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A Review of Self-Compacting Concrete Incorporating Waste Materials

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ABSTRACT

As environmental concerns gain prominence worldwide, the significance of sustainable building practices cannot be understated. The burgeoning production of waste annually exacerbates these concerns, with projections indicating a likely increase in volume and corresponding environmental pollution. This review study offers a sustainable approach to address this issue by exploring the potential of waste materials, namely, calcium carbide waste (CCW), crumb rubber (CR), and fly ash (FA), in the redevelopment of Self-Compacting Concrete (SCC). A comprehensive literature review was undertaken, encompassing several key areas: the properties of SCC, the influence of CCW on concrete workability, setting and strength (compressive, tensile, and flexural), and the characteristics of SCC incorporating crumb rubber. A detailed examination of design methodologies for SCC was conducted, including the Japanese design method, the European guidelines for SCC mixed design approach, and the mixed design according to BS EN 206:2013. Acceptance criteria for SCC set by various institutions were also evaluated, along with the composition and classification of rubber aggregates. Findings from the review suggest that CCW is a viable partial substitute for cement and cementitious materials in SCC. The consistency, along with the initial and final setting times of cement, exhibited an increase with the inclusion of FA and CCW. It is recommended that future studies consider up to a 50% FA content to produce grade 40 High Volume Fly Ash Self-Compacting Concrete (HVFA-SCC) with CCW and crumb rubber. This approach not only advances sustainable building practices but also proposes a novel solution for waste management.

1. INTRODUCTION

Due to escalating demand, the prevalent usage of natural coarse and fine aggregate in concrete production is facing depletion. Alleviating the strain on this crucial resource and ensuring its preservation have become imperative. The construction industry necessitates sustainable alternatives to natural aggregates [1, 2]. Kasyar et al. [3] conducted an investigation into the utilization of waste crumb rubber to replace natural aggregates in Self-Compacting Concrete (SCC). Waste materials are employed to modify the mechanical and durability properties of SCC, adapting it for diverse applications. The adoption of lightweight materials, like crumb rubber concrete, simplifies the use of SCC in tall building construction and facilitates ease of pumping to greater construction heights. These outcomes not only lead to cost reduction and energy savings but also promote ecological equilibrium and conserve natural resources [4]. The sources of these natural resources encompass agricultural, industrial, and municipal waste, as illustrated in Figure 1.

Incorporating waste tire rubber crumb as a partial replacement for aggregates in Self-Compacting Concrete has exhibited several advantages, including heightened toughness, energy absorption, fatigue life, and thermal conductivity, alongside reduced brittleness. However, research has pointed out that the addition of crumb rubber diminishes the mechanical properties of the concrete [5]. Various approaches to mitigate this effect have proven to be ineffective and impractical. The utilization of High-Volume Fly Ash (HVFA) has shown promise in mitigating these effects; nonetheless, mechanical properties can be further enhanced through the use of HVFA as supplementary cementitious materials [6]. A significant drawback of HVFA is its lower early strength development owing to slower pozzolanic reactivity. However, incorporating calcium carbide waste as an additive to the cementitious material can trigger the pozzolanic reaction of HVFA at an early stage, consequently augmenting early strength development [7].

Moreover, the quest for cost-effective and environmentally friendly concrete has spurred the use of a large volume of fly ash (50% and above) to achieve the desired concrete properties. This approach substantially reduces cement demand, atmospheric pollution, and heat emissions typically associated with cement production and concrete mixing [8]. While extensive research has established the theoretical and practical foundations for conventional rubberized concrete [9], the attention in SCC research has primarily been on properties concerning high-volume fly ash and a limited focus on rubberized concrete, with minimal emphasis on admixture properties. Specifically, the properties of HVFA in rubberized

Self-Compacting Concrete containing calcium carbide waste remain underexplored in both normal and adverse conditions. Hence, this research aims to expand the knowledge domain concerning the behavior of rubberized Self-Compacting Concrete incorporating HVFA and calcium carbide waste in various conditions. Given its status as a nascent technology, SCC warrants deeper investigations [10]. It is imperative to scrutinize and apply locally available materials for SCC production. The findings of this research are anticipated to guide future researchers [11-13].

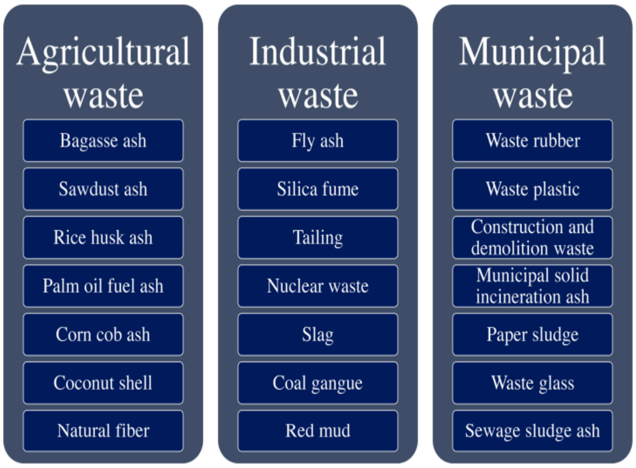


Figure 1. Waste materials from natural resources employed to develop SCC

2. SELF-COMPACTING CONCRETE

In recent years, the use of Self-Compacting Concrete (SCC) has increased, and many articles have been published [14]. The introduction of SCC represents a significant technological advance leading to higher-quality concrete and efficient construction processes [15]. Researchers can build thinner building elements with SCC and more complex and exciting shapes [16]. SCC production allows concrete to be pumped to height and pass through congested reinforcements without compaction other than the concrete's weight. As a result, SCC can be used to reduce construction time, labour costs, and construction site noise levels [17]. To improve workability and reduce segregation, it is always necessary to use a chemical additive when manufacturing SCC. The coarse aggregate content in SCC and water ratio to binder are lower than in ordinary concrete. SCC is heavily laden with fine particles, including lime particles, fly ash and slag from blast furnaces to prevent the gravity separation of bigger particles in the new mix [18-19]. Awang et al. [20] observed that SCC's strength and drying shrinkage was similar to conventional concrete with the same water-cement ratio. The study conducted by Wang et al. [4] compared SCC to conventional concrete. It showed SCC to be less permeable and absorbent due to the capillary phenomenon. This result may be due to the less porous areas and the finer pore structure.

2.1 High-volume fly ash

The build-up of coal firing at thermal power facilities, known as coal fly ash (CFA), has received international attention as hazardous waste. The two main issues with CFA are the toxic, heavy metal sifted into the groundwater and the substantial amount of acreage required for its disposal. CFA was previously thought to be a waste and water pollutant. However, it is a helpful material that has proven valuable, particularly in Kelechi et al. [21]. HVFAC results from substantial where fly debris surpasses 30% of all cementations materials. One of the spearheading uses of HVFA was building the Ravenous Pony Dam in Montana (ACI, 2014). The exploration found various advantages related to utilising HVFA, for example, minimal expense, strength, further developed insurance against sulfate assault, low intensity of hydration, and phenomenal usefulness. From that point forward, HVFA has been utilised to develop dams, marine slipways, sewage treatment works, substantial viaducts, structures, establishments, and holding walls [22]. Expanding how much fly debris in concrete has its difficulties. At basic levels, issues can happen with long fix times and postponed strength improvement, bringing about lower early strength and slower development. These drawbacks are particularly apparent in chilly environment concrete [23]. An ideal measurement of fly ash is available in concrete mixes in some random situations, greatly enhancing the overall benefit of fly ash utilisation by affecting construction speed or reducing the project's long-term performance. Optimal fly ash measurement is one component of a wide range of parameters and must be solved on a case-by-case basis [24]. Adequate initial strength and cure time are achieved using a wide range of water-reducing agents to achieve very low water/cement ratios. Studies have shown that large quantities of fully hardened fly ash concrete with a low water/cement ratio exhibit excellent properties. Later, but have a high water/cement ratio produced and cured under normal conditions [25]. Studies have yet to be carried out on the behaviour of concrete structures made of HVFA concrete. For example, the Nicole Valley Institute of Technology at Caribou University (Merit et al.), built in 2001, applies an Eco-Smart and HVFA concrete design with 50% fly ash in the foundation cement material [26].

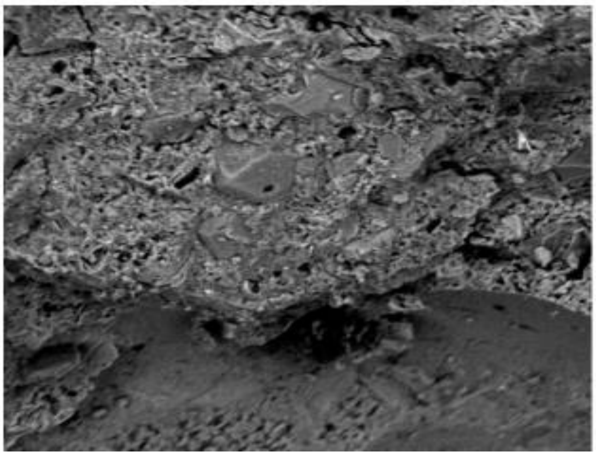
SCC with a significant FA had comparable strength and attenuation to regular concrete. Additionally, the shrinking resembled that of conventional concrete. Results are based on various water-to-binder concentrations. Compared to a concrete mix made entirely of Portland cement, using fly ash and blast furnace slag in SCC lowers the dose of hyperplastic agent needed to achieve a similar slump flow [27]. SCC's elasticity and shrinkage were not all that different from the equivalent characteristics of regular concrete. According to a test conducted by Al-Feel and Al-Saffar [28], the best results came from water-cured specimens to examine the effects of curing techniques on the compressive, splitting, and flexural strength of Self-Compacting Concrete—compression capacity. Reschner [29] studied the application of high-volume fly ash concrete (HVFAC) using dippy structural moulds. Their test results showed that the fly ash replacement increases the strength of HVFAC by up to 50%. Kou and Poon [30] showed that curing conditions significantly affect cement hydration. The hydration process stopped all remaining capillary water due to evaporation for samples exposed to 90% RH (initially cured at 100% relative humidity (RH) for 6 or 12 hours).

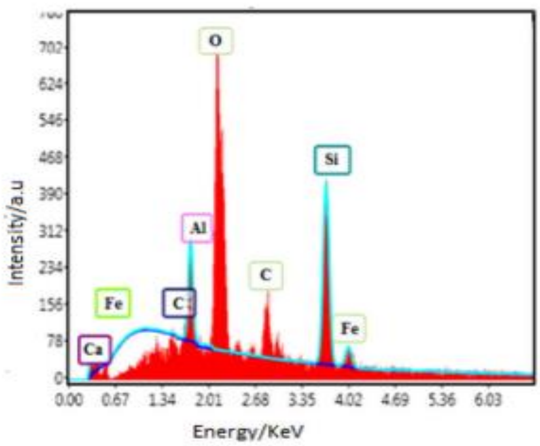
Research by Yung et al. [31] researched the impact of relieving conditions on the mechanical properties of self-stacking concrete. It showed that the water fix test generally showed the most elevated esteem, trailed by the fixed relieved test piece and air restoring, regardless of the substantial's sort, age, and test strategy. SCC with silica smoulder shows the most elevated esteem in compressive and elasticity trial of concrete, then, at that point, SCC with fly debris, then PC concrete with all solidifying periods and conditions. An examination by Ravikumar et al. [32] plans to make and assess SCCs produced using a high volume of oven debris. The aftereffects of the review propose that the mix of quarry dust (QD), silica smoulder (SF), and oven heater (KA) can work on the functionality of SCC over the singular utilisation of QD, SF, and KA. While KA can likewise decidedly affect early mechanical properties, SF has worked on the connection between the total grid shaped by the less permeable substantial progress zones. SF might lessen all out-water ingestion, yet QD and KA do not have a similar impact at 28 days. However, the chemical composition of fly ash has a very high calcium oxide content. It consists of excellent spherical particles, making blending with other concrete constituents easier. Small amounts of iron, magnesium, and alkali oxides are also found. Typical physical properties of FA are given in Table 1. Furthermore, Table 2 shows the chemical composition of fly ash samples from various research.

Table 1. Typical range of physical properties of FA

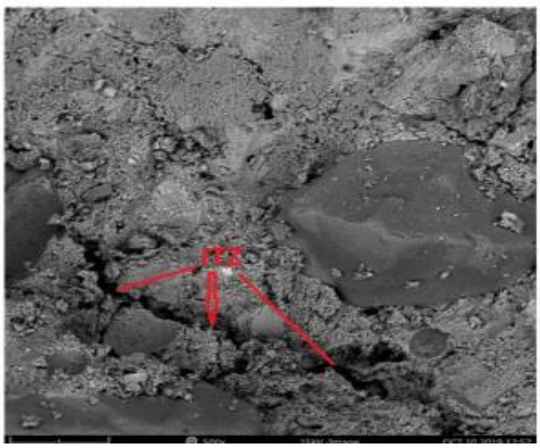
Property	Value
Density	500-994 kg/m^3
Specific gravity	1.0-4
Average particle size	1.0-6.92(µm)

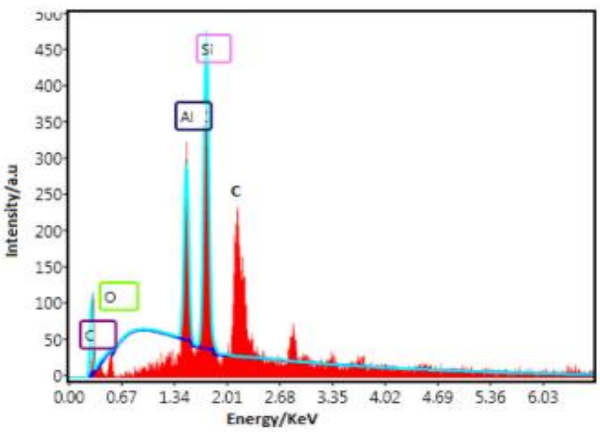
Kelechi et al. [33] used the response surface technique to optimise the parameters for the developed SCC for industrial applications. The passing ability, slump flow, and discrimination resistance were s Self-Compacting Concrete 's newly developed (SCC) features. At the same time, flexural strength, compressive strength, and fracturing tensile strength. SEM and EDX were employed to study the impact of FA and CCR on the microstructural characteristics of the SCC investigated. The results are shown in subgraphs (a) and (c) of Figure 2 to be the hardened properties. According to the trial findings, adding FA and CCR enhanced passing performance and slump flow. The segregation resistance was improved with the rise in substitution material proportion, but it was delayed by raising the CR content. Similar to how CR, CCR, and FA increased SCC strength, the opposite was true at more significant replacement percentages than 10% CR, 10% CCR, and 40% FA. For all P-value reactions of less than 5%, it was discovered that the suggested models were applicable. ITZ, depicted in subgraph (b) of Figure 2, is a porous border of width between 10 and 50 m in the mixture of cement and aggregate, where failure prematurely starts due to crack formation with load application, leading to a further decrease in strength. The including and CCR also refine the microstructure by strengthening the weak adhesion between the strengthened cement framework and CR. From Figure 2a, the FA and CCR are added, and the extra $Ca(OH)_2$ reacts with them to produce more C-S-H gel, which further densifies the ITZ between the strengthened cement paste and CR to refine the pore structure. Figure 2c shows numerous pores on the morphology, which may be caused by excess $Ca(OH)_2$, which is simple to leak out, forming voids in the matrix. Due to the fly ash, Si, Ca, and Al are in large quantities in subgraphs (ai) and (ci) of Figure 2. This demonstrates that fly ash has pozzolanic properties.



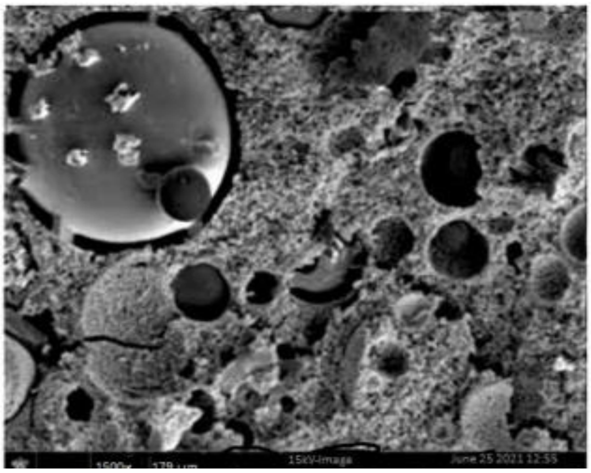


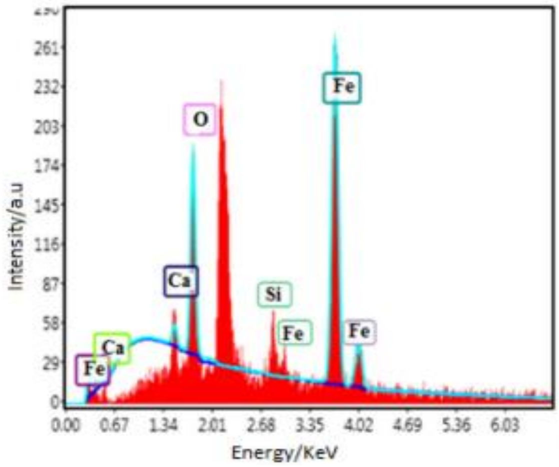
(a) FESEM image of control mixture and (ai) EDX of control mixture





(b) FESEM image of mixture R20C10H0 and (bi) EDX of CR-20%, CCR-10% and FA-0%





(c) FESEM image of mixture R20C10H401 (ci) EDX of mixture of CR-20%, CCR-10% and FA-40%

Figure 2. FESEM and EDX of selected SCC mixes

Table 2. Percentage analysis of the chemical structures of fly ash samples

Oxides	Adamu et al. [34]	Wanasinghe et al. [35]	Tajunnisa et al. [36]	Swami [37]	Wardhono [38]	Panda et al. [39]
SiO_2	57.06	50.14	41.17	59.75	30.55	77.10
Al_2O_3	20.96	29.08	34.48	25.29	18.74	17.71
Fe_2O_3	4.15	9.66	11.54	6.47	7.48	1.21
CaO	9.79	4.03	1.89	6.48	28.43	0.62
MgO	1.75	1.11	1.74	1.18	0.00	0.90
K_2O	1.53	1.53	1.05	–	0.45	–
Na_2O	2.23	–	0.96	–	1.5	0.80
SO_3	–	0.77	0.65	1	3.33	2.20
TiO_3	0.68	–	–	0.65	1.35	–
BaO	–	–	–	–	–	–
LOI	1.25	0.63	–	4.71	0.57	0.87

2.2 Implementation of calcium carbide waste

Calcium carbide waste (CCW) is a by-product of combustible acetylene gas. It is also known as carbide lime sludge or lime hydrate. The chemical equation for calcium carbide combines calcium with carbides, CaC_2. Although most materials are generated industrially, natural calcium carbide is colourless. This crucial gas is created when calcium carbide reacts with water and is used in oxygen-acetylene forging [40]. The chemical reaction's expression is as follows in Eq. (1).

$$\underset{\text{Calcium carbide}}{CaC_2} + \underset{\text{Water}}{2H_2O} = \underset{\text{Hydrated-Lime}}{Ca(OH)_2} + \underset{\text{Acetylene}}{C_2H_2} \quad (1)$$

The CCW from acetylene gas production is typically disposed of in landfills and can cause additional problems, such as the leaching of harmful compounds and alkalis into groundwater. Countries like China use large quantities of acetylene as a manufacturing fuel because it is more economical to manufacture and use domestically than to import oil primarily for the same purpose. Interestingly, acetylene can even be used to speed up fruit ripening. In the same way, ethylene is used. Other uses for calcium carbide include acetylene production in charcoal lamps, a fertiliser chemical, and steel manufacturing. In order to eliminate this type of waste or reduce its accumulation, it is therefore very beneficial to utilise CCW as a construction material. One of these methods is to replace some of the ordinary Portland cement (OPC) in the concrete. Andrew [41] conducted a test on the toxicity of CCW. He discovered that industrial or agricultural wastes could economically replace the quality of traditional building materials with unique treatments and or in combination with other materials. The chemical analysis of CCW showed high calcium oxide content (CaO) similar to OPC with a similar chemical composition. Typical physical properties of CCW are given in Table 3.

Table 3. Typical range of physical properties of CCW [41]

Property	Value
Particle size (typical)	<1 um
Density	2300-2700 kg/m^3
Specific gravity	2.0-4
Surface area	13,000-30,000 m^2/kg

Table 4. Chemical components of calcium carbide waste samples

Oxides	Basu et al. [42]	Bayuaji et al. [43]	Tuleun and Jimoh [44]	Adamu et al. [45]
SiO_2	2.8	3.19	1.54	2.1
Al_2O_3	0.5	2.01	0.50	0.5
Fe_2O_3	0.54	0.87	0.03	0.54
CaO	95.69	91.48	67.02	95.69
MgO	–	0.23	1.26	–
K_2O	0.47	0.07	0.05	0.47
Na_2O	–	0.72	0.02	–
SO_3	0.31	0.27	–	0.31
TiO_3	–	0.14	–	–
BaO	0.09	–	–	0.09
LOI	–	–	1.02	–

However, the chemical conformation of CCW has a very high calcium oxide content and consists of excellent spherical elements. Small quantities of iron, magnesium, and alkali oxides are additionally discovered. Table 4 shows various research studies' chemical compositions of calcium carbide waste samples.

2.2.1 Impact of calcium carbide waste on the concrete workability

Yunusa [46] observed decreased workability with increased CCW content proportion in concrete. The Compacting factor values can be categorised as low (0.85) in the values that fall within the medium range of slump (35mm – 75mm) following BS 1881. The higher replacement levels (15 – 25%) were in the S1 classification (10mm – 40mm), while the lower levels were in the S2 classification (50mm – 90mm). Tuleum and Jimoh [47] discovered that the mortar's workability decreased with increased CCW replacement of cement. With an almost 30% decrease at 25% replacement compared to conventional concrete. The study concluded that concrete workability decreases with increased CCW and increases the water-cement ratio for increased consistency. The authors state this was due to more water required to coat the fresh concrete mix's surface. Haruna and Adamu [48] concluded that adding CCW in SCC reduces its workability, although it is still within EFNARC specified value range. Research by Manasseh [49] to examine RHA and CCW's effect on concrete properties showed that workability generally reduces with increased CCW and RHA. Abdurra'uf et al. [50] examined the properties of mortar containing calcium carbide waste. The study discovered a progressive increase in the mortar's workability as the percentage of CCW increased. According to Adamu et al. [51], as the quantity of replacement for cement with RHA and CCW increases, the workability of the concrete decrease.

According to Uche et al. [52], cement was partly replaced for waste management by calcium carbide residue (CCR), which is incredibly rich in calcium oxide. Crumb rubber (CR), made from recycled tires, was ground into fine aggregate to replace the fine aggregate partly. Therefore, this study examined the impact of CR and CCR on the heat/temperature resilience and durability characteristics of Self-Compacting Concrete (SCC). In order to investigate the effects of CR and CCR on SCC properties, create models for the SCC's properties, and optimise the mixes for the best outcomes, the experiment was planned using response surface methodology. The characteristics considered were the durability of acid attack obstruction (H_2SO_4 attack), salt attack obstruction ($MgSO_4$ attack), and water absorption. After heating the specimens to 200°C and 400°C, weight loss and remaining shear strength were considered when evaluating heat resistance. The data indicated that CR and CCR harm the SCC's acid and salt resistance. CCR marginally enhanced the SCC's heat resilience at 200°C, whereas CR adversely affected it. High levels of correlation and predictability were present in the models created using RSM, and they were necessary. The optimal properties were 2.9% CR as an acceptable complete replacement and 5.5% CCR as a concrete replacement. The models developed can predict the solidity performance of SCC blends about corrosive and salt impact flexibility and the effects of increased temperatures by using CR, CCR, and fly debris as the parameters. Less testing should be conducted, saving time, money, and effort.

2.2.2 Impact of CCW on the concrete porosity

Ghorbani et al. [53] investigated the characteristics of geopolymer slurry made with fly ash and CCW. According to their study, samples with the most significant concentrations of CCW and FA at 56 days of age had minor porosity. Júnior et al. [54] also found that porosity increased when CCW was used as a cement substitute in masonry.

2.2.3 Impact of CCW on concrete setting time

Gora et al. [55] found that CCW replacement decreased concrete's initial and final setting time and was mainly reduced at 5% replacement, indicating that early strength gain was initiated due to CCW addition to the concrete mix. Morla et al. [56] observed that the geopolymer paste with the lowest CCW level exhibited a lower initial and final setting time. The results from the comprehensive strength of Geopolymer Concrete (GPC) and Regular Portland Concrete (OPC) on the 7th and 28th days are shown in Figure 3. Barreto et al. [57] researched concrete properties at 0, 5, 10, 15, and 20% replacement of OPC with CCW after 28 days of curing, showing that both the initial and final setting time decreased with CCW. Results of the 0 alongside 20% formulations' SEM fractographic analysis are shown in Figure 4. The existence of C-S-H, illogical and CH crystals was confirmed in subgraphs (a) and (b) of Figure 4, corresponding to the reference concrete. Figures 4c and 4d show that the existence of CH was not confirmed, indicating that the CH content in this C20% concrete had decreased. This early strength development was attributed to the vast CaO content of CCW in reaction with water.

Manasseh [49] examined the properties of RHA and CCW on concrete, the author varied RHA from 0 to 30% at 10% intervals, and CCW from 0 to 40% varied at 10% level observed a decrease in the setting time of concrete at 10% CCW replacement but increased above 10% CCW for all samples. This the studyImages attributed to low heat liberation due to reactivity loss associated with CCW compared to cement. According to Abdurra'uf et al. [50], the mortar's initial and final setting time increased with CCW to investigate the properties of calcium carbide-modified mortar.

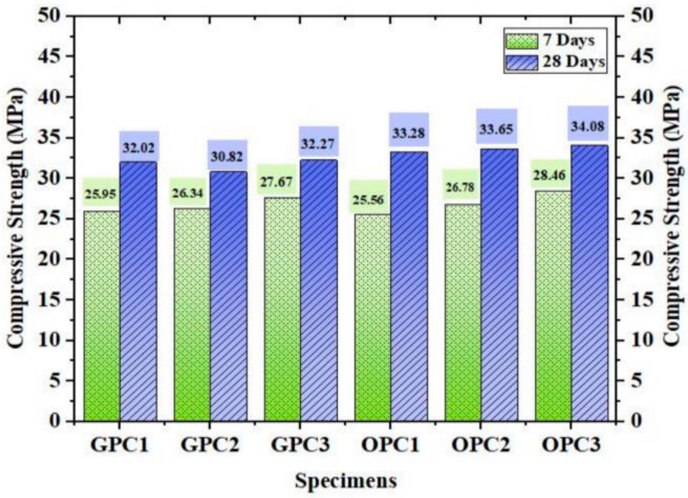


Figure 3. Analysis of the 7-th day and the 28th-day of the OPC and GPC of the compressive strength for all the specimens

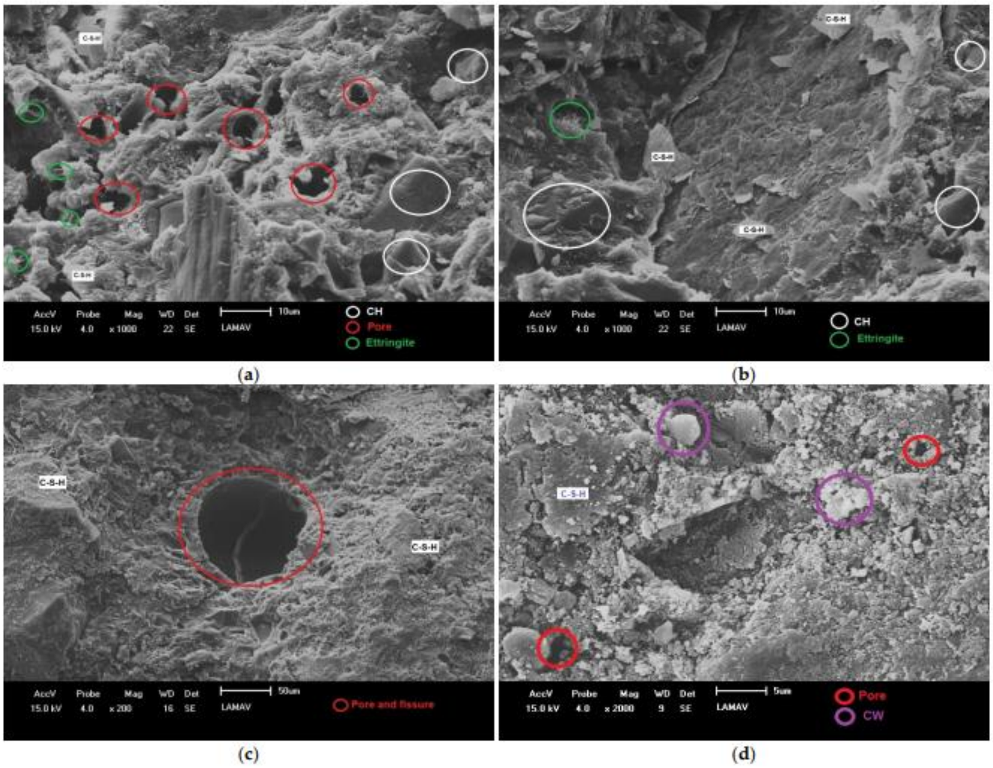


Figure 4. The concrete study of the SEM analysis: (a) and (b) C-0%; (c) and (d) C-20%

2.2.4 Impact of CCW on the concrete compressive strength

From the research by Basu et al. [42] to partially replace cement with CCW, the compressive strength decreased as the replacement level increased. However, the 5% replacement CCW presented an exception. The strength value (25.26 N/mm2) increased over the conventional concrete (23.26 N/mm2) before decreasing the other higher replacement levels. Optimum compressive strength is achieved at a 5% replacement level. Makaratat et al. [58] mixed CCW with fly ash for cement substitution and obtained an excellent compressive strength rating of 28.4 N/mm2 in a report of a similar nature. They concluded that, except for masonry construction, substituting cement with over ten per cent CCW will not provide the necessary strength for durable concrete carrying a significant load.

Hassan et al. [59] used a proportion of water to the cement of 0.4 to assess the fresh and toughened characteristics of a self-compacted cement comprising CCW and sorghum peeling ash (SHA) in the proportions of 30:70 and 1.5–3.75%, respectively, as binders. They found that the Mortar met the ASTM C270 type N requirements and had a maximum compressive strength of 14.08 MPa [60]. According to Lotfy [61] research, compressive strength is adequate for concrete at 10% cement replacement. However, with over 10% cement replacement, the condition becomes unsatisfactory after 14 and 28 days of curing. Gora et al. [55] examined the impact of CCW (0, 1, 2, 3, 4, and 5%) on the compressive strength of Mortar at ages 7, 28, and 56 days after relieving. The CCW mortar's compressive strength increased by 8% at 2% concrete replacement after 56 days of relieving age, representing the most improvement above the control case. Portland cement and CCW underwent secondary soaking in this manner. The Ugwu et al. [62] study examined Self-Compacting Concrete's flow and mechanical characteristics containing quarry dust, calcium carbide, and pulverised fuel ash. At intervals of 5%, the cement content was replaced by 5-20%. The anticipated increase in compressive strength was attained at 15% of quarry dust and pulverised fuel ash and 20% cement replacement with pulverised fuel ash but declined at 20% CCW. According to Liang et al. [63], as the percentage of CCW in the paste decreases, so does the compressive strength of geopolymer paste. Therefore, using CCW as a filler geopolymer paste is advised.

A comparative study conducted by Tuleun and Jimoh [47] to evaluate the performance of concrete at 0, 5, 10, 15, and 20% substitution of OPC with CCW reveals a maximum improvement in compressive strength of 19.9% at 5% replacement. Additionally, they saw that the compressive strength reduced after 5% and then increased as the curing age grew. The features of Self-Compacting Concrete using rice husk ash (RHA) and calcium carbide waste (CCW) were studied. 10% RHA was added to the cement content as an additive, and 0-20% CCW was substituted for cement at intervals of 5%. Also, the author discovered a slightly different trend; the author observed 10% RHA and 10% CCW peak compressive strength values of 35Mpa and 39.53 Mpa, similar to the compressive strength values of 37.11N/ and 40N. However, the conventional concrete at 28 and 56 days reduced after that beyond 10%.

2.2.5 Impact of CCW on the concrete tensile strength

Karthiga et al. [64] researched the properties of concrete at 0, 5, and 10. 15 and 20% OPC replacement with calcium carbide. They concluded a 4.6% maximum increase in concrete tensile strength at 5% cement replacement with CCW than conventional concrete. They also observed a steady decrease in tensile strength as the percentage of cement replacement increased. The splitting tensile strength of the SCC mix hybridised with RHA and CCW investigated by Haruna and Adamu [48] shows a 57 and 61% increase at 3 and 28 days, respectively, for a mix containing 10% RHA 0% CCW when compared with the reference mix. Similarly, they discovered a 10% RHA and 10% CCW maximum tensile strength value of 1.69 N, similar to the 1.71 N obtained for the reference concrete. After that, a general decrease in tensile strength was experienced beyond 10% on porous concrete and also increased splitting tensile strength on cement replacement with 10% CCW and above 28 days.

2.2.6 Impact of CCW on the concrete flexural strength

The excellent engineering and physical qualities of calcium carbonate whisker (CCW) and its affordable price and straightforward manufacturing method have made it a widely used material. In this research, Xing et al. [65] created modified asphalt by mixing CCW with the asphalt binder. Using various experimental techniques, the morphological features, thermal performance, and rheological qualities of CCW and the modified asphalts were investigated. The surface of CCW was treated with the silane coupling agent (2 wt%, KH-570) to improve the compatibility of bitumen and CCW. The results indicate that CCW can be added to asphalt to enhance its softening point, lowering its penetration and ductility. Additionally, the modified asphalt's rutting resilience has been somewhat improved. Huang et al. [66] used SEM, XRD, and TG-DSC to describe the hydration products, microstructure, and thermal stability of cement-based materials created by mixing nano-SiO_2 and calcium carbonate whiskers. The mechanical characteristics and thermal transmission of thermal-insulated cement mortar were also investigated by incorporating 0%, 1%, 2%, 3%, 5%, and 10% calcium carbonate whisker and 1% nano-SiO_2. The findings of the tests showed that by incorporating nano- and millimetre-scale materials, C-S-H gels were produced from the secondary hydration reaction between nano-SiO_2 and $Ca(OH)_2$ crystal, filling the gaps in the cement base and enhancing the cement base's pores. Additionally, calcium carbonate whiskers serve as fibres and particles, creating a bridging effect in the cement foundation and a dense network flocculation structure. Calcium carbonate whisker and nano-SiO_2 can be added to cement grout to increase its tensile strength. Mohammed [67] studied the effect of CCW on concrete properties by replacing cement with CCW at varying percentages. It concluded that the Modulus of Rupture, a measure of flexural strength, decreased as the percentage of CCW increased. Conventional concrete had the highest Modulus of Rupture value.

Zhang et al. [68] To work on the leftover compressive effectiveness of rubber-treated concrete, a new multi-scale fibre-built-up concrete produced using elastic (MSFRRC) is created. It contains steel strands, polyvinyl liquor (PVA) filaments, and calcium carbonate bristles. In this exploration, comparable volumes of scrap elastic with sizes going from 0.4 mm to 0.8 mm are utilised to supplant 10%, 20%, and 30% of the sands. Examinations are additionally led into the disappointment component of acoustic outflow innovation and the warm effect on the microstructure of rubber-treated concrete examples. The outcomes show that adding multi-scale fibre can prevent cracks and dangerous spalling from shaping in hot conditions. Besides, by considering scrap elastic, multi-scale strands, and high temperatures, exact recipes are proposed to gauge the lingering pressure strain association of MSFRRC under uniaxial pressure.

3. SELF-COMPACTING RUBBERISED CONCRETE

The ability of rubberised materials to improve workability when implemented in the development of self-compacted concrete proves its viability in the manufacturing industry. The test results from Güneyisi et al. [69] showed that increasing the rubber content between 0% and 50% reduces compressive strength and elasticity. Shao et al. [70] Investigate the possibility of using granulated rubber instead of coarse sand for manufacturing concrete pavers. The crumb rubber was treated with SBR latex. It was concluded that the density and the compressive strength decrease systematically as the rubber content increases. Ghedan and Hamza [71] studied the compressive strength and thermal conductivity of rubberised concrete and rubber particles treated with 0.1% SICAN water as a coupling agent compared to traditional concrete. Test results show that adding rubber particles to concrete makes it lighter and reduces compressive strength. Lin et al. [72] discovered self-compressing rubber concrete's mechanical and dynamic properties (SCRC). The rubber aggregate addition improved the deformability. It significantly reduced the open displacement of flex cracks compared to the reference mix. As the proportion of rubber aggregate increased, the dynamic elasticity and speed of the ultrasonic pulse decreased. Qaidi et al. [73] investigated the bending fatigue behaviour of SCRC with and without steel fibres. Adding scrap rubber to the SCC increased the flex fatigue resistance by approximately 15%. Adding steel fibre to the SCRC increased the fatigue resistance from 25% to 50%. From all the studies, it can be inferred that rubber as an aggregate reduces some of the concrete's mechanical properties, which is why a replacement ratio of more than 30% is not recommended [74]. This decrease in strength is caused by the weak bond between the rubber particles and the cement matrix and by measuring the rubber's coarse grain [75]. In addition to the limitations of the traditional replacement of aggregates for rubber waste, particle size distribution is another essential aspect of the formulation of self-filled rubber concrete. Large and small particle size distribution measurements improve particle packing, fill voids, and concrete durability. The rubber particles' surface is rough, increasing the cohesion force but significantly reducing workability [76]. The value and frequency of the dynamic elastic coefficient's vibration damping coefficient are significant in structural applications. Improving it means improving reliability regarding natural disasters, accidental or hydrostatic loads, and fragmentation. Concrete made from scrap tire residues will delay microcracks' appearance in the matrix, reduce shrinkage, and allow it to absorb more energy than traditional SCCs [77].

Recent studies have shown that the pretreatment of rubber particles has been performed with a water-soluble synthetic polymer solution to compensate for the low mechanical properties of some SCRCs, which is more efficient as mechanical results improve—proven. The results found in the literature show that the option of the elastic total to SCC further develops influence opposition, and this increment corresponds to how much elastic is added [78]. A few creators report that self-stacking elastic cement retains more energy, and better isolates sound waves. Accordingly, SCRC can be applied to precast mechanical strain components requiring high flexibility upkeep, joining high ease with mechanical pressure support [79]. This is a property not maintained by traditional self-filled concrete. From all the previous studies, it is clear that an alternative solution for the disposal of waste tires is incorporating a concrete mix. This innovative option has environmental, economic, and performance benefits implemented with a granular distribution and appropriate proportions. Also, tires with suitable casing can be recycled and reused. According to CONAMA resolution 416/2009 [80], the reform process can be characterised by reabsorption. This is a modified process by replacing the tread and shoulders of the used tires and the entire side surface. They are also known as retreading or remodelling. Scraping the layer to be modified creates residues in the form of fibres and rubber dust. This granulocyte is widely used as an aggregate in cement-based matrices [81]. The recycling process breaks unusable tires into smaller tires. Grinding can be done at room temperature or in a cryogenic process. The tire is first processed into 50mm flakes at room temperature, and then these flakes are sent to a shredder and reduced to 10mm. Therefore, some steel is removed, and the rest is removed magnetically after the crusher 10mm crushed rubber is required, but most construction applications require finer grades in the 2 to 0.84mm [82].

3.1 The characteristic of Self-Compacting Concrete with the inclusion of crumb rubber

3.1.1 Flow-ability (Filling ability)

The SCC should be able to stream and fill the entire form area with its weight. Thus, one of the main characteristics of Self-Compacting Concrete is stream capacity linked to functionality [83]. The V-pipe test measures the stream season of SCC, and the downturn test evaluates the stream capacity of SCC without even a hint of deterrents, according to the European Self-Compacting Substantial Rules (2005). Instead of using fine total by volume, Bignozzi and Sandrolini [84] used 0, 22.2, and 33.3% powdered elastic powder (0.05-0.7 mm). 22.2% of elastic powder expanded, but it did not affect the settlement. Amran et al. [85] tested crumb rubber SCC samples (up to 2 mm) with different volume substitution rates of 10%, 20%, 30%, and 40% sand. Based on their test data, the flow-ability (slump test value) was reduced by 11.5%, with the rubber content's replacement from 0% to 40%.

Topçu and Bilir [86] supplanted the total in an SCC elastic substance of 60, 120, and 180 kg/m3. The tests they completed showed that the stream capacity expanded somewhat as the elastic substance expanded in various combinations. The settlement test information shows the stream measurement is 69-80 cm. V-pipe test results at different per cent elastic substances are additionally satisfactory, with V-channel stream times going from 4.37 to 15.25 seconds. Uygunoglu and Topçu [87] supplant sand with various extents of waste elastic (1-4 mm) of 0% to half (by weight of sand) by a 10% span. They inferred that raising the elastic substance diminished the rut of the blend. As indicated by their outcomes, the downturn esteem shifts from 110 to 230 mm with the SCC blend, adding an elastic substance of half relying upon the various extents of hydroplastic specialists. V-channel's stream time improved essentially with the expansion in the elastic substance of a hydro-plastic specialist proportion of 0.47. Ganesan et al. [88] supplanted the sand with 15% and 20% body integrals of squashed elastic and steel strands. They reasoned that the rut diminished with expanding elastic substance. Nonetheless, the downturn is diminished when steel strands are integrated into these rubbers' altered SCCsd. The V channel time is developed to add an elastic substance to the SCC. Güneyisi et al. [89] utilised scrap elastic and tire chips to not entirely supplant the satisfactory and coarse totals of the SCC blend at different levels. Given the experimental outcomes, the settlement width (i.e., 680-750mm) of the SCC with morsel elastic is bigger than the settlement measurement (i.e., 560-710mm) of the tire chips.

3.1.2 Passing ability

The ability of new material to pass through barred openings, such as scattered steel reinforcing bars, without halting up or isolating itself is known as passing skill. According to the European Rules from 2005, the "L-Box" and the “J-Ring” tests should be used to determine the Self-Compacting Concrete's passing skill. Instead of macroaggregates by volume, Bignozzi et al. [84] used 0, 22.2, and 33.3% pulverised elastic powder (0.05-0.7 mm), and 22.2% of the powdered elastic affected the j-ring test values. However, adding 33.3% granulated rubber increased the ring test value. Amran et al. [85] tested clam rubber SCC samples (up to 2 mm) with different volume substitution rates of 10%, 20%, 30%, and 40% sand. The L box test verifies the passing ability. They concluded that adding 40% rubber content to the SCC reduced the passing ability of the SCC by 13.1% compared to that of the SCC without rubber content. Rahman et al. [90] investigated rubber-modified Self-Compacting Concrete's basic properties with different rubber contents. The L-box test results concluded that the rubber-modified SCC had a considerably lower passing ability ratio (0.28 to 0.4) than the average SCC and that increasing the super-plasticizer did not improve the passing ability. The study replaced the sand with 15% and 20% shredded rubber and a volume fraction of steel fibres. Based on their L-box test data, it is clear that there is no significant difference in the passing ability of conventional SCC and rubberised SCC containing viscosity modifiers.

3.1.3 Compressive strength

Of all the concrete properties, the most important is that which gives an idea of all the concrete characteristics, which is why the compressive strength of concrete is paramount to engineers. Generally, compressive strength is primarily calculated by casting a 6 “x 6” x 6 “cube and crushing it in a compressive strength tester. Rahman et al. [90] conducted a test on SCC replacing sand with 0%, 10%, 20%, 30%, 40%, and 50% (weight of sand) of various rubber waste (1-4 mm). They concluded that using tire aggregates reduced the compressive strength for seven days by 40-64% and the compressive strength for 28 days by 48-58%. Topçu et al. [91] replaced fine aggregate, or sand, with four specific crumb rubber contents of 0%, 5%, 15%, and 25% by volume. From these test data, it is clear that the compressive strength of concrete decreases sufficiently as the rubber aggregate content increases, regardless of the sample’s age. The creators utilized destroyed elastic (2-6 mm) from scrap tires as a halfway trade for coarse total, fine total, and a blend of coarse and fine total. They presumed that supplanting FCR (a mix of fine and disintegrated elastic) gives the best compressive strength. Gesoğlu and Güneyisi [92] utilized piece elastic and tire tips to somewhat supplant the fine and coarse totals of the SCC blend at different levels. The compressive qualities are acquired in the scope of 31.0 to 62.8 Mpa; the creator then presumed that integrating elastic tires into the SCC may justify the decreased compressive strength. Still, self-filled concrete with 25% rubber crumbs or tire chips can achieve a compressive strength greater than 30 Mpa. Yakhlaf [93] prepared SCC samples using different proportions of rubber powder (0-40% by volume of sand) and different cement-based materials. It was decided that these proportions of crumbled rubber reduce compressive strength by approximately 59.25%. On the other hand, Metakaolin can improve the compressive strength of self-compacting rubber concrete mixes by 49.2%. Wang et al. [94] also concluded from their study that the compressive strength of SCC gradually decreased with clam rubber. Figure 5 depicts the characterisation of fly ash and CCW SEM and EDX Image of and particle size investigation of aggregates. From Figure 5b, the EDX shows that silicon and aluminium are of high values. This has proven that fly ash contains a high amount of silicon particles. That reduces the wear rate of any composite form with fly ash. Figure 5d shows the EDX Image of CCW with the potential amount of calcium, silicon, and little carbon.

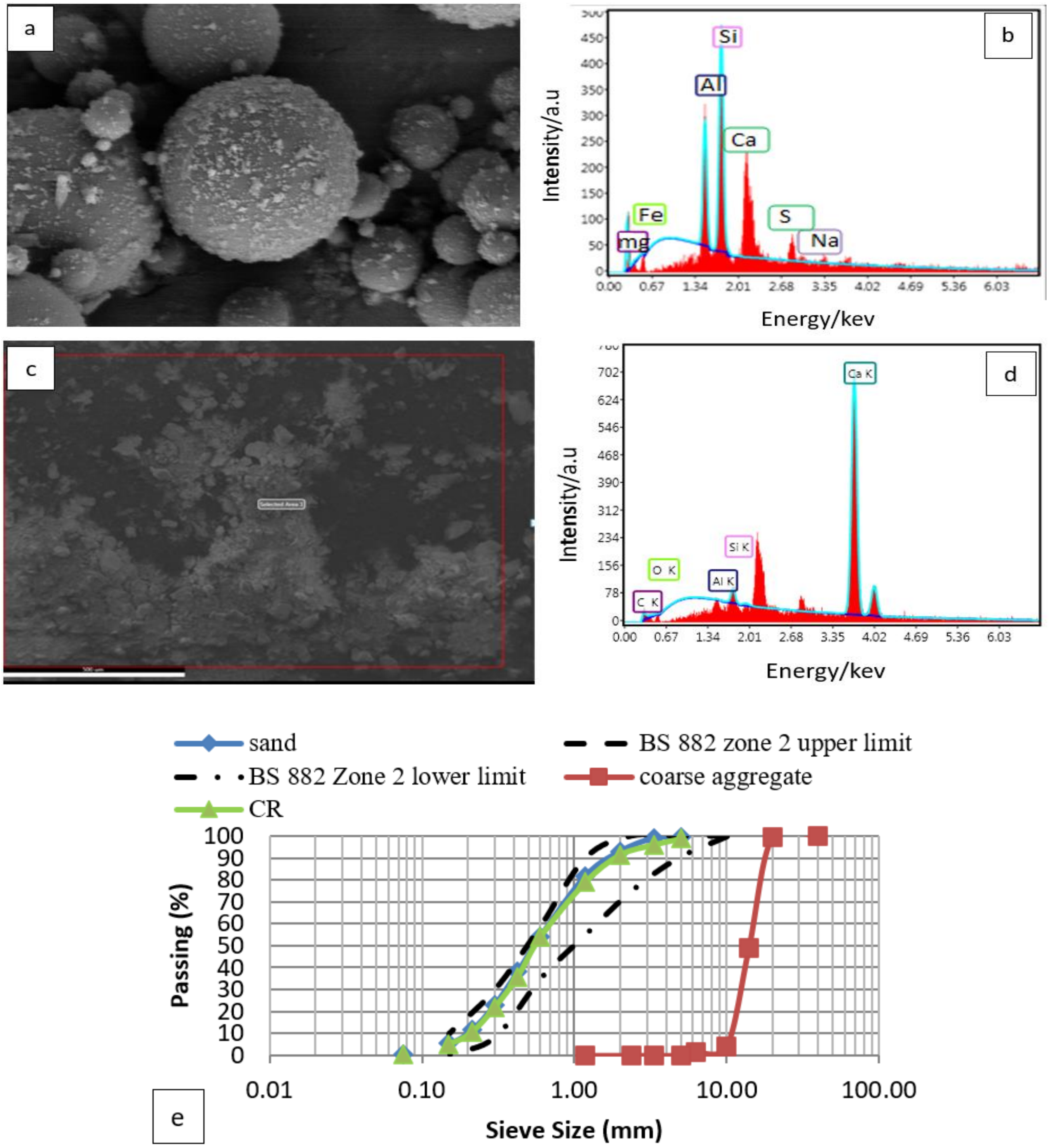


Figure 5. Characterization of fly ash, (a) SEM image of fly ash, (b) EDX image of fly ash, (c)SEM image of CCW, (d) EDX image of CCW, and (e) Particle size investigation of aggregates

4. SUMMARY OF PREVIOUS RESEARCH STUDY AND RESEARCH GAP ANALYSIS

The summary of the literature review is presented in Table 5. It reiterates the previous findings on the utilisation of Fly ash and calcium carbide waste as cement replacements in concrete. Also, the adequacy of crumb rubber utilisation as a substitute to fine aggregate was confirmed from the previous research.

From the summary analysis from Table 5, the need to discuss the various design method is significant, as shown in Section 5.

Table 5. Summary analysis of various work on the development of SCC utilising waste product

Authors	Study	Findings	Research Gaps
Hilal [95]	(a) Studied the effect of various CR sieve sizes on the Hardened properties of SCC. (b) Varied sieve no 18, 5 and mixture of the two sizes of CR each at 5, 10, 15, 20, and 25% using constant water to binder ratio of 0.35. (c) The research was conducted to ascertain the effect of various sieve sizes of CR on the hardened properties of SCC.	(a) All the hardened strength properties are reduced with increased CR variation and size. (b) Coarse CR usage decreases the strength properties of SCC more compared to fine CR.	(a) The research could not investigate the strength at an early age. It only studied the 90days strength because of low strength gain at early ages when fly ash is utilised in SCC. CCW is incorporated in this research to bridge this gap and enhance early strength development.
Kumar et al., [96]	(a) Reviewed the effects of utilisation of various industrial rejects (waste)on the strength properties of SCC.	(a) Using industrial wastes such as Fly ash, nano, micro silica, foundry sand, recycled waste aggregate, and waste fibres resulted in a sustainable, greener SCC with enhanced properties.	The review only considered the utilisation of FA and never CCW and CR in SCC, so this research tends to investigate their effect to bridge the gap.
Mandal et al. [97]	Reviewed various literature to validate the suitability of Ground Granulated Blast Furnace Slag (GGBFS) and fly ash for use in geopolymer concrete.	Low fly ash and increasing GGBFS enhanced the increase in the strength of concrete.	This research was basically on geopolymer concrete rather than on SCC.
Rout et al. [98]	(a) Studied the performance of roller-compacted concrete pavement containing CR and nano-silica (NS). (b)Varied CR (0, 10, 20, and 30%) and NS (0, 1, 2, 3) at four levels.	(a) The ideal mix was produced by replacing 10% of the volume of fine aggregate with CR and adding 1.13% more NS by weight of cementitious components. (b) A 10% substitution enhanced compressive strength and durability against abrasion. With a 20% substitution of fine particles with CR, the flexible capacity of the RCR also rose.	(a) Though RSM was used to design and model the experiment, and CR and NS were varied at four levels and modelled using RSM, the research was conducted on Conventional concrete, not SCC. Moreover, NS enhanced the strength instead of CCW and FA.
Bušić et al. [99]	The study checked on a few papers to discover the new and solidified properties of SCC containing CR substitution of the fine and coarse total.	(a) To maintain satisfactory SCC new properties, total supplanting with CR should be at most 20%. (b) For CR substitution SSC to be used in a few primary applications, the substitution level should be resolved sanely. (c) To ensure good strength properties of SCC, Fine CR is more suitable than coarse CR replacement of aggregate.	None of the papers reviewed so far has a combination of CR, CCW, and FA. Hence it is relevant to examine the effect of these three components in an SCC concrete mix.
Shi et al. [100]	Concentrated on the impact of CCW on mortar's new and solidified properties.	(a) Addition of 5% CCW by weight of cement reduced the mortar's initial and final setting time. (b) increase in CCW improves the workability of the mortar. (c) Increase in compressive and flexural strength on the increase of CCW up to 2% but decreased beyond 2% CCW by weight of cement content.	Though the effect of CCW on the properties was studied, the research was based on a mortar and not SCC.
Saleh et al. [101]	Explored the impact of the use of CCW and FA on setting time, compressive strength, porosity, ultrasonic heartbeat speed (UPV), and penetrability of geopolymer concrete	(a) Addition of 100% mix reduced the porosity of the geopolymer. (b) The greater the amount of FA utilised, the higher the compressive strength. (c) The lower the waste carbide utilised, the higher the compressive strength. (d) The highest yield of UPV was achieved at 100% FA and 50% CCW composition. (e) Composition with 100% FA and	The effect of FA and CCW was studied, but it was on geopolymer, not SCC.

Authors	Study	Findings	Research Gaps
Chen et al. [102]	(a) Utilized 10% rice husk ash (RHA) as an additive to cement and varied CCW at 0, 5, 10, 15, and 20% replacement. (b) Inspected the new and solidified properties of the SCC blend.	50% CCW yields the most negligible permeability (a) Addition of CCW reduces the workability of SCC. (b) Maximum compressive strength more significant than the control mix was obtained at 10% RHA and 0% CCW replacement. (c) Other mechanical properties decreased with increased RHA and CCW content.	Although RSM was used to design and model the experiment, and CCW was utilised in the SCC production, CR was not incorporated into the mix. RHA was used for 0% control mix and at only 10%, but for this study, FA is replaced at five levels which will help to dictate the effect of FA at various % variations.
Bakhoum et al. [103]	Studied the effect of cement replacement with Fly ash in high volumes of 40, 50, and 60% on the compressive strength of concrete.	Grade 40 concrete can be achieved when HVFA is incorporated into concrete	Conventional concrete was produced in the research, whereas for this current research, SCC is studied.
Vijay et al. [104]	Investigated the properties of substantial asphalt when concrete is supplanted with an HVFA of half of 100%.	(a) The optimum superplasticiser dosage for HVFA concrete is 1.25% of the total cementitious material for improved workability. (b) Flexural strength of the concrete pavement at 90 days increased by 6.27% compared to the control sample at 28 days. (c) HVFA are more economical and will be particularly beneficial when the gain in early strength is not paramount in pavement construction.	Although HVFA was implemented for the research, it was tested at only 50% replacement, but for this study, it will be varied at five levels of 20, 40, 60, and 80%. Also, the properties of SCC are studied and not concrete pavement.
El Marzak et al. [105]	Study the workability, original mechanical and dynamic possessions of rubber-modified SCC.	The result shows that the test samples' slump passing and filling abilities were lower than average SCCs, but the dynamic properties were improved.	The microstructure of the failure mode was not determined, and the responses were not optimised.
Bieszczad et al. [106]	Replaced 15% volume of gravel with waste tyre particles.	The compressive strength of the aggregate was reduced by roughly 49.8% compared to standard concrete due to the inclusion of rubber.	However, nothing was added to the mix to reduce the drastic decrease in.
Meyyappan et al. [107]	Waste tire rubber was used to substitute a portion of the fine gravel at volume ratios of 5% to 20% interval.	The result shows that the sample significantly increased the anti-sulfate corrosion, and 5% had increased compressive strength at 91 days.	However, the concrete's fresh properties and early strength were not studied.

5. DESIGN METHODS FOR SCC

There is no standard method for designing SCC mixes. Many academic institutions and contractors developed their mix ratio methods. SCC was first developed in Japan [108]. Various design approaches have been taken in other countries to optimise it. First, super-plasticizer and cement are the most expensive components. Studies often focus on reducing paste content. The aggregate skeleton can be optimised for high fill densities [109]. Reducing the coarse aggregate content, reducing the maximum aggregate size, and adding round aggregate instead of crushed aggregate are common concepts for optimising a granular skeleton. Second, the cement has been replaced by adding water and viscosity agents and fillers. Third, adding entrapped air increases the content of the paste. Fourth, manufacturing and designing concrete elements offers the possibility of further optimisation [110]. Various method of designing SCC is discussed as follows:

5.1 Japanese design method

The Japanese design method is relatively labour-intensive. Still, it provides a basic interpretation of the relations of SCC components [111]. The method is to adjust the SCC at three different levels.

i. Executing paste investigates,
ii. Optimising the mortar phase, and
iii. Finally, adjust the SCC to the concrete level.

Ozawa et al. [112] used this method to perform an initial mix test with a coarse aggregate content of 45% by volume and an acceptable aggregate content of 55% by volume of concrete mortar using a Japanese mixed design method. These mixtures were cast with a super-plasticiser content of 1% to 2% of the cement content.

5.2 Mix design approach by the European guidelines for SCC

Laboratory studies are necessary for this design strategy to confirm that the initial mixed composition's characteristics match the desired characteristics and classifications. The blended composition should be modified as needed [113]. The mix should be tested at full scale in a concrete factory and, if required, on-site to guarantee fresh and hardened qualities after all requirements have been met. The methodology outlined here serves as the foundation for mixed design.

i. Evaluate the water need and improve the paste's flow and stability.
ii. Calculate the amount of sand to add to the mixture and the ratio needed to achieve the desired toughness.
iii. Test your sensitivity to minute changes in the amount. (robustness).
iv. Include the correct quantity of coarse aggregate.
v. Produce a fresh SCC in the lab mixer and perform the required tests.
vi. Examine the cured SCC's characteristics.
vii. Use the plant mixer to make a trail mix.

5.3 Mix design according to BS EN 206:2013

While planning a blend, it is more helpful to consider the general extent of critical parts by volume instead of mass. More changes are expected to meet strength and other execution prerequisites [114]. Below is the typical range of ratios and quantities to obtain self-compaction.

i. It is more helpful to think about the relative proportions of important components by volume rather than mass when creating a mix. More adjustments are required to achieve strength and other performance standards [114]. The typical range of ratios and amounts to achieve self-compaction is shown below.
ii. A volume ratio of 0.80 to 1.10 for water to powder.
iii. Per cubic meter, 160–240 litres (400–600 kg) of total particle composition.
iv. The mix's typical coarse aggregate percentage ranges from 28% to 35% by volume.
v. The specifications of EN 206 are used to determine the water-to-cement ratio. The water content is typically no more than 200 litres per square meter.
vi. The amount of sand balances the volume of other ingredients.

Generally, it is advisable to design the concrete conservatively to maintain the specified excellent properties, despite the expected variation in raw material quality [115]. Some fluctuations are expected in the aggregate's water content, which is acceptable at the mixed design stage. Viscosity-modifying admixtures are often helpful to compensate for fluctuations in sand grade and added water content. Laboratory tests should be used to verify the properties of the initial mix composition. If necessary, the mixed composition should be adjusted. Once all requirements are met, the mix must be tested full-scale in a concrete plant or field. You should consider a fundamental mix redesign if you are not getting enough performance.

5.4 Mix design by EFNARC (2002)

The following is an example of the steps to design an SCC mix efficiently. It is based on the method developed by Okamura [112]. The classification is determined as follows:

i. Description of the required air content (mainly 2%)
ii. Purpose of the amount of coarse aggregate
iii. Fortitude of sand content
iv. Paste composition design
v. Determination of optimal water proportion and super-plasticiser powder dosage in the concrete.
vi. Finally, the properties of the concrete are evaluated by standard tests.

However, the acceptance criteria for SCC are presented in section 6 of this study.

6. COMPOSITION OF RUBBER TIRE AND CLASSIFICATION OF RUBBER AGGREGATES

Flexible/elastomers, Carbon gloomy, Metal, Material, Zinc Oxide, Sulfur, Added Substances, and Carbon-based Substances are only a few materials used to make elastic tires. Rubber aggregate can be obtained in many forms and sizes, as shown in Figure 6.

a. Tire chips or shredded rubber from tires are typically utilised as coarse material and have been partially supplanted by natural gravel. The image is as it is displayed in subgraph (a) of Figure 6 [116].
b. Aggregate made of crumb rubber: The size of crumb rubber is typically between 4.75 and 0.425 mm. As indicated in subgraph (b) of Figure 6 [117], it was utilised by most researchers as a fine aggregate or partial replacement for natural sand.
c. Tire rubber that is in the granular form: This rubber aggregate goes through a 0.425 mm sieve. It was used by several researchers in the SCC mixture and is shown in subgraph (c) of Figure 6 [118].
d. Fibre rubber collates: As shown in Figure 6, some researchers employed strips of shredded rubber that were 68 mm long and ranged in length from 8.5 to 21.5 mm on average [119-121].

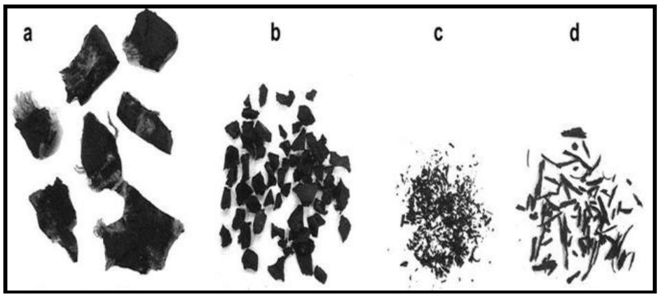


Figure 6. Categories of rubber combination: (a) chiselled rubber, (b) morsel rubber, (c) coarse rubber, (d) fibre

Kelechi et al. [122] In this work, the durability characteristics of SCC with CR changed with fly ash and CCW are examined. Water absorption, acid attack, salt resistance, and increased mix temperatures are considered while determining durability. The mixtures with no-fly ash content and their replica mixtures with fly ash replacing 40% of the cement were used in the experiment. In the mixes, CCW was used as a partial substitute for cement at 0%, 5%, and 10% by volume, and CR was used to partially replace fine aggregate in proportions of 0%, 10%, and 20% by volume. The findings show that mixes with fly ash exhibited stronger resistance to salt ($MgSO_4$) and acid (H_2SO_4), with up to 23% more resistance than mixes without fly ash, as shown in subgraphs (a) and (b) of Figure 7.

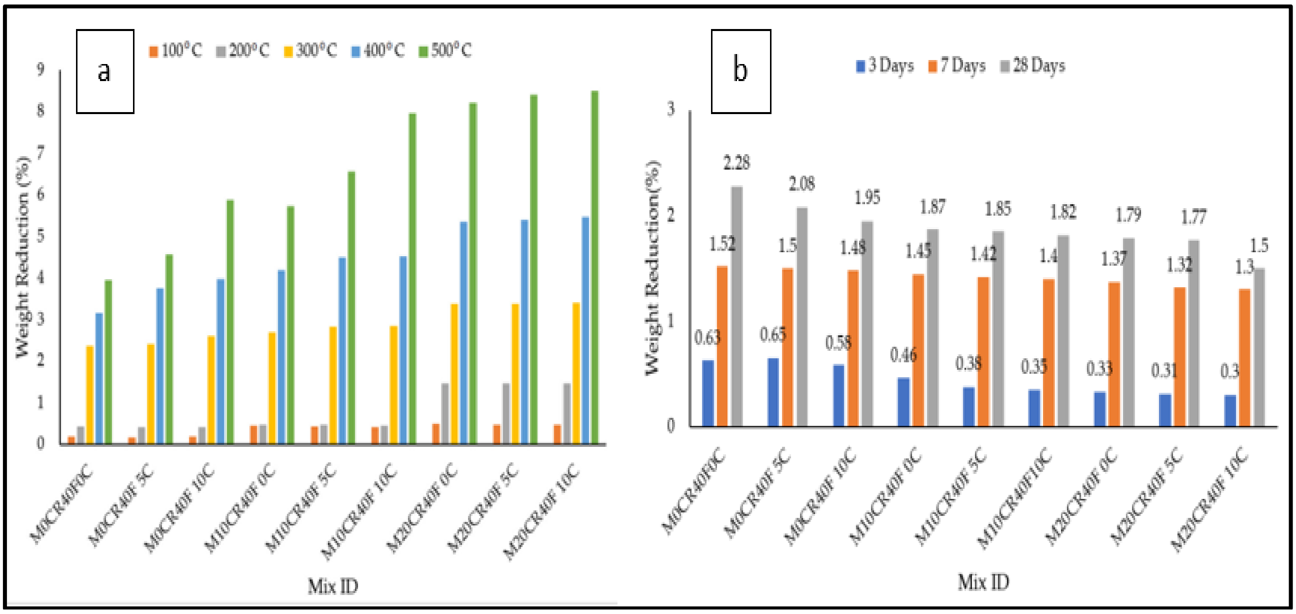


Figure 7. (a) Impact of high temperature on the weight and (b) the Absorption periods in MgSO4 for SCC combinations comprising fly ash, CR, and CCW [122]

7. CHALLENGES AND BENEFITS OF IMPLEMENTING FA, CR, AND CCW FOR THE DEVELOPMENT OF SCC

The application of CCW increases the temperature rise, higher internal stresses, oxidation of exposed reinforcement, reduced ability to withstand freeze/thaw, and an upsurge in the sulfuric acid attack. And a rise in the rate of drying shrinkage from 10 to 50 % can all be a consequence of the characteristics of self-compacting rubber-concrete [123]. Also, Poor-quality fly ash can make the concrete more susceptible to water and harm the structure. The outcome revealed that the weight of substantial volume dropped by 3% for every 10% addition of crumb rubber. With more crumb rubber quantity, the strength in compression and splitting also diminished. The disadvantages of the waste materials produced by expired tires, excess CCW and fly ash in the environment can further damage and affects the cultivable lands, contaminate water, courses air pollution, affect the waste management system, endanger lives and properties whereby cause a dearth of useful land, as presented in Figure 8.

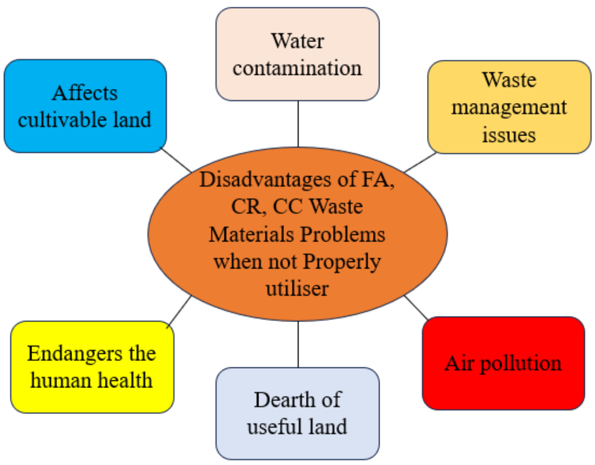


Figure 8. Disadvantage of excess waste materials if not used as a reinforcement or substitute for cement

Therefore, these disadvantages can be appropriately managed to obtain the benefit of utilising natural properties. Implementing it will guarantee that all of this industrial waste is consumed. Including calcium carbide waste changed the consistency of cement paste while reducing drying shrinkage and setting times [124]. It might be employed as an accelerator. The workability of concrete was also somewhat improved by CCW addition. The compressive strength of concrete was enhanced by adding up to 0.5% CCW. Applying the polyvinyl acetate enhancer increased compressive strength from 11 to 17% for various crumb rubber materials, with the 30% crumb rubber substitution yielding a maximum strength improvement of 17% [125]. Crumb rubber concrete has outstanding freeze-thaw features. Currently, the development of Self-Compacting Concrete involves substituting up to 50% of the cement with high-volume fly ash. A good slump flow of the SCC is made feasible by the considerable amount of fly ash. Figure 9 depicts the overview of the implementation of these waste materials in developing SCC.

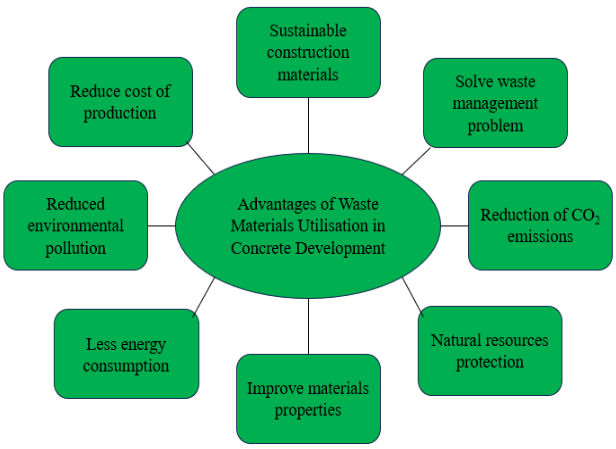


Figure 9. The benefit analysis of CR, FA, and CCW implementation

8. CONCLUSIONS

This study has successfully conducted a comprehensive review on developing self-compacting rubber concrete using calcium carbide waste and fly ash. Also, rubber tires are utilised in concrete in three different ways: as coarse aggregate replacements (rubber aggregates), as fine aggregate replacements (rubber crumbs), and as extremely tiny aggregate replacements (ground rubber). Concrete's characteristics are changed when rubber aggregates are added. From the review process, the following finding base on the study conducted has the conclusions drawn:

i. FA is a good pozzolana, and the fly ash sample obtained from Nigeria coal cooperation Enugu is classified as belonging to Class F.
ii. Calcium carbide waste is suitable for partial replacement for cement and cementitious materials in SCC.
iii. The consistency and initial and final cement setting times increased with FA and CCW content.
iv. SCC loses its fresh properties but has good segregation resistance as FA and CCW content increases.
v. Concrete's ductility, durability, damping ratio, impact resistance, and toughness can all be improved by adding rubber. However, it lessens the material's elastic modulus, tensile strength, and compressive strength.

9. RECOMMENDATIONS

Based on the study conducted, the following recommendations are made.

i. FA is recommended for use as pozzolana.
ii. FA is recommended for the partial replacement of cement in a temperate area where a binder of high consistency is required.
iii. FA is recommended to control segregation and bleeding in Self-Compacting Concrete.
iv. Up to 50% FA content is recommended to produce grade 40 HVFASCCCR containing CCW.
v. FA is recommended for use as a partial replacement of cement to improve the resistance of concrete in sulphate in sulphate-prone environments.
vi. Further research needs to be conducted on some of the beneficial properties of crumb rubber in concrete, such as Damping ratio, Fatigue performance.
vii. Long-term field performance of rubberised CCW-modified Self-Compacting Concrete with or without fly ash must be examined to examine the research experiment's findings. This can be executed by constructing a minor HVFASCCCRCCW building and examining its performance by subjecting it to usage over time.

REFERENCES

[1] Duan, Z., Lv, Z., Xiao, J., Liu, C., Nong, X. (2023). Study the performance of recycled coarse and fine aggregates as microbial carriers applied to self-healing concrete. Materials, 16(6): 2371. https://doi.org/10.3390/ma16062371

[2] Sangmesh, B., Patil, N., Jaiswal, K.K., Gowrishankar, T.P., Selvakumar, K.K., Jyothi, M.S., Jyothilakshmi, R., Kumar, S. (2023). Development of sustainable alternative materials for the construction of green buildings using agricultural residues: A review. Construction and Building Materials, 368: 130457. https://doi.org/10.1016/j.conbuildmat.2023.130457

[3] Kasyar, K., Nagapan. S., Abdullah, A., Ullah, K., Deraman, R., Yunus, R., Sohu, S. (2017). Cost implication analysis of concrete and masonry waste in construction project. Pertanika Journal Science and Technology, 25(S): 177-184.

[4] Wang, W., Shen, A., Lyu, Z., He, Z., Nguyen, K.T. (2021). Fresh and rheological characteristics of fiber reinforced concrete-A review. Construction and Building Materials, 296: 123734 https://doi.org/10.1016/j.conbuildmat.2021.123734

[5] Najim, K.B., Hall, M.R. (2017). Structural behaviour of steel-reinforced structural plain self-compacting rubberised concrete (PRC/SCRC). Journal of Construction and Building Materials, 73: 490-497. https://doi.org/10.1016/j.conbuildmat.2014.09.063

[6] Iqbal, H.W., Hamcumpai, K., Nuaklong, P., Jongvivatsakul, P., Likitlersuang, S., Chintanapakdee, C., Wijeyewickrema, A.C. (2023). Effect of graphene nanoplatelets on engineering properties of fly ash-based geopolymer concrete containing crumb rubber and its optimization using response surface methodology. Journal of Building Engineering, 75: 107024. https://doi.org/10.1016/j.jobe.2023.107024

[7] Sujay, H.M., Nair, N.A., Rao, H.S., Sairam, V. (2020). Experimental study on durability characteristics of composite fiber reinforced high-performance concrete incorporating nanosilica and ultra fine fly ash. Construction and Building Materials, 262: 120738. https://doi.org/10.1016/j.conbuildmat.2020.120738

[8] Bui, P.T., Hung, K.M., Huynh, T.P. (2023). Short-term performance of cement paste with high-volume fly ash: Effect of silica fume addition. Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2023.03.133

[9] Samarul, H., Anwar, H., Syed, A., Zishan, R. (2017). Analysis of cost (M30 grade) of concrete by partially replacing fly ash with cement and adding steel fibre. International Journal of Engineering Research and Management Studies.

[10] Sousa, V., Bogas, J.A., Real, S., Meireles, I., Carriço, A. (2023). Recycled cement production energy consumption optimisation. Sustainable Chemistry and Pharmacy, 32: 101010. https://doi.org/10.1016/j.scp.2023.101010

[11] Vinogradov, A., Merson, E., Myagkikh, P., Linderov, M., Brilevsky, A., Merson, D. (2023). Attaining high functional performance in biodegradable Mg-alloys: An overview of challenges and prospects for the Mg-Zn-Ca system. Materials, 16(3): 1324. https://doi.org/10.3390/ma16031324

[12] Natarajan, K.S. (2023). Gravimetric steel weight loss in Self-Compacting Concrete blended with wood ash and silica fume. Environmental Science and Pollution Research, 30(4): 9483-9495. https://doi.org/10.1007/s11356-022-22780-9

[13] Malazdrewicz, S., Ostrowski, K.A., Sadowski, Ł. (2023). Self-Compacting Concrete with recycled coarse aggregates from concrete construction and demolition waste–Current state-of-the-art perspectives. Construction and Building Materials, 370: 130702. https://doi.org/10.1016/j.conbuildmat.2023.130702

[14] Yu, Y., Yao, M. (2023). Is this pear sweeter than this apple? A universal SSC model for fruits with similar physicochemical properties. Biosystems Engineering, 226: 116-131. https://doi.org/10.1016/j.biosystemseng.2023.01.002

[15] Collepardi, M., Collepardi, S., Ogoumah, O., Troli, R. (2003). Laboratory- test and filed-experience SCCs. Proceedings of the third international symposium on Self-Compacting Concrete, Reykjavik, Iceland. pp. 904–912.

[16] Sonebi, M., Ibrahim, R. (2007). Assessment of the durability of medium strength SCC from its permeation properties. In 5th International RILEM Symposium on Self-Compacting Concrete, Ghent, Belgium, pp. 677-782.

[17] Holton, I. (2004). Self-Compacting Concrete, BRE Information Paper, Report IP 3/04. British Research Establishment, Watford, UK.

[18] Güneyisi, E., Gesoglu, M., Naji, N., İpek, S. (2016). Evaluation of the rheological behavior of fresh self-compacting rubberized concrete by using the Herschel-Bulkley and modified Bingham models. Archives of Civil and Mechanical Engineering, 16: 9-19. https://doi.org/10.1016/j.acme.2015.09.003

[19] Hossain, K.M.A., Lachemi, M., Sammour, M., Sonebi, M. (2013). Strength and fracture energy characteristics of self-consolidating concrete incorporating polyvinyl alcohol, steel, and hybrid fibres. Construction and Building Materials, 45: 20-29. https://doi.org/10.1016/j.conbuildmat.2013.03.054

[20] Awang, H., Atan, M.N., Abidin, N.Z., Yusof, N. (2016). Cost-reduction of Self-Compacting Concrete incorporating raw rice husk ash. Journal of Engineering Science and Technology, 11(1): 96-108.

[21] Kelechi, S.E., Adamu, M., Uche, O.A.U., Okokpujie, I.P., Ibrahim, Y.E., Obianyo, I.I. (2022). A comprehensive review on coal fly ash and its application in construction. Cogent Engineering, 9(1): 2114201. https://doi.org/10.1080/23311916.2022.2114201

[22] Nayak, D.K., Abhilash, P.P., Singh, R., Kumar, R., Kumar, V. (2022). Fly Ash for sustainable construction: A review of fly ash concrete and its beneficial use case studies. Cleaner Materials, 6: 100143. https://doi.org/10.1016/j.clema.2022.100143

[23] Mohammed, B.S., Adamu, M. (2018). Mechanical performance of roller-compacted concrete pavement containing crumb rubber and nano silica. Construction and Building Materials, 159: 234-251. https://doi.org/10.1016/j.conbuildmat.2017.10.098

[24] Lees, H., Järvik, O., Konist, A., Siirde, A., Maaten, B. (2022). Comparison of the ecotoxic properties of oil shale industry by-products to those of coal ash. Oil Shale, 39(1): 1-19. https://doi.org/10.3176/oil.2022.1.01

[25] Zhang, C., Fu, J.X., Song, W.D., Du, C.F., Fu, H.T. (2021). High-volume ultrafine fly ash-cement slurry mechanical properties and strength development model establishment. Construction and Building Materials, 277: 122350. https://doi.org/10.1016/j.conbuildmat.2021.122350

[26] Arrigoni, A., Panesar, D.K., Duhamel, M., Opher, T., Saxe, S., Posen, I.D., MacLean, H.L. (2020). Life cycle greenhouse gas emissions of concrete containing supplementary cementitious materials: Cut-off vs. substitution. Journal of Cleaner Production, 263: 121465. https://doi.org/10.1016/j.jclepro.2020.121465

[27] Baiee, A.T. (2018). Flexural strength and durability of reinforced concrete beams strengthened with high performance textile reinforced mortar. University of Brighton. https://ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.774357.

[28] Al-Feel, J.R., AlSaffar, N.S. (2009). Properties of Self-Compacting Concrete at different curing condition and their comparison with properties of normal concrete. Al-Rafidain Engineering Journal (AREJ), 17(3): 30-38.

[29] Reschner, K. (2016). Scrap Tire Recycling - A Summary of Prevalent Disposal and Recycling Methods. Berlim - Alemanha. Disponívelem: http://www.entire-engineering.de/accessed on 20 de agosto de 2016.

[30] Kou, S., Poon, C.S. (2009). Properties of Self-Compacting Concrete prepared with coarse and fine recycled concrete aggregates. Cement Concrete Composites, 31(9): 622-627. https://doi.org/10.1016/j.cemconcomp.2009.06.005

[31] Yung, W.H., Yung, L.C., Hua, L.H. (2013). A study of the durability properties of waste tire rubber applied to Self-Compacting Concrete. Construction and Building Materials, 41: 665-672. https://doi.org/10.1016/j.conbuildmat.2012.11.019

[32] Ravikumar, D., Peethamparan, S., Neithalath, N. (2010). Structure and strength of NaOH activated concretes containing fly ash or GGBFS as the sole binder. Cement and Concrete Composites, 32(6): 399-410. https://doi.org/10.1016/j.cemconcomp.2010.03.007

[33] Kelechi, S.E., Uche, O.A.U., Adamu, M., Alanazi, H., Okokpujie, I.P., Ibrahim, Y.E., Obianyo, I.I. (2022). Modelling and optimization of high-volume fly ash Self-Compacting Concrete containing crumb rubber and calcium carbide residue using response surface methodology. Arabian Journal for Science and Engineering, 47(10): 13467-13486. https://doi.org/10.1007/s13369-022-06850-1

[34] Adamu, M., Mohammed, B.S., Shafiq, N., Liew, M.S., Alaloul, W.S. (2018). Effect of crumb rubber and nano silica on the durability performance of High Volume Fly Ash roller compacted concrete pavement. International Journal of Advanced and Applied Sciences, 5(10): 53-61. https://doi.org/10.21833/ijaas.2018.10.008

[35] Wanasinghe, D., Aslani, F., Ma, G. (2022). Effect of carbon fibres on electromagnetic-interference-shielding properties of geopolymer composites. Polymers, 14(18): 3750. https://doi.org/10.3390/polym14183750

[36] Tajunnisa, Y., Sugimoto, M., Sato, T., Ekaputri, J.J., Shigeishi, M. (2016). Characterization of low calcium fly ash for geopolymer paste. Structural Faults and Repair.

[37] Swami, L. (2015). Uses of fly ash in construction industry. International Journal of Latest Trends in Engineering and Technology (IJLTET), 6(1).

[38] Wardhono, A. (2018). Comparison study of class F and class C fly ashes as cement replacement material on strength development of non-cement mortar. IOP Conference Series: Materials Science and Engineering, 288: 012019. https://doi.org/10.1088/1757-

899X/288/1/012019
[39] Panda, S., Panigrahi, R., Narshimam, M. (2019). A review on utilization of alkali activated flyash and ggbfs as green concrete. Adalya Journal, 8(7): 91-96.
[40] Colin, M. (2006). The Fundamentals of Explosion Welding: 6th Edition. Shangh Publishers. Delhi. India.
[41] Andrew, A. (2012). Carbide waste retains toxicity long term after disposal. Geosciences E-journals, 41(38).
[42] Basu, M., Pande, M., Bhadoria, P.B., Mahapatra. S.C. (2009). Potential fly ash utilization in Agriculture: A global review. Progress in Natural Science, 19(10): 1173-1186. https://doi.org/10.1016/j.pnsc.2008.12.006
[43] Bayuaji, R., Putri, N.S., Ming, L.Y., Mortar, N.A. (2020). Study of the utilization of carbide waste and fly ash on geopolymer paste. IOP Conference Series: Materials Science and Engineering, Lodz, Poland, pp. 012042. https://doi.org/10.1088/1757-899X/743/1/012042
[44] Tuleun, L.Z., Jimoh, A.A. (2018). Laboratory evaluation of the performance of calcium carbide waste (hydrate lime) in concrete. Webs Journal of Science and Engineering Application, 8(1): 494-502.
[45] Adamu, M., Olalekan, S.S., Aliyu, M.M. (2020). Optimizing the mechanical properties of pervious concrete containing calcium carbide and rice husk ash using response surface methodology. Journal of Soft Computing in Civil Engineering, 4(3): 106-123. https://doi.org/10.22115/scce.2020.229019.1216
[46] Yunusa, S.A. (2015). Investigation into the use of calcium carbide waste as a partial replacement of cement in concrete. International Journal of Engineering and Management, 5(2): 675-680.
[47] Tuleun, L.Z., Jimoh, A.A., John, W. (2019). Performance of rice husk ash-calcium carbide waste in concrete. Advanced Material Research, 1155: 41-53. https://doi.org/10.4028/www.scientific.net/AMR.1155.41
[48] Haruna, S.I., Adamu, M. (2020). Effect of hybridization of calcium carbide waste and rice husk ash on the properties of Self-Compacting Concrete. Journal of Ceramics and Concrete Sciences, 5(3): 1-10.
[49] Manasseh, J. (2010). Effect of carbide waste on the properties of rice husk ash concrete. Global Journal of Engineering Research, 8(1&2): 57-65.
[50] Abdurra'uf, M.G., Ogork, E.N., Haruna, S.I. (2017). Effect of calcium carbide wastes as an admixture in mortar. Scholars Journal of Engineering and Technology (SJET), 5(11): 655-660.
[51] Adamu, M., Ayeni, K.O., Haruna, S.I., Mansour, Y.E.H.I., Haruna, S. (2021). Durability performance of pervious concrete containing rice husk ash and calcium carbide: A response surface methodology approach. Case Studies in Construction Materials, 14: e00547. https://doi.org/10.1016/j.cscm.2021.e00547
[52] Uche, O.A., Kelechi, S.E., Adamu, M., Ibrahim, Y.E., Alanazi, H., Okokpujie, I.P. (2022). Modelling and optimizing the durability performance of self consolidating concrete incorporating crumb rubber and calcium carbide residue using response surface methodology. Buildings, 12(4): 398. https://doi.org/10.3390/buildings12040398
[53] Ghorbani, S., Sharifi, S., Ghorbani, S., Tam, V.W., de Brito, J., Kurda, R. (2019). Effect of crushed concrete waste's maximum size as partial replacement of natural coarse aggregate on the mechanical and durability properties of concrete. Resources, Conservation and Recycling, 149: 664-673. https://doi.org/10.1016/j.resconrec.2019.06.030
[54] Júnior, N.S.A., Silva, G.A., Dias, C.M., Ribeiro, D.V. (2019). Concrete containing recycled aggregates: Estimated lifetime using chloride migration test. Construction and Building Materials, 222: 108-118. https://doi.org/10.1016/j.conbuildmat.2019.06.136
[55] Gora, A.M., Ogork, E.N., Haruna, S.I. (2017). Effect of calcium carbide waste as admixture in mortar. Scholars Journal of Engineering and Technology (SJEY) 5(11): 665-660. https://doi.org/10.21276/sjet.2017.5.11.8
[56] Morla, P., Gupta, R., Azarsa, P., Sharma, A. (2021). Corrosion evaluation of geopolymer concrete made with fly ash and bottom ash. Sustainability, 13(1): 398. https://doi.org/10.3390/su13010398
[57] Barreto, E.D.S., Stafanato, K.V., Marvila, M.T., de Azevedo, A.R.G., Ali, M., Pereira, R.M.L., Monteiro, S.N. (2021). Clay ceramic waste as pozzolan constituent in cement for structural concrete. Materials, 14(11): 2917. https://doi.org/10.3390/ma14112917
[58] Makaratat, N., Jaturapitakkul, C., Laosamathikul, T. (2010). Effects of calcium carbide residue–fly ash binder on mechanical properties of concrete. Journal of Materials in Civil Engineering, 22(11): 1164-1170. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000127
[59] Hassan, A.A., Lachemi, M., Hossain, K.M. (2012). Effect of metakaolin and silica fume on the durability of self-consolidating concrete. Cement and Concrete Composites, 34(6): 801-807.
[60] Song, H.W., Jang, J.C., Saraswathy, V., Byun, K.J. (2007). An estimation of the diffusivity of silica fume concrete. Building and Environment, 42(3): 1358-1367. https://doi.org/10.1016/j.buildenv.2005.11.019
[61] Lotfy, A., Karahan, O., Ozbay, E., Hossain, K.M., Lachemi, M. (2015). Effect of kaolin waste content on the properties of normal-weight concretes. Construction and Building Materials, 83: 102-107.
[62] Ugwu, O.O., Nwoji, C., Onyia, M., Gber, A., Tarzomon, T.T., Ogbo, E.H. (2018). Development of self compacting concrete using industrial waste as mineral and chemical additives. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), 15(5): 45-58. https://doi.org/10.9790/1684-1505034558
[63] Liang, G., Liu, T., Li, H., Wu, K. (2022). Shrinkage mitigation, strength enhancement and microstructure improvement of alkali-activated slag/fly ash binders by ultrafine waste concrete powder. Composites Part B: Engineering, 231: 109570. https://doi.org/10.1016/j.compositesb.2021.109570
[64] Karthiga, S., Devi, C.R., Ramasamy, N.G., Pavithra, C., Sudarsan, J.S., Nithiyanantham, S. (2020). Analysis on strength properties by replacement of cement with calcium carbide remains and ground granulated blast furnace slag. Chemistry Africa, 3: 1133-1139. https://doi.org/10.1007/s42250-020-00169-w
[65] Xing, X., Pei, J., Li, R., Tan, X. (2019). Effect and mechanism of calcium carbonate whisker on asphalt binder. Materials Research Express, 6(5): 055306. https://doi.org/10.1088/2053-1591/aafa2c
[66] Huang, W., Zhang, Y.Y., Ge, J.J., Fang, Z.P. (2023). Properties of cement-based material mixed with nano-SiO_2 and calcium carbonate whisker. Journal of Yangtze River Scientific Research Institute, 40(1): 171-175.

https://doi.org/10.11988/ckyyb.20210825
[67] Mohammed, A.D. (2020). Influence of silica-nano particles on properties of rice husk ash and calcium carbide waste binder based mortar. Doctoral dissertation, Department of Building, Federal University of Technology Minna.
[68] Zhang, Y., Zhang, S., Zhao, W., Jiang, X., Chen, Y., Hou, J., Wang, Y., Yan, Z., Zhu, H. (2023). Influence of multi-scale fiber on residual compressive properties of a novel rubberized concrete subjected to elevated temperatures. Journal of Building Engineering, 65: 105750. https://doi.org/10.1016/j.jobe.2022.105750
[69] Güneyisi, E., Gesoglu, M., Naji, N., İpek, S. (2016). Evaluation of the rheological behavior of fresh self-compacting rubberized concrete by using the Herschel-Bulkley and modified Bingham models. Archives of Civil and Mechanical Engineering, 16: 9-19. https://doi.org/10.1016/j.acme.2015.09.003
[70] Shao, R.Z., Wu, C.Q., Li, J., Liu, Z.X., Wu, P.T., Yang, Y.K. (2023). Mechanical behaviour and environmental benefit of eco-friendly steel fibre-reinforced dry UHPC incorporating high-volume fly ash and crumb rubber. Journal of Building Engineering, 65: 105747. https://doi.org/10.1016/j.jobe.2022.105747
[71] Ghedan, R.H., Hamza, D.M. (2011), Effect of rubber treatment on compressive strength and thermal conductivity of modified rubberized concrete. Journal of Engineering and Development, 15(4): 21-29.
[72] Lin, Q., Liu, Z., Sun, J., Yu, L. (2023). Comprehensive modification of emulsified asphalt on improving mechanical properties of crumb rubber concrete. Construction and Building Materials, 369: 130555. https://doi.org/10.1016/j.conbuildmat.2023.130555
[73] Qaidi, S.M., Dinkha, Y.Z., Haido, J.H., Ali, M.H., Tayeh, B.A. (2021). Engineering properties of sustainable green concrete incorporating eco-friendly aggregate of crumb rubber: A review. Journal of Cleaner Production, 324: 129251. https://doi.org/10.1016/j.jclepro.2021.129251
[74] Khalil, E., Abd-Elmohsen, M., Anwar, A.M. (2015). Impact resistance of rubberized Self-Compacting Concrete. Water Science, 29(1): 45-53. https://doi.org/10.1016/j.wsj.2014.12.002
[75] Kılıç, A., Atiş, C.D., Teymen, A., Karahan, O., Özcan, F., Bilim, C., Özdemir, M. (2008). The influence of aggregate type on the strength and abrasion resistance of high strength concrete. Cement and Concrete Composites, 30(4): 290-296. https://doi.org/10.1016/j.cemconcomp.2007.05.011
[76] Karahan, O., Özbay, E., Hossain, K., Lachemi, M., Atiş, C.D. (2012). Fresh, mechanical, transport, and durability properties of self-consolidating rubberized concrete. ACI Materials Journal, 109(4).
[77] Reschner, K. (2016). Scrap tire recycling - a summary of prevalent disposal and recycling methods. Entire-Engineering, 1: 115-240.
[78] Rahim, N.I., Mohammed, B.S., Abdulkadir, I., Dahim, M. (2022). Effect of crumb rubber, fly ash, and nanosilica on the properties of Self-Compacting Concrete using response surface methodology. Materials, 15(4): 1501. https://doi.org/10.3390/ma15041501
[79] Chen, J., Zhuang, J., Shen, S., Dong, S. (2022). Experimental investigation on the impact resistance of rubber Self-Compacting Concrete. Structures, 39: 691-704. https://doi.org/10.1016/j.istruc.2022.03.057
[80] da Silva, F.M., Barbosa, L.A.G., Lintz, R.C.C., Jacintho, A.E.P. (2015). Investigation on the properties of concrete tactile paving blocks made with recycled tire rubber. Construction and Building Materials, 91: 71-79. https://doi.org/10.1016/j.conbuildmat.2015.05.027
[81] Angelin, A.F., Andrade, M.F., Bonatti, R., Lintz, R.C.C., Gachet-Barbosa, L.A., Osório, W.R. (2015). Effects of spheroid and fiber-like waste-tire rubbers on interrelation of strength-to-porosity in rubberized cement and mortars. Construction and Building Materials, 95: 525-536. https://doi.org/10.1016/j.conbuildmat.2015.07.166
[82] Swaminathan, P., Karthikeyan, K., Subbaram, S.R., Sudharsan, J.S., Abid, S.R., Murali, G., Vatin, N.I. (2022). Experimental and statistical investigation to evaluate impact strength variability and reliability of preplaced aggregate concrete containing crumped rubber and fibres. Materials, 15(15): 5156. https://doi.org/10.3390/ma15155156
[83] Valizadeh, A., Hamidi, F., Aslani, F., Shaikh, F.U.A. (2020). The effect of specimen geometry on the compressive and tensile strengths of self-compacting rubberised concrete containing waste rubber granules. Structures, 27: 1646-1659. https://doi.org/10.1016/j.istruc.2020.07.069
[84] Bignozzi, M.C., Sandrolini, F. (2006). Tyre rubber waste recycling in Self-Compacting Concrete. Cement and Concrete Research, 36(4): 735-739. https://doi.org/10.1016/j.cemconres.2005.12.011
[85] Amran, M., Onaizi, A.M., Fediuk, R., Vatin, N.I., Muhammad Rashid, R.S., Abdelgader, H., Ozbakkaloglu, T. (2022). Self-healing concrete as a prospective construction material: A review. Materials, 15(9): 3214. https://doi.org/10.3390/ma15093214
[86] Topçu, İ.B., Bilir, T. (2009). Experimental investigation of some fresh and hardened properties of rubberized Self-Compacting Concrete. Materials & Design, 30(8): 3056-3065. https://doi.org/10.1016/j.matdes.2008.12.011
[87] Uygunoğlu, T., Topçu, I.B. (2010). The role of scrap rubber particles on the drying shrinkage and mechanical properties of self-consolidating mortars. Construction and Building Materials, 24(7): 1141-1150. https://doi.org/10.1016/j.conbuildmat.2009.12.027
[88] Ganesan, N., Raj, J.B., Shashikala, A.P. (2013). Flexural fatigue behavior of self compacting rubberized concrete. Construction and Building Materials, 44: 7-14. https://doi.org/10.1016/j.conbuildmat.2013.02.077
[89] Güneyisi, E., Gesoğlu, M., Algın, Z., Mermerdaş, K. (2014). Optimization of concrete mixture with hybrid blends of metakaolin and fly ash using response surface method. Composites Part B: Engineering, 60: 707-715. https://doi.org/10.1016/j.compositesb.2014.01.017
[90] Rahman, M.M., Usman, M., Al-Ghalib, A.A. (2012). Fundamental properties of Rubber Modified Self-Compacting Concrete (RMSCC). Construction and Building Materials, 36: 630-637. https://doi.org/10.1016/j.conbuildmat.2012.04.116
[91] Topçu, I.B., Bilir, T., Uygunoğlu, T. (2009). Effect of waste marble dust content as filler on properties of s Self-Compacting Concrete. Construction and building Materials, 23(5): 1947-1953. https://doi.org/10.1016/j.conbuildmat.2008.09.007
[92] Gesoğlu, M., Güneyisi, E. (2011). Permeability properties of self-compacting rubberized concretes. Construction and building materials, 25(8): 3319-3326.

https://doi.org/10.1016/j.conbuildmat.2011.03.021
[93] Yakhlaf, M. (2013). Development of carbon fiber reinforced self-consolidating concrete patch for repair applications. Master's thesis, University of Waterloo. http://hdl.handle.net/10012/7479.
[94] Wang, W.C., Wang, H.Y., Lo, M.H. (2015). The fresh and engineering properties of alkali activated slag as a function of fly ash replacement and alkali concentration. Construction and Building Materials, 84: 224-229. https://doi.org/10.1016/j.conbuildmat.2014.09.059
[95] Hilal, N.N. (2017). Hardened properties of Self-Compacting Concrete with different crumb rubber size and content. International Journal of Sustainable Built Environment, 6(1): 191-206. https://doi.org/10.1016/j.ijsbe.2017.03.001
[96] Kumar, K.R., Shyamala, G., Awoyera, P.O., Vedhasakthi, K., Olalusi, O.B. (2021). Cleaner production of Self-Compacting Concrete with selected industrial rejects-an overview. Silicon, 13: 2809-2820. https://doi.org/10.1007/s12633-020-00636-6
[97] Mandal, R., Panda, S.K., Nayak, S., Chakraborty, S. (2022). Efficacy of pond ash (PA) combined with ground granulated blast furnace slag (GGBFS) in producing cement-less mortar. Structures, 45: 748-757. https://doi.org/10.1016/j.istruc.2022.09.060
[98] Rout, M.D., Sahdeo, S.K., Biswas, S., Roy, K., Sinha, A.K. (2023). feasibility study of reclaimed asphalt pavements (RAP) as recycled aggregates used in rigid pavement construction. Materials, 16(4): 1504. https://doi.org/10.3390/ma16041504
[99] Bušić, R., Miličević, I., Šipoš, T.K., Strukar, K. (2018). Recycled rubber as an aggregate replacement in Self-Compacting Concrete—literature overview. Materials, 11(9): 1729. https://doi.org/10.3390/ma11091729
[100] Shi, Y.X., Zhao, Q.X., Xue, C.H., Jia, Y.L., Guo, W.C., Zhang, Y.Y., Qiu, Y.X. (2023). Preparation and curing method of red mud-calcium carbide slag synergistically activated fly ash-ground granulated blast furnace slag based eco-friendly geopolymer. Cement and Concrete Composites, 139: 104999. https://doi.org/10.1016/j.cemconcomp.2023.104999
[101] Saleh, S., Mahmood, A.H., Hamed, E., Zhao, X.L. (2023). The mechanical, transport and chloride binding characteristics of ultra-high-performance concrete utilising seawater, sea sand and SCMs. Construction and Building Materials, 372: 130815. https://doi.org/10.1016/j.conbuildmat.2023.130815
[102] Chen, R., Congress, S.S.C., Cai, G., Zhou, R., Xu, J., Duan, W., Liu, S. (2023). Evaluating the effect of active ions on the early performance of soft clay solidified by modified biomass waste-rice husk ash. Acta Geotechnica, 18(2): 1039-1056. https://doi.org/10.1007/s11440-022-01630-5
[103] Bakhoum, E.S., Amir, A., Osama, F., Adel, M. (2023). Prediction model for the compressive strength of green concrete using cement kiln dust and fly ash. Scientific Reports, 13(1): 1864. https://doi.org/10.1038/s41598-023-28868-7
[104] Vijay, K., Prathipati, S.T., Sagar, T.S., Paluri, Y. (2023). Evaluating the effect of steel fibers on the mechanical performance of high-volume fly ash concrete. IOP Conference Series: Earth and Environmental Science, 1130(1): 012018. https://doi.org/10.1088/1755-1315/1130/1/012018
[105] El Marzak, M., Serroukh, H.K., Benaicha, M., Zhu, J., Alaoui, A.H., Burtschell, Y. (2023). Rubber aggregates' effect on the rheological and mechanical behavior of Self-Compacting Concrete. Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2023.03.146
[106] Bieszczad, A., Popardowski, E., Lubińska, W., Gliniak, M., Nawalany, G., Sokołowski, P. (2023). Possibility of using waste materials as substitutes for gravel or water in concrete mix. Materials, 16(5): 1810. https://doi.org/10.3390/ma16051810
[107] Meyyappan, P.L., Selvasofia, S.A., Asmitha, M., Praveena, S.J., Simika, P. (2023). Experimental studies on partial replacement of crumb rubber as a fine aggregate in M30 grade concrete. Materials Today: Proceedings, 74: 985-992. https://doi.org/10.1016/j.matpr.2022.11.350
[108] Islam, M.T., Chadee, D., Polonsky, M.J. (2023). How and when does relational governance impact lead-time performance of developing-country suppliers in global value chains? Supply Chain Management: An International Journal, 28(1): 179-192. https://doi.org/10.1108/SCM-05-2021-0255
[109] Farouk, A.M., Rahman, R.A., Romali, N.S. (2023). Economic analysis of rehabilitation approaches for water distribution networks: Comparative study between Egypt and Malaysia. Journal of Engineering, Design and Technology, 21(1): 130-149. https://doi.org/10.1108/JEDT-03-2021-0174
[110] Roquier, G. (2023). Estimation of voids in a multi-sized mineral aggregate for asphalt mixture using the Theoretical Packing Density Model. Construction and Building Materials, 367: 130302. https://doi.org/10.1016/j.conbuildmat.2023.130302
[111] Minas, I.S., Anthony, B.M., Pieper, J.R., Sterle, D.G. (2023). Large-scale and accurate non-destructive visual to near infrared spectroscopy-based assessment of the effect of rootstock on peach fruit internal quality. European Journal of Agronomy, 143: 126706. https://doi.org/10.1016/j.eja.2022.126706
[112] Ozawa, K., Maekawa, K., Okamura, H. (1990). High performance concrete with high filling capacity. In Admixtures for Concrete-Improvement of Properties: Proceedings of the International RILEM Symposium, Barcelone. pp. 51-62.
[113] Qin, J.K., Pang, X.Y., Santra, A., Cheng, G.D., Li, H.L. (2023). Various admixtures to mitigate the long-term strength retrogression of Portland cement cured under high pressure and high temperature conditions. Journal of Rock Mechanics and Geotechnical Engineering, 15(1): 191-203. https://doi.org/10.1016/j.jrmge.2022.02.005
[114] Mansour, M.A., Ismail, M.H.B., Imran Latif, Q.B.A., Alshalif, A.F., Milad, A., Bargi, W.A.A. (2023). A systematic review of the concrete durability incorporating recycled glass. Sustainability, 15(4): 3568. https://doi.org/10.3390/su15043568
[115] Monte, F.L., Bamonte, P., Beltrami, C. (2023). Study on the effects of cooling phase and construction technology on the fire performance of R/C tunnels. Tunnelling and Underground Space Technology, 132: 104838. https://doi.org/10.1016/j.tust.2022.104838
[116] Ganjian, E., Khorami, M., Maghsoudi, A.A. (2009). Scrap-tyre-rubber replacement for aggregate and filler in

concrete. Construction and Building Materials, 23(5): 1828-1836. https://doi.org/10.1016/j.conbuildmat.2008.09.020
[117] Hernandez-Olivares, F., Barluenga, G., Bollati, M., Witoszek, B. (2002). Static and dynamic behaviour of recycled tyre rubber-filled concrete. Cement and Concrete Research, 32(10): 1587-1596. https://doi.org/10.1016/S0008-8846(02)00833-5
[118] Ling, T.C., Nor, H.M., Hainin, M.R., Chik, A.A. (2009). Laboratory performance of crumb rubber concrete block pavement. International Journal of Pavement Engineering, 10(5): 361-374. https://doi.org/10.1080/10298430802342740
[119] Huang, B., Li, G., Pang, S.S., Eggers, J. (2004). Investigation into waste tire rubber-filled concrete. Journal of Materials in Civil Engineering, 16(3): 187-194. https://doi.org/10.1061/(ASCE)0899-1561(2004)16:3(187)
[120] Emiroglu, M., Kelestemur, M.H., Yildiz, S. (2007). An investigation on ITZ microstructure of the concrete containing waste vehicle tire. In Proceedings of 8th International Fracture Conference, pp. 453-459.
[121] Mutalib, N.A.N.A., Mokhatar, S.N., Budiea, A.M.A., Jaini, Z.M., Kamarudin, A.F., Noh, M.M. (2021). A review: Study on waste rubber as construction material. IOP Conference Series: Materials Science and Engineering, 1144(1): 012003. https://doi.org/10.1088/1757-899X/1144/1/012003
[122] Kelechi, S.E., Adamu, M., Mohammed, A., Ibrahim, Y.E., Obianyo, I.I. (2022). Durability performance of Self-Compacting Concrete containing crumb rubber, fly ash and calcium carbide waste. Materials, 15(2): 488. https://doi.org/10.3390/ma15020488
[123] Yang, K., Long, G.C., Tang, Z., Wu, H., Ma, G., Cheng, Z.Q., Xiang, Y., Xie, Y.J. (2023). Enhancement in strength and toughness of ultra-high performance concrete (UHPC) from micron-and nano-scale. Journal of Building Engineering, 69: 106308. https://doi.org/10.1016/j.jobe.2023.106308
[124] Daiy, H., Najafi, Y., Ragheb, Z.D., Abedi, H.R. (2023). A review study on thermal stability of psowder-based additively manufactured alloys. Journal of Alloys and Compounds, 965: 171384. https://doi.org/10.1016/j.jallcom.2023.171384
[125] Günen, A., Gürol, U., Koçak, M., Çam, G. (2023). A new approach to improve some properties of wire arc additively manufactured stainless steel components: Simultaneous homogenization and boriding. Surface and Coatings Technology, 460: 129395. https://doi.org/10.1016/j.surfcoat.2023.129395