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Production of structural concrete and the effects of various waste materials on concrete used as partial replacements for cement

Samreen Bano[a*], Neha Mumtaz[a], Farheen Bano[b], Vikash Singh[a] & Syed Aqeel Ahmad[a]

[a] Department of Civil Engineering, Integral University, Lucknow 226 002, India

[b]Faculty of Architecture and Planning, Abdul Kalam Technical University, Lucknow 226 007, India

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Supplementary cementitious materials (SCMs) are additives incorporated into concrete mixtures to enhance their properties and minimize their environmental impact. Common SCMs include fly ash, slag, silica fume, red mud, construction and demolition waste (C&D), and mortar waste. The addition of SCMs in construction practices offers the advantage of reducing the amount of Portland cement needed in concrete production, which is a significant contributor to carbon dioxide emissions, thereby lowering greenhouse gas emissions. Furthermore, the addition of SCMs can improve the durability and performance of concrete, making it a more sustainable option for construction projects.Consequently, the construction industry is actively researching and developing novel materials to further enhance the sustainability of concrete. Various alternatives exist for cement substitution, aiming to enhance the overall quality of concrete without compromising its strength. This research study has been focused on assessing the effects of substituting cement with mortar, red mud, and eggshells in the M25-grade of the concrete mixture. The evaluation involved measuring the compressive strength, flexural strength, split tensile strength, and flexural strength at curing periods of 7, 14, and 28 days. The findings have revealed that the application of these waste materials resulted in superior structural properties of concrete compared to traditional concrete compositions. Additionally, the micro-structural characteristics of different waste materials have been investigated through scanning electron microscopy (SEM), and energy dispersive X-ray spectroscopy (EDX).

Keywords : Red mud, C&D waste, Eggshell powder, Compressive strength, Split tensile strength, Flexural strength

1 Introduction

The main objective of this study was to evaluate the performance of concrete incorporating eggshell powder waste as a cement replacement, specifically at replacement volumes of 5%, 10%, 15%, and 20%. It was observed that the utilization of eggshell powder waste harmed the durability of the resulting concrete. Notably, concrete specimens containing eggshell powder exhibited higher water absorption when cured in water as compared to those cured in air. The increased water content in the curing environment facilitated the formation of a greater quantity of calcium-silicate-hydrate (C-S-H) gel in the eggshell concrete. This resulted in improved gap filling and reduced permeability of the concrete. The compressive strength and flexural strength measurements of eggshell concrete specimens demonstrated that water-cured samples exhibited higher values compared to air-cured samples. Specifically, the compressive strength of water-cured eggshell concrete was 67% higher, while the flexural strength was 32% higher compared to air-cured eggshell concrete.

In contrast, the flexural strength of air-cured eggshell concrete showed significant decreases compared to water-cured samples. The reduction in flexural strength for air-cured eggshell concrete was observed as 19.7%, 20.1%, 20.8%, and 26.1% for replacement volumes of 5, 10, 15, and 20%, respectively[1]. The findings of this study propose the utilization of a blend of red mud, dredged sludge from a lake, and stabilized sewage sludge as a viable option for plant cultivation. Previous studies have demonstrated the effectiveness of this approach, affirming its successful implementation[2]. Based on the research findings, all investigated mixtures containing different ratios of red mud (RM) exhibit remarkable tensile strain capacities, with a maximum achievable strain of 7.43%. Furthermore, employing RM ratios below 10% shows promise in enhancing the tensile and compressive strengths of the mixtures without adversely affecting their mechanical properties. During the test, it is possible to observe the expansion of cracks and the directions they take (which are

Corresponding author (E-mail: samreenbanolaz786@gmail.com)

represented by considerably higher strain values than those of the areas that surround them[3]. The primary objective of this study was to determine the chemical and physical properties of empty fruit bunch (EFB) and oil palm mesocarp fibres (OPMF) ashes to design the most effective pozzolanic composite possible for use as a cement replacement material (CRM). The oil palm is a species of palm tree that is native to many areas of Western and Central Africa, as well as parts of Southeastern Asia, for the most part, Indonesia and Malaysia. It is also cultivated in some parts of South America[4]. In the current study, it was demonstrated that a geopolymer that was prepared from red mud and fly ash (RM -FA-geopolymer) had a significantly high grade of concrete, 65 MPa under experimental conditions that were optimized. After 28 days of curing, it was perceived that the maximum compressive strength of 65 MPa was attained in the presence of 10 % by weight of red mud. In contrast, the compressive strength of the fly ash-based geopolymer (FA- geopolymer) measured 53 MPa when subjected to the same experimental conditions. In the field of geopolymer applications, fly ash and red mud both have the potential to be used. A geopolymer with improved performance was produced by combining red mud and fly ash in a proportion of 10 % by weight, which resulted in the fly ash[5]. Bauxite is one of the utmostvital naturally occurring sources for the production of aluminium. Bauxite is responsible for the production of approximately 97% of all aluminium that is produced worldwide. Because RM has a higher concentration of alkali, it is regarded as hazardous waste and poses potential dangers to the surrounding environment if it is disposed of incorrectly. According to literature, annual RM production would reach 120 million metric tons in 2007, and the world's stockpile would exceed 2.65 billion metric tons. Depending on the annual Al_2O_3 production statistics between the years 1998 and 2015, it is possible to conclude that RM output increased overall[6]. In this study, a supplement consisting of wood shaving as hand wood waste sawdust (WWA) of pre treated timber was added to a concrete mix with the following proportions: 1:2:4:0.56 (cement: sand: coarse aggregate: water-cement ratio). The compressive strengths and the water absorption of the matrix were analyzed. When there is a higher percentage of ash in WWA concrete, the compressive strength of the specimens decreases as compared to the reference mix. It seems that the addition of between 5 and 10% of WWA by weight of cement is the optimal amount that formed the most important difference between the 28-day strength and the 90-day strength. According to the findings, the ratio of flexural strength to compressive strength is somewhere in the range of 18–31%[7]. The guiding methodology for the utilization of recycled materials and waste products has been provided as an overview, while a fairly detailed quantification work example of steel slags has been presented in this particular piece of writing. The main aim of this paper is to present a suitable methodology for utilizing recycled materials and waste products and to provide examples of quantification work that should be carried out to ensure their appropriate use in construction. This paper's secondary objective is to present some examples of how recycled material can be used in construction. Slags can also be divided into two different categories: "Ferrous" slags, which are utilized in the production of iron and steel, and "Nonferrous" slags, which are utilized in the refining of copper and nickel. The work that has been done recently with slag to quantify it includes the following examples. Quantification-Criterion for the use of steel slag as a granular material and conditions for the use of steel slag in rigid applications respectively[8]. To improve the quality of the concrete, cadmium and lead-containing sandblasting residue were added to the mix. The observation made in the study was that the strength of the concrete decreased proportionally with the amount of waste material added. The researchers correlated the results to determine the amount of extra cement that needed to be added along with the waste material to maintain the desired design strength of the concrete. This was done to ensure that the addition of waste materials did not compromise the overall strength and quality of the concrete being used in construction. This paper investigates the properties of concrete produced by incorporating hazardous waste as an ingredient. The study focuses on examining the characteristics of the concrete made using hazardous waste. The study revealed that the strength of the concrete mixed with glass bead waste was influenced by two factors: the intended strength of the concrete and the ratio of the weight of the glass bead waste to the weight of the concrete. Based on the findings, it is assumed that the cadmium present in the waste material is securely bound within the solid concrete matrix and is unlikely to contribute to environmental degradation as a result of its presence[9].This study describes the behavior of soils that have been mixed with industrial waste materials such as fly ash (FA) and bagasse ash (BA) to improve the safe bearing capacity of the soil. These stabilizers' physicochemical properties as well as their physical properties were investigated and compared, ranging from 5 to 35% by weight of soil. Admixing of all of these stabilizers results in a significant improvement in soaked CBR and unconfined compressive strength (UCS) values, as well as a dramatic decrease in dry density[10]. Concrete that has been demolished, waste from agricultural practices, broken glass, and discarded plastic all contribute to the waste, which presents a disposal challenge once these materials have been used. Based on the conclusions of the study, the strength of this type of concrete, which is made up of reused aggregate, is not less than 90% of that of conventional concrete[11]. It has been suggested in a study that eggshells is a way of making the environment better because it decreases the need for waste management and the eggshells themselves can be utilized as useful raw materials in the making of nanomaterials[12]. Investigating the impact of different waste on concrete's physical, mechanical, and microstructural qualities in the construction industry has been discussed and explored in this paper through experimental study.

2 Materials and Methods

2.1 Red mud waste

Red mud is a residue generated during the Bayer process, which is used to refine bauxite ore into aluminium metal. In this process, the ore is treated with caustic soda to dissolve the aluminium-bearing minerals, leaving behind red mud as a byproduct as depicted in Fig. 1(a). Before using red mud in laboratory tests, it is air-dried to remove any moisture present in it. The chemical composition of red mud is shown in Table 1.

2.2 Eggshell waste

Eggshells as shown in Fig. 1(b) consist mainly of calcium carbonate, which is a major component found in limestone. Incorporating eggshell powder into concrete offers several advantages. It helps improve the strength and durability of the concrete while reducing the amount of cement required. It is important to note that the use of eggshells in concrete is still a relatively new concept and further research is necessary to fully understand its potential and limitations. Table 1 presents the chemical composition of eggshells, highlighting their calcium carbonate content. This information can aid in assessing the suitability of eggshells as supplementary material in concrete production.

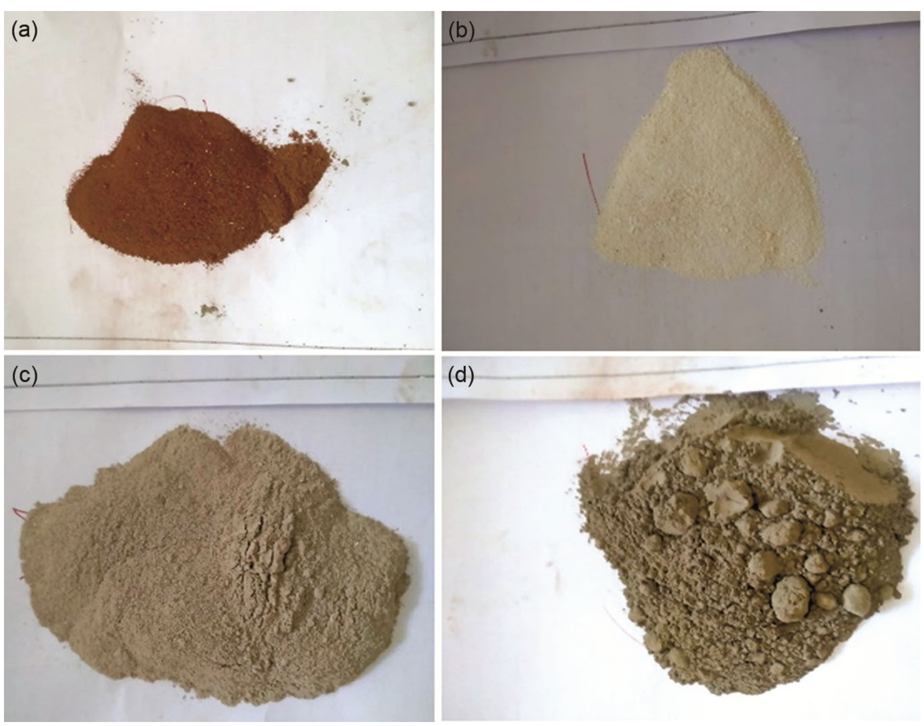

Fig. 1 — Pictorial view of (a) Red mud (b) Eggshell powder (c) C&D waste, (d) PPC cement.

Table 1 — Chemical composition of cement, eggshell, red mud and C&D waste

Element	Weight%	Atomic%	Element	Weight%	Atomic%	Element	Weight%	Atomic%	Element	Weight%	Atomic%
Portland pozzolona cement			Eggshell waste			Red mud waste			C&D waste		
O K	53.33	72.51	C K	61.58	73.96	O K	47.63	67.25	O K	36.37	59.1
Mg K	0.53	0.47	O K	22.83	20.59	Na K	5.46	5.36	Mg K	0.73	0.78
Al K	0.96	0.78	S K	5.83	2.62	Al K	15.75	13.19	Al K	4.54	4.38
Si K	9.42	7.29	Ca K	6.59	2.37	Si K	5.59	4.5	Si K	11.78	10.9
S K	0.75	0.51	Zr L	2.29	0.36	Ti K	1.79	0.84	S K	0.52	0.42
K K	0.58	0.32	I L	0.87	0.1	Fe K	21.14	8.55	K K	1.06	0.7
Ca K	32.38	17.57	Pt M	0	0	Pt M	2.63	0.3	Ca K	28.65	18.58
Fe K	0.4	0.16							Ti K	0.75	0.4
Zr L	1.65	0.39							Fe K	5.65	2.63
									Sb L	7.19	1.54
									I L	2.76	0.57

- O- oxygen
- K- potassium
- Mg- magnesium
- Al- aluminium
- Si- silica
- S- sulphur
- Ca- calcium
- Fe- iron
- Zr- zirconium
- L- lanthanum

2.3 Construction and demolition waste

Construction and demolition (C&D) waste as shown in Fig. 1(c) is generated during the construction, demolition, and repair of buildings and structures. It represents a significant portion of the total waste generated worldwide, with the construction industry being a major contributor. C&D waste encompasses various materials, including concrete, wood, glass, plastics, metals, gypsum, and bricks, among others. These materials result from activities like excavation, demolition, and site clearance. Proper management of C&D waste is crucial to mitigate environmental and health risks. One approach to address this issue is by utilizing C&D waste as a partial replacement for cement in concrete production, promoting a more sustainable and eco-friendly construction process. However, incorporating C&D waste in concrete requires careful consideration of factors such as the quality and type of waste materials, potential contaminants present, and adherence to relevant standards and regulations governing their use in construction. The chemical composition of waste mortar is shown in Table 1.

2.4 Cement

Throughout the entire investigation, Portland pozzolanic cement, as depicted in Fig. 1 (d), was utilized. The physical characteristics of the cement adhere to the specifications outlined in IS:1489-2015[13], validating its compliance with the established limit.

Table 2 — Physical properties of cement

S. No.	Name of Test	Result
1	Fineness modulus (by dry sieving)	6.21
2	Consistency Test	33%
3	Initial Setting time	48 minutes
4	Final Setting time	187 minutes
5	Specific gravity	2.13
6	Compressive strength	34 MPa

Table 3 — Physical properties of coarse and fine aggregates

S. No.	Property	20mm	10 mm	Fine Aggregate
1.	Specific gravity (SSD based)	2.68	2.64	2.52
2.	Water absorption	0.22 %	0.43%	1.65%
3.	Free (surface) moisture	Nil	Nil	Nil

Table 2 provides a comprehensive overview of the cement's physical properties, while Table 1 presents its chemical properties.

2.5 Fine aggregate

For this particular investigation, the fine aggregate utilized is river sand categorized as zone II, possessing a fineness modulus of 2.33. The fine aggregate employed in the study adheres to the stipulated requirements specified in IS 383:2016[14]. Detailed information regarding the physical properties of the fine aggregate can be found in Table 3.

2.6 Coarse aggregate

In this study, natural aggregates with particle sizes of 20 and 10 mm were utilized, conforming to the specifications outlined in IS 383:2016[14]. The physical properties of the coarse aggregate are presented in Table 3.

3 Results and Discussion

3.1 Mix design and casting

The concrete mix design for the M25 grade was conducted by the specifications outlined in IS:10262-2019[15] and IS 456:2000[16] standards. A water-to-cement ratio of 0.42 was employed throughout the experiment while varying amounts of waste material ranging from 0% to 20% were incorporated into the mix. To achieve the desired workability, the concentration of the superplasticizer was adjusted, considering a specific gravity value of 1.08. The substitution of cement with waste material was done in incremental steps of 0% to 20%. The target mean strength for the concrete mix was set at 31.6 N/mm^2. Previous studies have indicated that a maximum substitution level of 15% is recommended to avoid the formation of honeycombed and non-uniform concrete mixes when the proportion of waste material is increased. The workability was assessed at a 100 mm slump value, and the degree of supervision during the experiment was considered mild. The proportions of the waste material in the concrete were prepared under the guidelines specified in IS:10262-2019[15] and IS 456:2000[16]. Coarse aggregates of 20 mm and 10 mm sizes were utilized in the mix.The replacement of waste material with their varying percentageis shown in Tables 4 to 12 with nomenclature.

Table 4 — Compressive strength of different combinations of red mud (RM) and cement (C) with nomenclature

S. No.	Sample Combination (%)	Nomenclature
1.	0RM + 100C	RC-1
2.	5RM + 95C	RC-2
3.	10RM + 90C	RC-3
4.	15RM + 85C	RC-4
5.	20RM + 80C	RC-5

Table 5 —Compressive strength of different combinations of eggshell waste (EW) and cement (C) with nomenclature

S. No.	Sample Combination (%)	Nomenclature
1.	0EW + 100C	EC-1
2.	5EW + 95C	EC-2
3.	10EW+ 90C	EC-3
4.	15EW + 85C	EC-4
5.	20EW+ 80C	EC-5

Table 6 — Compressive strength of different combinations of Construction and demolition waste(C&D) and cement (C) with nomenclature

S. No.	Sample Combination (%)	Nomenclature
1.	0CD+ 100C	CD-1
2.	5CD + 95C	CD-2
3.	10 CD + 80C	CD-3
4.	15 CD + 85C	CD-4
5.	20 CD + 80C	CD-5

Table 7 — Split tensile strength of Different combinations of red mud and cement (C) nomenclature

S. No.	Sample Combination (%)	Nomenclature
1.	0RM + 100C	RC-6
2.	5RM + 95C	RC-7
3.	10RM + 90C	RC-8
4.	15RM + 85C	RC-9
5.	20RM + 80C	RC-10

Table 8 — Split tensile strength of Different combinations egg shell and cement (C) nomenclature

S. No.	Sample Combination (%)	Nomenclature
1.	0EW + 100C	EC-6
2.	5EW + 95C	EC-7
3.	10EW+ 90C	EC-8
4.	15EW + 85C	EC-9
5.	20EW+ 80C	EC-10

Table 9 — Split tensile strength of Different combinations of mortar (C&D waste) and cement (C) nomenclature

S. No.	Sample Combination (%)	Nomenclature
1.	0CD+ 100C	CD-6
2.	5CD + 95C	CD-7
3.	10 CD + 80C	CD-8
4.	15 CD + 85C	CD-9
5.	20 CD + 80C	CD-10

Table 10 — Flexural strength of Different combinations of Red mud and cement(C) nomenclature

S. No.	Sample Combination (%)	Nomenclature
1.	0RM + 100C	RC-11
2.	5RM + 95C	RC-12
3.	10RM + 90C	RC-13
4.	15RM + 85C	RC-14
5.	20RM + 80C	RC-15

Table 11 — Flexural strength of Different combinations of eggshell and cement (C) nomenclature

S. No.	Sample Combination (%)	Nomenclature
1.	0EW + 100C	EC-11
2.	5EW + 95C	EC-12
3.	10EW+ 90C	EC-13
4.	15EW + 85C	EC-14
5.	20EW+ 80C	EC-15

Table 12 —Flexural strength of Different combinations of Construction and demolition (CD waste) and cement (C) nomenclature

S. No.	Sample Combination (%)	Nomenclature
1.	0CD+ 100C	CD-11
2.	5CD + 95C	CD-12
3.	10CD + 80C	CD-13
4.	15CD + 85C	CD-14
5.	20CD + 80C	CD-15

3.2 Test procedure

Concrete samples were assessed for strength following Indian standard specifications. Compressive strength tests were performed on cube-shaped specimens measuring 150 × 150 × 150 mm, following the guidelines specified in IS 516- (Part-1/Sec-1) 2021[17]. Split tensile strength tests were conducted on cylindrical specimens with a diameter of 150 mm and a height of 200 mm, following IS 5816-1999[18]. The compressive strength measurements were conducted using a compressive testing machine, with a loading rate of 14 $N/mm^2/min$, as per the specified requirements in the standard. The split tensile strength was assessed at a loading rate of 1.2 $N/mm^2/min$, following the provisions of IS 5816-1999[18]. In structural engineering, the flexural strength of a beam is a crucial parameter that determines its ability to safely carry loads. To assess this property, specimens measuring 100 × 100 × 500 mm were utilized. The flexural strength was determined using a specific loading rate of 0.1 kN/sec. The specimens underwent a curing process in portable water for different durations of 7, 14, and 28 days, following the guidelines specified in IS 516-2021[17]. The reported results represent the average values obtained from three samples, and a total of 24 cubes, 24 beams, and 24 cylinders were prepared for testing.

3.3 Compressive strength

Figures 2, 3, and 4 illustrate the compressive strength outcomes for different combinations of red mud, eggshell, and C&D waste concrete. In these combinations, varying proportions of the waste materials were used to replace cement by weight, while maintaining a water-cement (w/c) ratio of 0.42. The results indicate that the strength of all concrete mixes exhibited enhancement with an increase in the duration of the curing period. Upon the completion of the curing period, the compressive strength of the red mud concrete mixes was compared to a convenience sample that did not contain any waste materials. The findings reveal that the compressive strength of the red mud concrete mixes exhibited variations ranging from 2.82% to 6.05% in comparison to the control sample. Similarly, the compressive strength of the eggshell concrete mixes differed by 2.19% to 8.85%, while the mortar (C&D) concrete mixes displayed a variation of 2.9% to 13.83% when compared to the control sample. However, it is important to note that the observed strength enhancement was limited to

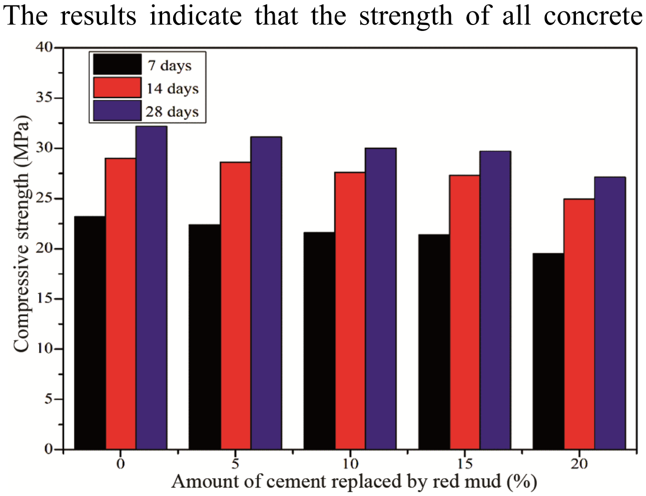

Fig. 2 — Compressive strength of red mud (replacing cement by weight) with a w/c ratio of 0.42.

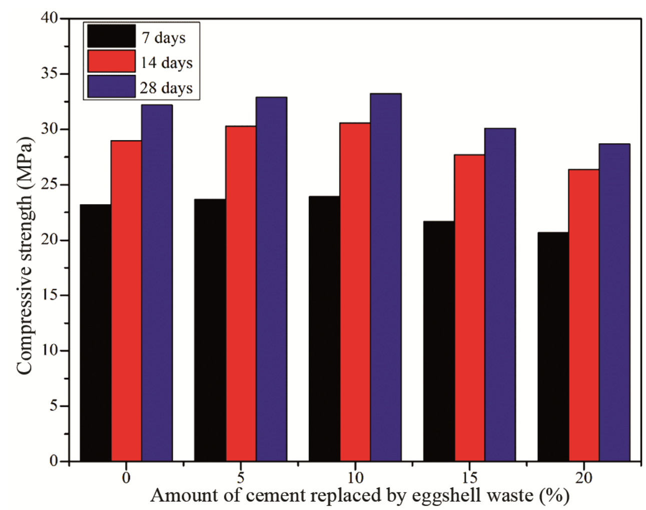

Fig. 3 — Compressive strength of egg shell (replacing cement by weight) with a w/c ratio of 0.42.

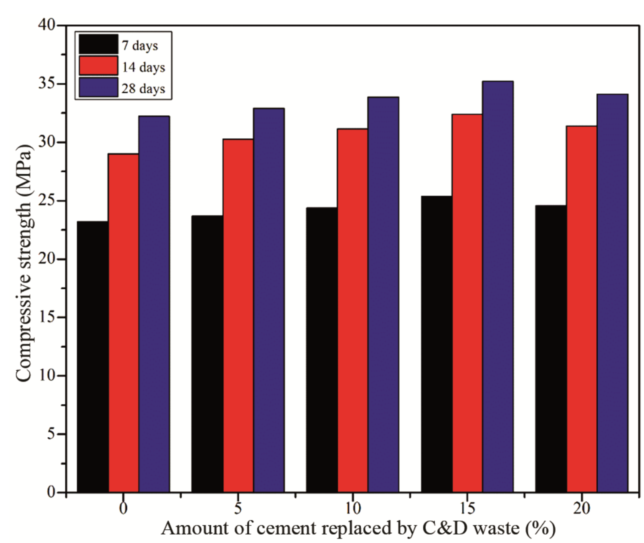

Fig. 4 — Compressive strength of red C&D waste (replacing cement by weight) with a w/c ratio of 0.42.

concrete mixes containing up to 20% of waste materials. Beyond this proportion, the strength showed a decline due to a partial pozzolanic reaction resulting from insufficient water content. The inclusion of silica and free lime in the red mud concrete contributed to the development of a C-S-H gel, which consequently led to a significant enhancement in strength during the later stages of curing. Notably, even with high levels of red mud replacement, the strength of the concrete did not deteriorate below that of conventional concrete.

3.4 Split tensile strength

To determine the split tensile strength of the waste materials, concrete samples with a diameter of 150 mm and a height of 200 mm were subjected to testing. The results obtained from these tests are presented in Figs 5, 6, and 7. A comparative analysis was conducted between the waste materials concrete and conventional concrete samples. After 28 days of curing, the split tensile strength of M25 grade concrete was measured as 3.12 MPa. For the concrete specimens with a water-cement ratio of 0.42, where waste materials replaced 5, 10, 15, and 20% by weight of the cement, the split tensile strength was evaluated after 7, 14, and 28 days of curing.

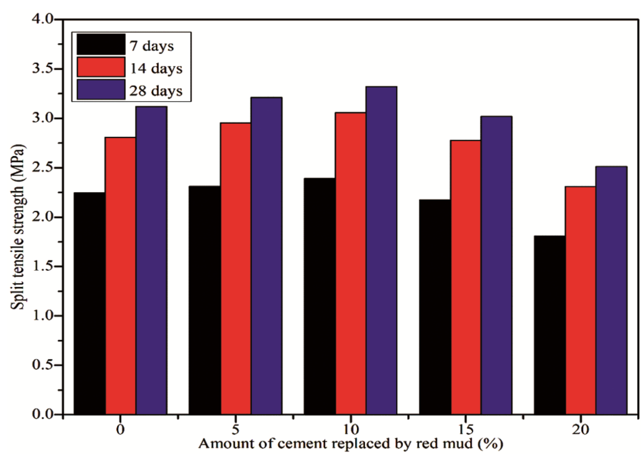

Fig. 5 — Tensile strength of red mud (replacing cement by weight) with a w/c ratio of 0.42.

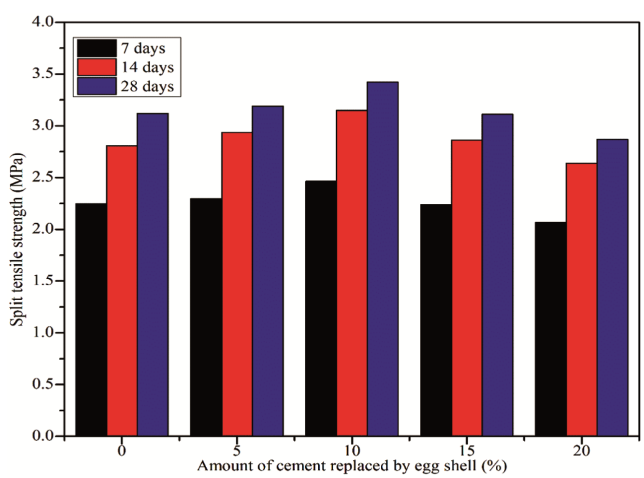

Fig. 6 — Tensile strength of Eggshell (replacing cement by weight) with a w/c ratio of 0.42.

3.5 Flexural strength

Flexural strength, also called bending strength, measures a material's resistance to deformation and fracture when subjected to bending stresses. It is a critical mechanical property in many engineering applications, such as building structures, bridges, and aerospace components. The flexural strength of a beam is a critical property in structural engineering, where it is used to determine the safe load-carrying capacity of a beam. Specimen of 100×100×500 mm, observed with the help of flexural and loading rate 0.1 KN/sec. The flexural strength of the beam is shown in Figs 8, 9, and 10 with different waste materials with varying percentages.

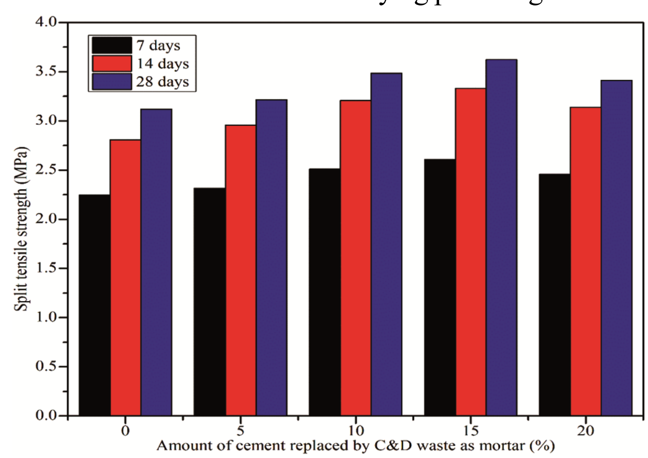

Fig. 7 — Tensile strength of C&D waste (replacing cement by weight) with a w/c ratio of 0.42.

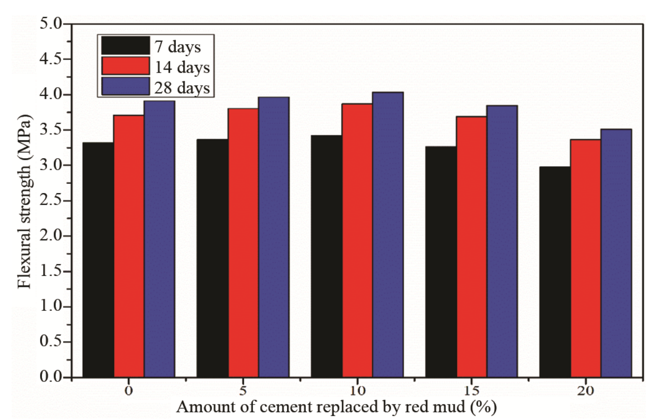

Fig. 8 — Flexural strength of red mud (replacing cement by weight) with a w/c ratio of 0.42.

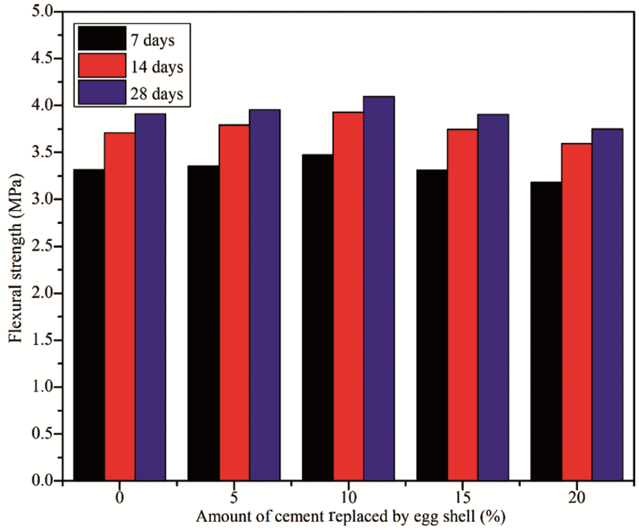

Fig. 9 — Flexural strength of eggshell (replacing cement by weight) with a w/c ratio of 0.42.

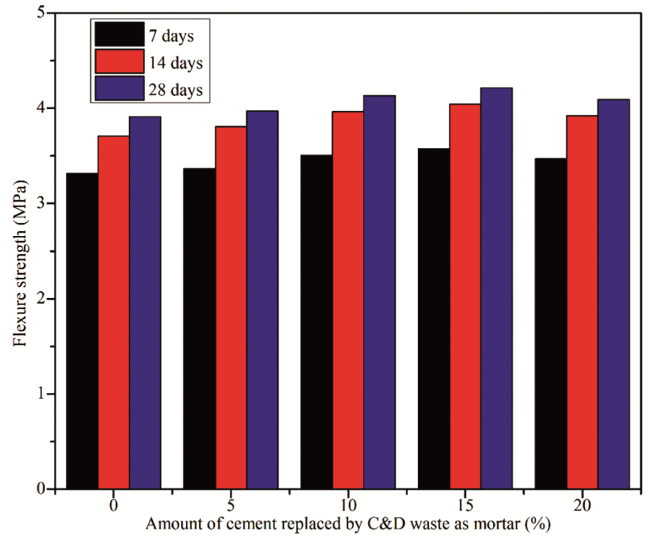

Fig. 10 — Flexural strength of C&D waste (replacing cement by weight) with a w/c ratio of 0.42.

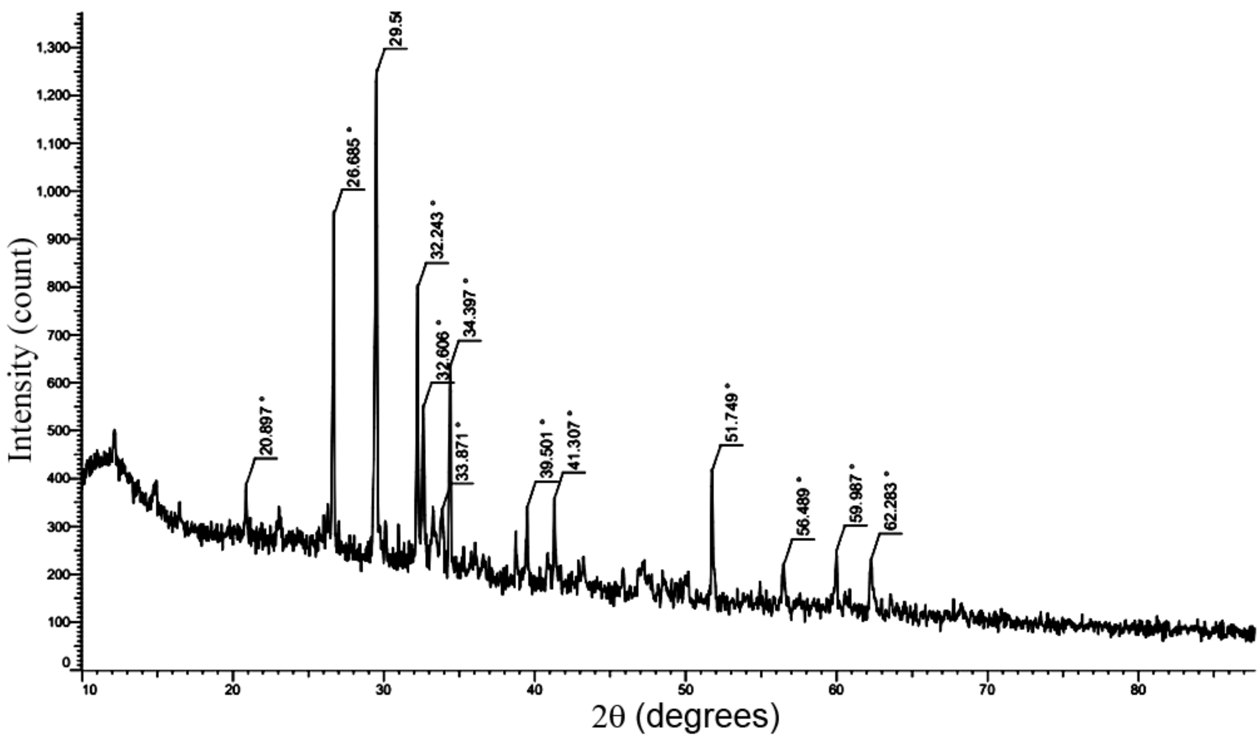

Fig. 11 — X-ray diffractograms of cement.

3.6 Microstructural characterization of red mud, cement, eggshell and mortar (C&D) waste

3.6.1 XRD analysis

SEM (Scanning Electron Microscopy) is a practice that provides high-resolution images of the surface morphology of materials using electron beams. XRD (X-ray Diffraction) is a method that analyzes the crystal structure of materials by measuring the scattering pattern of X-rays, providing information about their composition and arrangement of atoms. Figures 11, 12, 13, and 14 present the X-ray diffraction (XRD) diffractograms of cement, red mud, eggshell and C&D waste, respectively. These materials consist of several mineral phases, which include portlandite ($Ca(OH)_2$), quartz (SiO_2), gismondine ($CaAl_2SiO_8.4(H_2O)$), calcium carbonate,

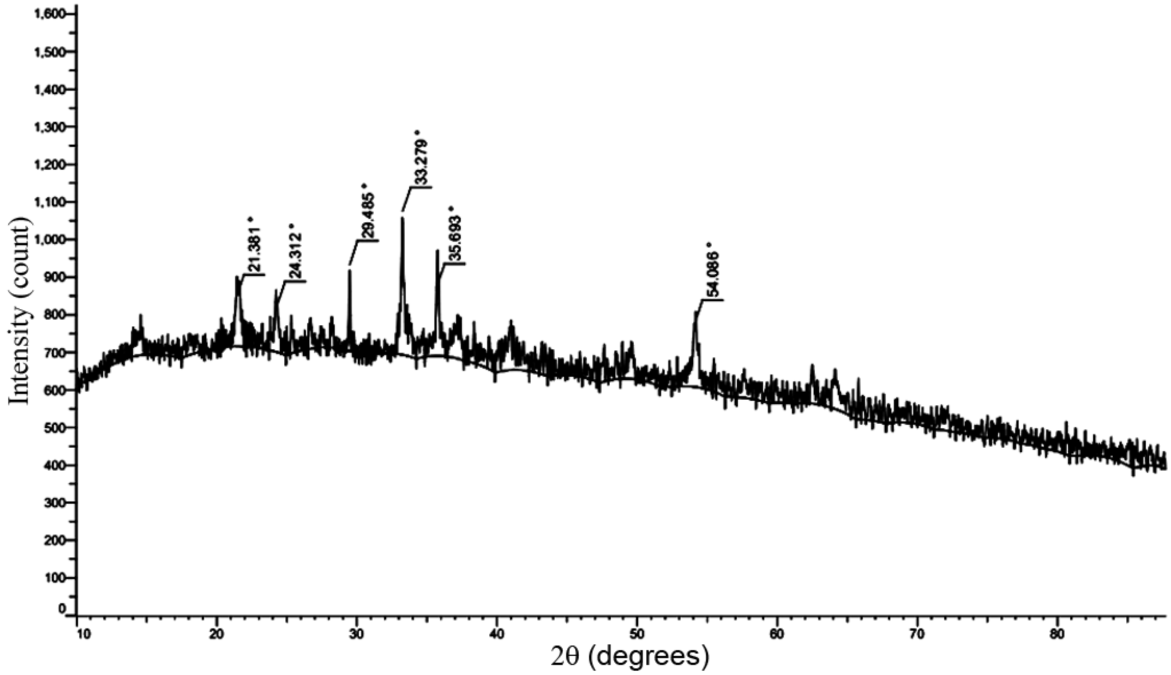

Fig. 12— X-ray diffractograms of red mud .

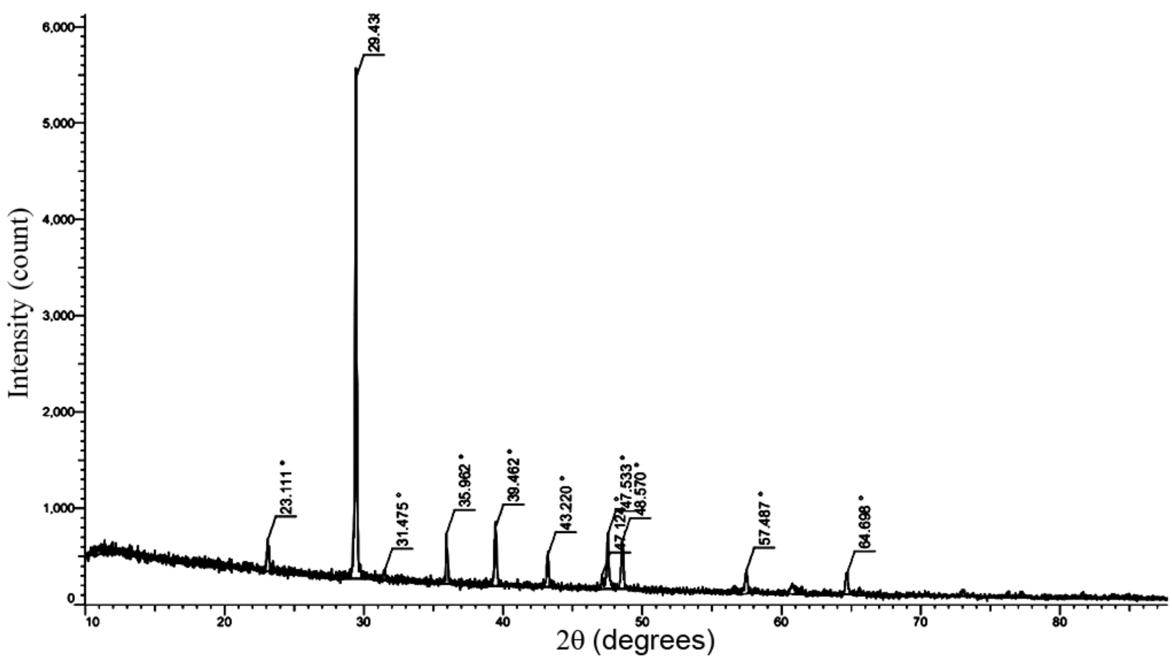

Fig. 13 — X-ray diffractograms of eggshell.

hatrurite (C_3S), larnite (C_2S), albite ($NaAl_2Si_2O_8$), and anorthite ($CaAl_2Si_2O8$).The red mud-incorporated concrete mixes exhibit an increased percentage of larnite and hatrurite compared to the concrete samples without red mud. Eggshell powder primarily comprises calcium carbonate ($CaCO_3$), along with minor quantities of other minerals such as magnesium, phosphorus, and potassium XRD analysis enables the identification of the crystal structure and preferred orientation of calcium carbonate minerals, namely aragonite or calcite, present in the eggshell powder. Construction and demolition (C&D) waste typically encompasses various minerals, including quartz (SiO_2), feldspar ($KAlSi_3O8$), and calcium

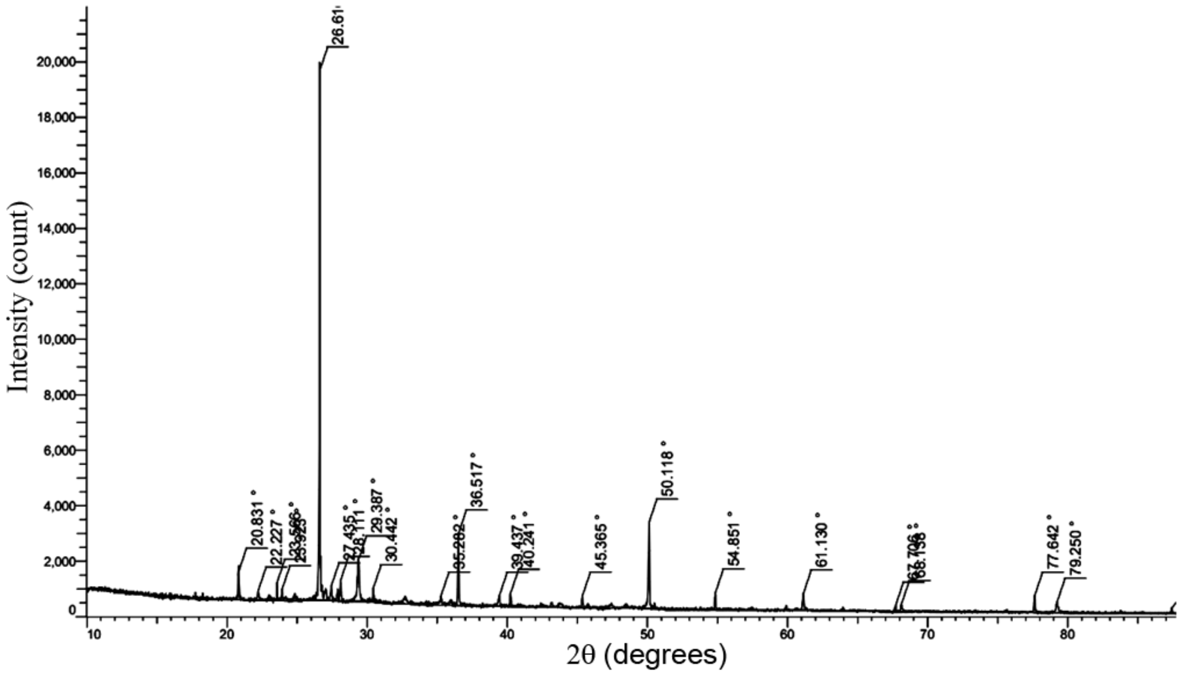

Fig. 14 — X-ray diffractograms of C&D waste.

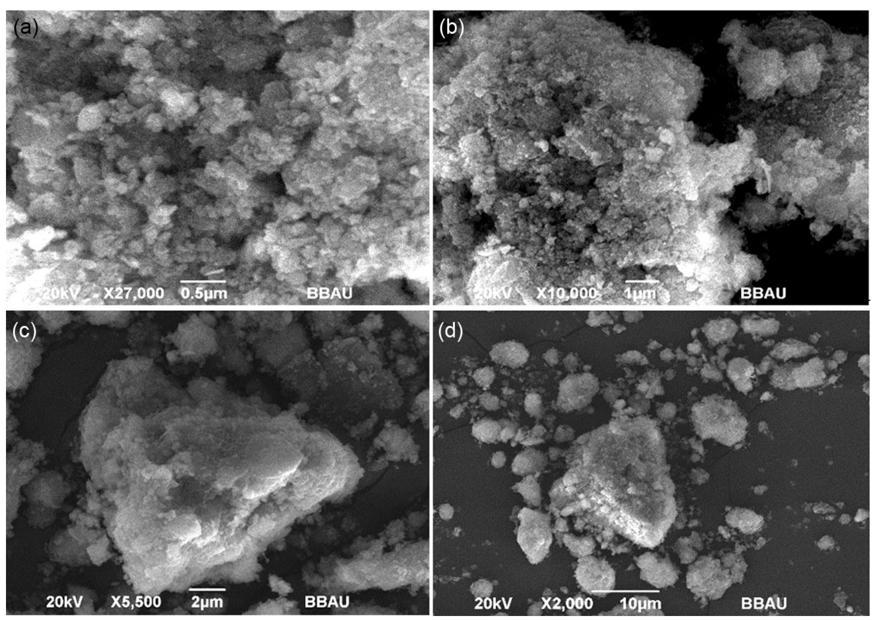

Fig. 15 —Scanning electron microscopy (SEM) of red mud at (a) 0.5μm, (b) 1μm, (c) 2μm, and (d) 10 μm magnifications.

silicate hydrate (C-S-H) phases. XRD analysis can determine the crystal structure and preferred orientation of these mineral phases in C&D waste, while also quantifying their relative proportions. Incorporating C&D waste as a constituent of mortar contributes to the formation of C-S-H gel, a crucial component of the cementitious matrix responsible for the strength and durability of mortar.

3.6.2 SEM-EDX analysis

In addition to assessing the strength, mechanical properties, and durability of red mud, eggshell, and C&D waste materials, microstructural analysis utilizing scanning electron microscopy (SEM) is essential for identifying the presence of hydrated phases. This analysis was conducted at Bheem Rao Ambedkar University in Lucknow. Figures 15 to 18

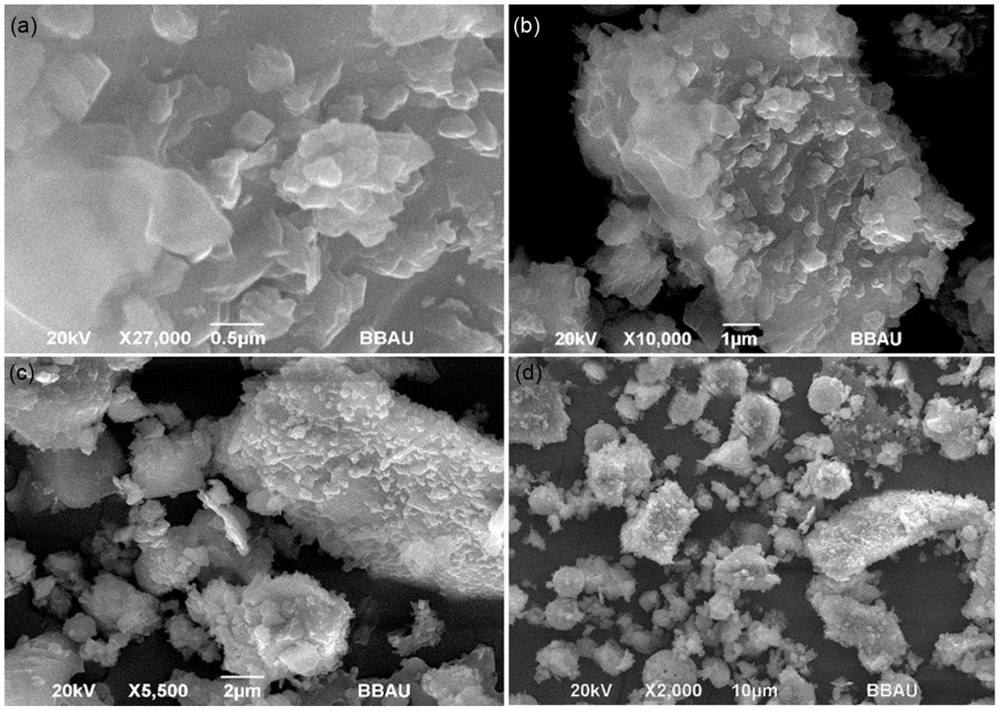

Fig. 16— Scanning electron microscopy (SEM) of cement (a) 0.5µm, (b) 1µm, (c) 2µm, and (d) 10 µm magnifications.

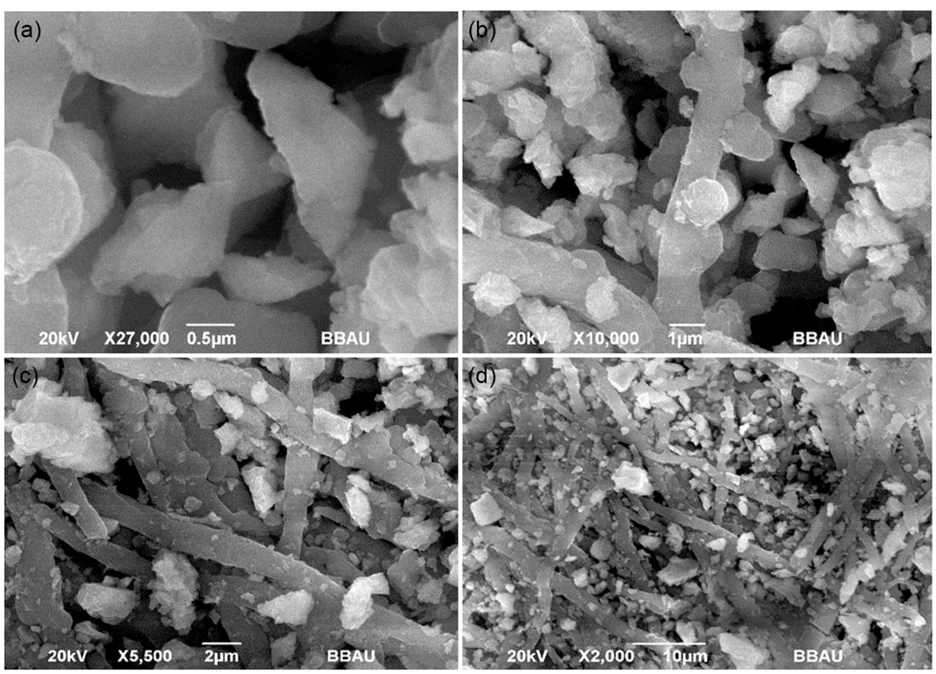

Fig. 17— Scanning electron microscopy (SEM) of eggshell (a) 0.5µm, (b) 1µm, (c) 2µm, and (d) 10 µm magnifications.

illustrate SEM images of all four samples. The elemental composition of the red mud, eggshell, mortar (C&D waste), and cement samples is already presented in Table 1. In the SEM images, the gel phase exhibits a compact microstructure with minimal pore presence. The Ca/Si ratio serves as an indicator of the stable formation of C–S–H gel. The reticular structure of C-S-H contributes to a dense microstructure with limited pores in the concrete.

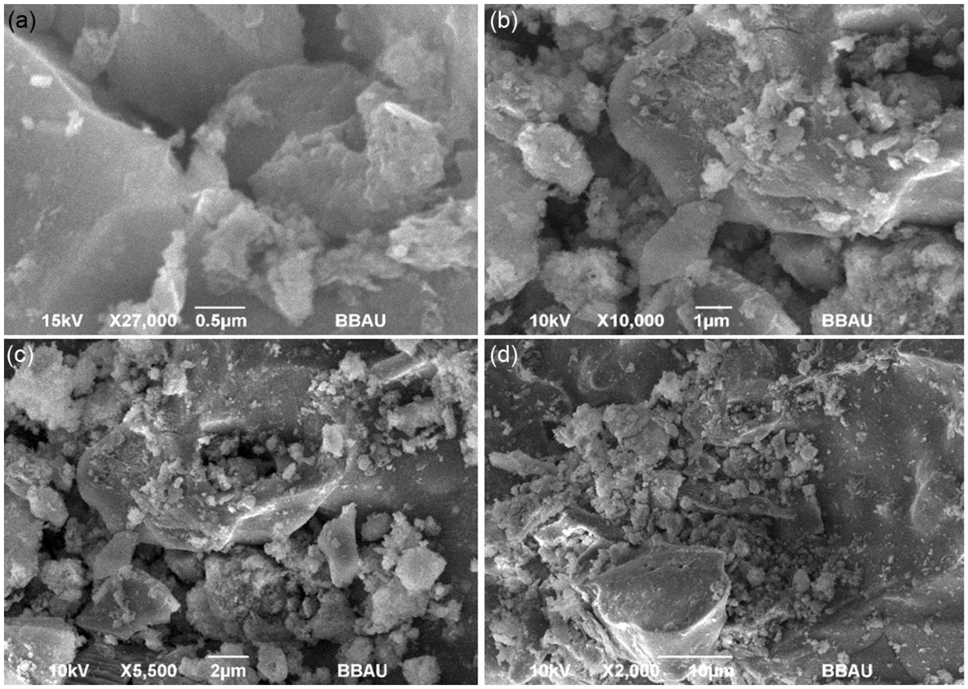

Fig. 18 — Scanning electron microscopy (SEM) of C&D waste at (a) 0.5µm, (b) 1µm, (c) 2µm, and (d) 10 µm magnifications.

4 Conclusion

1. Eggshells show promise as an additive for augmenting the mechanical properties of concrete, particularly in terms of flexural and tensile strength. The abundant presence of calcium carbonate in eggshells facilitates the formation of a more densely compacted matrix in concrete, leading to improved strength characteristics
2. Incorporating waste materials into construction presents a viable means of mitigating the environmental footprint of construction processes. However, it is crucial to ascertain that such use of waste materials does not adversely impact the strength and resilience of the resulting construction.
3. Construction and Demolition (C&D) waste can indeed have pozzolanic properties that can enhance the property of concrete like strength and durability. Pozzolanic materials are non-metallic substances that can undergo a reaction with calcium hydroxide in the presence of water, leading to the formation of calcium silicate hydrates (C-S-H) gel.This gel is the same binding agent that forms in the hydration of Portland cement, the primary binder in concrete. When C&D waste is used as a partial replacement for Portland cement, it can provide additional binding agents in the form of the C-S-H gel, resulting in a denser and stronger concrete matrix. This can lead to improved compressive, split, flexural strength and other mechanical properties of the concrete.
4. The utilization of red mud as a substitute for cement in concrete significantly increased the compressive strength across various red mud concrete blends. In the optimum condition, where 10% red mud replaced cement, the compressive strength witnessed a remarkable surge of 13.03% compared to the control samples.

The findings of this study suggest that waste materials can be an effective and sustainable replacement for cement in concrete production construction and other application. It improves compressiveand split tensile strength and leads to productive C-S-H gel formation. However, the use of Eggshells must be limited to a 15% replacement level to avoid a decrease in strength properties.

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