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EXPERIMENTAL STUDY OF CONCRETE WITH SUGARCANE BAGASSE ASH (SCBA) AT ELEVATED TEMPERATURE

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Abstract

The partial incorporation of natural pozzolans like sugarcane bagasse ash in concrete construction is of the prominent attention to meet the high demand for cement while also ensuring a sustainable environment. The sugarcane bagasse ash has higher percentages of silica compared to ordinary Portland cement (OPC). When sugarcane bagasse ash undergoes pozzolanic reaction, additional Calcium Silicate Hydrate (C-S-H) is formed in cement hydration matrix. This study concentrates on the effectiveness of using sugarcane bagasse ash (SCBA) as a cement substitute in concrete at prolonged elevated temperatures. For investigation different compositions of SCBA (5%, 10% and 15%) were added to the concrete with a water-cement ratio of 0.49. The compressive strength of the test samples was investigated at room temperature (26°C) for reference performance along with the several elevated temperatures of 60°C, 120°C, 180°C, and 240°C for two hours. Afterward, the concrete efficiency was assessed considering the residual compressive strength. The result shows an improvement of compressive strength up to 10% SCBA inclusion at room temperature. Moreover, concrete specimens which are exposed to elevated temperatures exhibit a notable decrement of compressive strength. However, the descending rate of compressive strength was low in case of SCBA concrete compare to other pozzolanic mixture. A 10% substitution of cement with sugarcane bagasse ash (SCBA) demonstrated most observable mixing in concrete considering cost effectiveness and resistance against elevated temperatures.

Keywords: Sugarcane Bagasse ash; pozzolanic material; Compressive strength; Elevated temperature; Environment sustainability

1.0 INTRODUCTION

Concrete is an extensively used and popular material due to its widespread success, which can be attributed to the fact that it is inexpensive, simple in manufacturing and can be used locally. The most widely used binder in concrete production is Portland cement. However, the use of cement has a significant effect on the environment for producing an enormous amount of greenhouse gases (i.e., CO_2), kiln and mineral dust from cement industries, gaseous emission (NOx, SOx, PM, TSP etc.) (Al Smadi et al., 2009; Capros et al., 2001; Hendriks et al., 1999; Humphreys & Mahasenan, 2002; Josa et al., 2007; Mishra & Siddiqui, 2014; Potgieter, 2012; Saheed Bada et al., 2013). Hendricks (Hendriks et al., 1999) reported that the reduction of CO_2 emissions extends to 20 to 40% by using the wastes in concrete. Moreover, utilization of recycled wastes from industries and agricultural works as supplementary cement materials (SCMs) in concrete production is gaining popularity around the world due to the growing environmental influence of the cement and concrete industry, as well as the rising demand for infrastructure in both developed and developing countries (Martirena & Monzó, 2018; Siddique, 2010). Several researchers reported about the pozzolanic characteristics of some agricultural and industrial waste (rice husk, sugarcane bagasse ash, corncob ash, municipal solid waste ash, biomass ash etc.), which can be utilized as a partial supplement of cement in concrete production (Joshaghani & Moeini, 2018; Martirena & Monzó, 2018; Nicoara et al., 2020; Paul et al., 2019; Singh et al., 2018).

Sugarcane bagasse is a form of agricultural waste that is generated during the sugar production process, which is used as an energy source in the sugar industry. After being used, approximately 0.62 percent of sugarcane is turned into bagasse ash (SCBA) (Klathae et al., 2020). Most studies show that replacing 10% to 15% of the cement with SCBA increases compressive strength and durability (Castaldelli et al., 2013; de Paula et al., 2010; Lima et al., 2021; Setayesh Gar et al., 2017; SRINIVASAN & Sathiya, 2010). Again, increment of SCBA content in concrete results in a marginal decrease in workability and prolonged setting time (Subramaniyan & Sivaraja, 2016). However, partial cement substitution by SCBA content exerts the reduction of chloride diffusion, GHG (CO_2) emissions and improves concrete's endurance to alkali attack (Amin, 2011; Fairbairn et al., 2012; Mulay, 2017). If the bagasse calcinates at a higher temperature, the pozzolanic reactivity of SCBA is intensified (Bahurudeen & Santhanam, 2015).

The physical and mechanical properties of the aggregates in concrete buildings are degraded in the event of a burning, resulting in a dramatic reduction in the load bearing capability of structures, which can also lead to the building collapsing in severe cases. As a result, studying the mechanical properties of concrete at elevated temperatures is crucial. Under intense high temperatures, cement-based structures have been thoroughly investigated and compressive strength increment up to a temperature of 300-400 °C is observed (Jamnu, 2017; Maluk, 2016). Surface cracks appear at higher continuous temperatures, becoming more evident at temperatures above 800 °C. Between 400 and 800 °C, the rate of strength loss is slow, but at higher temperatures, it is rapid. When exposed to temperatures above 1000 °C, concrete specimens typically disintegrate. Related behavior is seen in high-strength concrete. However, the strength loss tends to appear at lower prolonged temperatures (Husem, 2006; Jamnu, 2017). The application of supplementary cementitious materials is effective for both reducing the effects of extended temperatures and the mechanical behavior (Bayapureddy et al., 2020; Gholhaki et al., 2018; Nicoara et al., 2020; Oyelade et al., 2018; Paul et al., 2019; Rao & Tummalapudi, 2012; Umasabor & Okovido, 2018).

The foremost purpose of the research is to investigate the feasibility and efficacy of employing SCBA as supplemental cementing material at elevated temperatures. For 2 hours, the specimens were subjected to temperatures of 60 °C to 240°C and the residual compressive strength was measured to assess the efficiency of concrete.

2.0 MATERIALS AND METHODS

2.1 Cement

In this study, ordinary Portland cement (OPC) having a strength class of 52.5 N was used. The initial setting time for this cement was 45 minutes, and its early strength after two days was 20 MPa. OPC has a specific gravity of 3.12 and is composed of 95-100 percent clinker and 0-5 percent gypsum.

2.2 Aggregates

The fine aggregate in this analysis was coarse sand, while the coarse aggregate was crushed stone chips. Grading of aggregates is shown in **Table 1** and **Table 2** demonstrates the physical properties of these aggregates.

Table 1 Grading of aggregates

Sieve size, mm	Cumulative % passing of graded aggregates	
	Aggregates used for experiments	ASTM grading limit (Ref. ASTM C33-03)
25.0	100%	100
19.0	90%	90-100
12.5	35%	-
9.5	30%	20-55
4.75	10%	0-10
2.36	5%	0-5

Table 2 Aggregate physical properties

Physical Property	FA	CA
Bulk Specific Gravity (OD Basis)	2.52	2.66
Absorption Capacity (%)	1.35	0.69
Fineness Modulus (FM)	2.60	-
Dry Rodded Unit Weight (kg/m^3)	1602	1550

Table 3 The Physical and Chemical Composition of Bagasse Ash and OPC

Properties	Cement, %	SCBA, %	Reference
SiO_2	17-25	60-85	(Abbas et al., 2020; Balan L et al., 2018; Grau et al., 2015; Jagadesh et al., 2020; Norsuraya et al., 2016; Paul et al., 2019; R et al., 2012; Reddy & Kishore, 2017; Sales & Lima, 2010; Setayesh Gar et al., 2017)
Al_2O_3	3-8	4-20	
Fe_2O_3	0.5-6	1.3-7	
CaO	60-67	2.1-11.8	
SO_3	2-3.5	0.66-1.48	
MgO	0.5-4	1.10-2.51	
K_2O	0.35-0.53	1.69-3.53	
Loss of Ignition	<3	1.09-4.73	
Mean particle size (μm)	28	30	
Specific Gravity	3.10-3.25	2.218	

2.3 Sugarcane Bagasse Ash (SCBA)

2.3.1 Physical and Chemical Composition

Sugarcane Bagasse was accumulated from a local sugarcane juice shop (Figure 2). After drying, the bagasse was burned with a controlled temperature of 700°C for 1.5 hrs. SCBA consists of high SiO_2, Al_2O_3, material. So that it can be used as secondary cementitious material. Chemical composition of SCBA depends on burning temperature (controlled and uncontrolled) and duration. **Table 3** shows the physical and chemical composition of SCBA along with OPC.

2.3.2 Particle Size Distribution

Sieve analysis by washing (ASTM C117-17, 2017)) and hydrometer analysis (ASTM D7928 - 17, 2017)) were followed to determine particle size distribution (**Figure 1**). SCBA is extremely soluble, has a low density, and contains 80% fine particles with a diameter of less than 75 µm.

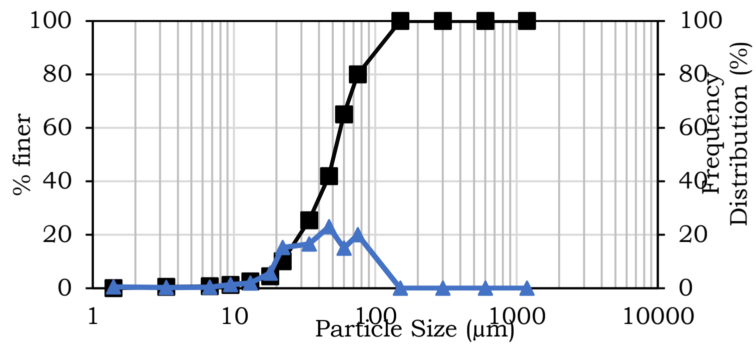
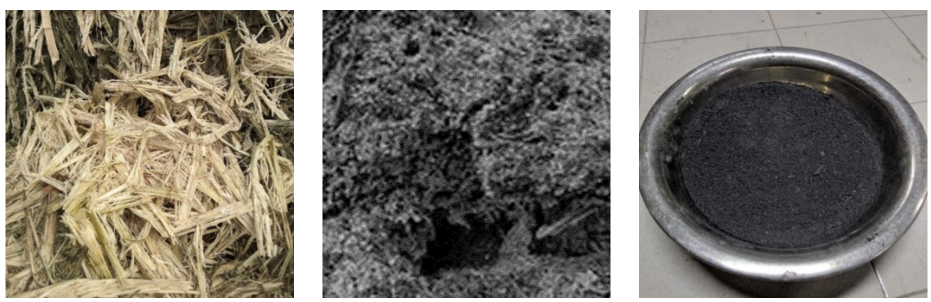


Figure 1: Particle size distribution of SCBA



(a) (b) (c)

Figure 2 (a) Sugarcane bagasse (raw), (b) SCBA (burned) (c) SCBA (after grinding)

2.4 Concrete Mix Proportion

The mix design (**Table 4)** was undertaken in accordance with the American Concrete Institute's guidelines, ACI 211.1-91 (ACI 211.1-91, 2009). The trail mixes were designed to achieve an intended strength of 25 MPa after 28 days and a slump value of 75-100 mm. All the aggregate delivered to the saturated and surface dry (SSD) condition before mixing. For a two-minutes duration of dry mixing, adequate quantity of fine aggregates (FA), coarse aggregate (CA), cement and SCBA were taken. After mixing with water concrete workability was measured using a slump cone. A tamping rod was used to tamp the concrete into the cube. Using a smooth steel trowel, the fresh concrete was completed. Within 24 hours, the molds are removed, and the test specimens are immersed in water to cure.

Table 4 Mix design of the concrete used in the experimental investigation

Sample Designation	% SCBA	Cement (kg/m³)	SCBA (kg/m³)	Water (kg/m³)	CA (kg/m³)	FA (kg/m³)
PC	0%	418.5	0	205	997	730.5
SCBA5	5%	397.58	20.92	205	997	730.5
SCBA10	10%	376.65	41.85	205	997	730.5
SCBA15	15%	355.73	62.77	205	997	730.5

2.5 Compressive strength testing

Some factors affect the compressive strength of concrete including the w/c ratio, quality of cement and concrete material, quality control during the manufacturing, and others. Generally, compressive strength is measured using either a cube or a cylinder. The cube has been used in this experiment. After 28 days of curing concrete cubes (150×150×150 mm) were air dried and placed in an electric oven at various (60 to 240 °C) temperature for two hours. The cubes were driven out from the oven and after cooling at room temperature, the uniaxial compressive strength test was carried out using Universal Testing Machine (UTM) (**Figure 3**).

Figure 2: Compressive Strength Testing

3.0 RESULTS AND DISCUSSION

3.1 Effectiveness of sugarcane bagasse ash on concrete

Figure *5* shows how concrete made with SCBA can maintain its strength even though 10% of the cement is replaced, because of the pozzolanic activity of SCBA. If the amount of SCBA in the system grows more than 10%, the compressive strength gradually decreases. However, Rice husk ash and/or other complementary mineral admixtures (i.e., fly ash) with different silica content are often shown the similar effects (Shang & Yi, 2013; Wang et al., 2017). According to **Figure 4**, there was a steady decline in compressive strength for all mixing proportions of concrete as the continuous temperature increased, regardless of cement substitution by SCBA.

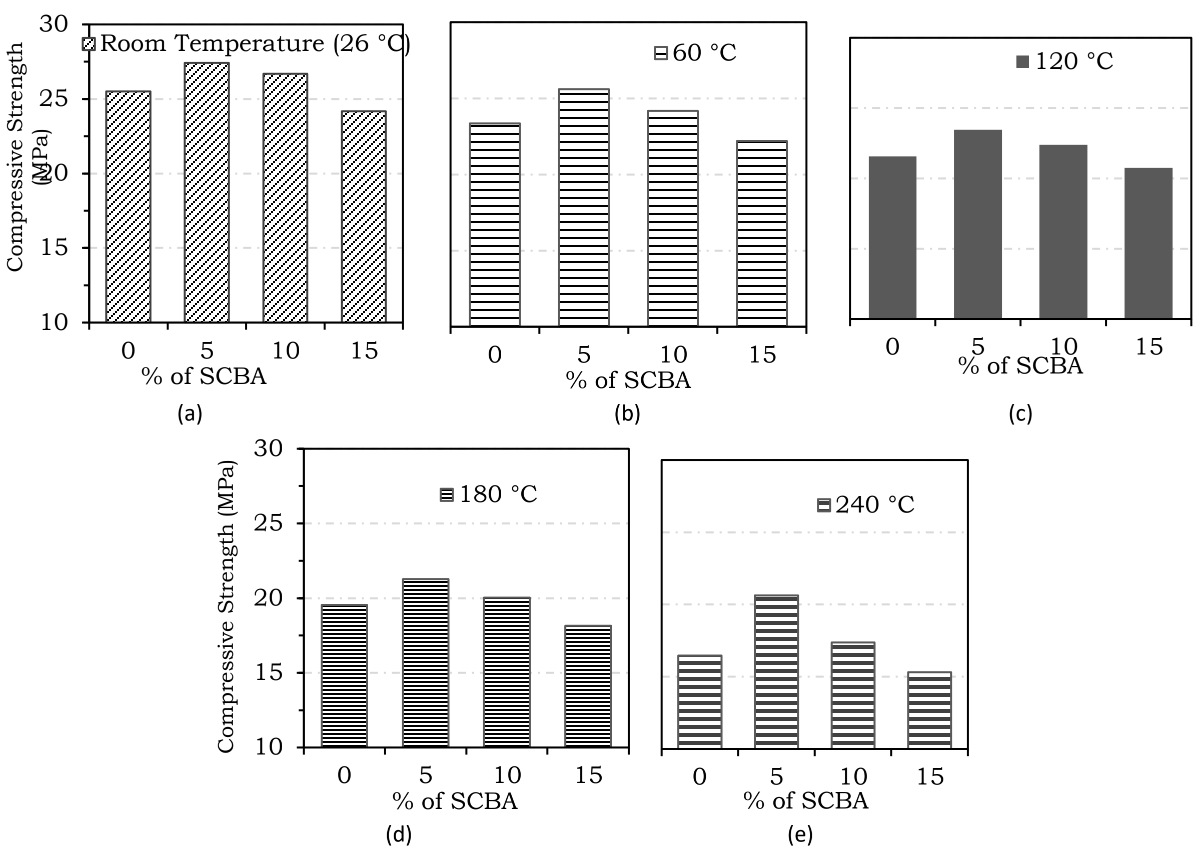


Figure 3: Comparison of Compressive strength with % of SCBA for (a) room temperature (26 °C), (b) 60 °C, (c) 120 °C, (d) 180 °C, (e) 240 °

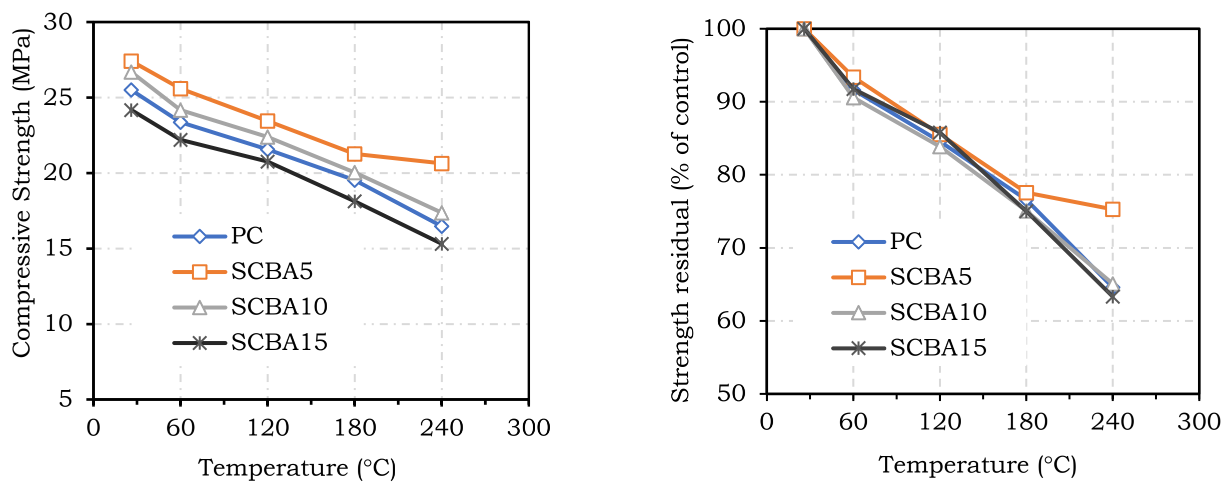
3.2 Influence of temperature on compressive strength

The compressive strength of plain concrete was compared with SCBA concrete. **Table 5** demonstrates the compressive strength of plain concrete and SCBA concrete at different elevated temperatures after 28 days of curing. As compared to the compressive strength of various mixes with plain concrete at room temperature of 26 °C an increment of compressive strength about 25.32% was found. However, at elevated temperature at 240 °C, compressive strength of concrete with 5% SCBA shows a decreasing pattern but it remains comparable with plain concrete with 7.53% higher compressive strength than normal concrete mixer (Rao & Tummalapudi, 2012) reported 10% cement replacement by rice husk ash shows the maximum increment of compressive strength compared to the plain concrete at the same temperature. Nevertheless, up to 240 °C, the residual strength of all mixes decreased significantly. Beyond the temperature of 180 °C, the rate of strength loss declines with a 5% substitution of cement (**Figure 5b**).

Table 5 Compressive strength of concrete

Temperature	SCBA (%)	Compressive Strength (MPa)	Strength increase / decrease (%)	RHA (%)*	Strength increase /decrease (%) *
Room Temperature (26 ˚C)	0	25.5	-	-	-
	5	27.42	7.53	5 (27 ˚C)	5.48
	10	26.69	4.67	10 (27˚C)	10.76
	15	24.18	-5.18	15 (27˚C)	-1.39
60 °C	0	23.36	-	5 (100 ˚C)	4.76
	5	25.6	9.59	10 (100˚C)	11.10
	10	24.17	3.47	15 (100˚C)	-1.15
	15	22.19	-5.01	5 (300˚C)	3.09
120 °C	0	21.57	-	10 (300˚C)	13.89
	5	23.46	8.76	15 (300˚C)	-3.95
	10	22.38	3.76		
	15	20.75	-3.80		
180 °C	0	19.53	-		
	5	21.27	8.91		
	10	20.03	2.56		
	15	18.14	-7.12		
240 °C	0	16.47	-		
	5	20.64	25.32		
	10	17.37	5.46		
	15	15.31	-7.04		

*** Rao et al; 2012**



(a) (b)

Figure 4: Comparison of (a) compressive strength with elevated temperatures (b) residual strength (normalized at room temperature of 26 °C) with elevated temperatures.

3.3 Regression Analysis

At different percentages of cement substitution with SCBA, a regression equation is found between compressive strength and exposure temperature. SCBA has a lower decremental rate of compressive strength than CCA (Corn cob ash) and FGP (Finely ground pumice) with a 5% cement substitution. However, for cement substitution more than 5% SCBA shows a strong sign of a higher decremental rate of compressive strength (**Table 6**).

Table 6 A summary of effect of temperature on compressive strength of concrete made with different cement replacement materials

Cement Replacement	W/C	R^2	Regression equation for elevated temperature, $\sigma_c = a + bT$	Reference
5% SCBA	0.49	0.9595	-0.0322T + 27.711	[a] Mwilongo et al., 2020 (Mwilongo et al., 2020) [b] Oyelade et al., 2018 (Oyelade et al., 2018) [c] Singh et al., 2018 (Singh et al., 2018) [d] Li et al., 2012 (Li et al., 2012) [e] Demirel & Keleştemur, 2010 (Demirel & Keleştemur, 2010)
5% NSHA[a]	0.5	0.7929	-0.0218T + 29.836	
5% PSMS[b]	0.45	0.5729	-0.0096T + 25.346	
5% CCA[c]	0.45	0.5556	-0.0327T + 38.413	
5% FGP[e]	0.5	0.5883	-0.0347T + 53.747	
10% SCBA	0.49	0.9872	-0.0412T + 27.285	
10% NSHA[a]	0.5	0.6451	-0.0261T + 35.698	
10% PSMS[b]	0.45	0.7666	-0.0149T + 28.43	
10% CCA[c]	0.45	0.5846	-0.0281T + 32.604	
10% GGBFS[d]	0.41	0.9504	-0.0481T + 49.579	
10% FGP[e]	0.5	0.4502	-0.029T + 52.573	
15% SCBA	0.49	0.9883	-0.0397T + 25.079	
15% PSMS[b]	0.45	0.6335	-0.0138T + 25.863	
15% CCA[c]	0.45	0.5805	-0.0198T + 26.735	
15% FGP[e]	0.5	0.4988	-0.0267T+ 49.908	
5% FGP + 10% SF[e]	0.5	0.5619	-0.0444T + 57.367	

NSHA: neem seed husk ash, PSMS: pulverized steel mill scale, CCA: corn cob ash, FGP: finely ground pumice, SF: silica fume, GGBFS: ground granulated blast furnace slag

3.4 Crack Pattern of Concrete Cube Specimen

The failure pattern of concrete cube specimens at room temperature are shown in **Figure 6**. The behavior of failure was individualized based on crack initiation, crack propagation and ultimate failure of the specimen. In all cases, failures are along the line of action of load. In the ultimate failure, concrete cube specimen with containing 0% and 5% replacement of cement the lateral sides get spalled, whereas in 10% and 15% replacement inclined micro-crack developed near the corner. Micro-crack was visualized in concrete at comparatively lower stress with 15% replacement than in concrete with 0%, 5% and 10 % replacement. The scattering of crack was rapid in concrete with 0% replacement. The angle of inclination with respect to centroidal axis was about 45° and 20° for concrete with 10% and 15% replacement.

PC SCBA5 SCBA10 SCBA15

Figure 5: Crack pattern of concrete (at room temperature 26^0C)

3.5 Environmental Sustainability With Cost Effectiveness

The primary environmental concern in cement production is the emission of greenhouse gases (CO_2, NO_x etc.), dust, SO_x, volatile and non-volatile organic compounds, radioactive metals etc. (Al Smadi et al., 2009; Capros et al., 2001; Hendriks et al., 1999; Humphreys & Mahasenan, 2002; Josa et al., 2007; Potgieter, 2012; Saheed Bada et al., 2013). To attain sustainability, hygiene and health safety natural wastes having pozzolanic characteristics (ashes from biomass, vegetable, municipal solid waste, rice husk etc.) are increasingly being used as supplemental cementitious materials (Bertolini et al., 2004; Madurwar et al., 2013; Martirena & Monzó, 2018; Mishra & Siddiqui, 2014; Siddique, 2010). However, these supplementary materials have an incredible effect on cost reduction. In the context of Bangladesh, considering the cost of cement around 450 Tk per bag (50 kg) and SCBA as 1.5 Tk/kg, the cost reduction is found to be 4-13% with a 5-15% addition of SCBA. **Figure 7** demonstrates that up to 10% cement replacement is the optimum condition associated with the compressive strength.

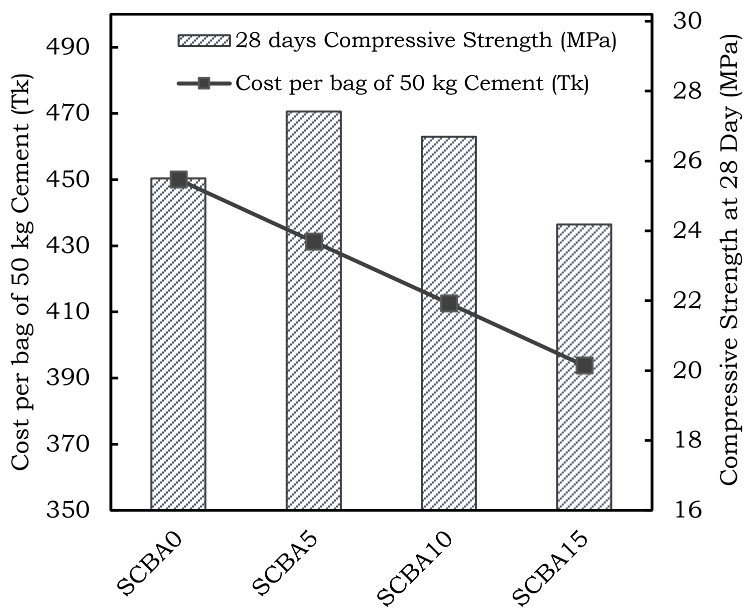


Figure 6: Comparison between cost reduction and percentage of cement replacement with SCBA

4.0 CONCLUSIONS

The possibility of utilizing SCBA as a supplement of cement in concrete for structures that are exposed to undergo high temperatures was investigated in this research. The following findings were obtained by relying on the residual compressive strength of the specimens exposed to elevated temperatures up to 240 °C with several percentages of cement substitution with SCBA-

- Incorporation of SCBA in concrete can maintain the compressive strength up to 10% cement substitution.
- The maximum compressive strength was found 25.32% for 5% cement substitution at room temperature with SCBA.
- For the uprising temperature, all samples showed a gradual fall in compressive strength.
- Based on regression analysis, SCBA shows a lower diminishing rate of compressive strength with temperature increment compare to other pozzolanic mixtures (CCA, FGP, GGBFS, SF).
- Based on cost effectiveness, the optimal condition for cost reduction considering compressive strength is 10% cement substitution. For 5-15% addition of SCBA, the cost saving is estimated at 4-13%.

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