DEVELOPMENT OF ENVIRONMENT FRIENDLY CONCRETE USING LOCALLY AVAILABLE MATERIALS

Muhammad Hamid Saeed

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A thesis submitted in partial fulfillment of requirements for the degree of

Master of Science

In

Structural Engineering

NUST INSTITUTE OF CIVIL ENGINEERING (NICE)

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING (SCEE)

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2021

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0972/102/Exams/Thesis-Cert
Dated ____ August 2021

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DECLARATION

I certify that this research work titled **"Development of environment friendly concrete using locally available materials"** is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledge / referred.

Muhammad Hamid Saeed
NUST2017MSCSE00000206197

ACKNOWLEDGEMENTS

All praise to **ALLAH ALMIGHTY** who blessed me with talent and courage to accomplish this project, and who fetch me to this stage and helped me to come up with this effort. Indeed, I could have done nothing without your priceless help and guidance, so indeed none be worthy of praise but You.

I would like to express special thanks to my supervisor **Dr. HammadAnis Khan** for his help throughout my thesis. His important guidance, innovative suggestions and kind behavior were source of motivation during the whole study. I am grateful to **Dr. RaoArslanKhushnood, Dr. UsmanHanif**and **Dr. Azam**for their kind help and facilitation throughout the project. I would also like to thank all the laboratory staff and technicians for their help, support and cooperation.

I am greatly thankful to my family members and especially my father who always believed in me and provided me all the support during my studies. Also, I owe special thanks to my friend Irfan Ahmed who were always around at hard times and provided their unequivocal support throughout research, for which my mere expression of thanks likewise does not suffice. I would also like to pay thanks to my colleagues of structural engineering for their support and cooperation. Finally, I am thankful to all the individuals who have backed me and rendered valuable assistance to my study.

Muhammad Hamid Saeed

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List of Acronyms

SCBA	Sugarcane Bagasse Ash
RHA	Rice Husk Ash
LS	Limestone
SD	Stone dust
CO_2	Carbon dioxide
FA	Fine aggregate
CA	Coarse aggregate
VPV	Volume of permeable voids
OPC	Ordinary Portland cement
SEM	Scanning electron microscope
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

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Abstract

Concrete's ingredients, cement, coarse and fine aggregates, are consumed in large quantities due to the world's ever-increasing demand for it. This puts strain on the cement industry, while coarse and fine aggregate production is similarly strained, resulting in environmental degradation.Locally available waste materials , Rice husk ash (RHA), Sugar cane bagasse ash (SCBA) and Limestone Powder (LS) were used as a partial substitution of cement along with Stone Dust (SD) as a partial substitution of sand in this study. Effect of these dually replaced waste materials on fresh and hardened concrete were examined. Percentage substitution of RHA, SCBA and LS were kept as 0 ,10, 15 and 20% along with 0 ,25 and 50% SD substitution. Result indicated the decrease in workability due to dual substitution. Fresh density increased by incorporating LS along with SD . Compressive, Tensile and Flexural strengths enhanced in case of RHA and SCBA substitution along with SD. Water absorption and volume of permeable voids improved by incorporating SD with sand in mixes. Drying shrinkage occurred faster at the first phase of 7 days and slowed down later. These substitution showed an improved behavior of concrete towards environment and will result in the utilization of waste materials and will reduce the strain on quarry sites and will provide an alternate option.

CHAPTER 1

1. Introduction

1.1 Background

Construction industry is one of the largest industry of the modern era and concrete has become the backbone of the construction industry. Concrete is now only second to water as far as the consumption by humans around the world is concerned. The consumption of the concrete is almost two times higher compared to the combine usage of other building materials used in construction[1, 2].Concrete has a wide range of application due to its remarkable nature and properties i.e. architectural structures , roads and bridges etc. Moreover, it is a durable material, and can last for hundreds of years [3]

Due to ever growing needs of concrete in the world, it's ingredients cement, coarse and fine aggregates are consumed in large quantity. This puts pressure on cement production industry, whereas coarse and fine aggregates production is similarly strained causing environmental degradation.. A rough estimate of cement production is approximately 4 billion tons annually and the projected demands of aggregates is four times the demands of cement[4].

Natural aggregate used in the traditional concrete are being extracted in large amount due their high demand and have become a matter of serious concern as far as the environmental point of view is considered. The creation of quarries for aggregate expansion not only destroys the natural ecosystem but also the movement of ground water and surface discharge is also disrupted[5]. This results in the creation of unhealthy environment and erosion of rivers , loss of coastal land and lowering of water table. It is estimated that 47 to 59 billion tons of material is globally extracted every year, out of which construction aggregates hold the largest proportion of around 68 % to 85 % [6]. Moreover, the over extraction of aggregates from rivers has cost severe damage to the river basins [7] and also resulted in the increase of pollution levels and disturbed the pH level of water [8] The balance between the consumption and production of natural aggregate has been disturbed due to over extraction.In order to economize construction of concrete structure and also to tackle the over extraction of aggregate, stone dust which is obtained from quarry sites and crusher plants as a waste material can be used as an alternate and can replace fine aggregates i.e., sand in concrete[9]. The utilization of this waste material will not only reduce the strain on quarry sites but will provide an alternate option.Stone dust is well suited for strength and economy of medium-grade concrete over normal sand [3]. The stone dust can effectively replace 40% fine aggregates [4].

1.2 Environmental impacts of Concrete

Due to the growing demands of these construction materials such as cement, worldwide concrete industry is facing a challenge to devise new ways to meet this growing needs. Today, because of the large amounts of CO_2 emitted, the cement industry is under close scrutiny. In fact, this industry accounts for 5–7% of the total anthropogenic carbon emissions [1]. In recent years, concern about the impact on the global climate of the anthropogenic carbon emissions has increased because of the growing awareness on global warming. As well as producing CO_2, the cement production process produces millions of tonnes of waste products of cement kiln dust each year, which contributes to the respiratory health risks of pollution [2]. In terms of reducing CO_2 emission, the cement industry has made significant progress in improving processes and effectiveness; however, further improvements are limited because CO_2 production is inherent in the fundamental calcinating process.

1.3 Waste materials as potential cement replacement materials

Secondary cementitious materials such as, ground limestone (LS) powder, fly ash, Rice Husk Ash (RHA), Sugarcane Bagasse Ash (SCBA), silica fumes and many other mineral admixtureswere introduced as a replacement for cement in this construction industry[10-12]. The use of these materials not only reduce pressure on the cement industry but also contribute to cope up with environmental challenges of greenhouse gases and ozone layer depletion[13]. These materials being a waste product from industry also reduce the cost of concrete and reduces the strain on the landfills, a site for the dumping of waste material [12].

Rice husk ash, the by-product of rice production, is generated globally in vast amounts and owing to the difficulty associated with its disposal, can cause RHA in rice producing nations to become an environmental threat that might lead to contamination of air and water. Rice husk ash is a natural pozzolan, a substance with a cementing property when used in combination with lime [26]. RHA can be carbon-neutral, contain little or no crystalline SiO_2 components, or have no hazardous substances, such as off-white rice husk ash. This RHA from off-white has been proven to be mixed with white Portland cement to an advantage of 15 percent to improve concrete performance without losing the finished product's aesthetics, and even displays stronger compressive and splits bending power than a control sample [12].

Sugar producing industries generate energy by burning sugarcane bagasse as a fuel, but they also generate a large amount of waste material known as bagasse ash, which causes waste disposal issues and pollution when disposed of in an open field (landfill). Waste from the sugar sector and bagasse bio-mass that is combusted in controlled conditions gives the ash amorphous silica, tested in certain parts of the world for its pozzolanic properties and found in certain substitution percentage values to improve certain properties such as compressive strength and water tightness in the concrete [31].

In concrete mixtures, stone dust can be used as a suitable substitute for natural sand, providing greater strength at a 50% substitution [14]. Crushed stone dust was used as a fine aggregate in concrete, and it was observed that the compressive and flexural strength of the concrete was increased [15]. In one study, the substitution of the fine aggregate by stone dust by 40 percent was found to be adaptable [16]. It was noted that the substitution of natural sand for crusher dust increased by 5 - 22 percent the compressive strength of the concrete[17]. However, other mechanical and fresh properties were not compared and its effect on the microstructure were ignored .

Burning biomass, a renewable source of energy, leads to an ash disposal problem. Agricultural residual ashes produced due to biomass burning, depletes the atmosphere by producing particles, damages the air quality and posing severe health issues such as cardiovascular diseases[18, 19]. Pakistan was ranked fifth and tenth largest producer of sugarcane and rice cultivation respectively in 2018,generating 67.1 million tonnes of bagasse waste and 10.8 million tonnes of rice husk waste, respectively [20] 0.2 [21] and 0.26 [22] million tonnes of rice husk waste and bagasse waste, have been burnt in brick kilns and in sugar mills for the energy generation . In Asia, the tremendous volume of biomass is burned, with about 34 percent leading to open-air combustion is also dumped in the landfills[23].

This capacity to substitute a proportion of Portland cement with such agricultural waste product would not only decrease the building costs of concrete in developing nations like Pakistan but would also offer a way of disposing of this ash with little alternative use. In addition, cement manufacturing is an energy-intensive process and would also reduce the amount of energy associated with concrete building by incorporating RHA and SCBA into the concrete as a partial substitute for Portland cement in addition to reducing the cost of concrete construction and providing means to disposal of agricultural waste product.

The plentiful depletion of natural resources, high carbon footprint of the cement production andthe ecologically harmful effects of industrial waste ashes are few of the primary environmental issues which need to be sorted out[12, 24]. Theinclusion ofRHA and SCBA in concrete will alleviate the impacts of waste ash disposal on environmental conditions and has the capacity to satisfy the growing demand for cement in the production of concrete[25]. Therefore, the current study uses these waste materials as a replacement for cement to investigate its overall impact on the strength and the properties of the concrete.

1.4 Problem statement

1. Concrete industry results in the degradation of the environment and depletion of the natural resources
2. The use of cement results in CO_2 emissions and need alternative materials

1.5 Objectives

The objectives set for the current study includes:

1. To evaluate the impacts of dual replacement of cement and sand
2. To analyze the physical and mechanical behaviors of the concrete
3. To develop environment friendly and economical concreted based on suitable replacement of waste materials

CHAPTER 2

2. Literature review

2.1. Studies incorporating RHA as a partial replacement of cement

Several researchers have worked on RHA and its partial replacement withcement[26]. It was reported that after incorporation of RHA, the compressive strength of RHA-mixed cement mixingcreased by 15percent compared to the control[12]. A similar pattern was observed for compressive strength byadding up to 20% and 30% RHA in the concrete matrix. This rise in compressive strength was linked to the pozzolanic reaction and a strong silica reactivity in RHA. Optimal RHA substitution recommended was 30% [27]. Furthermore, RHA improved the efficiency of high-performance concrete (HPC) by enhancing the mechanical properties both at early age and after long year by just replacing 30% of cement with RHA[28] It has been documented that enhanced compressive, splitting tensile and flexural strength in early and long years with an enhancement of the pozzolanic RHA reaction when used as partial replacement of cement up to 30%. A recent research has shown that the use of lime in RHA concrete could enhance its compression strength by 45% if cement is substituted by RHA by 15% [29].

One study examined the use of RHA in high strength mass concrete to reduce temperature; the results show that RHA is very effective at reducing mass concrete temperature compared with OPC concrete[7].The RHAs with finer particle sizes than OPC were later reported to improve concrete properties such that increased substitution results in reduced water absorption and the addition of RHAs increases the compressive strength [8].

In one of the study, the authors indicated the decline in compression strength in higher percentages of the RHA substitution. However, the targeted compression force addition to RHA has been achieved in place of cement by 10 percent cement substitution with RHA not only enhanced its compressive strength, but also enhanced its durability in normal and conventional concrete[5].Bui etal.,[6] reported in a 2005 survey that RHA as a reactive pozzolan significantly contributes to microscopic construction optimization of the transition interfaces area in high-performance concrete between paste and aggregate surfaces."

It was also reported that untreated RHA can also be used as a partial cement replacement in concrete with different mixturescompositions[30]. Removal of grinding costs improves the feasible use of RHA in concrete manufacturing, decreases landfill costs and offers a smarter and sustainable environment approach for energy conservation, and reduces carbon dioxide footprint of concrete[12, 24]. Higher percentages of RHA replacement result in a reduction in compressive strength [29]. However, replacing 10% of the cement with RHA resulted in the desired compressive strength. Using RHA instead of cement improves not only compressive strength but also durability in normal or conventional concrete [29]. “RHA as a reactive pozzolan helps significantly to the optimization of microscopic building of the transition interface zone between paste and aggregate surface in high performance concretes,” according to a 2005 study by Bui, D et al., [10]. “Investigations on binary mixtures with RHA replacing cement were first offered by Mehta in America, and they concentrated on key elements that may impact the rice husk burning process and improve the end product. Ordinary Portland cement can be used in high-strength RHA concrete with High Performance Concrete (HPC) ranging from 70 to 80 MPa [56].

2.2. Studies incorporating SCBA as a partial replacement of cement

Pozzolans are siliceous or aluminous minerals that have little or no cementitious value on their own but may react chemically with calcium hydroxide in finely split form in the presence of moisture at room temperature to create cementitious compounds [33]. Because of its silica (SiO2) concentration, SCBA functions as a pozzolanic material when added to cement, reacting with free lime released during cement hydration to create extra calcium silicate hydrate (CSH) as a new hydration product [31]. The mechanical strength of the cement mortar and concrete is increased by this extra CSH.

Two main variables influence the Pozzolanic activity of bagasse ash:

- The quantity of calcium hydroxide available to respond to bagasse ash.
- The reaction rate at which this temperature-based combination occurs.

The calcium hydroxide accessible relies on the chemical characteristics of the bagasse ash, its active phase nature, its SiO_2 concentration in active pozzolana and the $Ca(OH)_2$-bagasse ash content in the combination.

The response speed depends on physical parameters such the bagasse ash surface, the solid-to-water ratio and temperature of the combination. In contact with water Amorphous silica solubilizes and interacts with Ca^{+2} ions to a solution alkaline creating a hydrated silica similar to those generated by cement hydration processes. The great number of pores with irregular and heterogeneous forms that contributed to the adsorbent surface area has been noticed [31]. This exceptionally rough pores with a surface showed that the substance supplies binding places for concrete.

Similarly, there were many studies that were carried out with SCBA as a partial replacement of cement. The adequacy of SCBA in self-compacting matrix as an agent of viscosity was also observed[31] The percentage of SCBA additives for the special self-compacting blend of concrete were selected as 35.63%. The strength value of more than 34 Mpa was reduced for this blended concrete[22]. Few researchers analyzed the impact on the physical and mechanical properties of hardened concrete having bagasse ash as a partial substitute for the cement[31] They observed that bagasse ash was an efficient mineral mix with an optimum cement substitution ratio of around 20 percent [32]

SCBA incorporation into the concrete can also increase the mechanical properties of concrete at specific substitution levels[32] minimizes heat of hydration[33, 34] enhance the durability of concrete[35-37], and enhance the interface between the cement matrix and the aggregate[38]. These studies have shown the feasible use of SCBA in concrete as a partial replacement material and the possible technical benefits of SCBA. The use of the SCBA in cement materials is also extremely important in terms of waste control, environmental preservation, cost reduction and conservation of natural resources.

The impact of substituting SCBA with concrete was examined by Dhengare et al. [21]. The findings demonstrated that the maximal strength was reached at the replacement level of 15 percent. The impact of partial cement substitution was examined by Nagpal and Saxena[36]. The results showed that adding SCBA increases concrete workability. SCBA finely powdered, for a greater compressive strength, can substitute cement successfully than standard concrete. The latter claimed that the water cement ratio (W/C) also depends on the particle size of the cement and found that the smaller the particle size is, the better the concrete may be worked.

At 0 per cent , 5 per cent, 15 per cent and 26 per cent, Srivastava et al. [37] investigated the effect of partially replacing concrete with SCBA. The latter found that SCBA can be substituted in concrete with a maximum of 10 percent limit. The mechanical and physical characteristics of concrete with a SCBA replacement ratio of 0 to 30 percent by weight of cement were examined by Prasanna et al. [38]. The authors concluded that with the rise in SCBAcontent, the compaction factor reduced. The results also indicated that the strength increased at 5% of the SCBA substitution for compressive strength. This value nevertheless fell when the SCBA content was more than 5%.

In the ratio of 0 percent to 5 percent, 10 percent 15 and 20 per cent by weight of cement, Rambabu et al.[34] investigated the effect of sulphates on concrete with partial cement replacement. The results indicated that compressive strength rose as the concentration of SCBA increased and sulphates attack was prevented. SCBA can be substituted at 6 percent, according to the authors results, which are optimal values.At the rate of 2.5%, 5.0%, 7.5%, 10%, and 12.50%, Lathamaheswari et al.[20] analyzed the effect of cement substitution with SCBA. They indicated that SCBA's workability was not influenced by an increase in compression strength, tension, flexure and modular elasticity in comparison to control concrete. They also concluded that SCBA may be substituted by 7.5%. Quedou et al. [39] replaced the SCBA with a continuous water cement ratio of 0.53 (5 percent), 10 percent and 15 percent with SCBA. They found that the optimal 10% SCBA substitute level may give the concrete samples a greater compressive strength.

Jhason etal. [40] examined bagasse ash to substitute for cement, with a ratio of 0% to 20%. The authors reported that the downfall values had declined when the SCBA percentage had been raised, with a maximum compressive strength and split tensile strength at a replacement of

10%.The usage of SCBA in pavement concrete as a partial replacement in a range of 0 to 60 percent was assessed by Chindaprasirt et al.[41]. The authors held that the concrete characteristics of the pavement were considerably impacted by big bagasse ash particles. They also mentioned that with increasing SCBA, the mechanical characteristics, the unit weight, thermal conductivity and the surface abrasion declined. In addition, sulphuric acid weight loss reduced with an increase in bagasse ash sugar cane. The authors also noted that an increased concentration of SCBA enhanced the porosity of the floor concrete, thereby enhancing the absorption of water.The authors brought out the mechanical and longevity characteristics of pavement concrete using 20-40% SCBA.

The raw SCBA was tried by Battool et al. [42] in concrete, replacing it with 5% to 30% ratios. The authors stated that adding SCBA enhanced workability and was regarded the best 10 percent substitute for achieving high compression, flexural strength and traction strength.The processing procedures utilized for producing processed(SCBA) were analyzed by Praveenkumar et al. [43] and its characteristics were assessed on concrete. Up to 30 percent of SCBA were utilized and its effects on the mechanical and durability of hard concrete were examined. They concluded that BA in the mix provided a greater indicator of force activity. In addition, with a further addition of bagasse ash, particular gravity, workability, and air content reduced. The drop was attributable to the effect of filling, the air content and the permeability coefficient.The addition of SCBA to the water demand was decreased up to 10 percent and the compression strength and flexibility of cement mortar improved due to its high specific surface area, excessive silica and calcium oxide met the major pozzolana material demands

2.3. Studies incorporating LS as a partial replacement of cement

Limestone powder (LS) is also one of the material that is also widely used as a partial replacement of the cement due its very low embedded CO_2 emissions, high availability on earth and less cost[39] A suitable limestone powder content can influence positive properties of concrete, such as filling, nucleation, chemistry and enhance operability[40]

It was found that the incorporation of limestone powder has a positive effect on workability and time of mixing[41-44]In comparison, limits or acceptable contents of limestone powder in cement have a significant variation depending on the various requirements such as 35% in European (EN 197-1: 2000), 15% in Canadian (CSA A3001: 2010), 25% in Chinese (JC/T 600: 2010) and 15% in American (ASTM C595: 2012) standards[40]. But the optimal amount of high-performance concrete limestone powder has not yet been identified. The purpose of this study is to investigates the optimum limestone powder replacement in cement and to compare all these secondary cementitious materials (RHA,SCBA and LS) with respect to each other.

Allahverdi and Salem[55] examined concurrent impacts on the essential characteristics of the fresh and hardened Portland cement paste, both micro silica and LS i.e., pozzolanic activity and plasticity. The relative workability, compression forces of 7 and 50 days, water absorption, volume of permeable pore space, bulk specific gravitational characteristics have been developed and investigated. The test results for 7 and 50 days of compressive strength have shown that the compressive strength reduces always partially by the substitution of cement with calcareous powder.From the water absorption data, they found that the water absorption of the investigated hardening cement pastes increased asLScontent increased.

Ahmed and Mohammed [6] explore the impact of LS on compression strength and tensile strength as a compensatory material with cement and discuss the effect of high temperatures on such cement. The LS was employed to compensate for the varied cement ratio of (0, 10, 15, 20, 25) percentage points. Before and post exposure to high temperatures comprising (200, 400, 600) °C, compressive strength and tensile strength were studied. The results showed that LS offset both pressure and tensile strength variations. Negative consequences of calcareous quantity above 15 percent of cement weight on the characteristics observed.

Till now, multiple researches were performed to investigate the utilization of SCMs as partial replacement of cement [1] However, the comparison on the optimal performance of fresh physical mechanical properties with respect of each other was ignored. Secondly dual replacement of both cement and sand was never investigated. In this research, RHA, SCBA and LS were used separately as a partial replacement of cement while SD was used as a replacement of fine aggregate in theconcrete. Both of the replacements were done at the same time in order to obtain the optimum results. Moreover, the comparative analysis were performed on the fresh and hardened physio mechanical properties. Furthermore, microstructural investigation were also performed to support the behavior of these hardened properties.

2.4 Studies incorporating SD as a partial replacement of fine aggregate

Aggregate is one of the key components of concrete manufacture that accounts for 75% of the entire mixture. The strength of the resulting concrete depends on the characteristics of the utilized aggregates [34]. Construction industry is under pressure to discover alternative resources to provide the need for natural sand and aggregates because all components in concrete have geologic origins [34].

The proportioning, mixing, and compacting of the components are crucial to creating a strong, long-lasting concrete [34]. On site, 250-400 tonnes of stone debris are produced each year. Although designated locations have been identified for dumping, the stone cutting plants are dumping the powder in any adjacent pit or unoccupied spot around their unit. This causes significant environmental and dust pollution, as well as the occupancy of a large amount of land, especially when the powder dries out, so the stone waste must be disposed of immediately and used in the building sector [44]. The advantages of using by-products or aggregates produced as waste materials are significant in terms of reducing environmental load and waste management costs, lowering manufacturing costs, and increasing concrete quality.

For medium-grade concrete, stone dust is a better choice than sand in terms of strength and cost [48]. Stone dust may efficiently be replaced with 40 percent of fine aggregate [55]. The use of crusher dust as a 40% substitute for natural sand enhanced the compressive strength of the concrete mix by 22% [54].

The impact of partial substitution of fine aggregate with stone dust on concrete strength under compression and tension was examined in the current study in light of the foregoing findings.

CHAPTER 3

3 Materials and Methods

3.1 Materials

In this study ,three different groups of SCM binder-based systems were developed. In all of the experimental blends, general purpose type I ordinary Portland cement (OPC) was used as the principal binder, which was acquired from local market. Sugar Cane Bagasse Ash (SCBA) was acquired from the local source . It was the waste productwhich was produced inthe sugar mills for the energy generation. Rice Husk Ash (RHA), which was procured from a local source prepared from rice husk after burning at 700 ^{o}C.Limestone powder (LS) was procured from the local quarry.

All the materials were grinded and passed through 200 # sieve, prepared through grinding process before their usage as a partial replacement of cement. The percentage replacement of cement with RHA, SCBA and LS are shown in Table 4.

3.2 XRF analysis of the binding materials

To evaluate the chemical composition of cement, RHA,SCBA and LS , X-ray fluorescence (XRF) analysis was performed. Table 1 gives the chemical composition of raw materials. It was revealed that the main constituents were CaO, SiO_2, Al_2O_3, and Fe_2O_3. XRF spectrometry results of RHA and SCBA indicated a silica content of approximately 83% and 82% respectively whereas in case of LS the silica content was around to 1.5%.

Table 2. XRF Analysis of RHA, SCBA, LS and cement

Chemical Composition	RHA %	SCBA %	LS %	Cement
SiO_2	83.36	81.96	1.53	25
Al_2O_3	1.20	2.06	0.25	2.85
Fe_2O_3	1.92	1.94	0.21	0.51
CaO	10.54	6.09	52.46	67.02
MgO	0.00	0.81	0.92	1.21
K_2O	1.43	1.73	0.06	0.08
Na_2O	0.00	0.00	0.00	0.00
SO_3	0.16	4.15	0.07	3.74
Cl	0.008	0.026	0.00	0.01

3.3 XRD analysis of the binding materials

X-ray diffraction (XRD) analysis was carried out to identify the crystalline phases in cement, RHA ,SCBA and LS.in fig 1a the XRD pattern of cement shows a high number of specious diffractions and a predominance of C_3S and C_2S peaks, as well as ferrite, and calcite. In fig 1b&1cRHA and SCBA diffraction peaks were identified as cristobalite and quartz. The broad curves in the XRD pattern could be attributed to amorphous silica, while the peaks could be attributed to quartz contamination. As a result, it is possible to conclude that a significant portion of the silica in this material was in the amorphous phase.In fig 1d LS diffraction peaks were identified as quartz and calcite which are the most important mineralogical phases.

The specific gravities of all binder materials are shown in Table 2

Table 2.Specific gravities of binding materials

Material	Specific Gravity
Cement	3.11
RHA	1.96
SCBA	2.12
LS	2.70

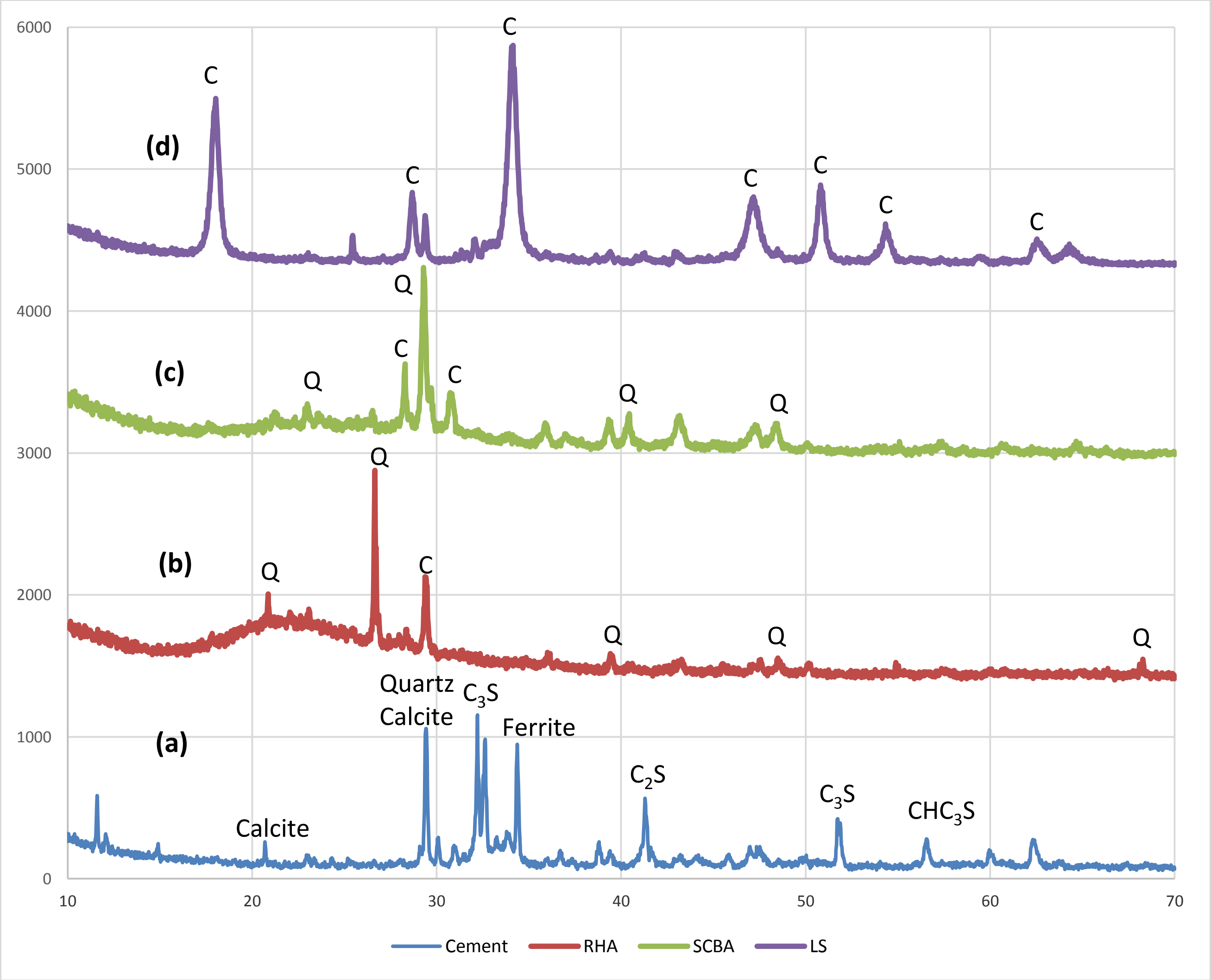


Figure 1. XRD analysis of (a) cement (b) RHA (c) SCBA (d) LS

All of the samples were mixed with dry Lawrancepur sand ranging in size from 4.75mm to 0.15 mm . The Coarse Aggregate (CA) consisted of crushed stone (Obtained from Margala crush) with a maximum size of 19 mm. ASTM C136 – 04[45] was used to perform the sieve analysis. The specific gravity and percentage of water absorption of fine and coarse aggregates was measured using ASTM C128 and ASTM C127,respectively. The physical properties of the aggregates are shown in Table 3. Stone dust (SD) was used as a partial replacement of sand and was acquired from quarry. Fig 2 and Table 4 shows the particle size distribution of100% sand, 100%SD, 25%SD75% and 50%SD50%sand.

Table 3.Physical properties of Fine and coarse aggregates

Material	**Unit Weight (Kg/m^3)**	**Bulk Specific Gravity (OD)**	**Bulk Specific Gravity (SSD)**	**Absorption**
Sand	1697	2.49	2.55	2.25
SD	1717	2.52	2.59	2.61
Crush	1799	2.68	2.69	0.4

Table 4.% passing of fine aggregates

% passing of fine aggregates

sieve no.	**sieve # mm**	**sand 100%**	**SD 100%**	**SD25sand75**	**SD50sand 50**	**ASTM**
4	**4.75**	100	100	100	100	95--100
8	**2.36**	96.5	98.5	97	97.5	80--100
16	**1.18**	75.5	87.5	78.5	81.5	50--85
30	**0.6**	49	71	54.5	60	25--60
50	**0.3**	36.2	48.2	39.2	42.2	10--30
100	**0.15**	9.7	19.7	12.2	14.7	2--10
200	**0.075**	2	4	2.5	3	0-10
	pan	0	0	0	0	

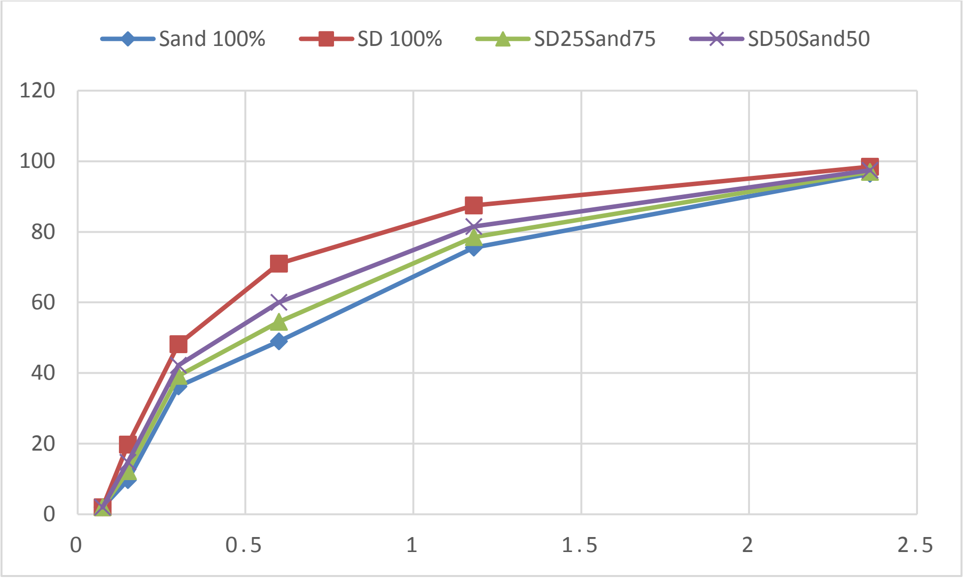


Figure 2. Particle distribution of fine aggregates

3.4 Mix Proportion

Partial replacement of cement and sand was done concurrently. RHA, SCBA and LS were used separately as a partial replacement of cement along with SD as a partial replacement of a sand. The partial replacement of RHA, SCBA and limestone powder with cement was kept at 0, 10, 15 and 20% respectively as a first variable whereas the SD was partially replaced with sand at 0, 25 and 50% as a second variable. The amount of coarse aggregates were kept constant, whereas the water to binder ratio was kept to 0.54. The naming adopted in this research is "SCM-SCM%-SD-SD%" e.g., RH10SD25 means that the mix was comprised of 10% RHA with 25% SD as the partial replacement of cement and sand, respectively. The control mix comprised of 100% OPC as a binder with sand as a fine aggregate. The mix design and proportioning of the materials is presented in Table 5.

Table 5.Mixture and proportioning of specimens.

Code	RHA %	SCBA %	LS %	SD %	WATER (kg/m^3)	CEMENT (kg/m^3)	RHA (kg/m^3)	SCBA (kg/m^3)	LS (kg/m^3)	SAND (kg/m^3)	SD (kg/m^3)	Aggregate (kg/m^3)	W/B
CONTROL	0	---	---	0	223	410	0	---	---	655	0	1229	0.54
RH10SD0	10	---	---	0	223	369	41	---	---	655	0	1229	0.54
RH15SD0	15	---	---	0	223	348	61	---	---	655	0	1229	0.54
RH20SD0	20	---	---	0	223	328	82	---	---	655	0	1229	0.54
RH0SD25	0	---	---	25	223	410	0	---	---	491	164	1229	0.54
RH10SD25	10	---	---	25	223	369	41	---	---	491	164	1229	0.54
RH15SD25	15	---	---	25	223	348	61	---	---	491	164	1229	0.54
RH20SD25	20	---	---	25	223	328	82	---	---	491	164	1229	0.54
RH0SD50	0	---	---	50	223	410	0	---	---	328	328	1229	0.54
RH10SD50	10	---	---	50	223	369	41	---	---	328	328	1229	0.54
RH15SD50	15	---	---	50	223	348	61	---	---	328	328	1229	0.54
RH20SD50	20	---	---	50	223	328	82	---	---	328	328	1229	0.54

BA10SD0	---	10	---	0	223	369	---	41	---	655	0	1229	0.54
BA15SD0	---	15	---	0	223	348	---	61	---	655	0	1229	0.54
BA20SD0	---	20	---	0	223	328	---	82	---	655	0	1229	0.54
BA0SD25	---	0	---	25	223	410	---	0	---	491	0	1229	0.54
BA10SD25	---	10	---	25	223	369	---	41	---	491	164	1229	0.54
BA15SD25	---	15	---	25	223	348	---	61	---	491	164	1229	0.54
BA20SD25	---	20	---	25	223	328	---	82	---	491	164	1229	0.54
BA0SD50	---	0	---	50	223	410	---	0	---	328	164	1229	0.54
BA10SD50	---	10	---	50	223	369	---	41	---	328	328	1229	0.54
BA15SD50	---	15	---	50	223	348	---	61	---	328	328	1229	0.54
BA20SD50	---	20	---	50	223	328	---	82	---	328	328	1229	0.54
LS10SD0	---	---	10	0	223	369	---	---	41	655	0	1229	0.54
LS15SD0	---	---	15	0	223	348	---	---	61	655	0	1229	0.54

LS20SD0	---	---	20	0	223	328	---	---	82	655	0	1229	0.54
LS0SD25	---	---	0	25	223	410	---	---	0	491	0	1229	0.54
LS10SD25	---	---	10	25	223	369	---	---	41	491	164	1229	0.54
LS15SD25	---	---	15	25	223	348	---	---	61	491	164	1229	0.54
LS20SD25	---	---	20	25	223	328	---	---	82	491	164	1229	0.54
LS0SD50	---	---	0	50	223	410	---	---	0	328	164	1229	0.54
LS10SD50	---	---	10	50	223	369	---	---	41	328	328	1229	0.54
LS15SD50	---	---	15	50	223	348	---	---	61	328	328	1229	0.54
LS20SD50	---	---	20	50	223	328	---	---	82	328	328	1229	0.54

3.5 Specimen Preparation

Concrete samples were casted and cured as to measure the compressive strength, split tensile strength, flexural strength, water absorption, drying shrinkage and volume of permeable voids . The specimens were cured at the relative humidity and temperature of 100% and 24 ± 2^{o}C respectively as per the ASTM C511 [46]

3.6 Testing procedures.

The workability of the concrete is one of the physical criteria affecting the strength, longevity and aspect of the finished surface. The workability of the concrete depends on the water cement ratio the amount and size ofaggregatesand the involvement of SCMs in the mixture of concrete.Workability of concrete was measured by slump cone test as per ASTM C143/C143M[47] For different water-cement ratios, the height of the collapse of the concrete cone was reported and compared with the control mix. Fresh density of the concrete was also measured during casting as per the ASTM C138/C138M [48]

According to ACI 318-19 section 26.12.3.1, all concrete mix formulations were checked for different properties in both the fresh and hardened condition. Each test outcome indicates the arithmetic average of three tested specimens[49].

The cylinders of diameter 100 mm and height 200 mm were casted to measure compressive and split tensile strength as per ASTM C39/C39M[50] and ASTM C496/496M [51],respectively. After 24 hours all of the samples were demolded and compressive strength was measured on 1, 7, 14 and 28 days during controlled curing. Similarly, split tensile strength was estimated after 28 days. The prisms of size 100 × 100 × 500 were casted as per ASTM C78 [52] and the flexural strength measured after 28 days curing of prism. Cubes of sizes 150 × 150 × 150 were casted and water absorption and volume of permeable voids were measured as per ASTM C642 [53]

As per the ASTM C490[54] concrete shrinkage was estimated. Three prisms of sizes 100 × 100 × 285 mm were casted. The samples were demolded after 24 hours, and the initial measurement was taken. The shrinkage was measured at days 1, 2, 3, 7, 14 and 28 days. The change in length L determine between concrete prism and reference bar. Concrete shrinkage at time period ‘x’ (L) is calculated as the change in L_x with respect to initial measurement Li divided by length of gauge (G) as below,

$$L = \frac{(L_x - L_i)}{G} \times 100$$

CHAPTER 4

4. Results and Discussions

4.1 Effect on workability

Figure 3 and Table 5depicts the slump value of control mix with respect to RHA ,SCBA and LS mixes. The slump value for control mix was recorded as 96 mm. The increase in SD from 0 to 25% resulted in a decrease in slump from 96 mm to 75 mm. Similarly, increase in SD up to 50% resulted in the decrease of slump to 56 mm. In case of RHA, highest slump value for RH10SD0 recorded was 93 mm and the lowest slump value for RH20SD0 recorded was 84 mm. Increase in both RHA and SD gradually decreased the slump up to 45 mm. In case of SCBA, highest slump value for BA10SD0 recorded was 94 mm and the lowest slump value for BA20SD0 recorded was 87 mm. Increase in both SCBA and SD gradually decreased the slump up to 46 mm. In case of LS, highest slump value for LS10SD0 recorded was 89 mm. and the lowest slump value for LS20SD0 recorded was 76 mm. Increase in both LS and SD gradually decreased the slump up to 34 mm. The surface of a substance has a clear relationship with the particle size and fineness of the material. The fineness of the RHA, SCBA, and LS increases the measurable surface area. The demand for water was increased in order to maintain the consistency of the mix .Overall decrease observed in slump by incorporating SD was due to the reason that the particle size of the SD was lesser than sand as observed in sieve analysis[55-59]

Table 6. Slump Values of All mixes

Slump Values of All mixes in mm					
Code	**Slump(mm)**	**Code**	**Slump(mm)**	**Code**	**Slump(mm)**
CONTROL			96		
RH10SD0	93	**BA10SD0**	94	**LS10SD0**	89
RH15SD0	88	**BA15SD0**	90	**LS15SD0**	82
RH20SD0	84	**BA20SD0**	87	**LS20SD0**	76
RH0SD25	75	**BA0SD25**	75	**LS0SD25**	75
RH10SD25	72	**BA10SD25**	72	**LS10SD25**	69
RH15SD25	68	**BA15SD25**	67	**LS15SD25**	61
RH20SD25	62	**BA20SD25**	64	**LS20SD25**	56
RH0SD50	56	**BA0SD50**	56	**LS0SD50**	56
RH10SD50	53	**BA10SD50**	52	**LS10SD50**	48
RH15SD50	48	**BA15SD50**	49	**LS15SD50**	40
RH20SD50	45	**BA20SD50**	46	**LS20SD50**	34

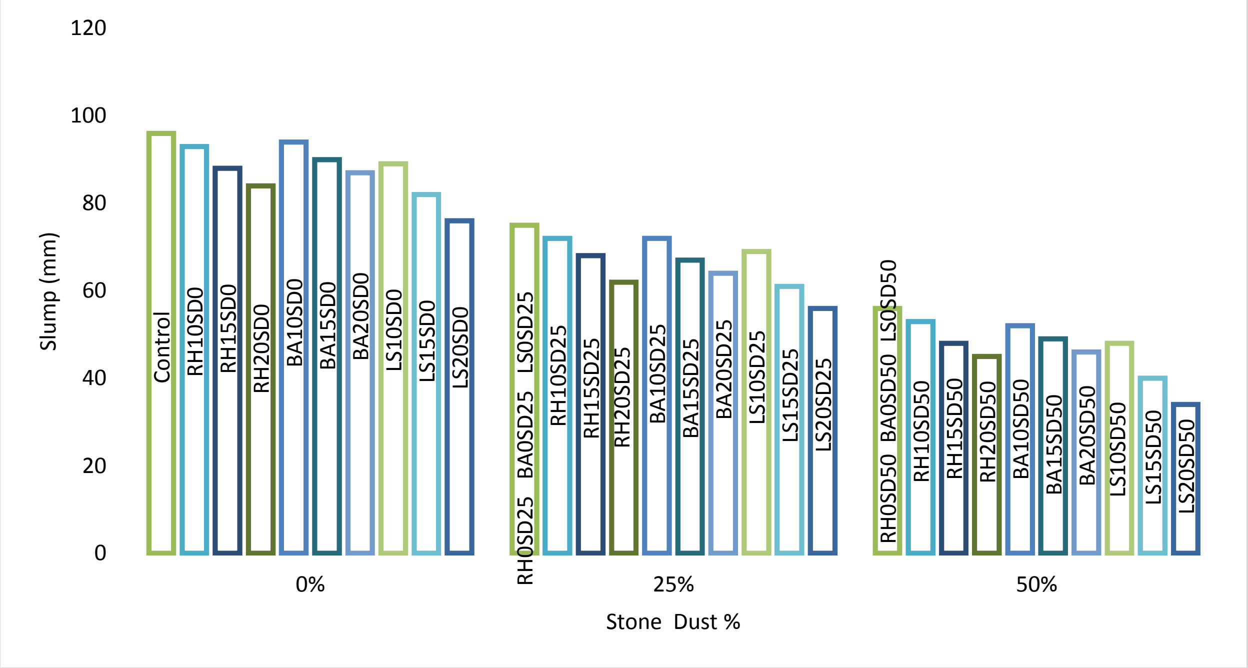


Figure 3. The relationship between percentages of SD and RHA, SCBA and LS with slump

Figure 4. Measurement of slump of a concrete mixture

4.2 Effect on fresh density

The cement utilized in this study was denser than RHA, SCBA, and LS, which is an important parameter to explore the influence of replacing RHA, SCBA, and LS with cement on concrete. Because the specific gravity of RHA, SCBA, and LS is lower than that of cement. Increasing the amount of RHA, SCBA, and LS in concrete led in lighter fresh density of concrete as compared to the control mix. The fresh density decreases gradually, and a very little decrease was detected due to the replacement of RHA, SCBA, and LS. The similar trend was observed in [60-62] The partial substitution of SD with sand resulted in a significant rise in fresh density.[63, 64].A 25% substitution of SD resulted in only 5.3 % increase in density with respect to control mix, while a 50% replacement resulted in 9.8% increase in density. Thus, the influence of SD on fresh density was stronger when sand was replaced with SD because of the finer partials and more specific gravity of the SD than when RHA, SCBA, and LS were replaced with cement. The combined outcome of replacing RHA, SCBA, and LS with cement and SD with sand indicated an increase in fresh density when compared to the control mix. The results of fresh density are shown in figure5 and table 7.

Table 7.. Fresh density values of all mixes

Fresh density values of all mixes

Code	**Mass (kg)**	**Volume(m^3)**	**Density(kg/m^3)**
CONTROL	6.912	0.003	2304
RH10SD0	6.87	0.003	2290
RH15SD0	6.834	0.003	2278
RH20SD0	6.795	0.003	2265
RH0SD25	7.284	0.003	2428
RH10SD25	7.245	0.003	2415
RH15SD25	7.206	0.003	2402
RH20SD25	7.173	0.003	2391
RH0SD50	7.656	0.003	2552
RH10SD50	7.62	0.003	2540
RH15SD50	7.578	0.003	2526
RH20SD50	7.542	0.003	2514
BA10SD0	6.879	0.003	2293
BA15SD0	6.843	0.003	2281
BA20SD0	6.816	0.003	2272
BA0SD25	7.284	0.003	2428
BA10SD25	7.257	0.003	2419
BA15SD25	7.221	0.003	2407
BA20SD25	7.188	0.003	2396
BA0SD50	7.656	0.003	2552
BA10SD50	7.623	0.003	2541
BA15SD50	7.596	0.003	2532
BA20SD50	7.566	0.003	2522
LS10SD0	6.891	0.003	2297
LS15SD0	6.87	0.003	2290
LS20SD0	6.846	0.003	2282
LS0SD25	7.284	0.003	2428
LS10SD25	7.257	0.003	2419
LS15SD25	7.236	0.003	2412
LS20SD25	7.206	0.003	2402
LS0SD50	7.656	0.003	2552
LS10SD50	7.632	0.003	2544
LS15SD50	7.605	0.003	2535
LS20SD50	7.575	0.003	2525

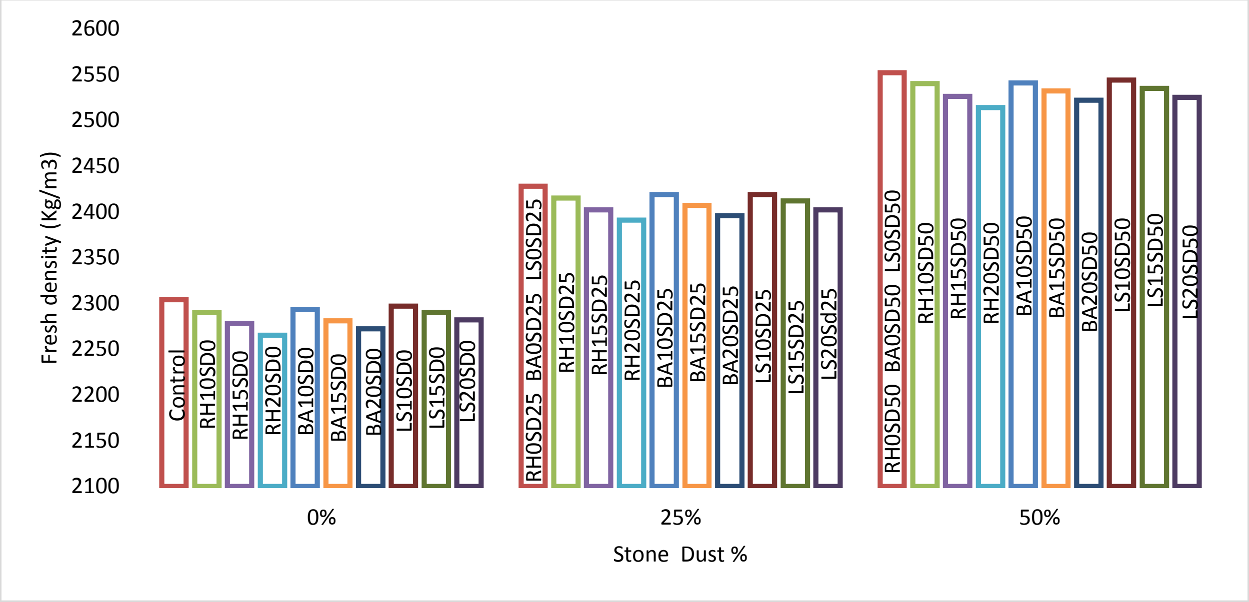


Figure 5. The relationship between percentages of SD and RHA, SCBA and LS with fresh density

Figure 6.Measurement of fresh density of concrete.

4.3 Effect on compressive strength of concrete

Table 8 and 9shows the compressive strength development of concrete mixes designed with a constant water to binder ratio of 0.54. It could be seen that at early age (1 and 7-day), the addition of RHA did not have any significant effect on the compressive strength of concrete. However, after 14 days, this blended cement concretehave developed a higher compressive strength compared to control mix. On the other hand, a simple comparison between the control mix and concrete mix with varying percentages (10%, 15% and 20%) of RHA (without stone dust) showed a slight decrease of the compressive strength at 1 and 7 days while at 14 and 28 days of wet curing, the strength of the blended cement with varying percentages (10% , 15% and 20%) of RHA has increased by around 7%. This decline in early age strength can be linked to the low pozzolanic activity of RHA, due to its coarser particles. Moreover, the reduction in volume of hydration products due to less favorable hydration rate is expected to result in the decrease in early age strengths[65, 66]

Combining SD with a varying amount of 25% replacement with sand along with RHA replacement has improved compressive strength at later ages as compared to both control mixes i.e., 100%OPC and RH20SD0. Increasing the SD content up to 25% replacement by weight of sand for RH0SD25 has showed an increase of compressive strength by 10%. However, beyond 25% replacement level RH0SD50, a drop in the compressive strength up to 11% was observed. However, when combined with 20% RHA replacement with cement and 25% SD replacement with sand i.e., RH20SD25 , strength improvement was obvious with up to 16% compared to the control mix.

The pozzolanic reactions in the RHA with portlandite ($CA(OH)_2$), produced during Portland cement hydration, are in reality responsible for the compressible force enhancement of the mixed cement concrete. This subsequent pozzolanic Calcium- Silicate-Hydrate (C-S-H) reaction lowers the quantity of Calcium Hydroxide (CH) and improves the porosity of C-S-H by filling the big capillary plants, hence refinement of the poresystem[67].Moreover, the modified fine aggregate combination has improved the packing, as the particle size of SD is smaller compared to sand.Thus, compressive strength increases over time with the presence of a mix with a binary system with RHA andSD, their effect on strength was clear.

The compressive strength of control mix containing SCBA continuously developed with the age. The mixes with SCBA (without SD) showed strength development after the final setting time compared to the control mix.This can be linked with the pozzolanic activity of SCBA.[68]After 28 days of curing, BA15SD0 showed optimum strength, which was 13% higher compared to control mix. Replacement of 25% SD in BA15SD25 gave 20% higher strength compared to control and 6% compared to BA15SD0.This increase in strength can be linked to the filler property of finer SD which have modified the microstructure and have improved the matrix. It was observed that the optimum value was achieved at 15 % SCBA replacement of cement and 25 % SD replacement of sand However, beyond this a slight decline in the compressive strength was observed.

Higher compressive strength in SCBA concrete compared to RHA and LS concretes can be linked to silica content, fineness, amorphous phase, specific surface area, degree of reactivity of SCBA and pozzolanic reaction between calcium hydroxide and reactive silica in SCBA .[69-73]

Table8represents the strength development of partially replaced concrete having LS and SD as the replacement of cement and sand respectively. It could be seen that the addition of LS did not have any significant effect on the compressive strength of concrete. The blended cement concrete mixes have developed a lower compressivestrength compared tothe control mix. A simple comparison between the control mix and concrete mix with varying percentages of LS (10% , 15% and 20%) without SD showed a remarkable decrease of the compressive strength. This reduction in compressive strength can be linked to the clinker dilution. This effect is a consequence of replacing a part of cement by the same quantity of limestone[74]

The optimum values in case of RHA and SCBA replacement was observed in RH20SD25 and BA15SD25, whereas in case of LS replacement, decline in strength was observed compared to control mix. The increase in strength compared to control was 16% in case of RH20SD25 and 20% in case of BA15SD25. in all the three binary blends of RHA , SCBA and LS , the maximum increase was observed in case of SCBA i.e., BA15SD25 , which was 20% higher compared to control and 4% compared to RHA matrixes.

Figure 7. Testing of Compressive strength of a concrete sample

Table 8. Compressive strength results of concrete comprising RHA, SCBA, LS and SD

Matrix	**RHA%**	**SCBA%**	**LS%**	**SD%**	**1-day compressive strength (MPa)**	**7-day compressive strength (MPa)**	**14-day compressive strength (MPa)**	**28 days compressive strength (MPa)**
CONTROL	0	---	---	0	4.2	17.6	24.7	27.3
RH10SD0	10	---	---	0	3.8	16.3	25.3	27.8
RH15SD0	15	---	---	0	3.3	17.1	25.7	28.3
RH20SD0	20	---	---	0	3.4	17.3	26.8	29.2
RH0SD25	0	---	---	25	5.8	18.9	25.8	30.1
RH10SD25	10	---	---	25	4.9	18.4	27.4	31.3
RH15SD25	15	---	---	25	5.1	18.8	27.7	31.4
RH20SD25	20	---	---	25	5.4	19.7	27.8	31.8
RH0SD50	0	---	---	50	4.8	17.2	20.1	24.3
RH10SD50	10	---	---	50	3.0	16.2	24.2	26.6
RH15SD50	15	---	---	50	3.3	16.7	26.6	27.1
RH20SD50	20	---	---	50	3.1	16.8	23.6	28.5
BA10SD0	---	10	---	0	5.1	18.9	24.6	29.7
BA15SD0	---	15	---	0	5.6	19.3	25.7	30.9
BA20SD0	---	20	---	0	5.3	18.6	25.2	29.8
BA0SD25	---	0	---	25	5.8	18.9	25.8	30.1
BA10SD25	---	10	---	25	5.9	19.1	26.3	31.3
BA15SD25	---	15	---	25	6.7	19.9	26.8	32.7
BA20SD25	---	20	---	25	6 .2	19.4	26.7	31.2
BA0SD50	---	0	---	50	4.8	17.2	20.1	24.3
BA10SD50	---	10	---	50	5.2	19.1	25.2	27.4
BA15SD50	---	15	---	50	5.7	18.7	25.3	26.2
BA20SD50	---	20	---	50	5.4	18.6	24.4	25.8
LS10SD0	---	---	10	0	3.7	14.8	20.2	25.5
LS15SD0	---	---	15	0	3.2	12.8	17.7	23.7
LS20SD0	---	---	20	0	2.5	10	16.3	21.8
LS0SD25	---	---	0	25	5.8	18.9	25.8	30.1
LS10SD25	---	---	10	25	3.9	15.6	19.1	26.6
LS15SD25	---	---	15	25	3.7	14.8	20.2	25.5
LS20SD25	---	---	20	25	3.1	12.4	17.2	21.2
LS0SD50	---	---	0	50	4.8	17.2	22.1	24.3
LS10SD50	---	---	10	50	3.6	14.4	19.7	22.0
LS15SD50	---	---	15	50	3.2	12.8	17.7	19.7
LS20SD50	---	---	20	50	2.8	11.2	15.7	17.5

Table 9. Compressive Strength of mixes at 28 days in MPA

Compressive Strength of mixes at 28 days in MPA

Code	**Sample 1**	**Sample 2**	**Sample 3**	**28 DAY(MPA) Average**	**Standard deviation**
CONTROL	27.6	27.2	27.1	27.3	0.26
RH10SD0	28.2	26.9	28.3	27.8	0.78
RH15SD0	28.6	28.1	28.2	28.3	0.26
RH20SD0	30.2	30.1	27.3	29.2	1.64
RH0SD25	30.4	29.8	30.1	30.1	0.3
RH10SD25	30.6	29.9	33.4	31.3	1.85
RH15SD25	30.2	31.6	32.4	31.4	1.11
RH20SD25	31.9	32.1	31.4	31.8	0.36
RH0SD50	23.6	26.1	23.2	24.3	1.57
RH10SD50	26.9	26.8	26.1	26.6	0.43
RH15SD50	28.3	28.6	24.4	27.1	2.34
RH20SD50	26.9	27.2	31.4	28.5	2.51
BA10SD0	28.9	30.1	30.1	29.7	0.69
BA15SD0	30.2	31.2	31.3	30.9	0.60
BA20SD0	30.1	29.2	30.1	29.8	0.51
BA0SD25	30.4	29.8	30.1	30.1	0.3
BA10SD25	30.9	31.2	31.8	31.3	0.45
BA15SD25	31.9	32.9	33.3	32.7	0.72
BA20SD25	29.7	29.3	34.6	31.2	2.95
BA0SD50	23.6	26.1	23.2	24.3	1.57
BA10SD50	28.1	25.9	28.2	27.4	1.3
BA15SD50	24.9	26.8	26.9	26.2	1.12
BA20SD50	26.9	25.4	28.1	26.8	1.35
LS10SD0	24.4	28.9	23.2	25.5	3.00
LS15SD0	23.5	24.7	22.9	23.7	0.91
LS20SD0	20.8	23.5	21.1	21.8	1.47
LS0SD25	30.4	29.8	30.1	30.1	0.3
LS10SD25	24.3	30.3	25.2	26.6	3.23
LS15SD25	23.6	28.6	24.3	25.5	2.7
LS20SD25	20.4	22.6	20.6	21.2	1.21
LS0SD50	23.6	26.1	23.2	24.3	1.57
LS10SD50	22.8	22.1	21.1	22.0	0.85
LS15SD50	17	24	18.1	19.7	3.76
LS20SD50	16.8	18.8	16.9	17.5	1.12

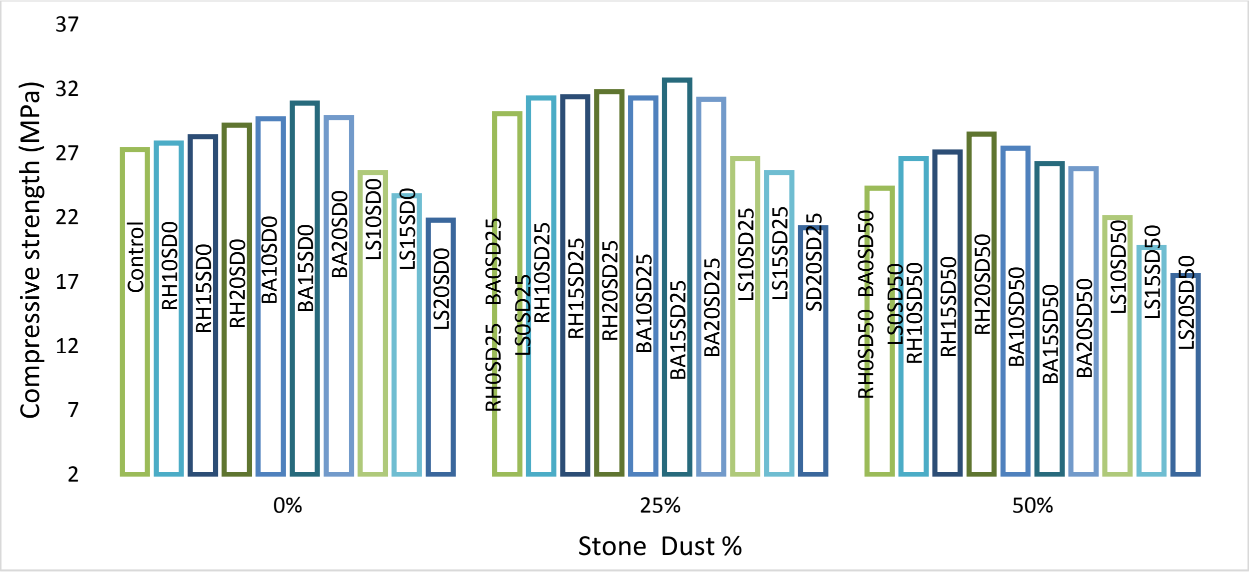


Figure 8. Compressive strength of mixes at 28 days

4.4Splitting tensile strength

Figure 9 and table 10shows the splitting tensile strength of mixes after 28 days of curing. RHA based concrete mixes showed tensile strength, with maximum value at 20% RHA content. The tensile strength of RH20SD0 was approximately 11% higher compared to control mix. Previous studies also confirmed the positive effect of RHA on tensile strength and linked this to the improvement of matrix[10, 67, 75, 76] .The partial replacement of SD with sand especially along with 20% RHA led to a significant improvement in the tensile strength. The substitution of sand with SD further enhanced the mechanical property. The tensile strength of RH10SD25, RH15SD25, and RH20SD25 was estimated to be 13%, 14.8%, and 15.5% higher compared to control mix, respectively. Similar to compressive strength, the highest tensile strength was obtained for a 25% SD replacement along with 20% RHA in case of RH20SD25. 50% partial replacement showed no major improvement in tensile strength compared to control and RHA modified mixes with 0% SD, except at 10% RHA[10, 77, 78]

Replacing cement with SCBA generally enhanced the splitting tensile strength , which reached its maximum value at 15% SCBA content in BA15SD0.. The tensile strength of BA15SD0 was approximately 12.7% higher compared to control mix. Previous studies confirmed the positive effect of SCBA on splitting tensile strength[33, 79, 80] . The partial replacement of SD with sand along with 15% SCBA in case of BA15SD25 led to an optimum value of tensile strength. The tensile strength of BA10SD25, BA15SD25, and BA20SD25 was 15.7%, 20%, and 17.24% higher compared to control mix, respectively. The highest tensile strength was obtained for 25% SD replacement along with 15% RHA and a slight decline was observed beyond this replacement .

Whereas in case of LS, gradual decrease in the tensile strength was observed. Up to 14 % decrease in tensile strength was observed with the 20% partial replacement of LS with cement in LS20SD0. Whereas the 25% replacement of sand with SD showed increase in tensile strength up to 10%in LS0SD25. The dual replacement of LS and SD resulted in gradual decrease. Maximum decrease was observed in case of LS20SD50 which was recorded up to 19%. The strength improvement is attributed to the effects of both RHA and SCBA in terms of physical effect. Effect of SD on the tensile strength of concreteby enhancing particle packing density as well as the chemical effect resulting from the additional C-S-H formed by the reaction of CH with these pozzolanic materials.The slight splitting tensile strength improvement is due to the pozzolanic reaction of pozzolana materials of RHA , SCBA and SD which fills the capillary pores, densifies concrete microstructure and enhance its strength properties as pointed out above

Table 10. Split Tensile Strength of Mixes at 28 days in MPA

Split Tensile Strength of Mixes at 28 days in MPA

Code	**Sample 1**	**Sample 2**	**Sample 3**	**Average (MPA)**	**Standard deviation**
CONTROL	2.69	2.99	3.02	2.90	0.18
RH10SD0	2.47	2.97	3.2	2.88	0.37
RH15SD0	2.78	3.08	3.71	3.19	0.47
RH20SD0	3.01	3.11	3.54	3.22	0.28
RH0SD25	3.42	2.89	3.29	3.20	0.27
RH10SD25	3.27	3.17	3.4	3.28	0.11
RH15SD25	3.12	3.22	3.65	3.33	0.28
RH20SD25	3.04	3.44	3.57	3.35	0.27
RH0SD50	2.91	3.24	2.31	2.82	0.47
RH10SD50	2.83	3.23	3.06	3.04	0.20
RH15SD50	2.74	3.44	3.27	3.15	0.36
RH20SD50	2.96	3.26	3.29	3.17	0.18
BA10SD0	2.77	3.3	3.47	3.18	0.36
BA15SD0	3.16	3.29	3.36	3.27	0.10
BA20SD0	2.99	3.22	3.09	3.10	0.11
BA0SD25	3.42	2.89	3.29	3.20	0.27
BA10SD25	3.347	3.477	3.247	3.357	0.11
BA15SD25	3.77	3.1	3.57	3.48	0.34
BA20SD25	3.69	3.02	3.49	3.40	0.34
BA0SD50	2.91	3.24	2.31	2.82	0.47
BA10SD50	3.17	3.4	3.27	3.28	0.11
BA15SD50	3.13	3.66	3.23	3.34	0.28
BA20SD50	3.12	3.25	3.62	3.33	0.25
LS10SD0	2.8	2.27	2.67	2.58	0.27
LS15SD0	2.34	2.21	2.71	2.42	0.25
LS20SD0	2.91	2.18	2.38	2.49	0.37
LS0SD25	3.52	2.89	3.19	3.20	0.31
LS10SD25	2.33	2.7	2.8	2.71	0.24
LS15SD25	2.59	2.36	2.76	2.57	0.20
LS20SD25	2.67	2.14	2.24	2.35	0.28
LS0SD50	2.91	3.24	2.31	2.82	0.47
LS10SD50	2.53	2.4	2.9	2.61	0.25
LS15SD50	2.54	2.01	2.41	2.32	0.27
LS20SD50	2.47	2.14	2.44	2.35	0.18

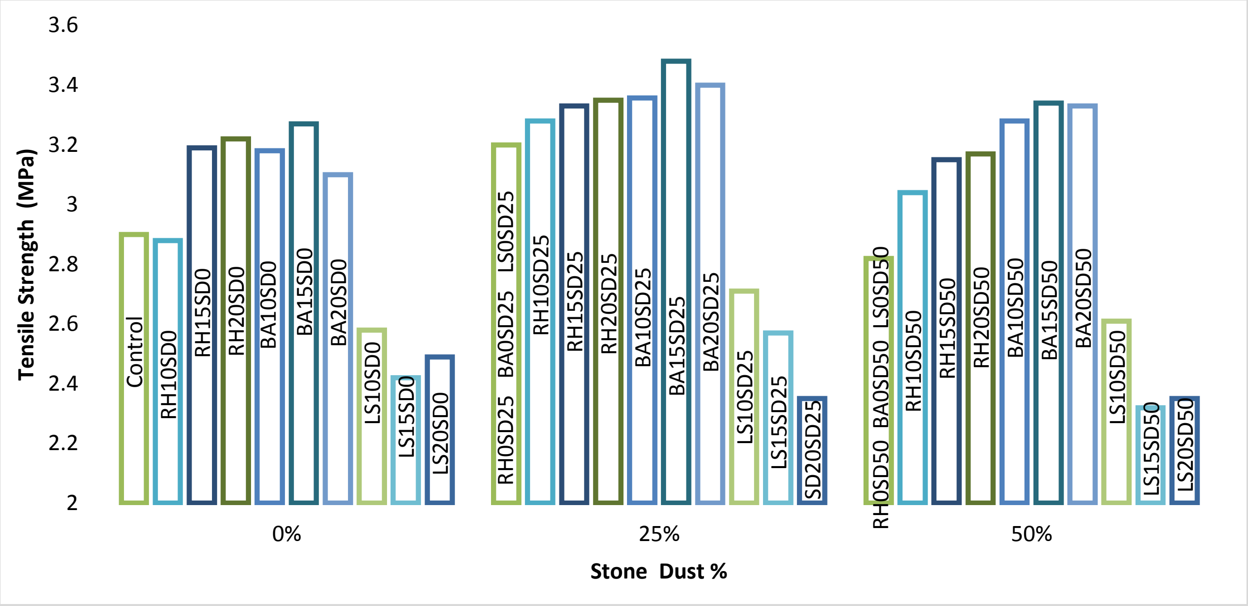


Figure 9. The relationship between percentages of SD and RHA, SCBA and LS with split tensile strength

Figure 10. Testing of a sample for split tensile strength

4.5 Effect on flexural strength of concrete

Figure 11 and Table 11depicts the Results of the flexural strength test of concrete specimens' water cured till 28 days. 20% RHA modified cement concrete mixes with SD contents varying up to 25% replacement RH20SD25 had exhibited optimum strength improvement as compared to the control mix. In comparison, for concrete with solely 20% RHA, the strength improvement ranged between 0.21%–1.5%. Similarly, to the compressive and tensile strengths, SD incorporated in the concrete mixes up to 25% replacement of sand has led to an increase in the flexural strength. In comparisonat 50% replacement of SD, a drop in the flexural strength was noticed. Theenhancement in the flexural strength resulted from the partialreplacement of cement by the combination of 20%RHAis entirely attributable to the secondaryC-S-H formed by the pozzolanic reaction between the CH and theRHA. It seems that adding up to 25% ofSD has densified the microstructure and improved thebonding strength of the blended cement concretes and led to theflexural strength increase[67, 75, 76]

15% SCBA added to the concrete blend BA15SD0 has led to a modest improvement of flexural strength at 28 days as the partial replacement of the cement. Combining 15% SCBA with many percentages of SD as partial sand substitution has resulted in a further 28-day bending strength increase. The maximum bending strength of SD is up to 25 percent and above this limit stagnates without any noticeable influence of the rise of SD content in the concrete mix. SD content in BA15SD25[31, 81].

Theflexural strength test results followed a similar trend as thatof compressive and tensile strength in case of LS partial replacement. While comparing to theControl, LS10SD0, LS15SD0 and LS20SD0 modified concrete yielded less flexuralstrength, whereas LS0SD25 modified concrete exhibitedimproved flexural strength. Flexural strengths of LS10SD0, LS15SD0 and

LS20SD0 concrete were found to be 3.87 MPa, 3.74 MPa and3.62 MPa, respectively, which were about 17% , 20% and 23% less than that of the Control mix . Moreover, the dual replacementi.eLS10SD25, LS15SD25 and LS20SD25 in concrete mixes increased the flexural strength as compared to the mixes with single replacement of LS, respectively. 50% SD modified mixes showed lower flexural strength compared to the 25% SD replaced mixes [82] Thus, from the flexural strength development perspective, LS partial replacementwith the cementwas found unsuitablein this study.

Figure 12. Testing of sample for flexural strength

Table 11. Flexural Strength of mixes at 28 days in MPA

Flexural Strength of mixes at 28 days in MPA

Code	**Sample 1**	**Sample 2**	**Sample 3**	**Average (MPA)**	**Standard deviation**
CONTROL	4.48	4.94	4.69	4.7	0.23
RH10SD0	4.75	4.93	4.45	4.71	0.24
RH15SD0	4.27	4.95	4.97	4.73	0.39
RH20SD0	5.01	4.89	4.41	4.77	0.31
RH0SD25	4.47	4.95	4.77	4.73	0.24
RH10SD25	5	4.78	4.5	4.76	0.25
RH15SD25	5.02	4.80	4.52	4.78	0.25
RH20SD25	5.16	4.94	4.36	4.82	0.41
RH0SD50	3.54	4.14	4.02	3.90	0.31
RH10SD50	3.15	4.13	4.35	3.91	0.63
RH15SD50	3.18	4.16	4.48	3.94	0.67
RH20SD50	3.73	4.21	4.03	3.99	0.24
BA10SD0	4.86	4.76	4.54	4.72	0.16
BA15SD0	4.71	5.01	4.59	4.77	0.21
BA20SD0	4.97	4.37	4.85	4.73	0.31
BA0SD25	4.47	4.95	4.77	4.73	0.24
BA10SD25	4.89	4.99	4.37	4.75	0.33
BA15SD25	4.35	5.05	5.03	4.81	0.39
BA20SD25	4.61	5	4.68	4.76	0.20
BA0SD50	3.54	4.14	4.02	3.90	0.31
BA10SD50	3.67	4.07	4.05	3.93	0.22
BA15SD50	3.63	4.33	4.31	4.09	0.39
BA20SD50	3.66	4.26	4.14	4.02	0.31
LS10SD0	3.51	4.01	4.09	3.87	0.31
LS15SD0	3.48	3.98	3.76	3.74	0.25
LS20SD0	3.56	3.86	3.44	3.62	0.21
LS0SD25	4.47	4.95	4.77	4.73	0.24
LS10SD25	3.69	4.09	4.07	3.95	0.22
LS15SD25	3.42	4.12	4.1	3.88	0.39
LS20SD25	3.44	4.04	3.92	3.80	0.32
LS0SD50	3.54	4.14	4.02	3.90	0.31
LS10SD50	2.8	3.56	3.42	3.26	0.40
LS15SD50	2.53	3.23	3.21	2.99	0.39
LS20SD50	2.5	3	3.08	2.86	0.31

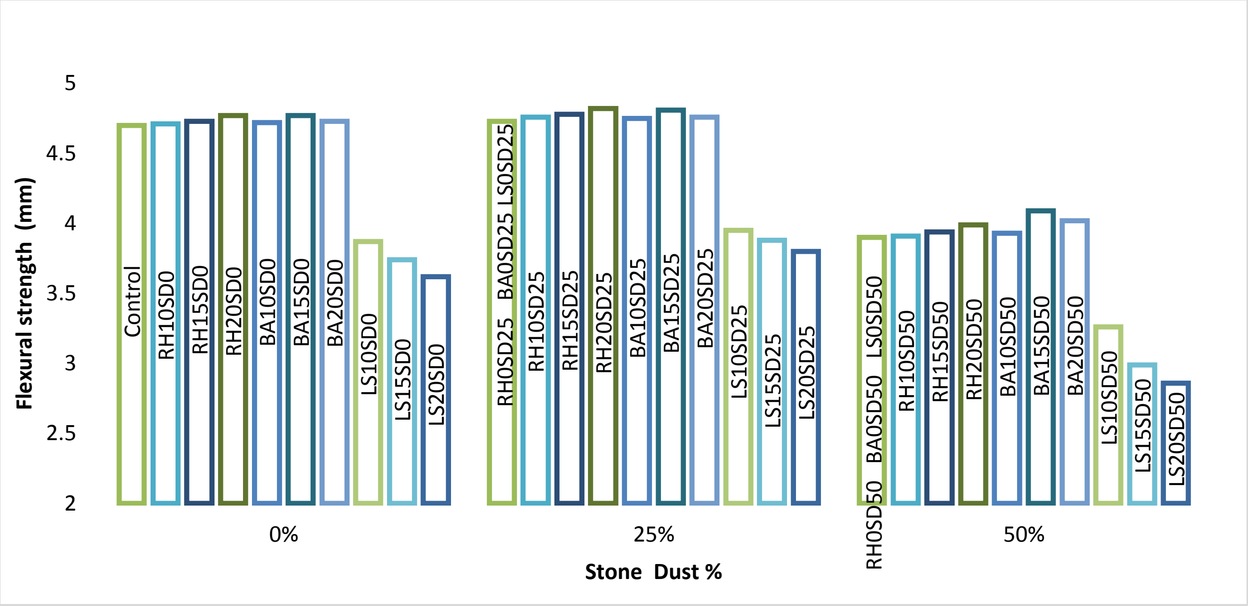


Figure 11. The relationship between percentages of SD and RHA, SCBA and LS with flexural strength

4.6 Water absorption

Figure 13 and Table 12depicts the results of water absorption of concrete mixes.The water absorption of control mix wasrecorded to 3.57% . Water absorption for RH10SD0, RH15SD0 and RH20SD0 were recorded to be 4.29, 4.75 and 4.92% , respectively, which were more compared to control mix. Incorporating SD resulted in decrease in water absorption due to packing of microstructure with finer particles recorded as 3.02 and 2.82% in RH0SD25 and RH0SD50, respectively. A small decrease was observed when the sand was replaced with the SD, whereas overall an increase of water absorption was observed after the dual replacement of both cement and a sand The increase in water absorption by incorporating RHA was due to the fact that RHA was finer than cement and also due to its hygroscopic nature as reported in[83, 84]

Similar trend was observed for concrete mixes containing SCBA as apartial substitution. The water absorption was increased from 3.57% to 4.95% when the percentage replacement of SCBA was increased from 0% to 20%. A moderate decrease was observed after incorporating LS as partial substitution. Incorporating LS from 0 to 20% in concrete resulted in decrease in water absorption from 3.57% to 3.02%. The dual substitution of LS and SD both resulted in decrease in water absorption.Optimum decrease was observed in LS20SD50 which was recorded as 2.59%[82, 85]

Table 12. Water absorption values of all mixes at 28 days

Water absorption values of all mixes at 28 days

Code	**Sample 1**	**Sample 2**	**Sample 3**	**Water Absorption (%)**	**Standard deviation**
CONTROL	3.56	3.61	3.54	3.57	0.036
RH10SD0	4.24	4.32	4.31	4.29	0.044
RH15SD0	4.81	4.76	4.68	4.75	0.066
RH20SD0	4.98	4.94	4.84	4.92	0.072
RH0SD25	2.97	3.03	3.06	3.02	0.046
RH10SD25	4.11	4.13	4.09	4.11	0.020
RH15SD25	4.68	4.53	4.50	4.57	0.096
RH20SD25	4.91	4.82	4.79	4.84	0.062
RH0SD50	2.78	2.81	2.87	2,82	0.046
RH10SD50	3.69	3.52	3.56	3.59	0.089
RH15SD50	4	3.81	3.80	3.87	0.113
RH20SD50	4.23	4.16	4.12	4.17	0.056
BA10SD0	4.39	4.28	4.26	4.31	0.070
BA15SD0	4.66	4.64	4.68	4.66	0.020
BA20SD0	4.98	4.96	4.91	4.95	0.036
BA0SD25	2.97	3.03	3.06	3.02	0.046
BA10SD25	4.14	4.14	4.08	4.12	0.035
BA15SD25	4.52	4.51	4.44	4.49	0.044
BA20SD25	4.9	4.82	4.83	4.85	0.044
BA0SD50	2.78	2.81	2.87	2,82	0.046
BA10SD50	3.28	3.17	3.12	3.19	0.082
BA15SD50	3.48	3.50	3.55	3.51	0.036
BA20SD50	3.98	3.86	3.83	3.89	0.079
LS10SD0	3.17	3.20	3.26	3.21	0.046
LS15SD0	3.1	3.12	3.17	3.13	0.036
LS20SD0	2.99	3.01	3.06	3.02	0.036
LS0SD25	2.97	3.03	3.06	3.02	0.046
LS10SD25	2.98	2.96	2.91	2.95	0.036
LS15SD25	2.83	2.85	2.93	2.87	0.053
LS20SD25	2.75	2.76	2.86	2.79	0.061
LS0SD50	2.78	2.81	2.87	2,82	0.046
LS10SD50	2.75	2.76	2.71	2.74	0.026
LS15SD50	2.63	2.61	2.71	2.65	0.053
LS10SD0	3.22	3.25	3.16	3.21	0.046

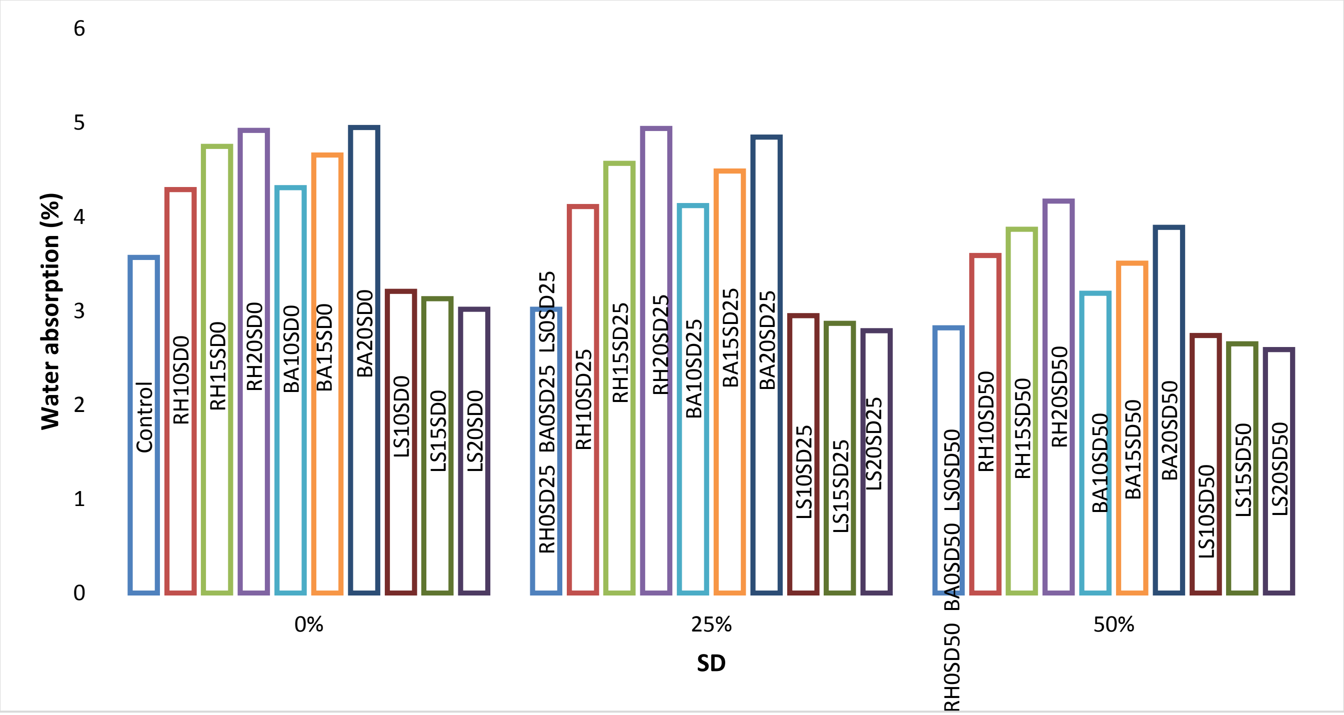


Figure 13. The relationship between percentages of SD and RHA, SCBA and LS with water absorption

4.7 Volume of Permeable voids

The results of volume of permeable voids (VPV) determined over 150 mm cubes for different mixes with varying amounts of RHA ,SCBA. LS with cement and SD with sand are represented in Figure 14 and Table 13.The VPV value of control mix was recorded as 7.29% which increases to 7.6% as the 20% RHA was replaced with the cement in case of RH20SD0. However, the VPV values of concrete having SD replacement with sand was decreased from 7.29% (control mix) to 6.6% as the substitution of sand with SD varied from 0% to 50% in RH0SD50. The decrease of VPV by incorporating SD was linked to the smaller particles of SD compared to sand, which resulted in filling of voids in concrete. Similar trends of increasing VPV values were observed in case of concrete mixes having replacement of cement with SCBA[86, 87]. The VPV value was increased from 7.29% to 7.67% with the increasing replacement percentage of SCBA from 0% to 20% for concrete with 0% SD replacement in BA20SD0.

Whereas in case of LS replacement, increase in the replacement ofLS in concrete led to decrease in VPV values. [88, 89]The decrease was observed 7.29% to 6.86% in case of only LS replacement with cement as in LS20SD0. Further decrease was observed as the sand with SD replaced along with the LS replacement in LS20SD50 from 7.29% to 6.17%. Hence the dual replacement in case of LS resulted further decrease leading to less pores in concrete as compared to RHA or SCBA replacement.

Moreover, the increase in the VPV values of concrete with a large amount ofRHA and SCBA incorporation resulted in the reduction of the amount of control matrixconcrete (normal concrete) and calcium hydroxide (from the hydration reaction). Asa result, it was not sufficient for inducing the reaction with silica from the RHA and similar in case of SCBA. For example, the VPV values of RH10SD0 ,RH15SD0. RH20SD0 mixes (at 28 days) were 7.32%, 7.44% and 7.59%, and the values of BA10SD0, BA15SD0and BA20SD0 mixes (at 28 days) were 7.37%, 7.48% and 7.67%, whichwere larger than 7.29%,those of the control mix.

The increased pores of the high quantities of RHA and SCBA influenced the quantity of cement needed. The outcome was lower hydration, especially when the pozzolanic response was modest. It should be noted that the benefit from pore refining persisted, but the porosity was increased, due to the inclusion of pozzolan. The fine particle size of pozzolan modified pore was, however, reduced by 10% for RHA and SCBA replacement, and concrete porosity was reduced.The incorporation of fine RHA and SCBA particles resulted in the segmentation of large holes and the enhanced nuclear sites for hydration in the cement paste precipitate[86].The poles and decrease of hydroxide calcium in the paste were impacted by this. The more the days were added, the greater the porosity of concrete was decreased because of cementitious components increased hydration.

Table 13. Volume of permeable voids for all mixes

Volume of permeable voids for all mixes

Code	**MASS of Oven Dry sample A (gm)**	**MASS Of Surface Dry sample after Immersion C (gm)**	**Apparent mass of sample D (gm)**	**VPV (C-A/C-D)X 100 (%)**
CONTROL	7896	8154	4615	7.29
RH10SD0	7882	8141	4602	7.32
RH15SD0	7869	8132	4593	7.44
RH20SD0	7858	8126	4587	7.59
RH0SD25	8126	8371	4832	6.93
RH10SD25	8092	8343	4804	7.11
RH15SD25	8071	8326	4787	7.22
RH20SD25	8063	8324	4785	7.38
RH0SD50	8293	8526	4987	6.60
RH10SD50	8268	8508	4969	6.79
RH15SD50	8251	8497	4958	6.97
RH20SD50	8236	8488	4949	7.14
BA10SD0	7887	8148	4609	7.37
BA15SD0	7879	8143	4604	7.48
BA20SD0	7871	8142	4603	7.67
BA0SD25	8126	8371	4832	6.93
BA10SD25	8099	8351	4812	7.14
BA15SD25	8091	8349	4810	7.29
BA20SD25	8080	8342	4803	7.42
BA0SD50	8293	8526	4987	6.60
BA10SD50	8271	8510	4971	6.75
BA15SD50	8258	8506	4967	7.02
BA20SD50	8241	8495	4956	7.19
LS10SD0	7972	8227	4688	7.23
LS15SD0	8008	8258	4719	7.08
LS20SD0	8039	8281	4742	6.86
LS0SD25	8126	8371	4832	6.93
LS10SD25	8199	8440	4901	6.83
LS15SD25	8232	8468	4929	6.67
LS20SD25	8267	8497	4958	6.51
LS0SD50	8293	8526	4987	6.60
LS10SD50	8367	8596	5057	6.47
LS15SD50	8396	8618	5079	6.28
LS20SD50	8428	8646	5107	6.16

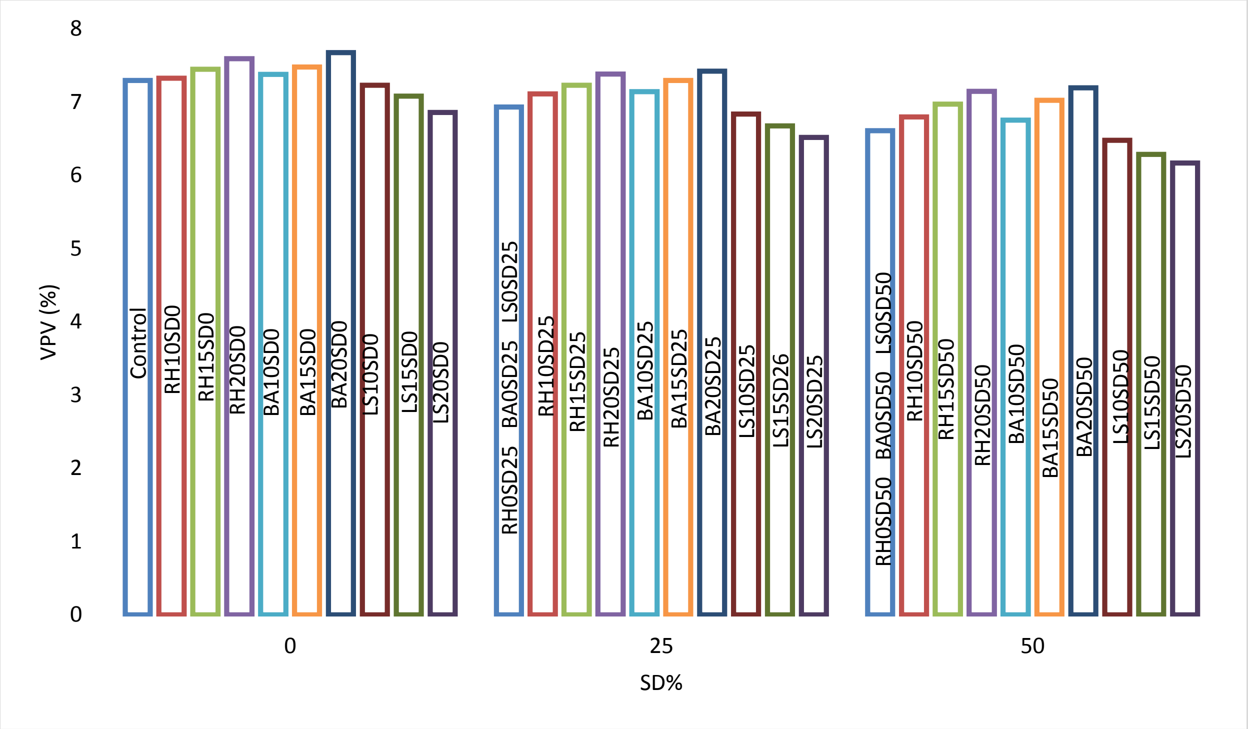


Figure14. The relationship between percentages of SD and RHA, SCBA and LS with VPV

4.8 Shrinkage

Figure 15, 16 and 17 depicts the effect of RHA, SCBA and LS as partial replacement of cement and SD as a partial replacement of sand on drying shrinkage till 28 days of drying period. It can also be seen in table 13, 14 and table 15. The values of drying shrinkage at 0, 1 , 2 , 3, 7,14 and 28 days were recorded . The partial replacement of RHA and SCBA to cement increased the drying shrinkage of the mixes at all drying ages[90]. Whereas the partial replacement of LS to cement reduced the drying shrinkage of the mixes at all drying durations. The ultimate shrinkage of all mixes was well below 500 x10^{-6} mm/mm in this study.

The maximum value of drying shrinkage was observed to be 478 × 10^{-6} mm/mm for the BA20SD0 mix at 28 days of drying, Whereas the minimum value of drying shrinkage was observed to be 291 x 10─6 mm/mm for the LS20SD50 mix at 28 days of drying. For control mix in this study the ultimate drying shrinkage at 28 days was observed to be 456x10^{-6} mm/mm which increased as the partial replacement of RHA and SCBA with cement increased whereas the value of shrinkage decreased as the dual substitution of SD with sand increases. The ultimate drying shrinkage observed for the mix having 50% SD substitution was $404x10^{-6}$ mm/mm. The ultimate shrinkage decreased by 9.6 and 11.4% respectively for 25% and 50% substitution of SD with sand as compared to the control mix.

The reduction in drying shrinkage with the partial substitution of LS can be attributed to the pore refinement that occurred due to particle shape and pore size distribution of LS[91]. The improvement in pore structure of concrete reduced evaporation of water through the capillary pores during drying, hence lowered the drying shrinkage. Similar observation of reduced drying shrinkage in concrete containing LS, with a particular physical characteristics, was made by Gameiro et al.[92]. It was also observed that the drying shrinkage of mortar mixes remained unaltered up to 50% substitution of river sand with SD [93] .

A thorough examination of the shortening development curve showed by the drying shrinkage test results of a mix indicates that the shortening development curve consists of two phases: shrining occurred more quickly in the first phase, and the shrinkage rate decreases in the second period. In early years, the decline was shown to fluctuate more in comparison to the decline in later days For all mixtures, these two stages may be observed. The demarcation between both phases was achieved by counting the times when the mix shrinkage reached half the last strain. For all combinations it was found to be almost equivalent to 7 days. Thus, it was the initial phase of dehydration until 7 days of drying, when about 50% of the last dehydration occurred.

Table 14. Shrinkage values of mixes incorporating RHA

Shrinkage values of mixes incorporating RHA												
Days	**Control**	**RH10 SD0**	**RH15 SDO**	**RH20 SD0**	**RH0SD25**	**RH10 SD25**	**RH15 SD25**	**RH20 SD25**	**RH0SD50**	**RH10 SD50**	**RH15 SD50**	**RH20 SD50**
0	0	0	0	0	0	0	0	0	0	0	0	0

1	-84	-90	-95	-97	-72	-77	-85	-90	-60	-63	-69	-74
2	-176	-184	-189	-194	-132	-138	-145	-154	-118	-119	-126	-132
3	-280	-292	-302	-306	-212	-217	-226	-235	-196	-200	-205	-212
7	-404	-408	-413	-419	-390	-399	-404	-411	-372	-376	-382	-396
14	-431	-434	-440	-448	-408	-417	-425	-418	-398	-404	-412	-418
28	-456	-452	-462	-471	-412	-423	-427	-423	-304	-411	-419	-429

Table 15. Shrinkage values of mixes incorporating SCBA

Shrinkage values of mixes incorporating SCBA												
Days	**Control**	**BA10SD0**	**BA15SDO**	**BA20SD0**	**BA0SD25**	**BA10SD25**	**BA15SD25**	**BA20SD25**	**BA0SD50**	**BA10SD50**	**BA15SD50**	**BA20SD50**
0	0	0	0	0	0	0	0	0	0	0	0	0
1	-84	-92	-96	-99	-72	-79	-86	-93	-60	-66	-75	-82
2	-176	-187	-192	-197	-132	-141	-148	-157	-118	-123	-131	-137
3	-280	-297	-305	-309	-212	-220	-229	-238	-196	-201	-211	-215
7	-404	-412	-416	-421	-390	-402	-411	-421	-372	-383	-394	-401
14	-431	-438	-442	-451	-408	-419	-426	-434	-398	-409	-418	-425
28	-456	-466	-471	-478	-412	-426	-434	-442	-304	-417	-427	-431

Table 16. Shrinkage values of mixes incorporating LS

Shrinkage values of mixes incorporating LS												
Days	**Control**	**LS10SD0**	**LS15SDO**	**LS20SD0**	**LS0SD25**	**LS10SD25**	**LS15SD25**	**LS20SD25**	**LS0SD50**	**LS10SD50**	**LS15SD50**	**LS20SD50**
0	0	0	0	0	0	0	0	0	0	0	0	0
1	-84	-80	-78	-72	-72	-66	-59	-55	-60	-57	-51	-48
2	-176	-169	-166	-159	-132	-123	-118	-115	-118	-114	-109	-102
3	-280	-273	-270	-265	-212	-202	-193	-189	-196	-189	-185	-178
7	-404	-396	-389	-382	-390	-381	-372	-367	-372	-367	-362	-357
14	-431	-422	-416	-406	-408	-402	-397	-391	-398	-392	-386	-379
28	-456	-441	-432	-424	-412	-406	-399	-395	-384	-381	-377	-371

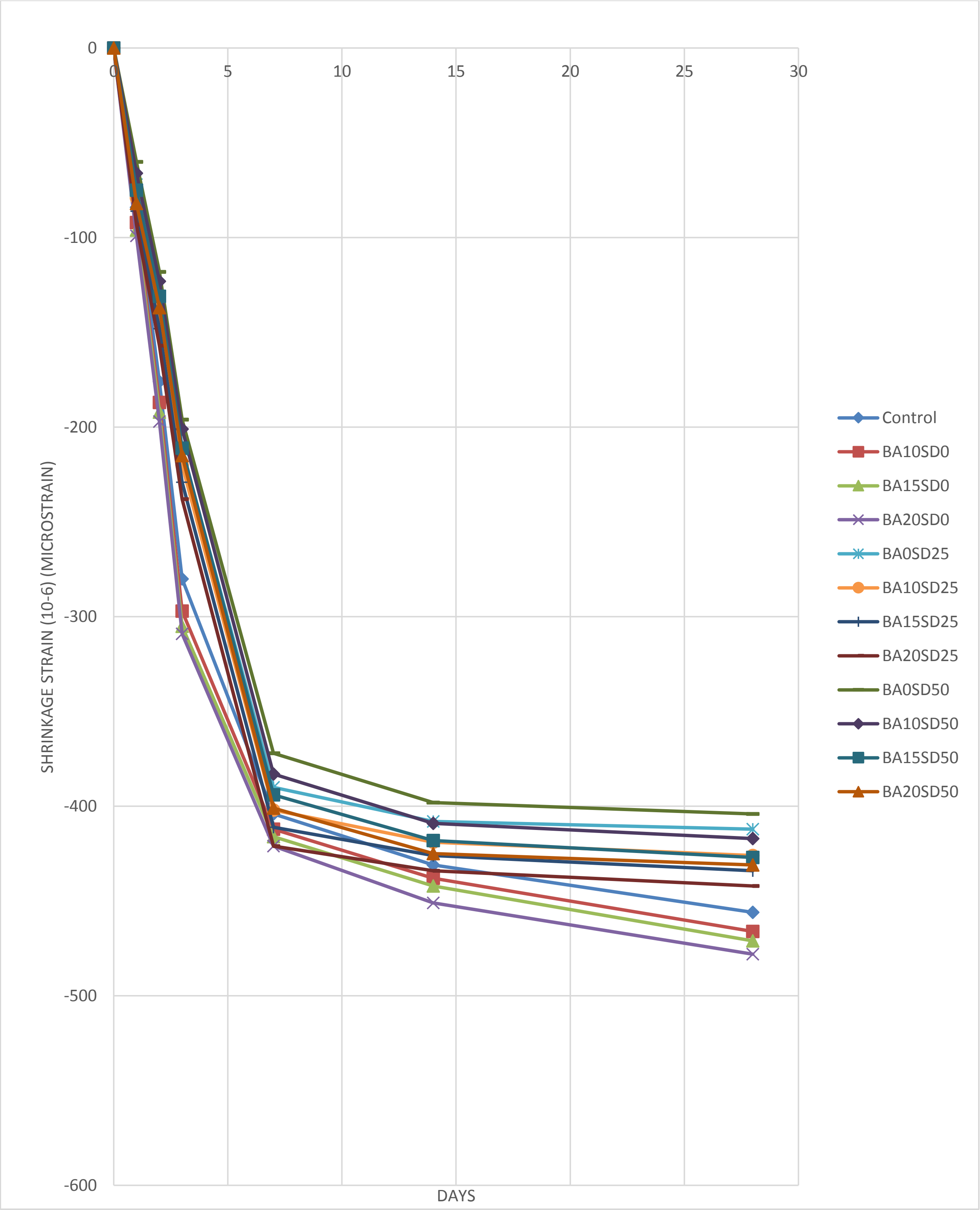


Figure 15. The results of Shrinkage strain of concrete incorporating SD and SCBA

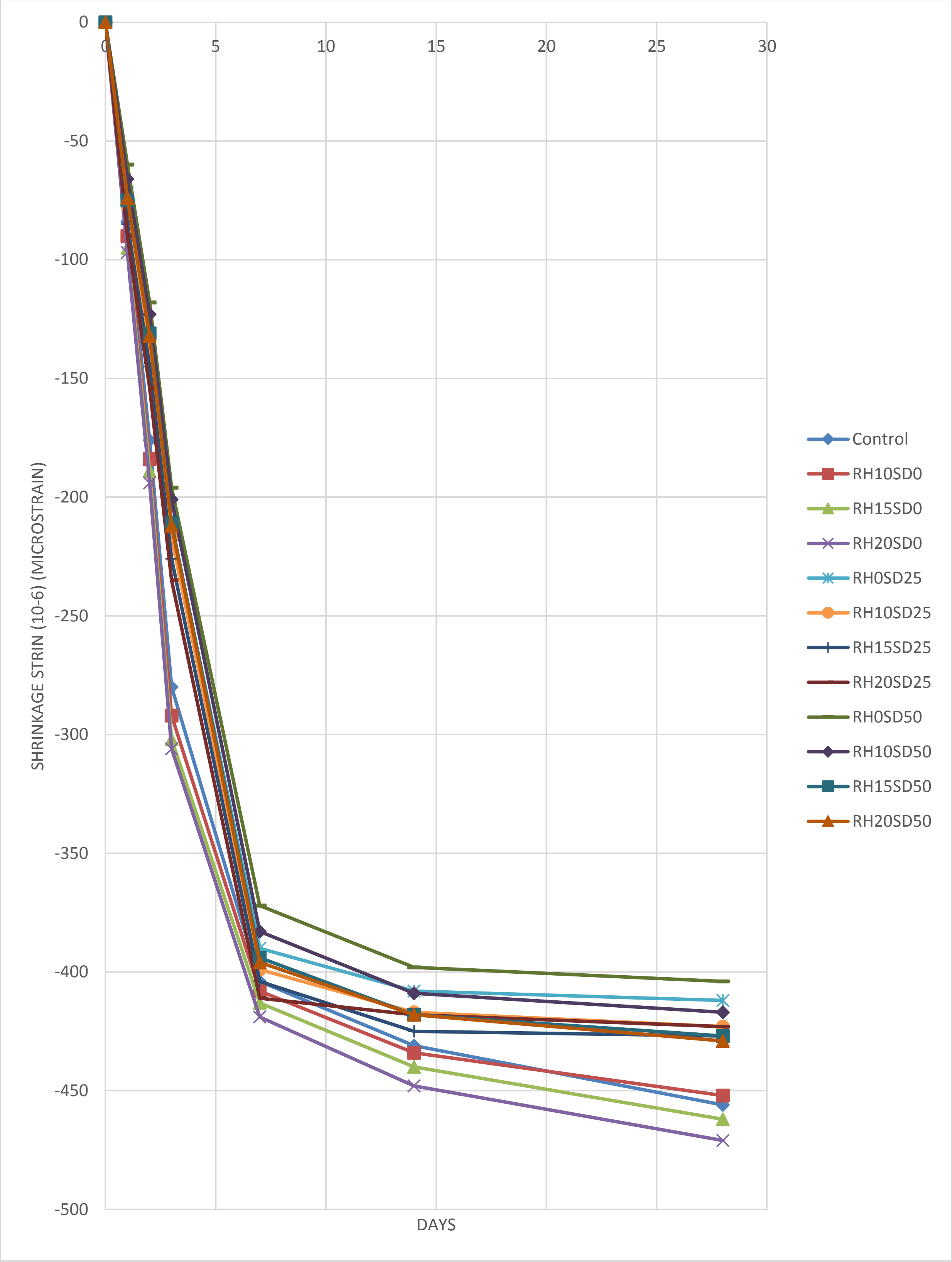


Figure 16. The results of Shrinkage strain of concrete incorporating SD and RHA

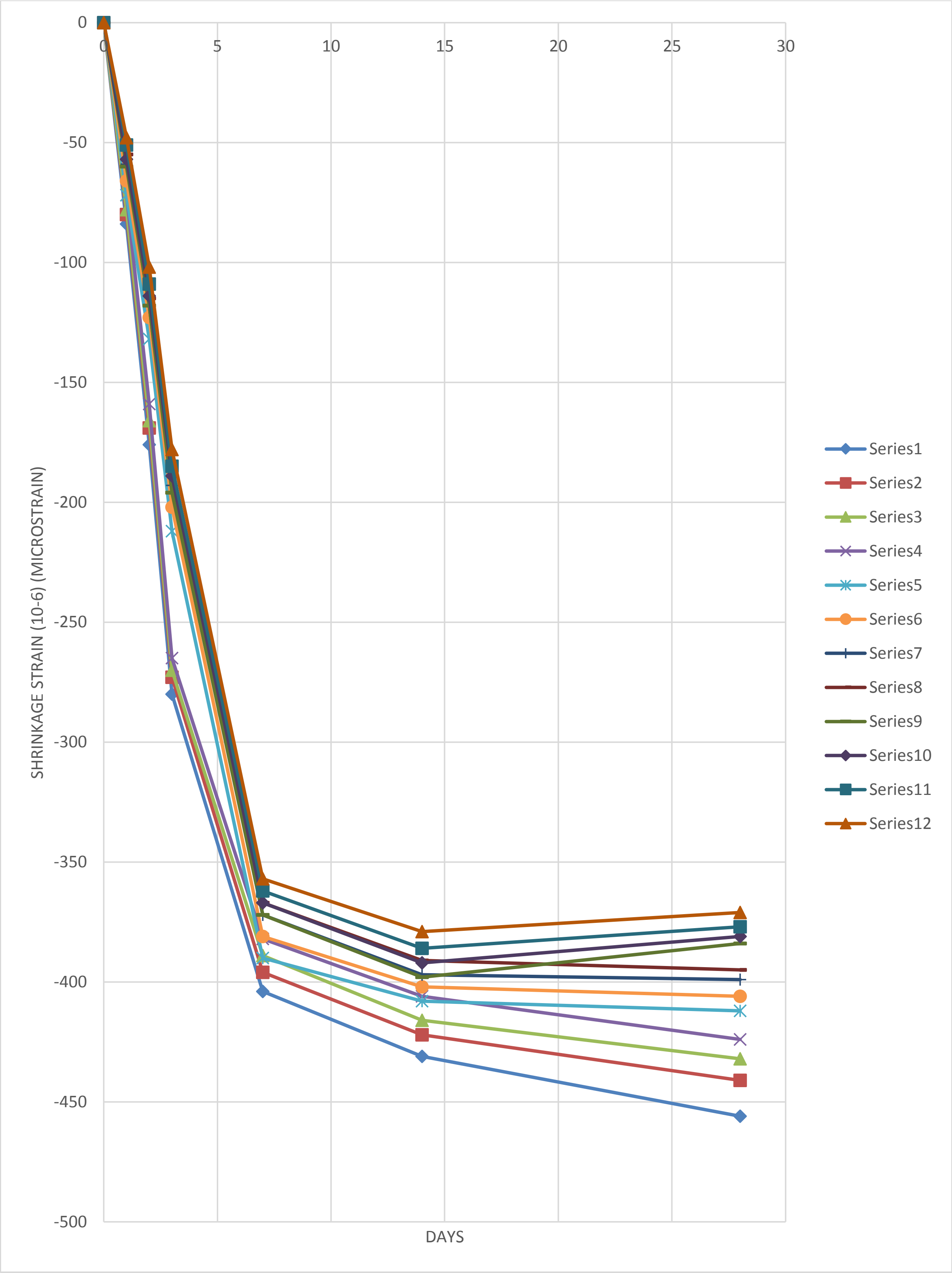
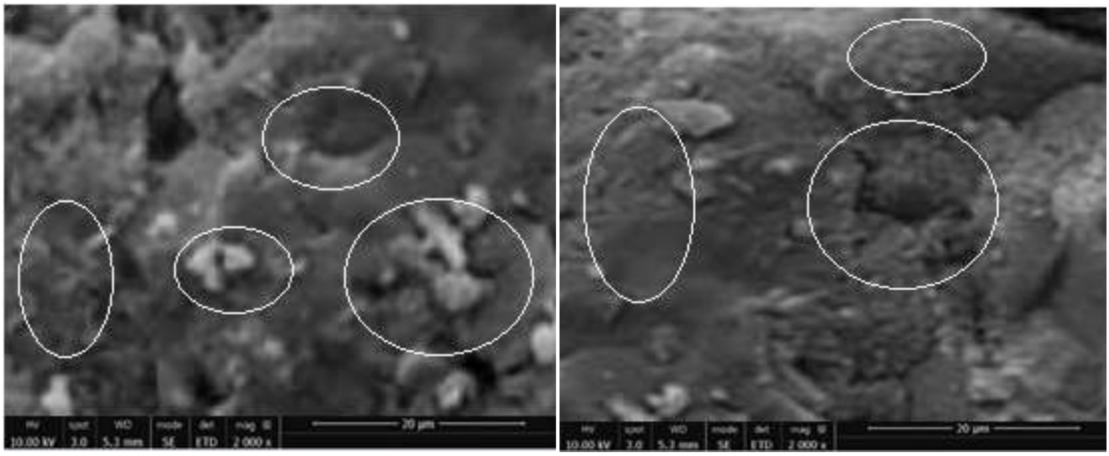


Figure 17.The results of Shrinkage strain of concrete incorporating SD and LS

4.9 SEM analyses

Fig 18 (a) presents the 28-day SEM micrograph of common concrete. The shape of the hydration phases is difficult to define, indicating that the hydration is increasingly slowing down. This is due to the fact that cement hydrates overlap to fill out the inner space of a concrete matrix in order to produce a smaller compact structure with a reduced volume of pore. Despite a few microcracks were found, they were evenly distributed with no tendency of directional propagation. Fig.18(b) shows a high-density structure in RHA concrete, which creates additional hydration products after 28 days as a result of the secondary hydration process. In the C-S-H clusters, the needle-liking ettringite was intimately incorporated and formed a spatial network structure leaving extremely little interstices in the matrix. The RHA concrete exhibits less microcracks compared to the control mix. Figure 18(c) demonstrates that CH, C-S-H and pores exist in SCBA mixes for 28 days with an examination of the morphology. An analysis does not identify clearly other products of hydration such as monosulphate and ettringite. C-S-H gel development was detected 28 days later. They are formed as a continuous fibrous network.. The mix BA20SD0 with 20% bagasse also showed a highly dense network of C-S-H. However, the presence of pores is slightly identified in it with a large pore structure. The presence of CH is indicated by hexagonal type plates in the SEM micrographs. They are mostly present as stacks of hexagonal plates arranged continuously over one other. The microstructure of LS concrete is more compact than that of normal concrete as observed in Fig18(d).This is why the use of calcareous in concrete may greatly improve denser concrete growth. LS particles are distributed as nuclear sites in the cement composite into C-S-H gelsfunction. Particles of claystone obstructed the interstices between particles of cement. After 28 days, needle-like ettringite were detected with a C-S-H gel that was well hydrated.

Some of the fractures coupled with weakly crystalline portlandite crystals (circled into the picture) distributed over the mortar matrix were present in the microstructure of the concrete produced with an LS replacement. Previous investigations show that bonding might be reduced with the presence of portlandite in concrete. Similarly, in cast concrete using standard concrete, massive portlandite crystals with many breaks were found.The microstructure of the concrete cast with 20% LS was nonetheless reasonably thick without an observed interface fracture. In and around interfaces no portlandite crystal was found. A thick microstructure in contrast to sand was also shown in the morphology of concrete cast with SD contents. Due to the presence of a fine LS, micro-bluing at the whole interface decreased the formation of crack and portlandite. The thick concrete microstructure with 25 percent SD increased its strength, water permeation resistance and non-porosity.



(a)

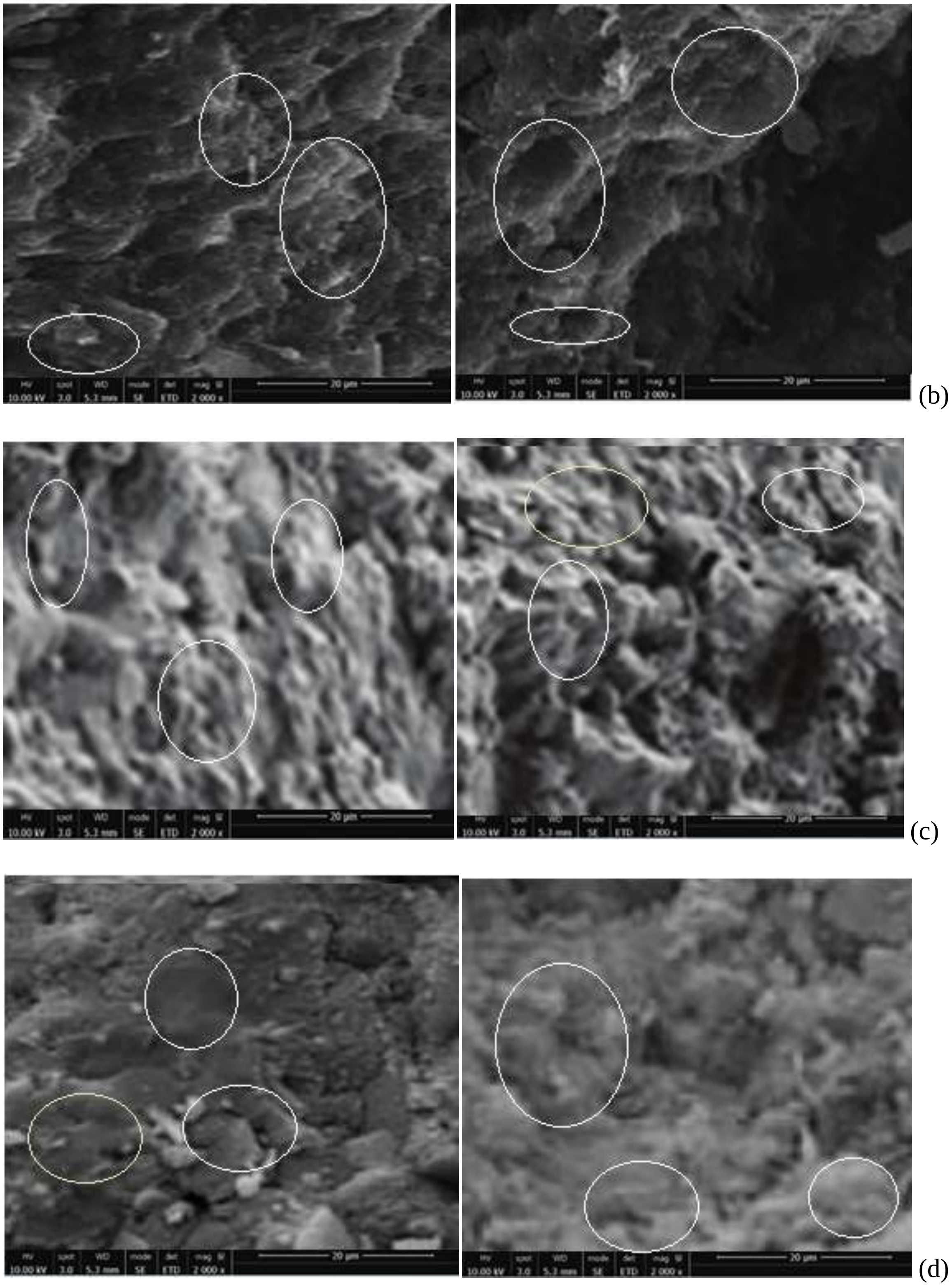


Fig 18 : SEM analysis of concrete incorporating RHA ,SCBA , LS and control mix

4.10 Carbon footprint of materials

The major greenhouse gas causing global warming is considered to be the carbon dioxide. There have been several potential initiatives to minimize CO_2 emissions by replacing the huge use of cement with various alternative cement materials. RHA, SCBA and LS are among these materials an attempt at reducing concrete cement content. In addition, it minimizes the scanty landfilling and waste management using these residue materials in the concrete industry. The impacts of alternative concrete on the environment were thus also assessed.The embodied energy of individual materials has been obtained from various courses. For example, the embodied energy for cement was taken as 0.73 kgCO_2 eq/kg given in ICE (Inventory of Carbon and Energy) whereas the values for RHA ,SCBA and LS were taken to be 0.057, 0.051 and 0.032 kgCO_2 eq/kg. in case of sand and SD values considered were 0.006 kgCO_{2e}eq/kg. The overall CO_2 emission values calculated for one cubic meter concrete were shown in table 17.

Table 17. CO2 emissions associated with per cubic meter of concrete

Code	**CO_{2e} Kg/kg**	**Code**	**CO_{2e} Kg/kg**	**Code**	**CO_{2e} Kg/kg**
CONTROL			303.23		
RH10SD0	275.64	**BA10SD0**	275.39	**LS10SD0**	274.61
RH15SD0	261.45	**BA15SD0**	261.08	**LS15SD0**	259.92
RH20SD0	248.04	**BA20SD0**	347.55	**LS20SD0**	246
RH0SD25	303.23	**BA0SD25**	303.23	**LS0SD25**	303.23
RH10SD25	275.64	**BA10SD25**	275.40	**LS10SD25**	274.61
RH15SD25	261.45	**BA15SD25**	261.09	**LS15SD25**	259.92
RH20SD25	248.05	**BA20SD25**	247.56	**LS20SD25**	246
RH0SD50	303.23	**BA0SD50**	303.23	**LS0SD50**	303.23
RH10SD50	275.64	**BA10SD50**	275.40	**LS10SD50**	274.61
RH15SD50	261.45	**BA15SD50**	261.09	**LS15SD50**	259.92
RH20SD50	248.05	**BA20SD50**	247.56	**LS20SD50**	246

Increase in Incorporation of waste materials resulted in decrease in carbon emission as shown in figure 19.The total CO2eq for RH20SD50 ,BA20SD50 and LS20SD50 concrete were 248 ,247 and 246 while the ordinary concrete emits 303.23 kg for 1 cubic meter of concrete.The total CO_2eq for RH20SD50 ,BA20SD50 and LS20SD50 concrete were 18.21 ,18.54 and 18.9 %

lower thanordinary concrete. This shows that reducing the cement content of the concrete is themost significant measure to be sustainable and environmentally friendly in the concrete industry.

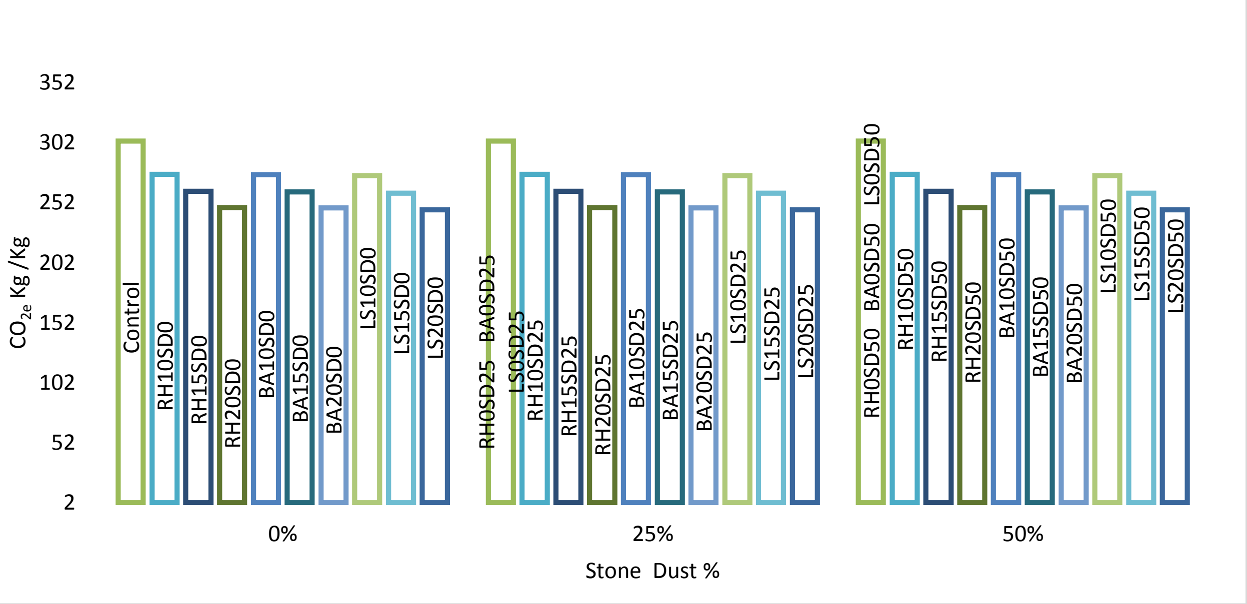


Figure 19.CO_{2e} emissions for all material mixes

4.11 Cost Analysis

Material costs are the main issue in the constructionindustry, and building materials usually have severe environmental effects. By using locally available waste materials as an alternative for cement and natural aggregates the cost of materials can be reduced to produce concrete product. The following information was analyzed during this study.

As per mix designs during this research study, the ratios and prices of coarse and fine aggregates were assumed as per local market rate. The factor affecting the cost of concrete was the use of RHA, SCBA and LS as partial replacement of cement and SD as partial replacement of sand. A bag of 50 kg cement waspurchased at a local market at a price of 13 Rupees per kg . The cost of RHA ,SCBA and LS was 2.4 ,2 and 1.2 rupees per kg respectively.The cost for sand and SD was 1 and 0.37 rupees per kg respectively whereas the cost of coarse aggregate was 1.5 rupees per kg.

Many other important elements, such as transport, tax, delivery and labor costs, are present in cost analysis. In analyzing these elements rely on project size, project location, seasonal variability, market variations etc. However, there is a significant degree of uncertainty. The cost analysis is thus based on materials for this investigation.The values of cost analysisperformed was shown infigure 20 and table 18.The cost comparison was made for 1 cubic meter of concrete incorporating dual replacement with control. Based on the achieved costsper cubic meter , the concrete RH20SD50 was 13.7% cheaper than ordinary concrete, whereas the concrete BA20SD50 was 14.15% cheaper than ordinary concrete and the concrete LS20SD50 was 15% cheaper than ordinary concrete.

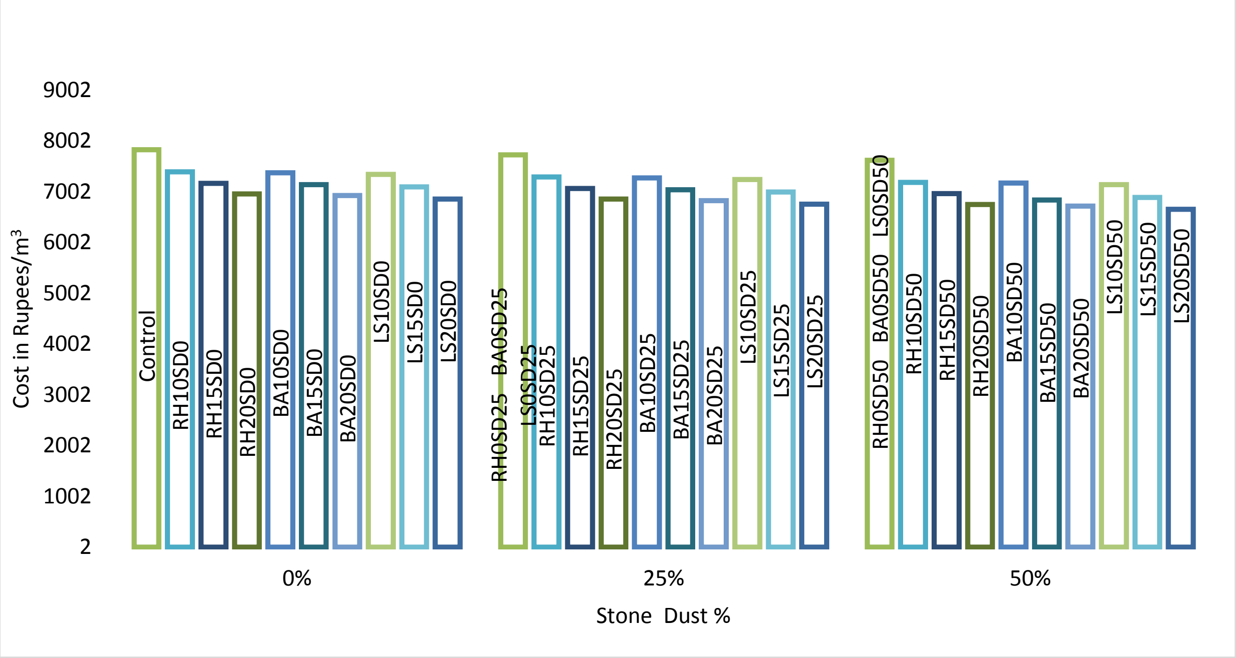


Figure 20. Cost pe cubic meter of concrete

Table 18. Cost analysis of all mixes in rupees

Code	**Cost in Rs per m^3**	**Code**	**Cost in Rs per m^3**	**Code**	**Cost in Rs per m^3**
CONTROL			7828		
RH10SD0	7393	**BA10SD0**	7377	**LS10SD0**	7344
RH15SD0	7168	**BA15SD0**	7144	**LS15SD0**	7095
RH20SD0	6959	**BA20SD0**	6926	**LS20SD0**	6860
RH0SD25	7726	**BA0SD25**	7726	**LS0SD25**	7726
RH10SD25	7291	**BA10SD25**	7275	**LS10SD25**	7242
RH15SD25	7066	**BA15SD25**	7042	**LS15SD25**	6993
RH20SD25	6856	**BA20SD25**	6824	**LS20SD25**	6758
RH0SD50	7622	**BA0SD50**	7622	**LS0SD50**	7622
RH10SD50	7188	**BA10SD50**	7171	**LS10SD50**	7139
RH15SD50	6963	**BA15SD50**	6838	**LS15SD50**	6890
RH20SD50	6753	**BA20SD50**	6720	**LS20SD50**	6655

CHAPTER 5

5. Conclusions and Recommendations

5.1 Introduction

There were four materials utilized in the current study that consisted of three secondary cementitious materials and one material used was an inert filler. Locally available waste materials , Rice husk ash (RHA), Sugar cane bagasse ash (SCBA) and Limestone Powder (LS) were used as a partial substitution of cement along with Stone Dust (SD) as a partial substitution of sand in this study. The partial substitution of secondary cementitious material was varied from 0 to 20% , wnereas the partial substitution of inert filler was varied from 0 to 50%.

5.2 Conclusions

Based on the experimental results, following conclusions can be drawn:

1. By increasing the RHA , SCBA and LS as partial replacement of cement along with SD in mixloss of slump was observed, however.Moreover, the maximum decrease in slump was measured in LS20SD50.
2. Density of fresh concrete was also improved by the use of SD as a partial replacement of sand in all mixesin concrete. Similar trend was found in case of LS, however in case of RHA andSCBA incorporationslight decrease in density was observed.
3. Significant enhancement of compressive strength was measured by the incorporation of 25% SD as partial replacement of sand. The optimum strength compared to control was observed in case of 20% RHA and 15% SCBA. The observed increase of compressive strength as compared to control sample was 16.5%. in case of RHA and 19.8% in case of SCBA replacement along with SD replacement i.e., in RH20SD25 and BA15SD25, respectively . In

case of LS replacement up to 20% decline in compressive strength was observed i.e., in LS20SD0.In case of LS replacement, a slight decrease in compressive strength was observed.

4. Split tensile strength and flexural strength was also enhanced similar to compressive strength. Increase in Split tensile strength up to 15.5% in case of RHA and 20% in case of SCBA was observed as the dual replacement with cement and SD with sand was made i.e., RH20SD25 and BA15SD25. Whereas LS replacement resulted in decrease up to 18% in case of LS20SD50.
5. Higher absorption of water was observed in RH20SD0 and BA20SD0. Incorporation of SD resulted in the decrease of water absorption which may also be noted as in case of volume of permeable voids. On other hand replacement of LS with cement along with dual replacement of SD with sand resulted in a gradual decrease in water absorption.
6. As the amount of replacement increases in case of RHA and SCBA the values of shrinkage also increases slightly in first 7 days ,after that the change in drying shrinkage was not of high value. Whereas the SD replacement showed a very small change in shrinkage as the percentage increases. Similar trend of decrease was observed in case of LS replacement.
7. Low-cost mechanically enhanced concrete can be produced by incorporating 20% of RHA and 15% SCBA respectively, along with SD as a partial replacement of sand
8. Use of RHA and SCBA results in decrease of cement production which may have good impact on environment and reduce the carbon footprint whereas the use of SD in concrete can effectively minimize the disposal of wasteful and conserve the depleting resource of natural river sand.

5.3 Recommendations

1. High volume replacement of RHA , SCBA and LS, as a replacement of cement in concrete can be studied, similarly SD can be used in concrete to eliminate the use of natural sand, as it is evident from test results that the strength of concrete does not degrade appreciably by the replacement of stone dust so even 50 percent replacement of SD may be recommended.
2. Research be carried out on the use of more natural pozzolanic materials as a dual replacement in both cement and sand such as wheat, corn, bamboo ashes, similarly like SD industrial waste such as coal ash waste ceramic waste, leather industry waste and rubber tire waste can be used
3. Dual replacement of RHA ,SCBA and LS along with SD in cement mortar for brick masonry and plaster also need to be evaluated.
4. Research can be carried out on small fractions of SD i-e 30%, 35%, 40% and 45% in order to evaluate the further optimum values between 25 and 50%.
5. Mathematical models may be derived for this study to get percentages of RHA, SCBA, LS and SD for desired strengths

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