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COMBINED EFFECTS OF EGGSHELL POWDER AND STEEL FIBRE ON THE MECHANICAL CHARACTERISTICS OF CONCRETE

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ABSTRACT

The findings of an experimental investigation of the mechanical characteristics of plain and eggshell powder (ESP) concretes, both with and without steel fiber, are presented in this work. Using eggshell powder instead of cement is a feasible alternative for creating environmentally friendly concrete. At the same time, it improves the disposal of eggshell, which is commonly discarded as household waste and ends up in landfills. The several benefits of steel fiber reinforced concrete (SFRC) are that it prevents macro crack propagation, prevents macro cracks by increasingly of macroscopic size, improves ductility and residuary strength since of the initials cracks form, and has a high degree of toughness. To develop of the eggshell powder included steel fibre reinforced concrete mixtures, Ordinary Portland cement (OPC 43 grade) was partially replacement with ESP 0%, 5%, 10% and 15% by weight of the total binder content. The steel fibers were incorporated into the mixture at volume fractions of 0.5%, 1.0%, and 1.5%. Hook ended steel fibres with length/aspect ratios of 50 were to create fibre reinforced concrete. On the compressive, flexural, splitting, and bonding strengths of the concretes, the effects of ESP and steel fiber reinforcement were examined. Additionally, examinations of the eggshell powder and cement's microstructure using XRD and SEM were performed. The tests were performed after 7, 14, and 28 days of the curing period. The optimum increases in the mechanical properties of concrete produced 10% eggshell powder and with 10% eggshell powder and 1% steel fibre (SF).

Keywords: Concrete, Eggshell Powder, Microstructure Characteristics, Steel Fiber, Mechanical Strength.

I. INTRODUCTION

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, Muhammad N.A.et al. [1]. At a rate of 2.5 percent per year, cement production is predicted to increase from 2300 million tons in 2005 to 3500 million tons in 2020 and 3700–4400 million tons by 2050. 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 A., Mohammed M.A. et al [2]. 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 ($CaCO_3$), 0.80% calcium phosphate ($Ca_3(PO_4)_2$), 1.30% magnesium carbonate ($MgCO_3$), and 4.20% organic matter, is added to concrete to improve its mechanical and physical qualities as a source of calcium., Samit N., B.W. Chong. and Ashraf T.et al.[3,4,5]. They discovered that the addition of different proportions of limestone components changed the concrete's flexural and compressive strengths by causing more C-S-H gels to form., Hussein M. Hamada [5]. Waste eggshell samples had a density of about 2.47 g/cm3, which is within the range of calcium carbonate materials. 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 complete transformation from one phase to another was not witnessed, and the proportion of calcite to aragonite in the balanced state was roughly 30:70. Starting with pure aragonite at the beginning of the milling process produced a similar outcome., Matej Balaz. and P. Pliya, D. Cree.[6,7]. In recent years, ultra-high performance steel fibers concrete (UHPSFC) has shown to be an appealing use of composite materials in a variety of structural applications such as bridges, high-rise structures, nuclear power plants, and so on.

UHPSFC's exceptional properties are achieved through a low water to cement ratio, the elimination of coarse aggregate, and the presence of micro steel fibers, resulting in higher concrete compressive strength up to five times that of ordinary concrete, higher concrete tensile strength up to ten times that of ordinary concrete, and greater ductility and durability than ordinary concrete. Because corbel behavior is mostly controlled by shear, it is highly intriguing to use UHPSFC in corbel manufacture., Maha M.S. Ridha [8]. Industrial activities generate a significant amount of nonbiodegradable solid waste, such as paints, chemical solvents, paper products, sandpaper, radioactive wastes, industrial by-products, metals, and agricultural wastes such as sugar cane bagasse and natural fibers, among others., Arun K. P., Ankur G. [9]. Furthermore, three various shapes of steel fibers (straight, corrugated, and hooked end) were investigated, with the results indicating that hooked-end steel fibers performed the best. As a result, hooked-end steel fibers were used in this study., Ahmed S. Eisa [10]. Numerous types of fibers, including as glass, carbon, steel, polypropylene, polyvinyl alcohol, basalt, and mixed fibers, are utilized in the production of fiber-reinforced concrete (FRC). The use of steel fibers improves the durability of concrete in normal conditions, but this improvement declines in a highly corrosive environment, particularly once cracks form., Mohy S. F. et al. [11]. The ultimate load capacity of hidden beams in reinforced concrete can be increased by incorporating short glass fibers. Steel fibers are a type of metal reinforcement that is utilized to strengthen concrete. They are described as short, separate pieces that measure between 20 mm and 40 mm in length, with a length to diameter ratio (aspect ratio) ranging from approximately 20 to 100. The material is evenly spread and scattered throughout a soft concrete mixture using appropriate lengths between 30 and 35 mm, which are added to the mix., Mohamed S. Moawad et al. [12]. Seismic force can result in high shear stress on the lower levels of tall buildings. In addition, the building can collapse due to brittle shear failure. To prevent this, design codes provide guidelines for reinforcing shear and specifying rebar placement. However, using a large amount of reinforcement in concrete columns to prevent shear failure can make pouring the concrete more challenging., Hyun-Ho Lee. [13]. The fiber-reinforced concrete is categorized based on the amount of fibers present, such as low volume fraction (less than 1%), moderate volume fraction (between 1% and 2%), and high volume fraction (greater than 2%). According to reports, the addition of steel fiber to concrete in a volume range of 1-1.5% can significantly enhance its tensile strength by up to 100%, flexural strength by 150-200%, and compressive strength by 10-25%.The weight of concrete structures is significantly greater than the load they are designed to support. As the construction of tall buildings and large-scale concrete structures has become more common, there has been extensive research and successful development of lightweight concrete with various types of lightweight aggregates (LWA) in recent years., M. Kalpana, Ahoh Tayu [14]. It was observed that adding steel fiber in volume fractions ranging from 0.5-2.0% to concrete made with lightweight coarse aggregate such as pumice improved the splitting and flexural tensile strengths by 61-140% and 117-200%, respectively., Maha M.S. Ridha et al [15]. It was determined that eggshell replacement of cement at 10% and 15% generated M25 concrete with greater strength than the control [16]. Similarly, Tan et al. n et al. [17]. Using 10% and 15% eggshell replacement, concrete was produced that exceeded 50 MPa after 28 days. Aside from improving mechemical performance, eggshell substitution increased concrete durability and decreased water absorption., R. Othman et al [17]. The mechanical properties of concrete have not been studied in relation to the combination of eggshell powder and steel fibers, and further investigation is still required. Hence, in this study, the researchers examined the impact of incorporating eggshell powder and steel fibers on the performance of reinforced concrete beams, cubes, and cylinders. The study involved substituting a portion of ordinary Portland cement (OPC) with eggshell powder at varying percentages (5%, 10%, and 15%). Additionally, hooked end steel fibers were incorporated at different volume fractions (0.5%, 1%, and 1.5%).

II. RESEARCH SIGNIFICANCE

Eggshell powder can be utilized as a filler substance for cement or fine aggregates and may have positive impacts on concrete, which depend on the amount of eggshell powder used and its chemical composition. On the other hand, it is well known that the inclusion of discontinuous discrete fibers enhances a variety of concrete qualities, depending on the type of fiber, the amount added, and the aspect ratio. The impact of the presence of eggshell powder and fibers on concrete is still not well understood. This study examined the characteristics of fresh and hardened concretes with varying amounts of eggshell powder and different types of fibers, including different aspect ratios and volume percentages.

III. EXPERIMENTAL STUDY

3.1 Materials

3.1.1 Cement

The cement used was ordinary Portland cement of grade 43. Cement has a density of 3160 kg/m^3 and a specific surface area of 3520 cm^2/g.

Table 1: shows the physical properties of the cement used in this study.

Physical Properties	Values
Consistency (%)	28
Initial setting time (min.)	112
Final setting time (min.)	388
Specific gravity	3.14
Bulk density (kg/m3)	1440
Specific surface area (cm2/g)	3520
Color	Grey

3.1.2 Fine aggregate

The fine aggregate utilized was river sand, which was sieved through a 4.75 mm sieve. The fine aggregates used are in accordance to IS: 383-1970.

Table 2: displays the properties of the fine aggregate.

Physical Properties	Values
Specific gravity	2.67
Fineness modulus	2.53
Water absorption (%)	1.1
Zone	i

3.1.3 Coarse aggregate

The crushed gravel used for the coarse aggregate had a size of 20 mm were used to perform the aggregate tests. The coarse aggregates used are in accordance to IS: 383-1970.

Table 3: displays the properties of the coarse aggregate.

Physical Properties	Values
Nominal size (mm)	20
Specific gravity	2.65
Fineness modulus	6.98
Water absorption (%)	0.45
Impact value (%)	17.1
Crushing value (%)	15.9

Table 4: Chemical composition of eggshell powder

Component %	Cao	Sio_2	Al_2O_3	Fe_2O_3	Na_2O	K_2O	SO_3	MgO	P_2O_5	SrO	LOI
Eggshell powder	83.2	0.15	0.28	0.18	0.11	0.06	0.25	0.1	0.55	0.38	14.5

3.1.4 Steel fibre

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Figure 1 depicts end-hooked steel fibers with dimensions of 50 mm length, 1.0 mm diameter, and 50 aspect ratio.

Table 5: defines the characteristics of steel fibers.

Length (mm)	Diameter (mm)	Aspect ratio	Tensile strength (MPa)	Density (kg/m^3)
50	1	50	1100	7800

3.1.5 Admixture

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

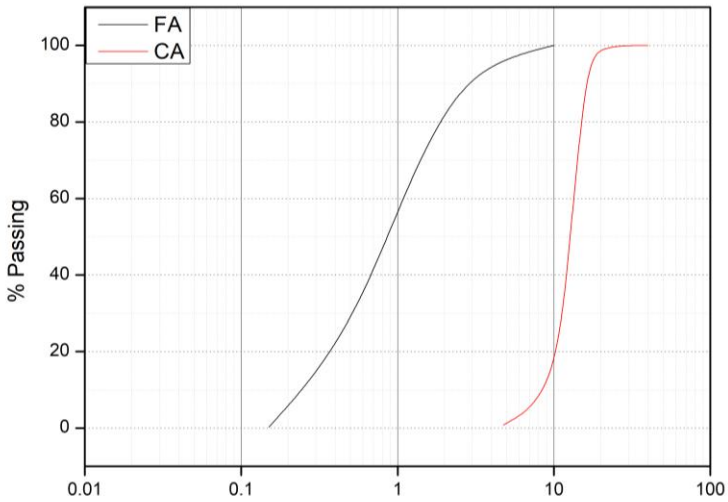

Figure: 1. Shows the distribution of particle sizes for both natural fine and coarse aggregate.

IV. METHODOLOGY

The concrete mixtures were designed to create plain and eggshell powder and steel fiber incorporated concretes, with a water-to-binder ratio of 0.4. The measurements taken for high-strength concrete mixes in their fresh state included the setting time, workability, and air content. Modified concretes containing eggshell powder were created by substituting 5%, 10%, and 15% of the cement with ESP, based on weight. Steel fiber (SF) reinforced concretes were made by adding 0.5%, 1.0%, and 1.5% of the total concrete volume to the concrete. 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 20^{0}C, with a variation of ± 2^{0}C. 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.

V. MIX PROPORTIONS

Therefore, a total of 13 distinct concrete mixtures were created in order to analyze the mechanical characteristics of the concretes. For the first three minutes, combine the cement, eggshell and aggregates in a dry mixture. The steel fibers were then gradually added and stirred for another 1 minute 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.

Table 6: Mix proportion of M35 grade concrete

Design mix	Quantity per M^3

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W/C ratio	0.4
Cement	395 kg/m3
Workability	98 mm
Fine aggregate	715 kg/m3
Coarse aggregate	1157 kg/m3
Water	158 kg/m3
Superplasticizer	3.16 kg/m3

Table 7: Results of hardened mix properties of concrete

Series	Eggshell powder (%)	Aspect ratio (l/d)	Volume of fibres (%)	Compressive Strength (28 days) (MPa)	Splitting tensile strength (28 days) (MPa)	Flexural strength (28 days) (MPa)
PC1	0.0	-	0.0	45.37	3.57	6.67
EP2	5.0	-	0.0	46.40	4.18	6.98
ES3	5.0	50	0.5	47.03	5.17	7.91
ES4	5.0	50	1.0	47.98	5.28	7.99
ES5	5.0	50	1.5	49.23	5.43	8.04
EP6	10	-	0.0	48.00	4.32	7.93
ES7	10	50	0.5	48.89	5.38	8.20
ES8	10	50	1.0	52.98	5.83	8.33
ES9	10	50	1.5	50.39	5.55	8.21
EP10	15	-	0.0	38.93	3.50	6.00
ES11	15	50	0.5	43.00	4.73	6.91
ES12	15	50	1.0	45.20	4.97	7.21
ES13	15	50	1.5	46.00	5.09	7.82

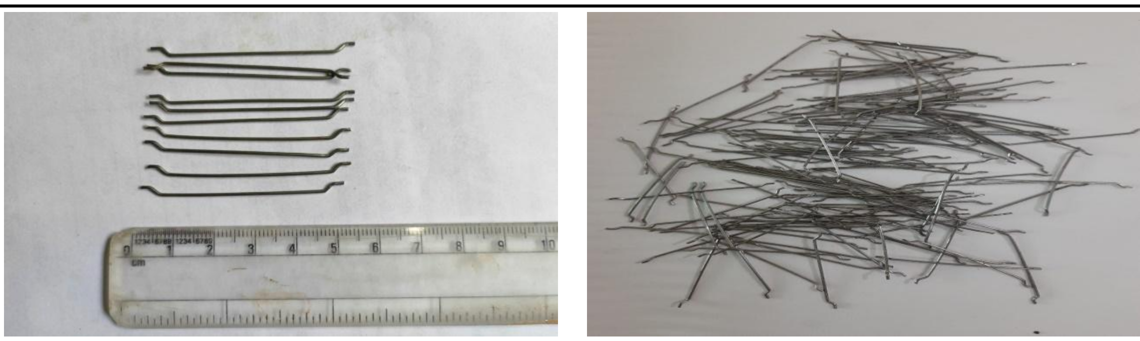

Figure: 2. Hooked end steel fibers of length 50mm and diameter 1mm.

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Figure: 3. Eggshell Powder.

VI. RESULTS AND DISCUSSION

Mechanical properties of concrete

6.1 Compressive strength of concrete

The compressive strength results for specimens at 7, 14, and 28 days are shown in Table 6. The conventional grade EP-1 concrete had compressive strengths of 30.13, 39.76, and 45.37 N/mm2. The compressive strength of the concrete without steel fibers significantly improved when the amount of eggshell powder was increased. The percentages of increase were calculated as 8.20%, 6.0%, 2.27% and 15.78%, 9.0%, 5.79% for eggshell powder contents of 5%(EP2), and 10%(EP6) respectively, compared to plain concrete (PC1), after 7, 14, and 28 days. The compressive strength decreased by 13.35%, 8.87, and 14.19% at 7, 14, and 28 days when the percentage of eggshell powder varied from 15% (EP10). This outcome is clearly dependent on enhancing the binding strength of the cement paste-aggregate interface through the filling impact of eggshell powder. At 7, 14, and 28 days, the largest improvements in compressive strength were recorded with 10% eggshell powder and 1% steel fiber (ES8) contents of 14.39%, 17.13%, and 16.78% respectively. Fig.4 depicts the difference in compressive strength for different amounts of replacement.

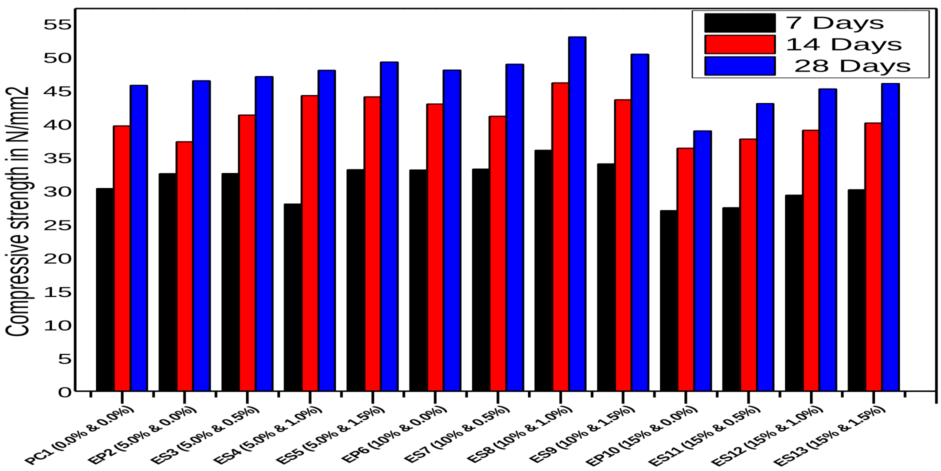

Figure: 4- Compressive strength of concrete for different design mixes.

6.2 Splitting tensile strength test

The findings from the tensile test conducted after 28 days are displayed in Table 6. The tensile strength of PC1 (conventional grade) concrete is 2.37, 3.12, and 3.69 N/mm2 for cure durations of 7, 14, and 28 days, respectively. By adding more eggshell powder and steel fiber, the splitting tensile strengths of the concretes significantly improved. The splitting tensile strengths of the concretes without steel fibers increased by 7.83%, 6.50%, 17.08% and 9.97%, 21.85%, 21.08%, for the 5%, and 10% eggshell powder contents, respectively, compared to the plain concrete (PC1) at 7, 14, and 28 days. The split tensile strength decreased by 13.21%, 11.10%, and 19.07%, at 7, 14, and 28 days when the percentage of eggshell powder varied from 15%.The

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concrete made with 10% eggshell powder and 1% steel fiber content showed the highest improvement in splitting tensile strength were obtained as 36.0%, 44.03%, and 6330%, compared to plain concrete (PC1) after 7, 14, and 28 days. 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.

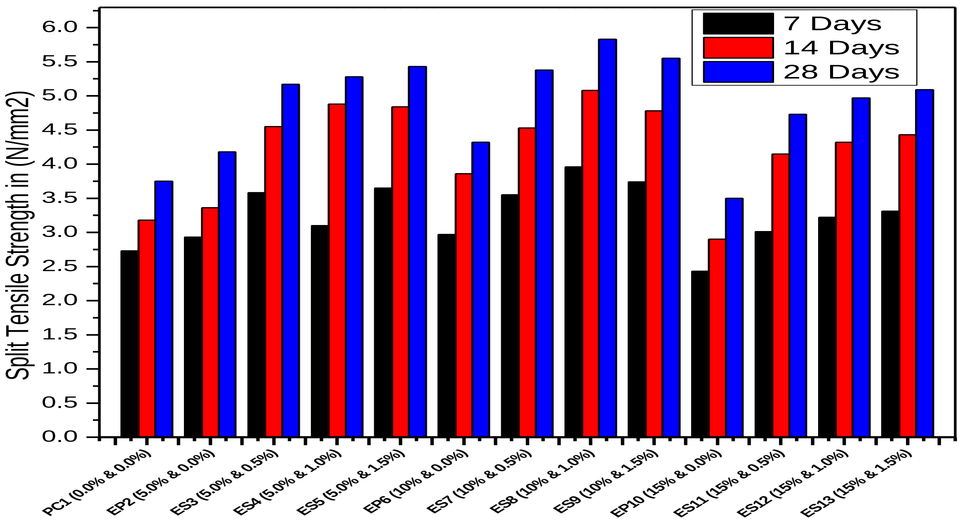

Figure: 5- Split tensile strength of concrete for different design mixes.

6.3 Flexural strength test

Table 6 displays the findings from the flexural test conducted after a period of 7, and 28 days. 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 5.49 and 6.81 N/mm2, respectively. The flexural strengths of the concretes without steel fibers increased by 7.0%, 4.65% and 15.08%, 18.89% for the eggshell powder contents of 5%, and 10% respectively. The split tensile strength decreased by 20.26% and 10.04% at 7, and 28 days when the percentage of eggshell powder varied from 15%. The flexural strength showed the maximum improvements with the addition of 10% eggshell powder and 1% steel fibre. The increases were recorded as 35.13% and 24.89% at 7 and 28 days, respectively. It can be inferred that longer and thicker steel fibres are more effective in slowing down the formation of cracks. Figure 6 shows the correlation between the flexural strength and the amount of eggshell powder for various volumes of steel fibre.

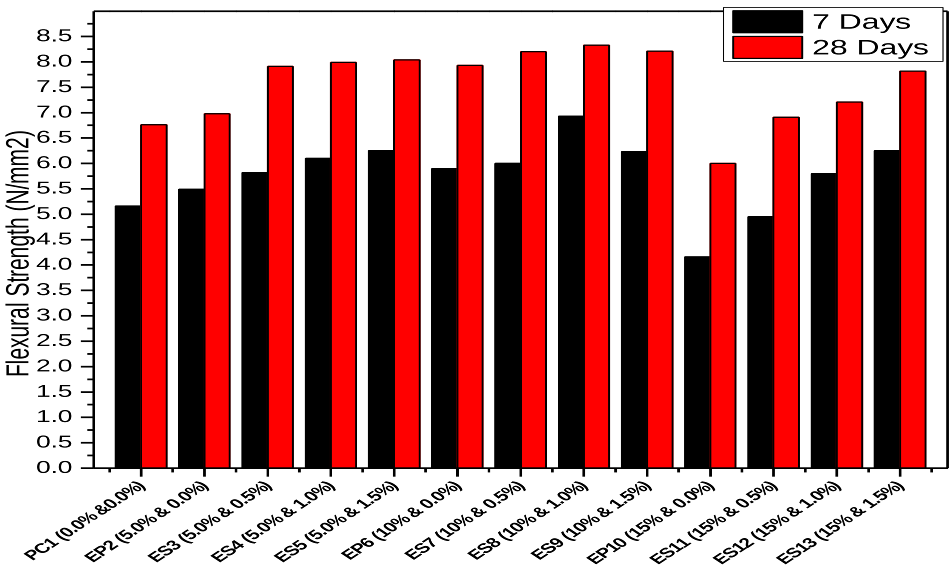

Figure: 6- Flexural strength of concrete for different design mixes.

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6.4 Microstructure study of material

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.

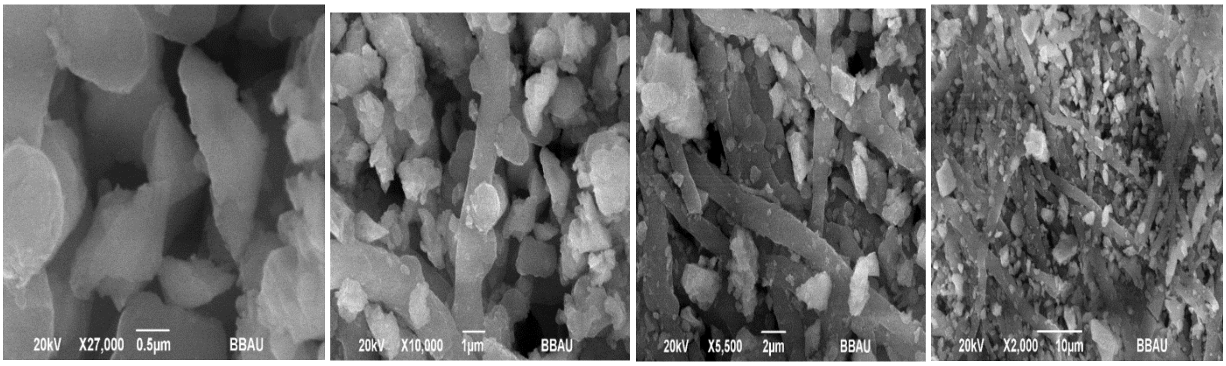

Figure: 7(a) - Scanning electron microscopy (SEM) of Eggshell at different magnifications

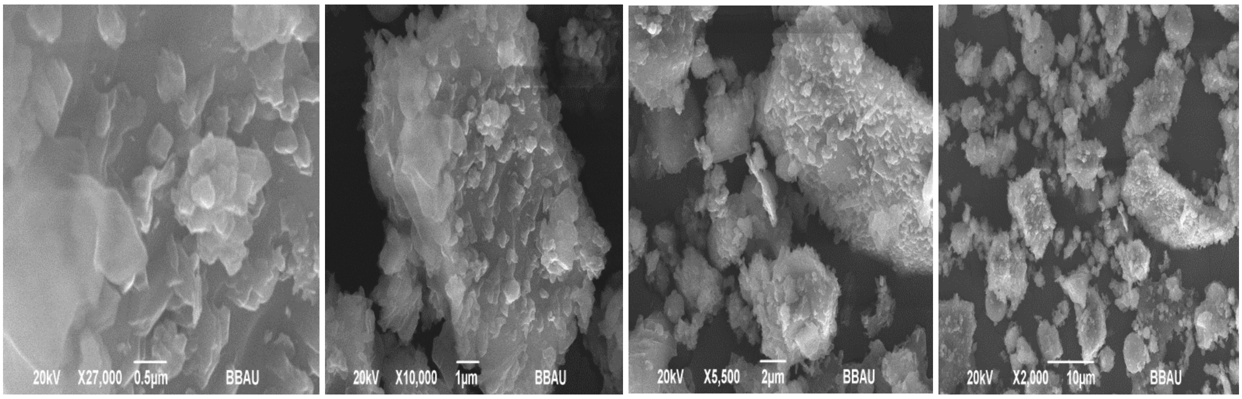

Figure: 7(b) - Morphology of cement mortar (a) 0.5μm (b) 1μm (c) 2μm (d) 10μm

6.5 X-ray diffraction analysis (ESP)

Figure 8 (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.

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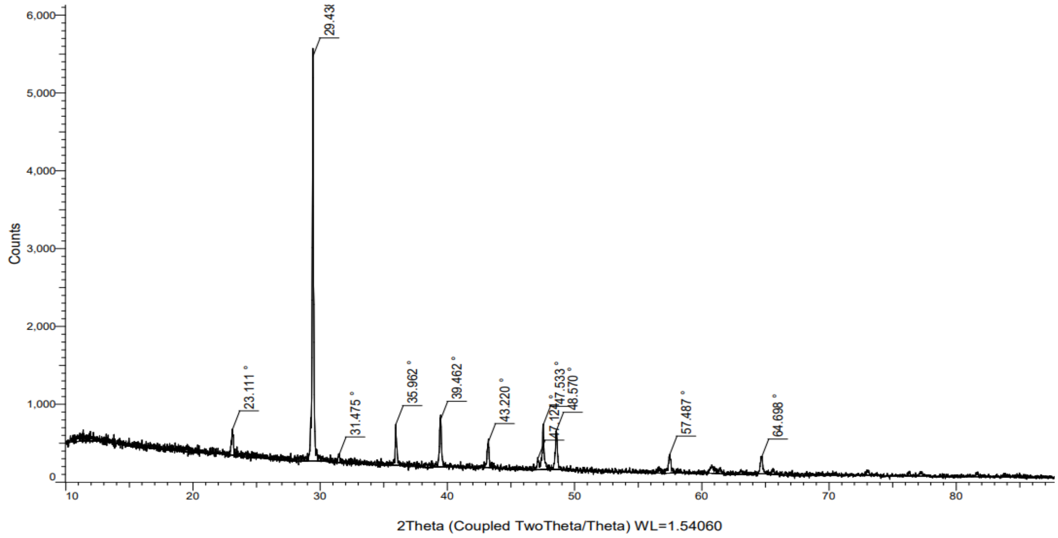

Figure: 8(a) - XRD pattern of eggshell powder

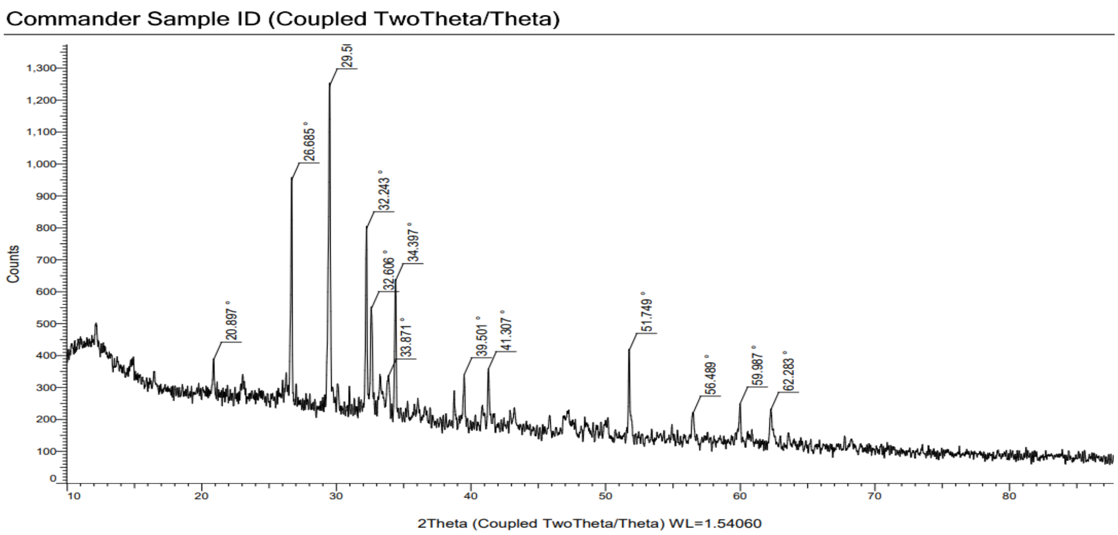

Figure: 8(b) - XRD pattern of cement

VII. CONCLUSION

- The addition of eggshell powder and steel fibre in concrete decreases the workability of concrete mixes.
- The use of steel fibres improved the compressive, tensile strength and flexural strengths and increased the ductility of the material. The addition of steel fibres slowed the growth of cracks, improving the durability and service load of the structure. This study to the advancement of environmentally friendly and sustainable construction methods by offering useful insights into the characteristics and performance of SF-concrete.
- Using waste eggshells in construction materials will contribute to sustainable development by addressing environmental concerns associated with the disposal of eggshell waste, conserving natural resources, creating cost-effective materials, and reducing CO2 emissions.
- The highest mechanical properties were observed when 10% of the cement was replacement with eggshell powder.
- The maximum inclusion of eggshell powder to use is 10%, which results in improved compressive strength of 48.00 N/mm2, as well as increased flexural and split tensile strengths of 7.93 N/mm2 and 4.32 N/mm2 respectively after 28 days.
- The optimum inclusion level of hooked steel fiber in ESP (10%) is 1% and the highest increase in compressive, flexural and split tensile strengths of BASFC is 16.78%, 24.89% and 38.19% at 28 days, respectively.

- According to the overall analysis, it is feasible to improve the properties of Electrical Steel Plant (ESP) in concrete by producing it in nanoparticle form. This increased amount of calcium has been shown to enhance the strength of concrete. Based on these discoveries, the following areas are suggested for future studies:
- Study can be conducted to investigate different techniques for synthesizing EP nanoparticles and improve the process to obtain specific properties.
- The impact of the temperature at which the ESP is calcinated, both below and above 900 °C.
- By exploring these subjects in future study we can gain a more comprehensive knowledge of the possible advantages and uses of EP nanoparticles in concrete. This will ultimately contribute to the creation of construction materials that are both more effective and environmentally friendly.
- The compressive strength of eggshell powder concrete with steel fibers was determined by replacing 10% of the cement with eggshell powder and adding 1% steel fibers by volume of concrete is the maximum. Among the various combinations of eggshell powder replacement (5%, 10%, and 15%) and steel fiber addition at these levels (0.5%, 1%, and 1.5%). Hence, ESPSFRC is suggested for lighter structures, large structures, and new design products. By using these cementitious ingredients, the concrete will include less typical Portland cement. – eggshell powder

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