.2018.04.008.

[44] Gebremariam, A. T., Di Maio, F., Vahidi, A., & Rem, P. (2020). Innovative technologies for recycling End-of-Life concrete waste in the built environment. Resources, Conservation and Recycling, 163, 104911. doi:10.1016/j.resconrec.2020.104911.

[45] ASTM C128-22. (2022). Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate. ASTM International, Pennsylvania, United States. doi:10.1520/C0128-22.

[46] Aldayel Aldossary, M. H., Ahmad, S., & Bahraq, A. A. (2020). Effect of total dissolved solids-contaminated water on the properties of concrete. Journal of Building Engineering, 32, 101496. doi:10.1016/j.jobe.2020.101496.

[47] Su, N., Miao, B., & Liu, F. S. (2002). Effect of wash water and underground water on properties of concrete. Cement and Concrete Research, 32(5), 777–782. doi:10.1016/S0008-8846(01)00762-1.

[48] BS-3148. (1980). Method for test for water for making concrete. British standard institute, London, United Kingdom.

[49] ACI 211.1-91. (1991) Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete. American Concrete Institute (ACI), Michigan, United States.

[50] ASTM C136-09. (2014). Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates. ASTM International, Pennsylvania, United States. doi:10.1520/C0136-06.

[51] Arhras, G., & Foo, H. C. (1994). A knowledge-based system for selecting proportions for normal concrete. Expert Systems with Applications, 7(2), 323-335. doi:10.1016/0957-4174(94)90047-7.

[52] ASTM C31/C31M-19a. (2016). Standard Practice for Making and Curing Concrete Test Specimens in the Field. ASTM International, Pennsylvania, United States. doi:10.1520/C0031_C0031M-19A.

[53] Akhtar, M. N., & Akhtar, J. N. (2018). Suitability of Class F Flyash for Construction Industry: An Indian Scenario. International Journal of Structural and Construction Engineering, 12(9), 892-897.

[54] Sithole, N. T., Tsotetsi, N. T., Mashifana, T., & Sillanpää, M. (2022). Alternative cleaner production of sustainable concrete from waste foundry sand and slag. Journal of Cleaner Production, 336, 130399. doi:10.1016/j.jclepro.2022.130399.

[55] ACI-214R-11. (2011). Guide to evaluation of strength test results of concrete. American Concrete Institute, American Concrete Institute (ACI), Michigan, United States.

[56] Moulay-Ali, A., Abdeldjalil, M., & Khelafi, H. (2021). An experimental study on the optimal compositions of ordinary concrete based on corrected dune sand—Case of granular range of 25 mm. Case Studies in Construction Materials, 14, 521. doi:10.1016/j.cscm.2021.e00521.

[57] Abu Seif, E. S. S., Sonbul, A. R., Hakami, B. A. H., & El-Sawy, E. K. (2016). Experimental study on the utilization of dune sands as a construction material in the area between Jeddah and Mecca, Western Saudi Arabia. Bulletin of Engineering Geology and the Environment, 75(3), 1007–1022. doi:10.1007/s10064-016-0855-9.

[58] Sabih, G., Tarefder, R. A., & Jamil, S. M. (2016). Optimization of Gradation and Fineness Modulus of Naturally Fine Sands for Improved Performance as Fine Aggregate in Concrete. Procedia Engineering, 145, 66–73. doi:10.1016/j.proeng.2016.04.016.

[59] ASTM C496/C496M-04e1. (2011). Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens. ASTM International, Pennsylvania, United States. doi:10.1520/C0496_C0496M-04E01.

[60] Rais, M. S., & Khan, R. A. (2020). Strength and durability characteristics of binary blended recycled coarse aggregate concrete containing microsilica and metakaolin. Innovative Infrastructure Solutions, 5(3). doi:10.1007/s41062-020-00365-0.