Nature Environment and Pollution Technology
An International Quarterly Scientific Journal
p-ISSN: 0972-6268
(Print copies up to 2016)
e-ISSN: 2395-3454
Vol. 22 No. 1 pp. 327-338 2023
Original Research Paper
https://doi.org/10.46488/NEPT.2023.v22i01.033
Open Access Journal

Evaluation of the Energy Factor and Equivalent CO_2 Gas Emission by Utilization of Industrial By-products in Concrete for Environmental Protection

B. Saravanan*†, R. Divahar, S. P. Sangeetha** and M. Bhuvaneshwari*****
*Department of Civil Engineering, Vinayaka Missions Research Foundation, Salem, Tamilnadu, India
**Department of Civil Engineering, Aarupadai Veedu Institute of Technology, Chennai, India
***Department of Civil Engineering, SRM Institute of Science and Technology, Kattankulathur, India
†Corresponding author: B. Saravanan; saravanan.civil@avit.ac.in; sprsaro600@gmail.com

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 07-07-2022
Revised: 22-08-2022
Accepted: 07-09-2022

Key Words:
Global warming
Pozzolanic reaction
Red mud
Silica fume
Environmental issues
Binary blended cementitious system
Ternary blended cementitious system

ABSTRACT

Climate change and global warming are two of the world's most pressing environmental issues. With CO_2 being one of the most significant greenhouse gases released into the atmosphere, and cement and concrete manufacturing accounting for roughly 10% of worldwide CO_2 emissions, the construction sector must employ an environmentally sustainable substance as a substitute for cement. The CO_2 emissions, energy factor, and strength qualities of concrete were investigated. Those negative reaction of conventional cementitious substances is reduced by the development of binary and ternary cementitious systems. In this study, two mineral admixtures obtained from industrial waste substances, red mud (RM) and silica fume (SF), had been used as the alternatives for cement and fine aggregate was fully replaced by manufactured sand (M-sand). An experimental examination of the compressive strength, water absorption, density of concrete, equivalent CO_2 emission, and energy factor for environmental benefits with the comparison of RM on SF-based eco-friendly concrete mix of M_{30} grade was used. A binary and ternary blended cementitious system with RM and SM was created with twelve various mix proportions, varying from 0-20% by 5% increases. From the binary blended cementitious system (BBS), based on the observed mechanical characteristic of concrete it was found that the optimum level of RM was 15% and SF was 10 % by the volume of cement. Similarly, for the ternary blended cementitious system (TBS), the level of 10% RM and 10% SF in the cement mixture provides a much higher improvement in compression strength compared to the alternative trials. The negative sign implies that replacing cement with RM and SF reduces energy consumption (-1.91% to -6.97%) and CO_2 emissions (-4.52% to -16.16%). The use of mineral admixtures such as RM and SM in supplementary cementitious materials results in a significant outcome and potential impact on the production of sustainable concrete that addresses environmental issues.

INTRODUCTION

A developing country like India requires enormous development of large infrastructural facilities which requires concreting for the infrastructural developments such as bridges, roads, and buildings. Concrete is a heterogeneous construction material formed by mixing cement and aggregates in the right amount of water to create a composite composition, that hardens with time. Consumption of concrete across the globe crosses 5.5 billion tonnes a year. The two main ingredients in concrete are cement and fine aggregates. Usually, a mix ratio is set at 15 to 20% of water, 60 to 75% aggregates, and 10 to 15% of cement. (Metilda et al. 2015, Venu Malagavelli et al. 2018). To lessen the CO_2 emissions brought on by the manufacture of portland cement and the significant demand for river sand. For sustainable construction, alternative materials must be found and used in concrete instead of fine aggregate and cement.

The cement industries are working on a sustainable approach to production to address environmental issues. Cost and energy-intensive aspects are issues in the manufacture of Portland cement. However, the main issue nowadays is that large amounts of greenhouse gases are produced, which have a negative impact on the environment. Several methods, substitutions, and supplements were used to lessen the use of portland cement (Kothai & Malathy 2015, Ushaa et al. 2015).

Additionally, within the forthcoming decade, as the construction intensity is at a very high level, the traditional fine aggregate, which was more suited to concrete, is anticipated to lose favor due to cost. As this anticipation of the proposed scarcity and unavailability of the natural fine aggregate (sand) is highly expected, M-sand could be the best alternative in the case that it satisfies the basic requirements to adapt to the concrete such as workability and strength (Verma et al. 2015, Mane et al. 2019, Nataraja et al. 2014).

Cement replaced partially with different percentages of Red mud, fly ash, Silica fume, GGBS, and metakaolin in the experimental concrete mix resulted in significant cost savings and the elimination of greenhouse gas emissions. (Anantha Lakshmi et al. 2016, Tanu & Sujatha 2022, Satyendra et al. 2015, Azad et al. 2021).

Red mud (RM) is a solid waste from bauxite ore processing with caustic soda to produce alumina (Al_2O_3). It increases the initial cement strength and sulfate attack resistance. Amorphous silicon dioxide and necessary fineness generate silica fume (SF), also known as micro silica, a highly reactive pozzolanic substance. SF is produced during the melting process used to produce silicon and ferrosilicon. M-sand is created by breaking down rock deposits into fine aggregate; it often has an angular form and size, a rougher surface, and a high concentration of microfine. In this investigation, binary and ternary cementitious systems were used to determine the performance of concrete, including silica fume and red mud substituted completely for fine aggregate in favor of M-Sand in the binary and ternary blends with regular portland cement.

Red mud was substituted for cement in concrete in various amounts during experiments, and it was found that 12.5% substitution provided the best compressive, flexural, and tensile strength. The findings show that red mud recycling can be employed in large-scale construction to reduce the financial and environmental costs associated with the production and use of conventional cement (Nenadovic et al. 2017, Shetty et al. 2014, Venkatesh et al. 2019). The workability was reduced while adding red mud which was rectified with the use of a super plasticizer (Al Menhosh et al. 2018, Ribeiro et al. 2012).

The compressive strength of the mix is significantly altered when cement containing a variable amount of silica fume is substituted. The required guarantee for employing silica fume to consistently replace cementitious pozzolanic components in concrete is provided by the larger improvements in average strength with 10% silica fume (Sobolev 2004, Wild et al. 1995, Behnood & Ziari 2008, Mazloom et al. 2004, Wong & Razak 2005). They concluded that, at room temperature, silica fume-containing concrete was significantly stronger than OPC concrete (Koksal et al. 2008, Bentur & Goldman 1989, Almusallam et al. 2004, Babu & Babu 2003). Similarly to this, the impact of silica fume on concrete's tensile strength at 28 days of age was examined (Hooton 1999, Bhanja & Sengupta 2005, Tanyildizi & Coskun 2008). They concluded that the silica fume-based concrete mixes will improve the tensile strength at the split. As a result, the environmental problems caused by the manufacturing and use of conventional cement will be resolved by this alternative cementitious material (Vivek et al. 2014).

Due to the rapid increase in construction activity and the need for construction materials, natural river sand has become scarce. As a result, a suitable substitute material that satisfies the necessary physical and mechanical requirements is needed. High tensile strength, high compressive strength, and high stiffness are characteristics of concrete that have had M-sand partially replaced; as a result, the concrete has a higher elastic modulus and less ductility (Weiguo et al. 2016, 2017 & 2018).

The objective of this research is to evaluate the mechanical properties of concrete and identify the optimum replacement % of silica fume and red mud with partially replacement cement and fully replacement M-sand with fine aggregate in concrete added with silica fume and red mud by its density of concrete, compressive strength, water absorption, equivalent CO_2 emission and energy factor for environmental benefits.

MATERIALS AND METHODS

Binder

The binder in concrete utilized for casting the requisite grade was OPC (53 grade). It confirms the specifications of IS: 12269 (1987), and its properties are given in Table 1.

Coarse Aggregate (CA)

Locally available Coarse aggregate used in the study of 20 mm size as per IS 383:1970. Some preliminary tests were done and their properties are described in Table 2.

Table 1: Physical properties of cement (53 grade).

Characteristics	Experimental Values
Soundness	1.2 mm
Specific gravity	3.15
Initial setting time	50 min
Final setting time	320 min
Consistency	32%
Compressive strength (MPa)	31.2 at 28 days

Table 2: Physical properties of CA.

Physical properties	Experimental Values
Surface Texture	Smooth
Specific gravity	2.8
Water absorption	3.5%
Fineness modulus	6.67
Impact Value	14.2

Table 3: Physical properties of M-sand.

Physical properties	Experimental Values
Size, micron	0.1
Surface area, $m^2.kg^{-1}$	20,000
Specific gravity	2.2
Bulk density, $kg.m^{-1}$	576

Water

Potable tap water was used to prepare and harden the concrete.

Manufactured Sand

As an alternative fine aggregate material, localized M Sand was used, which was tested for gradation and fineness according to IS: 383-1970 and the properties listed in Table 3.

Super Plasticizer

CONPLAST SP 430 was used as a water-reducing agent to achieve the necessary workability based on a new generation of modified sulfonated naphthalene polymers.

Red Mud

Red mud is a byproduct of the process used to make aluminum from its ore. The color of the resulting mud is determined by the original ore's makeup, or by the combination of minerals and bauxite. Fig. 1 shows the sample of mineral admixtures.

Silica Fume

The particle structure of the silica fume is very fine spheres and the chemical contents are high amorphous

(a) Red mud (b) Silica fume

Fig. 1: Sample of mineral admixtures.

Table 4: Chemical and physical composition of Red mud.

Chemical Composition (%)		Physical Possessions	Outcomes
SiO_2	3-50	Partial Size Distribution (in micrometer)	
Na_2O	4-4.5	D10	1.641
Al_2O_3	10-20	D50	14.41
Fe_2O_3	30-60	D90	62.458
TiO_2	2.5-.3.5	Specific Gravity($g.cm^{-3}$)	2.51
LOl	11-15	Fineness ($cm^2.gm^{-1}$)	1000-3000
CaO	1.5-2.5	pH	10.5-12.5

Table 5: Chemical and physical composition of silica fume.

Chemical Composition (%)		Physical Possessions	Outcomes
SiO_2	92.1		
MgO	0.3	Particle Size (typical)	<1μm
Al_2O_3	0.5	Specific Surface Area ($cm^2.gm^{-1}$)	2.22 13000-30000 $m^2.kg^{-1}$
Fe_2O_3	1.4	Bulk Density ($kg.m^{-3}$) Specific Gravity	450 2.22
SO_3	-		
LOl	2.8		
CaO	0.5		
Na_2O	0.3		
K_2O	0.7		

silicon dioxide. Small amounts of oxides of alkali metals, magnesium, and iron are also found. The physicochemical composition of red mud and silica fume is given in Table 4 and Table 5.

Experimental Investigation

Mix Proportioning

An M30 grade mix of concrete (1:1.765: 3.14) that complies with IS 10262:2009 codal provision was created. Based on different trial mixes with changing percentages of 0.25%, 0.5 %, 0.75 %, and 1 % of chemical admixture by the weight of cementitious material, the optimum dose of chemical admixture to be utilized in concrete is found.

Mix Preparation

The OPC, Red Mud, Silica fume, Coarse aggregate, and M-sand, are mixed with the designed proportion with power mixers thoroughly for 30 seconds in dry condition. Water cement ratio (0.4) and superplasticizer (1%) are added in portions in accordance with the design mix after the dry materials have been combined to create the concrete mixes. Tables 6 and 7 show the binary and ternary blended systems of mineral admixtures respectively.

Casting and Curing of Moulds

With the prepared concrete mix, 108 binary and ternary cementitious concrete specimens were cast in the size of standard concrete cubes, cylinders, and prisms in accordance with IS456:2000. The concrete specimens are dried in the curing tank at a constant temperature of 27°C for various lengths of time, including 7, 14, and 28 days. The casting, curing, and testing of specimens are shown in Fig. 2.

Table 6: Percentage of Red Mud (RM) and Silica Fume (SF) in BBS for kg for 1-m^3 concrete

Mix ID	Factors		M-Sand	CA	Water	Cement	Workability [mm]
	RM [%]	SF [%]	[kg.m^{-3}]	[kg.m^{-3}]	[kg.m^{-3}]	[kg.m^{-3}]	
RM0SF0	0	0	695	1254	157.6	435.00	85
RM5SF0	5	0	695	1254	157.6	413.25	78
RM10SF0	10	0	695	1254	157.6	391.50	76
RM15SF0	15	0	695	1254	157.6	369.75	76
RM20SF0	20	0	695	1254	157.6	348.00	74
RM0SF5	0	5	695	1254	157.6	413.25	80
RM0SF10	0	10	695	1254	157.6	391.50	78
RM0SF15	0	15	695	1254	157.6	369.75	75
RM0SF20	0	20	695	1254	157.6	348.00	72

Table 7: Percentage of Red Mud (RM) and Silica Fume (SF) in TBS kg for 1-m^3 concrete.

Mix ID	Factors		M-Sand	CA	Water	Cement	Workability (mm)
	RM [%]	SF [%]	[kg.m^{-3}]	[kg.m^{-3}]	[kg.m^{-3}]	[kg.m^{-3}]	
RM5SF15	5	15	695	1254	157.6	391.50	80
RM10SF10	10	10	695	1254	157.6	348.00	76
RM15SF5	15	5	695	1254	157.6	304.50	72

Fig. 2: Casting, curing, and testing of concrete specimen.

RESULTS AND DISCUSSION

Workability

In the context of concrete technology, "workability" refers to the characteristics of concrete that make it simple to lay, compact, and finish concrete. The slump cone test measures the workability of fresh concrete. Table 6 and Table 7 represent the slump characteristics of various combinations of concrete mixes.

Compressive Strength

The average compression strength of concrete cubes tested after 7, 14, and 28 days of curing is shown in Tables 8 and 9.

The compressive strength test results of the BBS with red mud and silica fume replacement are presented in Fig. 3.

At 28 days after being compressed, concrete in a BBS with 5%, 10%, 15%, and 20% red mud replacement (RM5SF0, RM10SF0, RM15SF0, and RM20SF0, respectively) had compressive strengths that were 1%, 7%, 10%, and 3% higher than those of the control mix (RM0SF0). Similarly, specimens with silica fume demonstrated a 2% lower compressive strength than the control mix during a 28-day compression test of concrete with 5% silica fume substitution (RM0SF5) than the control mix (RM0SF0). However, 10%, 15%, and 20% silica fume substitution (RM0SF10, RM0SF15, and RM0SF20) produced compressive strengths that were 7%, 1%, and 0.5% greater than the control mix (RM0SF0), respectively.

In TBS, at 28 days of compression testing of concrete with 5% RM and 15% SF, 10% of both RM & SF, 15% RM and 5% SF replacement (RM5SF15, RM10SF10 & RM15SF5) gave 4%, 15% and 9% higher compressive strength than the control mix (RM0SF0). The compressive strength test findings for red mud and silica fume in the TBS are shown in Table 9 and Fig. 4.

Table 8: Compressive strength of BBS.

Mix ID	Average Compressive Strength [Mpa]			Compressive strength variation as a percentage when compared to the control mix after 28 days
	7th	14th	28th	
	Days			
RM0SF0	21.98	27.22	32.80	-
RM5SF0	22.14	27.43	33.05	1%
RM10SF0	23.42	29.01	34.95	7%
RM15SF0	24.16	29.93	36.06	10%
RM20SF0	22.55	27.93	33.65	3%
RM0SF5	21.47	26.6	32.05	-2%
RM0SF10	23.42	29.01	34.95	7%
RM0SF15	22.15	27.44	33.06	1%
RM0SF20	21.88	27.10	32.65	0.5%

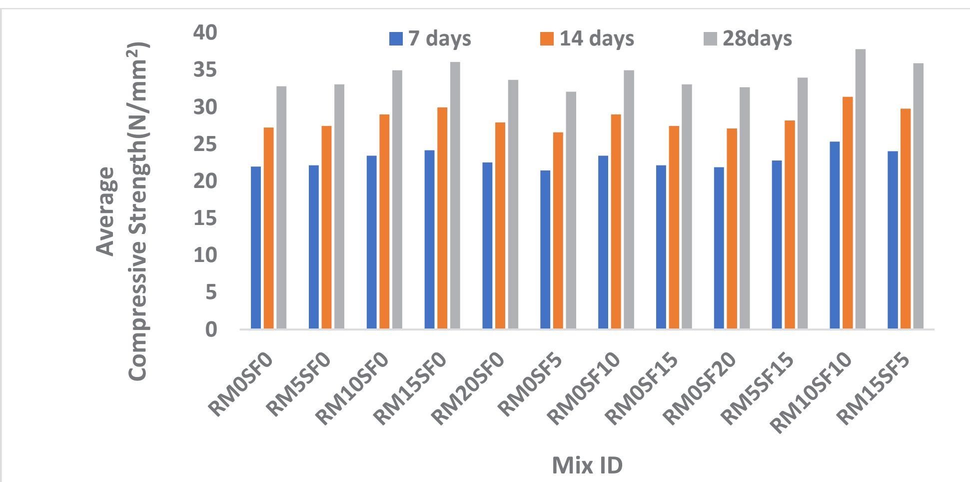

Fig. 3: Compressive strength comparison with BBS.

The mixtures with 15% red mud and 10% silica fume replacement have the highest compressive strengths (RM15SF0 & RM0SF10). Red mud speeds up the pozzolanic reaction between cementitious ingredients because of its high alkalinity (pH > 12) character (cement and red mud). The strength of the concrete was seen to decrease after the replacement of 10% silica fume and 15% red mud, but it was not lower than usual concrete mixtures. The concrete compressive strength decreased at a red mud replacement level of 20% due to insufficient cement hydration caused by the greater red mud and silica fume concentration. Metilda et al. (2015) provided a similar defense; red dirt has a large specific surface area in the concrete mix that absorbs more water, resulting in a lack of water for adequate cement hydration.

Water Absorption (WA)

Due to its porosity, concrete absorbs water, and the amount of water absorption is directly inversely proportional to the volume of pore space. Water absorption tests are carried out in line with IS 1124-1974, a standard test technique for water absorption, to get the parameter. A concrete test sample with dimensions of 150x150x150 mm and a replacement percentage of pozzolanic red mud and silica fume materials ranging from 0% to 20% were selected for testing and weighed before submersion in water. After that, the test sample spends 24 hours submerged in distilled water. After a predetermined age of curing for 7, 14, and 28 days, a water absorption test was performed. The specimen's weight before immersion is recorded as W1, and its weight following water immersion is recorded as W2. The percentage of water absorption W_A is calculated by Equation (1).

$$\text{WA}(\%) = \frac{(W2 - W1)}{W1} \times 100 \quad \ldots(1)$$

Where WA is the percentage of water absorption and W1 and W2 are the sample's initial weights before and after a 24-hour immersion, respectively.

At 7 days, concrete with 5%, 10%, 15%, and 20% replacement of red mud (RM5SF0, RM10SF0, RM15SF0, and RM20SF0, respectively) had water absorption that was 3.8%, 3.5%, 3%, and 2.5% higher than the control mix (RM0SF0). Similar to this, concrete with 5%, 10%, 15%, and 20% substitution of red mud (RM5SF0, RM10SF0, RM15SF0, and RM20SF0, respectively) over 28 days

Table 9: Compressive strength of TBS.

Mix ID	Average Compressive Strength [MPa]			Compressive strength variation as a percentage when compared to the control mix after 28 days
	7th Days	14th	28th	
RM0SF0	21.98	27.22	32.80	-
RM5SF15	22.77	28.20	33.98	4%
RM10SF10	25.33	31.37	37.80	15%
RM15SF5	24.05	29.80	35.90	9%

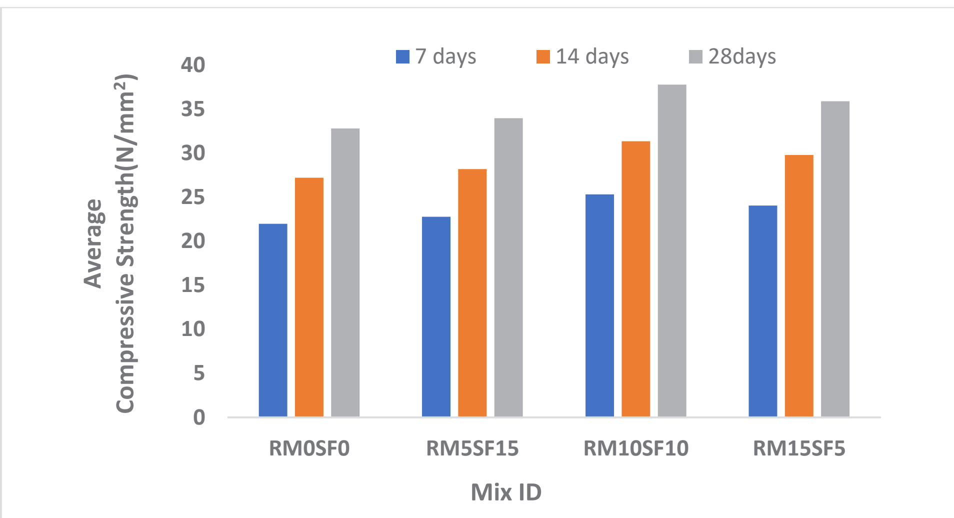

Fig. 4: Compressive strength comparison with TBS.

showed water absorption that was 3.6%, 2.5%, 2.6%, and 2.0% higher than the control mix (RM0SF0). Additionally, concrete 5%, 10%, 15%, and 20 % replacement of silica fume (RM0SF5, RM0SF10, RM0SF15, and RM0SF20) at 7 days had water absorption that was, correspondingly, 3.7%, 3.1%, 2.7%, and 2.3% higher than the control mix (RM0SF0). Similar to this, concrete with replacements of 5%, 10%, 15%, and 20% of silica fume (RM0SF5, RM0SF10, RM0SF15, and RM0SF20) over 28 days showed water absorption that was 3.2%, 2.9%, 2.5%, and 2.0% higher than the control mix (RM0SF0), respectively.

In a TBS, at 7 days concrete with 5% RM and 15% SF, 10% of both RM & SF, 15% RM, and 5% SF replacement (RM5SF15, RM10SF10, & RM15SF5), respectively, had water absorption that was 2.4%, 3.2%, and 3.0% higher than the control mix (RM0SF0). In a similar, concrete with 5% RM and 15% SF, 10% of both RM & SF, 15% RM, and 5% SF replacement (RM5SF15, RM10SF10, & RM15SF5), showed increased water absorption than the control mix by 2.2%, 3.0%, and 2.8% after 28 days (RM0SF0). The binary and ternary blend binder system shown in Tables 10 and 11 and Figs. 5 and 6 was replaced by the water absorption test findings for red mud and silica fume in the binary and ternary blended cementitious system.

The findings show that the values for water absorption decrease as curing age and replacement level increase. Red mud also increases pozzolanic activity later in life; this reduces connections between pores. Red mud's fineness (average particle size: 14 m), which seals all pores and microcracks in the concrete, is another factor that lowers water absorption. Due to its huge specific surface area, red mud and silica fume can reduce the amount of water that concrete absorbs. Nenadovic et al. (2017) provided a similar explanation, stating that the larger Ca $(OH)_2$ crystals were fractured into several smaller crystals and less orientated during the hydration process of red mud-based cement, which minimizes pore

Table 10: Water absorption of BBS.

Mix ID	The initial weight of the sample before immersion, W1 [kg]	Weight of the sample after 24 hours immersion, W2 [kg]			Percentage of water absorption, W_A [%]		
		7^{th}	14^{th}	28^{th}	7^{th}	14^{th}	28^{th}
		Days			Days		
RM0SF0	8.950	9.00	8.98	8.94	6.2	5.7	5.2
RM5SF0	8.624	8.95	8.94	8.93	3.8	3.7	3.6
RM10SF0	8.509	8.83	8.82	8.81	3.5	3.0	2.5
RM15SF0	8.412	8.66	8.65	8.63	3.0	2.8	2.6
RM20SF0	7.963	8.16	8.14	8.12	2.5	2.25	2.0
RM0SF5	8.524	8.87	8.86	8.84	3.7	3.4	3.2
RM0SF10	8.420	8.68	8.67	8.66	3.1	3.0	2.9
RM0SF15	8.135	8.35	8.34	8.33	2.7	2.6	2.5
RM0SF20	7.863	8.04	8.03	8.01	2.3	2.15	2.0

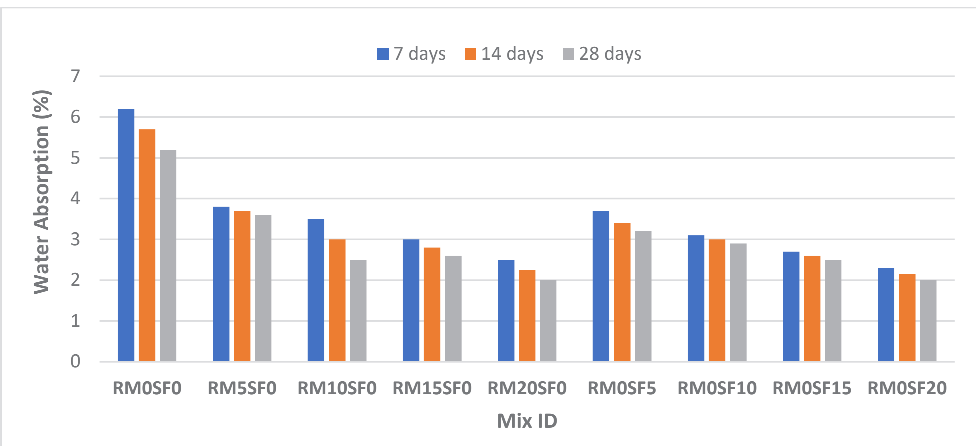

Fig. 5: Water absorption comparison with BBS.

Table 11: Water absorption of TBS.

Mix ID	The initial weight of the sample before immersion, W1 [kg]	Weight of the sample after 24 hours immersion, W2 [kg]			Percentage of water absorption, W_A [%]		
		7th	14th	28th	7th	14th	28th
		Days			Days		
RM0SF0	8.95	9.0	8.98	8.94	6.2	5.7	5.2
RM5SF15	8.10	8.29	8.28	8.27	2.4	2.3	2.2
RM10SF10	7.98	8.23	8.22	8.21	3.2	3.1	3.0
RM15SF5	7.85	8.08	8.07	8.06	3.0	2.9	2.8

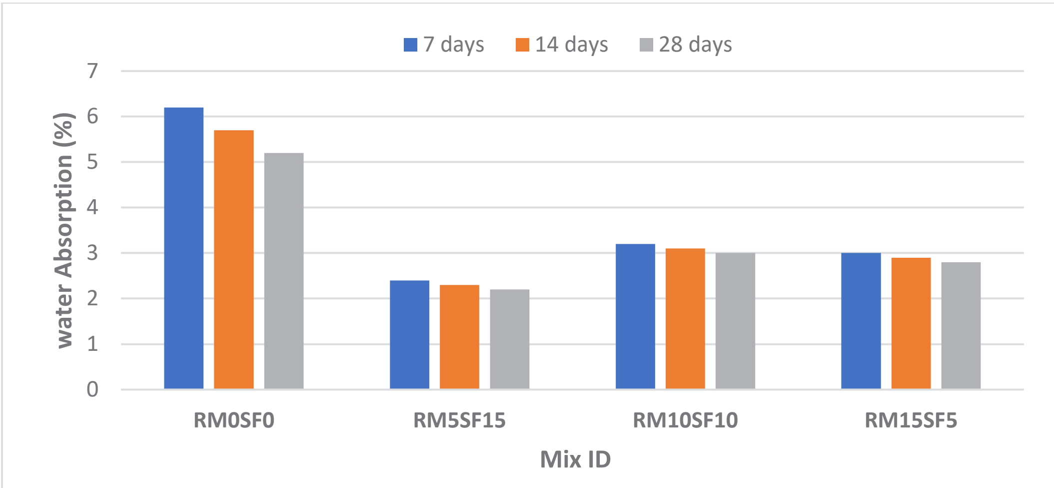

Fig. 6: Water absorption comparison with TBS.

connections and water absorption. Due to the impact of the pozzolanic and micro filler, the water absorption values of the concrete mixtures replaced with silica fume decreased as the amount of silica replacement increased.

Density of Concrete

Concrete density is a measurement of its weight. Based on its determined value of density, concrete is classified as either lightweight or regular weight. Getting the parameter is necessary. A concrete specimen of the M30 grade with dimensions of 150x150x150 mm and silica fume materials substitution percentage ranging from 0% to 20% was selected for testing. The specimen was weighed before being submerged in water to represent weight. The density is then calculated taking into account the concrete specimen's volume. Equation (2) is used to determine the density of concrete.

$$\rho = \frac{\textit{Mass of Concrete Specimen}}{\textit{Volume of Concrete Specimen}} \,[\text{kg/m3}] \qquad \ldots(2)$$

The control mix (RM0SF0) in a BBS reached a maximum density of 2651.85 $kg.m^{-3}$. Red mud and silica fume were used in place of cement, which reduced density. Fresh concrete densities decreased for 5%, 10%, 15%, and 20% red mud replacement (RM5SF0, RM10SF0, RM15SF0, and RM20SF0) mixes compared to control concrete by 3.61%, 4.9%, 5.98%, and 11%, respectively. For 5%, 10%, 15%, and 20% of silica fume replacement (RM0SF5, RM0SF10, RM0SF15, and RM0SF20) mixes were found to be 4.73%, 5.89%, 9.08%, and 12.12% respectively. Similarly, in TBS, the density of concrete with 5% RM and 15% SF, 10% of both RM & SF, 15% RM and 5% SF replacement (RM5SF15, RM10SF10 & RM15SF5) mixes was found to be 9.47%, 10.8%, and 12.26%, respectively. Because density depends on specific gravity, there has been a drop in density. The control mix has the highest density because cement has higher specific gravity than red mud and silica fume. The binary and ternary blend binder system depicted in Tables 12 and 13 and Figs. 7 and 8 were replaced by the concrete density test findings for red mud and silica fume in the binary and ternary blended cementitious system.

Equivalent CO_2 Gas Emission and Energy Factor

Compared to cement production, RM and SF production emits less CO_2 into the atmosphere. The CO_2 emissions

Table 12: Mass, volume and density of BBS.

Mix ID	Mass of Concrete Specimens [kg]	The volume of Concrete Specimen [m^3]	The density of Concrete [$kg.m^{-3}$]
RM0SF0	8.95	0.003375	2651.85
RM5SF0	8.624	0.003375	2555.25
RM10SF0	8.509	0.003375	2521.18
RM15SF0	8.412	0.003375	2492.44
RM20SF0	7.963	0.003375	2359.40
RM0SF5	8.524	0.003375	2525.62
RM0SF10	8.42	0.003375	2494.81
RM0SF15	8.135	0.003375	2410.36
RM0SF20	7.863	0.003375	2329.77

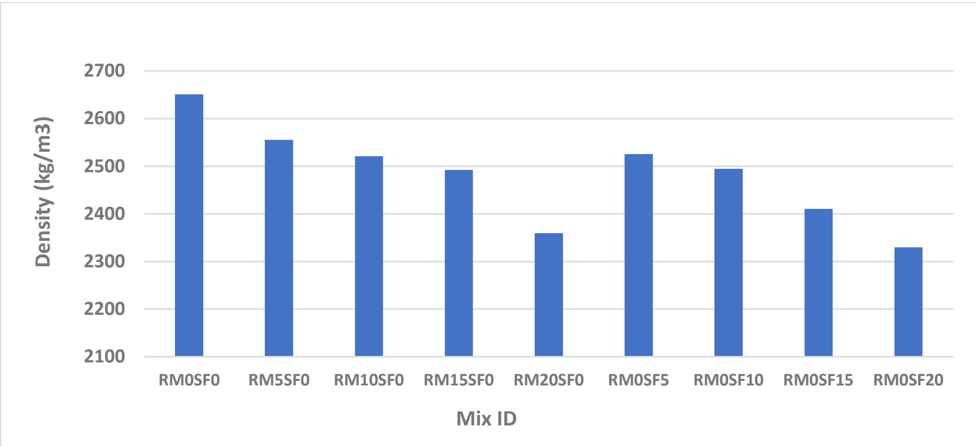

Fig. 7: Density of concrete comparison with BBS.

Table 13: Mass, volume and density of TBS.

Mix ID	Mass of Concrete Specimens [kg]	Volume of Concrete Specimen [m^3]	Density of Concrete [$kg.m^{-3}$]
RM0SF0	8.95	0.003375	2651.84
RM5SF15	8.10	0.003375	2399.99
RM10SF10	7.98	0.003375	2364.44
RM15SF5	7.85	0.003375	2325.92

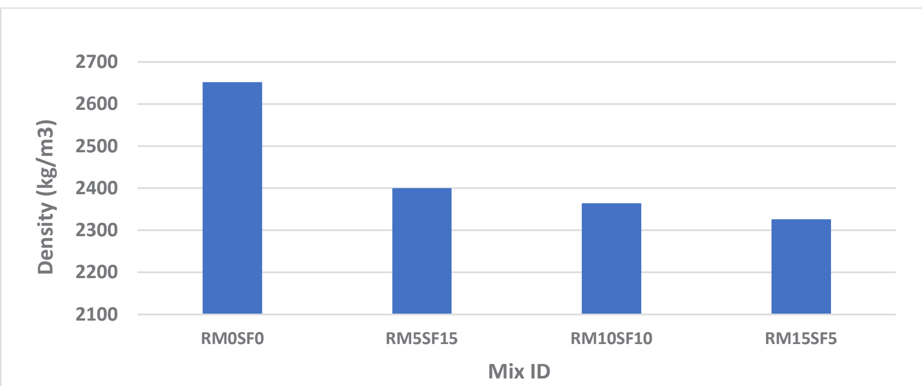

Fig. 8: Density of concrete comparison with TBS.

from the manufacturing of RM and SF (100 kg of CO_2 for every ton of RM produced and 14 kg of CO_2 for every ton of SF produced) are caused by the extraction of raw materials and the kiln, not by a chemical reaction (dehydroxylation). However, the decarboxylation of calcium carbonate during cement manufacturing results in the release of CO_2 (1 ton of cement produced equals 521.5 kg of CO_2; 1 ton of cement produced equals 478.5 kg of CO_2; Additionally, RM and SF demand less thermal energy during manufacture than cement (1 ton of RM produced needs 1.70 GJ) and SF (1 ton of RM produced needs 0.24 GJ) than the cement (1 ton of cement produced needs 4.65 GJ) (Kelechi et al. 2022, Cassagnabere et al. 2010).

Without taking into account the transportation of raw materials, carbon dioxide (CO_2) emission is calculated based on chemical reactions and energy consumption to manufacture 1 ton of cement and RM with SF, calculated as reported by Cassagnabere et al. (2010).

The emission of CO_2 and Energy saved were calculated as follows in Equations (3) & (4):

$$\textbf{Energy saved (\%)} = \frac{Ei-Eo}{Eo} \times 100 \quad \ldots(3)$$

Where,

E_o = Consumption of energy in control mix (RM0SF0)

E_i = Consumption of energy in binary and ternary cementitious systems.

$$\textbf{CO}_2\textbf{ Emission (\%)} = \frac{Ci-Co}{Co} \times 100 \quad \ldots(4)$$

Where,

C_o = Emission of CO_2 by control mix (RM0SF0)

C_i = Emission of CO_2 by binary and ternary cementitious systems.

The emission of CO_2 and Energy saved was calculated for all binary and ternary cementitious systems and control mix using Equations 3 & 4. Fig. 9 presents the values of energy consumption and CO_2 release into the atmosphere. The environmental balance for the binders (cement + RM + SF) based on the CO_2 emission and energy requirement is also presented in Table 14.

The negative sign implies that replacing cement with RM and SF reduces energy consumption (-1.91% to -6.97%) and CO_2 emissions (-4.52% to -16.16%). The result shows that the maximum replacement of RM with SF provides a positive environmental effect and saves raw materials consumption.

CONCLUSION

The results of an experimental investigation using red mud and a silica fume mineral additive to create binary and ternary blended cementitious systems. According to a study on compressive strength, the ideal proportion of red mud and silica fume in cement was 15% by volume and 10%. Similar results were found for the ternary blended system, where the replacement of 10% red mud and 10% silica fume combination produced the maximum compressive strength in comparison to all other combinations,

- The Compressive strength parameters showed that RM15SF0 and RM15SF5 give 10% and 9% higher than the control mix (RM0SF0) respectively. Red mud

Table 14: Environmental balance of binary and ternary cementitious systems based on the emission of CO_2 and energy saved for 1m^3 of concrete.

Mix ID	Energy (GJ)				CO_2 Emission ([g]							Environmental benefit regarding	
					Extraction & Kiln			Chemical reaction			Total	Energy [%]	CO_2 emission [%]
	OPC	RM	SF	Total	OPC	RM	SF	OPC	RM	SF			
RM0SF0	2.34	0.00	-	2.34	239.3	0	0	260.8	0	0	500.10		
RM5SF0	2.22	0.43	-	2.65	227.3	2.5	-	247.7	0	0	477.50	-1.91	-4.52
RM10SF0	2.11	0.85	-	2.96	215.3	5	-	234.7	0	0	455.00	-2.82	-9.02
RM15SF0	1.99	1.28	-	3.27	203.4	7.5	-	227.5	0	0	438.40	-4.32	-12.34
RM20SF0	1.87	1.70	-	3.57	191.1	10	-	220.3	0	0	421.43	-7.76	-15.73
RM0SF5	2.22	-	0.060	2.28	227.3	-	0.35	247.7	0	0	475.35	-1.65	-4.95
RM0SF10	2.11	-	0.119	2.23	215.3	-	0.7	234.7	0	0	450.70	-2.12	-9.88
RM0SF15	1.99	-	0.179	2.17	203.4	-	1.05	227.5	0	0	431.95	-2.87	-13.63
RM0SF20	1.87	-	0.238	2.11	191.1	-	1.4	220.3	0	0	412.83	-4.58	-17.45
RM5SF15	1.87	0.43	0.179	2.47	191.1	2.5	1.05	220.3	0	0	414.98	-5.38	-17.02
RM10SF10	1.87	0.85	0.119	2.84	191.1	5	0.7	220.3	0	0	417.13	-6.17	-16.59
RM15SF5	1.87	1.28	0.060	3.20	191.1	7.5	0.35	220.3	0	0	419.28	-6.97	-16.16

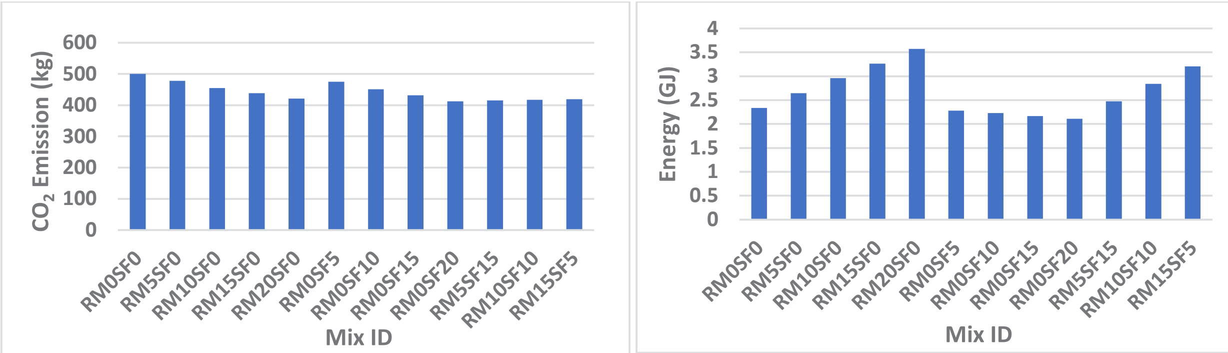

Fig. 9: Comparison of equivalent CO_2 emission of binary and ternary blended systems.

speeds up the pozzolanic reaction between cementitious ingredients because of its high alkalinity (pH > 12) nature.

- Due to the pozzolanic and micro filler effects, concrete specimens absorb less water. The water absorption values of concrete mixtures containing silica fume decreased as the amount of silica replacement increased.
- The concrete density revealed that the relationship between density and specific gravity is what causes the decrease in density. The control mix has the highest density because cement has higher specific gravity than red mud and silica fume.
- Equivalent CO_2 emission and energy factor with a negative sign indicate that RM and SF replace cement in a way that reduces both energy use (-1.91 to -6.97%) and CO_2 emissions (-4.52 to -16.16%). The outcome demonstrates that substituting RM with SF as much as possible has a favorable impact on the environment and reduces the use of raw materials.
- A pozzolanic substance with strong reactivity is silica fume. Due to its roughness and high content of amorphous silica content and red mud, a higher specific surface area accelerated the setting process and reduced the pozzolanic. By reducing porosity through the production of C-S-H gel, the combined effect of silica fume and red mud will obtain distinctive materials that will improve workability, strength, and higher chemical attack resistance.
- As the results found encouraging the utilization of red mud and silica fume can be applied in large-scale construction to compensate for the environmental and economical drags imposed by conventional cement production and usage. Therefore, red mud and silica fume are suggested for the creation of environmentally friendly, cost-effective, sustainable, and concrete with low CO_2 emissions, which will be especially useful today as the world is confronting the difficulties of global warming.

REFERENCES

Venkatesh, C., Nerella, R. and Chand, M.S.R 2020. Experimental investigation of strength, durability, and microstructure of red-mud concrete. J. Korean Ceram. Soc., 174-167 :57.

Shetty, K.K., Nayak, G. and Vijayan, V. 2014. Effect of red mud and iron ore tailings on the strength of self-compacting concrete. Eur. Sci. J., 10(21): 168-176.

Metilda, D.L., Selvamony, C., Anandakumar, R. and Seeni, A. 2015. Investigations on the optimum possibility of replacing cement partially with red mud in concrete. Sci. Res. Essays., 10(4):137-143.

Nenadovic, S., Mucsi, G., Kljajevic, L., Mirkovic, M., Nenadovic, M., Kristaly, F. and Vukanac, I. 2017. Physicochemical, mineralogical, and radiological properties of red mud samples as secondary raw materials. Nucl. Technol. Radiat. Prot., 32(3): 261-266.

Menhosh, A,A., Wang, Y., Wang, Y. and Nelson, L.A. 2018. Long-term durability properties of concrete modified with metakaolin and polymer admixture. Constr. Build. Mater., 172: 41-51.

Ribeiro, D.V., Labrincha, J.A. and Morelli, M.R. 2012. Effect of red mud addition on the corrosion parameters of reinforced concrete evaluated by electrochemical methods. IBRACON Struct. Mater. J., 5(4): 451-467.

Tanu, H.M. and Sujatha, U. 2022. Utilization of industrial and agricultural waste materials for the development of geopolymer concrete- A review. Mater. Today: Proc., 4: 192. https://doi.org/10.1016/j.matpr.2022.04.192.

Azad, N.M., Samindi, S.M. and Samarakoon, M.K. 2021. Utilization of industrial by-product /waste to manufacture geopolymer cement/concrete. Sustainability, 13(2): 873. https://doi.org/10.3390/su13020873.

Anantha Lakshmi, K., Anvesh Reddy, I.S. and Sai Kumar, A.V.S. 2016. Strength characteristics of concrete with partial replacement of cement with fly ash & metakaolin. Int. J. Innov. Sci. Res. Technol., 1(7): 18-22.

Satyendra, D., Rajiv, C. and Yadav, R.K. 2015. Experimental study of concrete with metakaolin as partial replacement of OPC. Int. J. Adv. Eng. Res. Sci., 2(6): 38-40.

Venu Malagavelli., Srinivas Angadi., Prasad, J.S.R. and Joshi, S. 2018. Influence of metakaolin in concrete as partial replacement of cement. Int. J. Civ. Eng. Technol., 9(7): 105-111.

Kothai, P. S. and Malathy, R. 2015. Effective utilization of wastes from steel industries in concrete. Nat. Environ. Pollut. Technol., 14(2): 419-422.

Mane, K.M., Kulkarni, D.K. and Prakash, K.B. 2019. Properties and microstructure of concrete using pozzolanic materials and manufactured sand as partial replacement of fine aggregate. SN Appl. Sci., 1: 1025.

Nataraja, M.C., Manu A.S. and Girih, G. 2014. Utilization of different types of manufactured sand as fine aggregate in cement mortar. Indian Concr J., 88(1):19-25.

Verma, K. and Pajgade, P.S. 2015. Effect of partial replacement of natural sand with crushed sand along with supplementary cementing materials (fly ash and GGBS). Int. J. Res. Eng. Technol., 4(1): 288-292.

Almusallam, A.A., Beshr, H., Maslehuddin, M. and Al-Amoudi, O.S.B. 2004. Effect of silica fume on the mechanical properties of low-quality coarse aggregate concrete. Cem. Concr. Comp., 26(7): 891-900.

Babu, K.G. and Babu, D.S. 2003. Behaviour of lightweight expanded polystyrene concrete containing silica fume. Cem. Concr. Comp. Res., 33(5): 755-762.

Behnood, A. and Ziari, H. 2008. Effects of silica fume addition and water-to-cement ratio on the properties of high-strength concrete after exposure to high temperatures. Cem. Concr. Comp., 30(2): 106-112.

Bentur, A. and Goldman, A. 1989. Curing effects, strength, and physical properties of high strength silica fume concrete. J. Mater. Civil Eng., 1(1): 46-58.

Bhanja, S. and Sengupta, B. 2005. Influence of silica fume on the tensile strength of concrete. Cem. Concr. Comp. Res., 35(4): 743-747.

Hooton, R.D. 1993. Influence of silica fume replacement of cement on physical properties and resistance to sulfate attack freezing and thawing, and alkali-silica reactivity. ACI Mater. J., 90(2): 143-52.

Koksal, F., Altun, F., Yigit, I. and Sahin, Y. 2008. Combined effect of silica fume and steel fiber on the mechanical properties of high-strength concretes. Constr. Build. Mater., 22(8): 1874-1880.

Mazloom, M., Ramezanianpour, A.A. and Brooks, J.J. 2004. Effect of silica fume on mechanical properties of high-strength concrete. Cem. Concr. Comp., 26(4): 347-357.

Sobolev, K. 2004. The development of a new method for the proportioning of high-performance concrete mixtures. Cem. Concr. Comp., 26(7): 901-907.

Tanyildizi, H. and Coskun, A. 2008. Performance of lightweight concrete with silica fume after high temperature. Constr. Build. Mater., 22(10): 2124-2129.

Wild, S., Sabir, B.B. and Khatib, J.M.1995. Factors influencing strength development of concrete containing silica fume. Cem. Concr. Res., 25(7): 1567-1580.

Wong, H.S. and Razak, H.A. 2005. Efficiency of calcined kaolin and silica fume as a cement replacement material for strength performance. Cem. Concr. Comp. Res., 35(4): 696-702.

Needhidasan, S., Ramesh, B. and Prabu, S.J.R. 2020. Experimental study on use of E-waste plastics as coarse aggregate in concrete with manufactured sand, Mater. Today Proc., 22(3): 715-721.

Weiguo, S., Yi, L., Zhongwen, W., Lianghong, C., Dingle, W., Yujie, W. and Xiaoli, J. 2018. Influence of manufactured sand's characteristics on its concrete performance. Constr. Build. Mater., 172: 574-583.

Weiguo, S., Zhenguo, Y., Lianghong, C., Liu, C., Yi, L., Hui, Y., Zili, L. and Jian, Bai. 2016. Characterization of manufactured sand: Particle shape, surface texture, and behavior in concrete, Constr. Build. Mater., 114: 595-601.

Weiguo, S., Yi, L., Lianghong, C., Xujia, H., Zhenguo, Y., Congcong, Zhou., Pengtao, H. and Zili, Lu. 2017. Mixing design and microstructure of ultra-high strength concrete with manufactured sand, Constr. Build. Mater., 143: 312-321.

Ushaa, T.G., Anuradha, R. and Venkatasubramani, G.S. 2015. Reduction of greenhouse gases emission in self compacting geopolymer concrete using sustainable construction materials. Nat. Environ. Pollut. Technol., 14(2): 451-454.

Vivek, S., Kumar., A. and Agarwal, S. K. 2014. Comparative Hydration Behavior of Metakaolin-Microfine System. J. Eng. Comp. Appl. Sci., 3(4): 60-65.

Cassagnabere, F., Mouret, M., Escadeillas, G., Broilliard, P and Bertrand, A. 2010. Metakaolin a solution for the precast industry to limit the clinker content in concrete: Mechanical aspects. Constr. Build. Mater., 24(7): 1109-1118.

Kelechi, S.E., Adamu, M., Mohammed, A., Obianyo, I.I., Ibrahim, Y.E. and Alanazi, H. 2022. Equivalent CO_2 Emission and cost analysis of green self-compacting rubberized concrete. Sustainability., 14: 137.