Mechanical Properties of Concrete that Replace Cement Partly by Using Eggshell Powder

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Abstract - There are many problems due to the cement industry around the world besides the air pollution by greenhouse gas emissions. The issue occurs when a large amount of CO2 is released during the process of converting calcium carbonate lime (CaCO3) into calcium oxide lime (CaO), which is the primary component of cement. This transformation is made in an oven-dry by burning fossil fuels, in a process that releases more carbon dioxide. Substitute materials are usually industrial and municipal wastes .In this study, eggshell powder (ESP) are considered cementitious materials and were added to the cement at different percentages to reduce the cement contents in the concrete industry. Eggshell powder amounts of 0%, 5%, 10%, and 15% by weight were added as ordinary Portland cement (OPC) replacements. The advantages are associated with the high calcium content and good filling effect of eggshell powder. The curing ages were 7, 14, and 28 days. This study evaluates the fresh and hardened properties of concrete. Also, EDX and SEM analyses were conducted on the ESP and concrete to analyze the microstructure. Adding ESP accelerates the concrete setting time compared with the control mix. At the optimal content of 10%, ESC has various advantages compared to conventional concrete.

Key Words: Concrete, Eggshell powder, Microstructure characteristics, strength.

1. INTRODUCTION

In the present day, our environment is being negatively impacted by the increase in population, as well as industrial and agricultural practices. These activities result in pollution and the creation of landfills, leading to a world filled with waste. The natural environment is significantly impacted by the manufacture of building materials. Because there are more requirements for buildings, there is a greater demand for cement-based materials (CBMs). Industrial and agricultural wastes are particularly notable among the various types of wastes produced., Blasius Ngayakamo et al [1]. The annual growth rate of cement production is 2.5%, with an increase from 2300 million tons in 2005 to 3500 million tons in 2020. It is projected to reach 3700-4400 million tons by 2050. Cement manufacturing results in substantial air emissions of greenhouse gases such as CO2, which have a significant impact on climate change. Each year, cement production generates 1350 million tons of greenhouse gases. However, eggshells are disposed of in landfills across the globe in significant quantities. Additionally, by 2030, the world's egg production will have increased by about 90 million tons. Because eggshells are classified as hazardous waste under European Union rules, finding alternative technologies to convert eggshells into components for other applications is critical, Mohamed Amin et al [2]. The cement industry is one of the leading sources of greenhouse gas emissions. Approximately 7% of the world's CO2 emissions come from this industry, with 900 kg of CO2 released into the atmosphere for every ton of cement produced. Eggshell has also been experimented with in civil engineering as a substitute for binders, fillers, and fine aggregates., B.W. Chong et al [3]. Egg hard shells are one sort of agricultural waste. Around 10% of an egg's total weight is comprised of the eggshell. It is estimated that over 8 million tons of eggshells are produced annually.,Chong Beng Wei et al [4]. Green concrete can be made using eggshell powder as a cement alternative. At the same time, it improves the disposal of eggshell, which is commonly discarded as household waste and ends up in landfills.The Environmental Protection Agency has classified eggshell waste as the 15th most significant pollution issue in the food industry. When eggshells are not disposed of correctly in designated areas, they can be a significant contributor to environmental pollution. This can lead to health risks in the future as the eggshells can promote the growth of fungi.,Marium W.,Muhammad Y.et al [5]. There is a significant quantity of eggshells that are not being used and are being discarded on the ground. Eggshells contain calcium carbonate, which is an important chemical compound needed to produce the binder gel (Calcium Silicate Hydrate) in cement materials. Hence, when in a powdered state, it has the potential to serve as a substitute for cement in building materials.,Navaratnarajah Sathiparan [6]. The eggshells also contain microelements such as magnesium, iron, copper, boron, sulfur, zinc, silicon, and molybdenum. The compressive strength of mortar was increased by 29% and 15% respectively when raw eggshell powder was used to replace 0%–20% of the fine aggregate in cement mortar.,Dikshita Nathet et al [7]. oyster-shells ash [8]. An alternative form of limestone bio-filler can be obtained from discarded eggshells. Previously, eggshell powders (ESP) were analyzed and found to contain around 96.9% calcium carbonate (CaCO3) with a calcite crystal structure, and approximately 1-3% organic matter by weight., Duncan Creea, Prosper Pliyab [8]. Different researchers use different sieve sizes, but many studies utilize a 90 μm sieve for replacing cement. A smaller dimension of 75 μm has also been examined, while a larger dimension of 2.36 mm has been investigated as well.Has also been attempted, with a similar outcome. The use of eggshell powder as fine as 300 μm demonstrates a research gap. The particle size distribution is similar to that of ultra-fine fly ash, a common pozzolan with particle sizes ranging from 1 to 100 μm. Having its great filling ability, it improves microstructure and reduces micro holes. ,Chong Beng Wei [9]. sugar cane bagasse ash [10]. The chemical, physical, and mineralogical properties of eggshell powder (ESP) differ slightly from those of cement. The effectiveness of ground brown and white chicken ESP in the replacement of typical lime stone in cement mortars was investigated. The researchers discovered that the inclusion of different percentages of limestone materials had an impact on the compressive and flexural strengths of concrete. This was because it led to the formation of extra C-S-H gels. Hussein M. Hamada et al [11]. The dust particles typically range in size from 1 to 100 μm in diameter. Pollutants combine to generate smog, which poses a significant risk to the environment and human health. Eggshell has also been tested in the field of civil engineering as a fine aggregate, filler, and substitute for binder. More comprehensive research, however, agreed on a more specific amount of constituents: 93.70% calcium carbonate (CaCO3), 0.80% calcium phosphate (Ca3 (PO4)2), 1.30% magnesium carbonate (MgCO3), and 4.20% organic matter, is added to concrete to improve its mechanical and physical qualities as a source of calcium. More comprehensive research, however, agreed on a more specific amount of constituents: 93.70% calcium carbonate (CaCO3), 0.80% calcium phosphate (Ca3(PO4)2), 1.30% magnesium carbonate (MgCO3), and 4.20% organic matter., Samit N., B.W. Chong. and Ashraf T.et al.[12,13]. It was determined that replacing 10% and 15% of cement with eggshells resulted in M25 concrete with higher strength compared to the control. Using 10% and 15% eggshell replacement, concrete was produced that exceeded 50 MPa after 28 days. Aside from improving mechanical performance, eggshell substitution increased concrete durability and decreased water absorption.Tan et al. n et al [14, 15]. primarily because the latter is more stable at high pressures and has a larger density (qcalcite = 2.71 g cm -1, qaragonite = 2.94 g cm -1). The entire conversion from one phase to another was not seen, and the equilibrium calcite-aragonite ratio was roughly 30:70. The same outcome was achieved when the milling process began with pure aragonite. Waste eggshell samples had a density of about 2.47 g/cm3, which is within the range of calcium carbonate materials. Eggshell's organic compound was found to be 5.36%. Matej Balaz. and P. Pliya, D. Cree.[16,17,18]. Except for boiling to remove biological contaminants, most experiments used eggshells without any thermal treatment prior to concrete mixing. This research looks at the performance of modified concretes that include calcinated eggshell powder as a partial fine aggregates replacement at 10%, 20%, 30%, and 40% replacement rates. were calcined to produce calcium oxide (CaO) or quicklime (Equation (1)) to improve the chemical properties of the material for strength development.

$$CaCO3 \rightarrow CaO \rightarrow CO2$$

The purpose of this research is to use eggshell powder as partial replacement cement and to investigate the mechanical properties of concrete. Eggshell powder amounts of 0%, 5%, 10%, and 15% by weight were added as ordinary Portland cement (OPC) replacements. The mechanical properties of concrete are then determined using compressive strength tests, tensile strength tests, and flexural strength tests. The eggshell powder is associated with the high calcium content and good filling effect of eggshell powder. The curing ages were 7, 14, and 28 days. This study evaluates the fresh and hardened properties of concrete. Also, EDX and SEM analyses were conducted on the ESP and concrete to analyze the microstructure.

1.1. PREPARATION OF EGGSHELL POWDER

The eggshells are cleaned with regular water as part of the process before they can be used as a substitute for cement. Aside from cleaning the eggshell from impurity, this Journal Pre-proof process also removes the thin membrane of the eggshell. Both the membrane and water used for this process can be recycled for other uses [4]. When the cleaning is finished, the eggshells should be dried. It is best to dry the eggshells as soon as possible before transporting them to the grinding facility. The drying procedure differs between studies. Some people like to dry their eggshell by simply placing it out in the sun [6]. The exposure time ranges from one to five days. Aside from air drying, the eggshell was also dried in an oven. The eggshells were dried in a hot air oven at 1800o for 24 hours. However, for the same length, a 105o oven will suffice. In another experiment, eggshells were heated at 110o for only 12 hours. The eggshells will then be crushed and ground into powder. Many studies do not go into detail about the tools and methods employed in this process [7,8]. However, it has been stated that eggshell can be ground with a steel drum. or machinery in a flour mill. To ground the eggshell by hand, a pestle and mortar is a good alternative. Finally, the eggshell powder is sieved to a micron size before being mixed with cement. The size of the filter varies between studies, however many employ a 90 μm sieve for this operation. A lower size of

75 µm has also been investigated [10,11,12]. and a bigger size of 2.36mm[15].

1.2 EGGSHELL COMPOUND

While $CaCO_3$ accounts for more than 90% of eggshell, other micro compounds like as boron, copper, iron, manganese, molybdenum, sulfur, magnesium, silicon, and zinc are also present. Eggshell contains about 4% organic substance [13]. According to one study, the constituents of eggshell include 95% $CaCO_3$ and 5% other minerals [15]. More comprehensive research, however, agreed on a more specific amount of constituents: 93.70% calcium carbonate ($CaCO_3$), 0.80% calcium phosphate ($Ca_3(PO_4)_2$), 1.30% magnesium carbonate ($MgCO_3$), and 4.20% organic matter [18]. The detailed chemical composition of eggshell based on numerous investigations is shown in Table 1.

Composition (% by mass)		[13]	Eggshell [15]	[18]
CaO	83.2	52.15	47.49	52.10
MgO	0.10	0.60	-	0.06
SiO2	0.15	1.22	-	0.58
Al2O3	0.28	0.28	0.11	0.06
Fe2O3	0.18	0.16	-	0.02
CI	-	0.011	-	-
SO3	0.25	-	0.38	0.62
K2O	0.06	-	-	0.25
Na2O	0.11	-	0.14	0.15
LOI	14.5	-	-	45.42

2. SIGNIFICANCE OF STUDY

Climate change is one of the disasters facing the world. It was necessary to reduce the environmental risks surrounding various industries, especially the cement industry, and the resulting carbon emissions and consumption of raw materials by using environmentally friendly materials that can add to or improve the properties of the concrete produced. Experimental program

3. EXPERIMENTAL PROGRAM

3.1 Materials

3.1.1 Cement

Ordinary Portland Cement (OPC) of grade 43 from the brand "ULTRATECH CEMENT" was utilized in this experiment. Cement has a density of 3160 kg/m3, CS of 45.25 MPa (28 days). and a specific surface area of 3510 cm2/gm. These test values are in accordance with the provisions of IS: 12269-1987. Table 2 shows the physical properties of the cement used in this study.

Physical Properties	Values
Fineness (in %)	96
Consistency (%)	28
Initial setting time (min.)	128
Final setting time (min.)	389
Specific gravity	3.14
Bulk density (kg/m3)	1440
Specific surface area (cm2/g)	3510
Color	Grey

3.1.2 Fine aggregate

The fine aggregate utilized was river sand, were used whilst river sands with a maximum size of 4.75 mm were used as fine aggregates. Its bulk density is 1680 kg/m3.The fine aggregates used are in accordance to IS: 383-1970. Table 3 displays the properties of the fine aggregate.

Physical Properties	Values
Specific gravity	2.65
Fineness modulus	2.53
Water absorption (%)	1.39
Zone	1

3.1.3 Coarse aggregate

The crushed gravel used for the coarse aggregate had a maximum size of 20 mm were used to perform the aggregate tests. The bulk density of 20 mm size aggregate was 1600 kg/m3. The coarse aggregates used are in accordance to IS: 383-1970. Table 4 displays the properties of the coarse aggregate.

Physical Properties	Values
Nominal size (mm)	20
Specific gravity	2.64
Fineness modulus	6.98
Water absorption (%)	0.45
Impact value (%)	17.12
Crushing value (%)	15.17

3.1.4 Admixture

High-range water-reducing (HRWR) Superplasticizer, FOSROC CONPLAST SP430G8 QCDA 820 Crete having density approximately 1.2kg/l. was used.

Distilled water was used in this research to ensure there are no impurities in the water. More water is added to the concrete than is required for the hydration reactions. This extra water is added to give concrete sufficient workability. The water volume (mL) was converted to weight unit (g) to facilitate the mixing process.

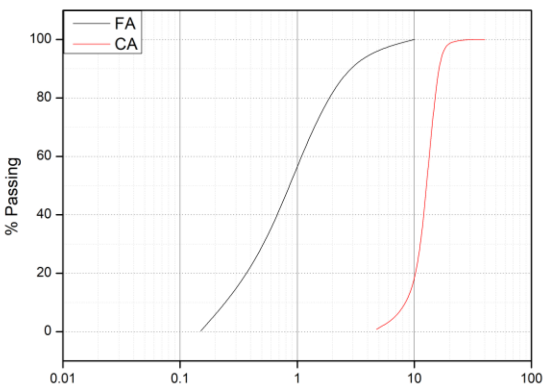

Figure:1. Shows the distribution of particle sizes for both natural fine and coarse aggregate.

4. METHODOLOGY

The concrete mixtures were designed to create plain and eggshell powder incorporated concretes, with a water-to-binder ratio of 0.4. The measurements taken for concrete mixes in their fresh state included the setting time, workability, and air content. The materials used in this study are easily found locally; including ordinary Portland cement (OPC), river sand as a fine aggregate, crushed granite as a coarse aggregate, and tap water, eggshells were supplied from Herblyf in brahmapur that used as partial cement replacement at 5%, 10% and 15% for the eggshells powder. In this study, M35 grade concrete mixes are prepared using OPC 43 Grade using IS 10262-2019.with required proportions: Total cement binder content = 395 Kg/m3, FA = 715 Kg/m3, CA=1155 Kg/m3, super plasticizer = 3.15 kg/m3 and w/c = 0.40. The cubes measuring (150 × 150 × 150) mm were utilized to measure the compressive strength after 7, 14, and 28 days.The tensile strength of a (100 × 200 mm) diameter and height cylinder was measured at 7, 14, and 28 days. The beam measuring (150 × 150 × 700) mm was subjected to flexural strength testing after 7 and 28 days. All of these samples were molded and subjected to vibration on a vibrating table to ensure sufficient compaction. After 24 hours, they were removed from the mold and placed in a standard conditioning room with a relative humidity of approximately 95% and a temperature of 20OC, with a variation of ± 2OC. After curing for 7, 14, and 28 days, a groove measuring 3 ± 1 mm in width and 25 ± 1 mm in depth was cut at the middle of the side surface for each sample. Mix proportions

5. MIX PROPORTIONS

Therefore, a total of 4 distinct concrete mixtures were created in order to analyze the mechanical characteristics of the concretes. Concrete examples with and without eggshell powder added as PC substitutes were created. For the first three minutes, combine the cement, eggshell and aggregates in a dry mixture to ensure that they were evenly distributed throughout the dry mixture. In the end, the dry mixture was combined with water and superplasticizer and mixed for an additional 2 minutes.The molds were then filled with a concrete mixture and compacted with a steel rod. The concrete samples were cured in fresh water for the duration 7, 14 and 28 days. The mixing design for the 4 types of concrete is presented in Table (5).

Table 5. Reference mix of M35 Grade of concrete

Series	A	B	C	D
Eggshell powder (%)	0.0	5.0	10	15
W/C ratio	0.4	0.4	0.4	0.4
Cement kg/m3)	395	375.3	355.5	335.8
Eggshell powder (kg/m3)	0.0	19.75	39.5	59.25
20mm Aggregate (kg/m3)	693.4	693.4	693.4	693.4
10mm Aggregate (kg/m3)	461.7	461.7	461.7	461.7
Water (kg/m3)	157	157	157	157
Fine aggregate(kg/m3)	715	715	715	715
Admixture (kg/m3)	3.15	3.15	3.15	3.15

Figure:2 Processing waste eggshell for use in cement concrete

6. FRESH PROPERTIES OF EGGSHELL CONCRETE

6.1 Workability

The workability of eggshell concrete (ESC) is less than that of normal ordinary Portland cement concrete (PC). The workability of ESC is decreased when the percentage of cement is increased with eggshell. Stated that this trend was attributed to the high water absorption of eggshell powder ESC which absorbs the water required for achieving a high workability.

6.2 Consistency and Setting Time

To assess the consistency and setting time of concrete, the Vicat equipment is utilized. Eggshell is an accelerator that reduces the setting time of cement.Conducted a thorough investigation on the function of eggshell as an accelerator. The initial and final setting time for OPC should not be less than 30 minutes or more than 10 hours. The reduction in setting time occurred as eggshell powder acted as filler.

Table 6 Results of hardened mix properties of concrete

Series	Eggshell powder (%)	Compressive Strength (28 days) (MPa)	Splitting tensile strength 28 days(MPa)	Flexural strength 28days) (MPa)
EP1	0.0	45.36	3.74	6.72
EP2	5.0	46.40	4.18	7.01
EP3	10	48.00	4.39	7.79
EP4	15	38.93	3.20	6.00

7. HARDENED PROPERTIES OF EGGSHELL CONCRETE

7.1 Compressive Strength

The results for compressive strength of 4 concrete mixes at the (7, 14, and 28 days) are presented in Figure (3). refers to the control mixture which contained cement only, without the inclusion of eggshell powder. The conventional grade EP-1 concrete had compressive strengths of 30.12, 39.48, and 45.36 N/mm2. The percentages of increase were calculated as 8.20%, 6.0%, and 2.29% for eggshell powder contents of 5% (EP2) respectively, compared to plain concrete (EP1), after 7, 14, and 28 days, at 7, 14, and 28 days. The maximum improvements in compressive strength were recorded with 10% eggshell powder (ES3) contents of 14.39%, 9.0%, and 5.82% respectively. This outcome is clearly dependent on enhancing the binding strength of the cement paste-aggregate interface through the filling impact of eggshell powder. The compressive strength decreased by 12.35%, 8.87%, and 14.18% at 7, 14, and 28 days when the percentage of eggshell powder varied from 15% (EP4). If the eggshell percentage continues to increase beyond the optimal level, it will lead to a decrease in strength. When eggshell powder is the only replacement material in the mix, the optimal eggshell powder content is 10%. The eggshell increases water demand, which increases water cement ration and so reduce strength.Fig.3 depicts the difference in compressive strength for different amounts of replacement.

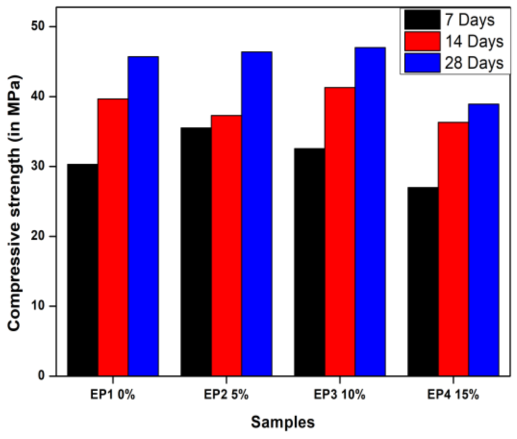

Figure: 3- Compressive strength of concrete for different design mixes.

7.2 Flexural Strength

Figure 4 shows the graph of the flexural strength of the concrete specimen over a period of 7 and 28 days. Flexural strength refers to the ability of concrete to resist deformation under bending moment. The formula provided in IS 516:1959 was used to calculate the results of all mixtures. The results for ordinary concrete after 7 and 28 days were calculated to be (EP1) 5.92 and 6.72 N/mm2, respectively.The flexural strengths of the (EP2) concretes increased by 6.9% and 4.32% for the eggshell powder contents of 5%, respectively. The flexural strength (EP3) showed the maximum improvements with the addition of 10%, eggshell powder, the increases were recorded as 13.08% and 16.00% at 7 and 28 days, respectively. The flexural strength (EP4) decreased by 19.38% and 10.71% at 7, and 28 days when the percentage of eggshell powder varied from 15%. Up to a certain amount, the flexural strength of ESC rises with increasing eggshell content. The addition of eggshell as a filler in concrete can enhance its flexural strength, resulting in a higher flexural strength compared to the control mixture. Fig.4 depicts the difference in split tensile strength for different amounts of replacement.

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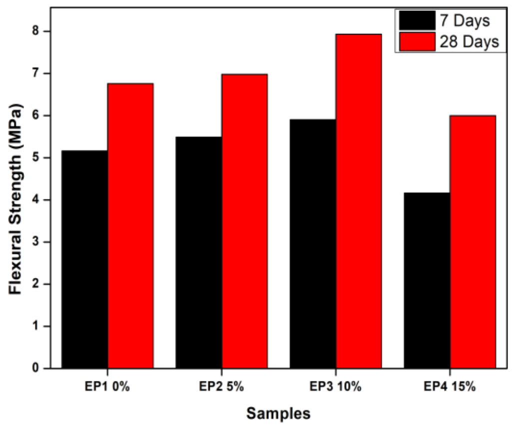


Figure: 4- Flexural strength of concrete for different design mixes.

7.3 Split Tensile Strength

The findings from the tensile test conducted after7, 14 and 28 days are displayed in Table 6. Split tensile test is an important parameter in concrete to understand its resistance to tensile crack. The tensile strength of EP1 (conventional grade) concrete is 2.38, 3.15, and 3.74 N/mm2 for cure durations of 7, 14, and 28 days, respectively. By adding more eggshell powder, the splitting tensile strengths of the concretes significantly improved. The splitting tensile strengths (EP2) of the concretes increased by 7.83%, 6.50%, and 11.76%, for the 5%, eggshell powder contents, respectively, compared to the plain concrete (EP1) at 7, 14, and 28 days. The concrete made with 10% eggshell powder content showed the highest improvement in splitting tensile strength (EP3) were obtained as 9.84%, 21.84%, and 17.38%, compared to plain concrete (EP1) after 7, 14, and 28 days. The split tensile strength (EP4) decreased by 12.21%, 9.10%, and 14.44%, at 7, 14, and 28 days when the percentage of eggshell powder varied from 15%. The split tensile strength is calculated using the formula recommended in IS 5816:1999. Fig.5 depicts the difference in split tensile strength for different amounts of replacement.

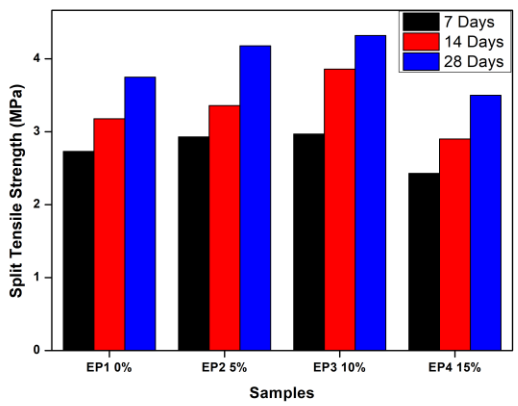


Figure: 5- Split tensile strength of concrete for different design mixes.

8. MICROSTRUCTURE STUDY OF MATERIALS

8.1 X-ray diffraction analysis (ESP)

Figure 6 (a) displays the XRD patterns of ESP. The XRD pattern of ESP primarily consists of calcite (CaCO3), which transformed into calcium oxide (CaO) during the calcination process. The analysis of the chemical and mineral composition showed that ESP does not possess the properties of a pozzolanic material because it lacks siliceous and aluminous components. Nevertheless, the powder made from discarded eggshells contains a significant amount of CaO, which is obtained through the calcination of calcite (CaCO3). This CaO is crucial in a pozzolanic reaction that affects certain cement-like properties in concrete. Calcite is the most thermodynamically stable mineral under normal conditions.

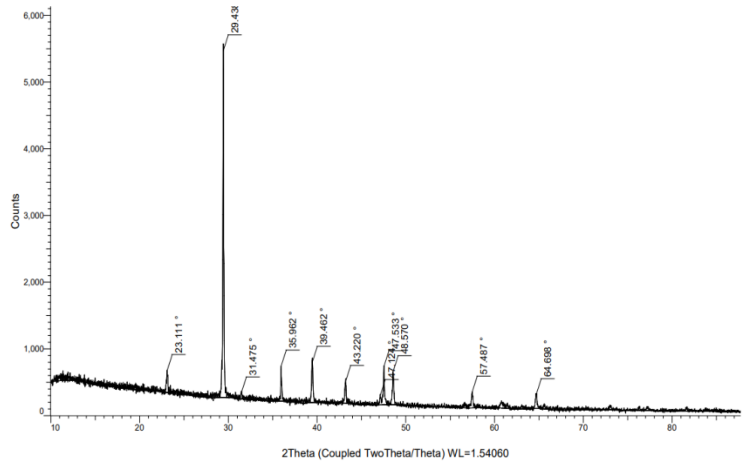


Figure: 6(a) - X - ray pattern of ESP and calcined ESP

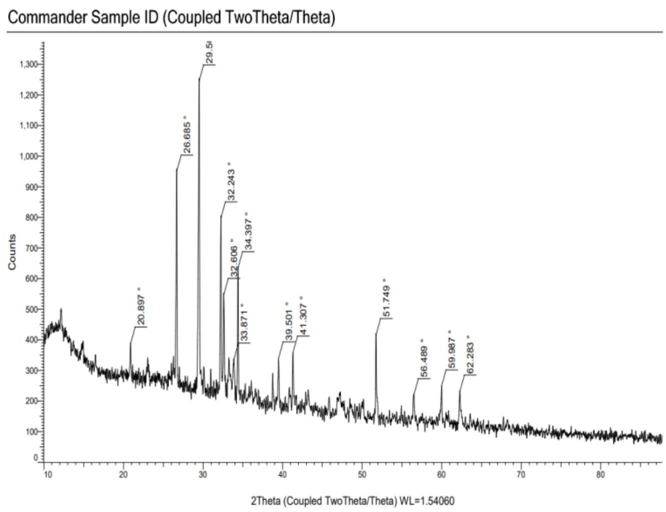


Figure: 6(b) - XRD pattern of cement

8.2 Scanning electron microscope (SEM) analysis of ESP

The ESP SEM micrograph in Fig. 7a depicts calcite particles with variable morphologies following grinding and sieving procedures. The distributed powder particles indicate that the

ESP is a non-plastic material. Concrete with ESP has extra CaO, which is needed to generate secondary C-S-H gel. The SEM analysis, characterized by its exceptionally fine resolution of 1 nanometre (nm), offered an unparalleled level of detail and precision. This high level of resolution was crucial in uncovering the eggshell's intricate mechanical and compositional nuances. The SEM examination uncovered a world of micro scale features, ranging from 1 to 10 micrometres (µm) in size, each contributing significantly to the eggshell's remarkable mechanical strength. SEM allowed for the identification and quantification of key components. The primary constituent, calcium carbonate, typically comprises about 94% of the eggshell's composition, offering the rigidity necessary for protection. It was noticed that the filler fineness could be increased to improve the mechanical properties of concrete. Another study discovered that inconsistency in ESP shape influenced the workability of the concrete mixture.

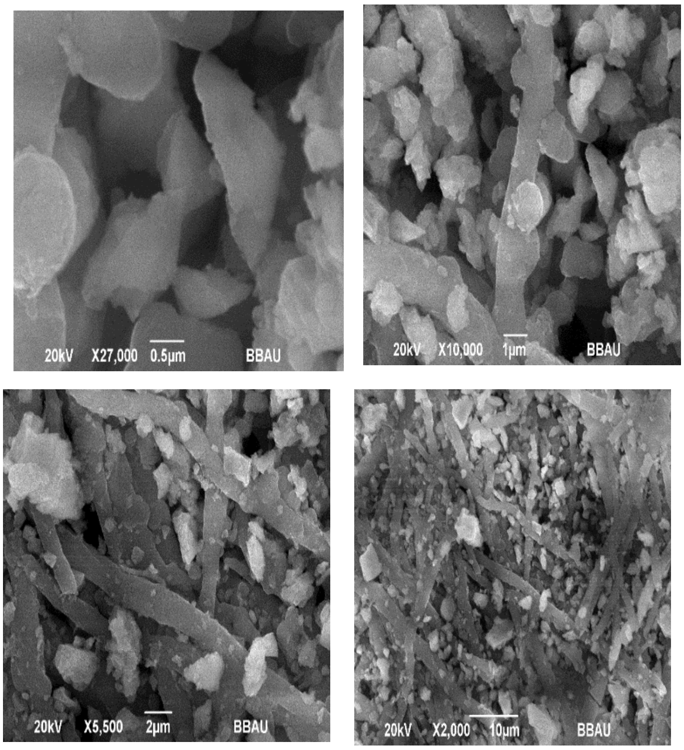
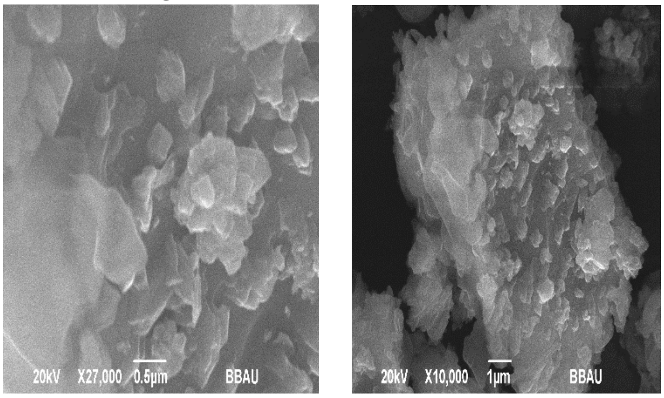


Figure:7(a)-Scanning electron microscopy (SEM) of Eggshell at different magnifications



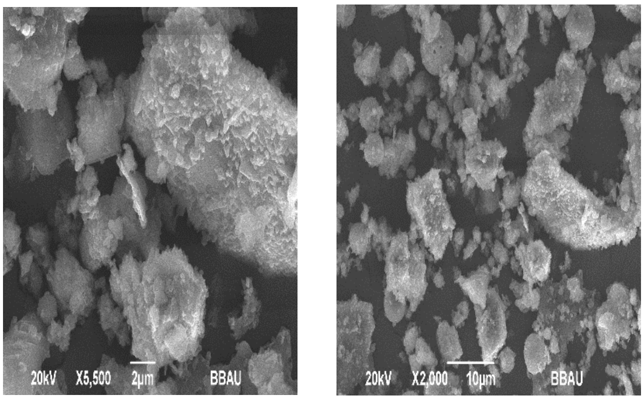


Figure:7(b)- Morphology of cement mortar (a) 0.5µm (b) 1µm (c) 2µm (d) 10µm

9. CONCLUSIONS

- Utilizing waste eggshells in construction materials will promote sustainable development by reducing environmental issues related to the dumping of waste eggshells, protecting natural resources, producing economical materials, and decreasing CO2 emissions.
- Workability of concrete mixes reduces with the addition of eggshell powder in concrete.
- The optimum inclusion level of eggshell powder (10%), with enhancement in compressive 48.00MPa, flexural and split tensile strengths of 7.79MPa and 4.39MPa for 28 days, respectively.
- The present work to study the influence of incorporation of the eggshell waste powders on the physical and mechanical properties of Portland cement concrete.Furthermore, this work examines the effect of the calcination process for eggshell powder, by comparing with un-calcined eggshell powder, on the performance of cement mortar. Utilizing use the eggshell as a replacement material for the cement-based materials, and thus would help overcome the eggshell waste problem.
- The surface morphology, CaO content and particle size of the ESP could affect the cement and concrete properties.
- The effects of ESP on concrete strength depend on its replacement level and the mixture proportions of concrete.
- Eggshell concrete has a significant lower setting time than conventional concrete.
- Overall, ESP can be prepared in a nanoparticle size to improve their characteristics in concrete. Using large amounts of ESP can increase the calcium content in concrete mixes, thereby increasing the concrete strength. Therefore, this study recommends the following topics for future studies:

- Eggshell lowers the workability of concrete.The decrease in workability when the percentage of eggshell in the mix increases. This is due to the high water absorption of eggshell at early stage of casting. Eggshell absorbs the water required to achieve a high workability.
- Concrete performance evaluation with EP nanoparticles: Experiments can be conducted to assess the mechanical characteristics, durability, and other performance features of concrete using ESP nanoparticles. This can aid in determining the efficacy of EP nanoparticles in enhancing concrete performance.
- Long-term durability evaluation: Future research could focus on determining the long-term durability of concrete including EP concrete. This can include being exposed to various climatic conditions and evaluating features such as chemical resistance, freeze-thaw cycles, and carbonation.
- By exploring these subjects in future studies, a more profound comprehension of the possible advantages and uses of EP nanoparticles in concrete can be achieved, resulting in the creation of construction materials that are both more effective and environmentally friendly.

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