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Research Article

Study the behaviour of cement mortar containing jute fiber along with partial replacement of cement with eggshell powder

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Abstract

The construction industry's key materials are mortar and concrete. Cement is a key component in the production of mortar and concrete. Natural limestone is used to make cement. When limestone is burned to make cement, carbon dioxide gas is liberated as a by-product, which is considered as a greenhouse gas with adverse environmental effects. Waste materials can be used in the manufacture of mortar and concrete to minimize negative consequences and natural resource utilization. In investigations, a powdered form of eggshell passed through a 90µm IS sieve and jute fiber was employed as a partial alternative for cement in the production of cement mortar. Eggshells are abundant in calcium oxide and have a chemical composition similar to natural limestone. The cement mortar is formed with a 1:3 mix ratio. ESP is added in percentages of 0%, 3%, 6%, 9%, and 12% by cement weight. Mechanical properties such as split-tensile, compressive and flexural strength with percent Jute fiber were compared to a nominal cement mortar cube. The ideal fiber length is 5-10mm. According to the findings, increasing the percentage of eggshell powder (ESP) in the mortar mix along with jute fiber (JF) increases the split-tensile, compressive and flexural strength of the cement mortar specimen. The effects of ESP and jute fiber on split-tensile, flexural and compressive strength, weight, water absorption, bulk density, and sorptivity has been evaluated.

Keywords: *Eggshell powder (ESP), Split-Tensile strength, Jute fiber (JF), Compressive Strength, Flexural strength.*

1. Introduction

The construction industry makes extensive use of mortar and concrete material. As per (WBCSD) World Business Council for Sustainable Development, concrete is a largely used human-made material that ranks after water as the most consumed material on the planet, with each man, woman, and kid using nearly three tonnes yearly. It is produced by mixing cementing components, water, aggregates, and often admixtures in the appropriate proportions. The mixture hardens into a rigid rock-like material known as concrete once it is placed in a mould and allowed to cure. Concrete is one of the most diverse man-made building materials widely available. It has substituted stone and brick masonry due to its ability to be cast in any shape desired. Concrete and mortar are extensively used by developing countries to develop their infrastructure, and India is one of them, with the government devoting the majority of its resources to enhancing the country's infrastructure. As a result, we can say that concrete and mortar are the building blocks of any country's development, and they are known as the backbone of infrastructural development.

The construction sector is currently unsustainable and industry relies heavily on cement. Because this material is currently in high demand, there is a need to find alternatives to replace it in concrete. Cement is a critical component in the production of concrete and mortar, and its manufacturing process requires a significant amount of energy. Secondly, it consumes a large number of natural resources, leaving no virgin material for coming generations. As a matter of fact, we have to use some waste material that can be easily used in the production of cement mortar without negatively impacting its properties. Ultimately, we want structures that are long-lasting and designed to carry heavy loads without deflection or cracking. To accomplish this, concrete with strong mechanical attributes such as compression, flexural, and split-tensile strength is required.

1.1 Objectives of work

The main purpose of this work is to examine the durability and mechanical characteristics of cement mortar by substituting small amount of cement with the powder of eggshell. As per current scenario, engineers prefer constructions with high split-tensile, flexural and compressive strength and durability attributes. To

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achieve the goal, several cement mortar trial mixes were created by changing the amount of ESP used as a substitute for cement in cement mortar. Many additional qualities, such as fresh properties like consistency, setting time, unit weight fluctuations, and hardened properties like weight loss, water absorption, and water sorption, have also been studied in order to accomplish the aforementioned objectives.

1.2 Scope of work

The scope of this work is to reduce the amount of cement used in cement mortar by substituting it with various percentages of ESP and JF. Trials were performed on the qualities of cement mortar made with OPC (43 grade), eggshell powder and jute fiber to determine the impact of ESP and JF on cement mortar split-tensile, flexural and compressive strength, water absorption, and water sorption.

2. Literature Review

(K. Uma Shankar J, *et al*, 2014) investigated efficient usage of ground granulated blast furnace slag (GGBS), ESP saw dust ash as industrial waste materials. The goal of this research is to see if ESP, GGBS and saw dust ash may be used to substitute cement in some applications. These industrial wastes have chemical compositions that are virtually identical to ordinary Portland cement (OPC). Eggshell is involved in all of the concrete cube combinations in this experiment, thus it plays a significant role. The industrial wastes are grinded to cement fineness, and the characteristics of cement are tested on the substituted sample, including fineness test, initial set time, final set time, soundness of cement, water absorption, and so on. The testing resulted in promising findings for the research. 50% GGBS, 20% ESP and 10% sawdust ash blend together to produce the cement sample.

(Mohamed Ansari M, *et al*, 2016) investigated the eggshell as a possible replacement for cement. The effect and experimental results of replacing the eggshell powder in cement are described in this paper. The compressive test was conducted on concrete that had been substituted with 10%, 15%, and 20% of ESP in Portland Pozzolana cement (PPC). Cubes of concrete measuring 150x150x150 mm size were tested for compressive strength. The compressive test was performed on a machine with a capacity of 100kN. The loading rate in the compressive strength test was 50kN/sec. The compressive testing was carried on 150mm cube specimens on day-7 and repeated on the day-28. The findings, which were obtained upon successful completion, depict that eggshell powder can be utilized as a cement substitute. The outcome shows that substituting eggshell powder with 10-15% is beneficial, and upon increasing the proportion of eggshell powder there is a reduction in compressive strength.

(Bysani Mythili, *et al*, 2017) investigated on Limited replacement of ESP with Cement in Concrete. This study presents the results of tests examining the use of ESP from the egg manufacturing industry as a sectional substitute for traditional cement in cement mortar. We reached on our decision based on the chemical structure of the powder made from eggshells and the cement mortar's compressive strength. Cement mortar with a 1:3 ratio in which ESP is substituted for 5%, 10%, 15%, 20%, 25%, and 30% of the cement weight. For cement replacement, eggshell powder generated from industrial waste is stacked in a variety of ratios. The admixtures used to reinforce the strength of the concrete at hardening ages which is 28 days are saw dirt ash and oxide, along with 5% of eggshell powder used as a partial replacement for cement, and it has been discovered that substitution of 5% eggshell powder with 22% micro silica is often overlaid with no compressive strength reduction.

(Doh Shu Ing, *et al*, 2014) studied the Eggshell Powder as Potential Filler in Concrete. In this study, 5 different ESP percentages with cement were added to the M-25 concrete mix. Plasticizing accelerator, portland cement, river sand, broken sandstone, and eggshell powder were most often utilized materials. All of the slump test findings of eggshell concrete in the experiment spanned from 65 to 75 mm, signifying a medium degree of workability. The compressive strength of 10% eggshell concrete was 42.82 N/mm^2, which is 57% greater than the standard specimen. The flexural strength rises from 2.36 to 3.50 N/mm^2 as ESP concentration is increased from 0% to 20%. Apart from that, the eggshell concrete has demonstrated a considerable declination in penetration and water absorption.

(Ngo slew kee, *et al*, 2010) studied the title of "Effect of coconut fiber and egg albumen in mortar for greener environment" and described the effects of egg & fibers of coconut on compressive and flexural strength of mortar. The effect of fibers of coconut and albumen of egg in mortar for a green environment were tested and their results on compressive and flexural strength of mortar were reported. For comparing the strength developments of each sample, three types of specimens were created and evaluated. The quality of the mortar constituting 0.1% fibers of coconut and 1% egg whites was better than the control mortar, but the mortar with 0.5% fibers of coconut and 5% egg whites was poorer. Although the mortar having 0.5 % for each coconut fiber and 1 % egg whites had a better quality than the control mortar, the mortar constituting 0.1% for each coconut fiber and 1% egg whites had a higher attribute.

(Pliya and Cree, *et al*, 2015) studied the brown and white ESP as a viable substitutes for traditional quarried limestone in Portland cement mortar. The goal of this research was to see how well brown and white chicken eggshell waste powders performed as prospective substitutes for quarried limestone in Portland cement mortars. A method for producing vast amounts of eggshells has been devised. Limestone replacements in the proportions of 0.0%, 5.0%, 10.0%, 15.0% & 20.0% by w 'weight' were added as OPC substitutes. The shape, temperature-induced deterioration and chemical composition of eggshell particles were all explored. The findings revealed that eggshells are mostly composed of calcite, with little quantities of organic membrane and matrix. The inclusion of various limestone components influenced the strength of the mortars. Even with 5% Portland cement substitution, they discovered that white and brown eggshells produced limestone powder had inferior attributes to natural conventional limestone.

3. Materials and Methodology

3.1 Cement

It is a fine powder with gummy qualities. The fundamental tests were conducted as per the relevant IS codes. Cement is a crystalline composite made up of calcium silicates and other calcium compounds that have hydraulic properties. Tetra-calcium alumina ferrite (C_4AF), Di-calcium silicate (C_2S), Tri-calcium aluminates (C_3A) and Tri-calcium silicate (C_3S) are the four key compounds that compose cement. The largest contributors to cement strength are di-calcium silicate (C_2S) and tri-calcium silicate (C_3S), which together make up around 70% of cement. When cement mixes with water, a chemical process occurs, referred to as "Hydration of cement." $Ca(OH)_2$ and C-S-H(gel) are the outcomes of this exothermic process. Calcium hydroxide has a smaller surface area and so cannot make a significant contribution to concrete strength. Fresh Ordinary Portland Cement (Ambuja Cement) of 43 grade tested at 28 days, as its use in making concrete and mortar specimens according to Indian standard IS 8112.

Table 1 OPC properties

S. No	Parameters	Values
1	Cement grade	43
2	Specific gravity(sg)	3.15
3	Fineness (cm2/gm)	2250(min.)
4	Standard Consistency	31.0%
5	Setting-time (Initial)	½ hour(min.)
6	Setting-time (Final)	10 hours(max.)
7	Compressive strength (MPa) Day-3 Day-7 Day-28	 23(min.) 33(min.) 43(min.)

3.2 Eggshell Powder (ESP)

Eggshells are agro-wastes produced by fast-food restaurants, bakeries, and chick hatcheries that could pollute the environment lead to environmental concerns and pollution that require remediation. The thickest portion of the eggshell is called as palisade layer and the deepest layer which is the maxillary-3rd layer grows on the periphery of the egg membrane and serves as the foundation for the palisade layer. Organic cuticle wraps the top layer known as the vertical layer. Magnesium carbonate (lime), calcium, and protein are the core elements of the eggshell. It is normal practice in many other countries to dry eggshell and serve it as a calcium source in animal nutrition. The harsh weather, raw water, and sun rays conditions have a considerable impact on the property of lime in eggshell waste. It is a fine-grained powder with the correct proportions that would be sieved to the suitable dimensions before being used with concrete or mortar.

Table 2 ESP properties

S. No	Parameters	Values
1	Specific gravity(sg)	0.86
2	Bulk Density (gm/cc)	0.81
3	Particle Density (gm/cc)	1.015
4	Hygroscopic Moisture (%)	1.18
5	Protein (gm)	3.92
6	Porosity(%)	25.4
7	pH	6.59
8	Surface Area (m^2/g)	21.7

Fig.1 Eggshell Powder (ESP)

3.3 Jute Fiber (JF)

Jute is one of the most cost-effective natural fibers. There are numerous inexhaustible resources available from the plant kingdom, including a wide supply of various plant fabrics such as Jute, banana, coir, as well as other natural fibers that are abundant in numerous parts of the globe. It is estimated that plenty of vegetable fibers have not yet been used in textile production. One of the rich sources of strong natural fiber of Jute comes from the plant kingdom. Lignin and cellulose are the two major chemical components of jute fibers. Lignin is a term that refers to a group of complex organic polymers. Cellulose is an organic polysaccharide made up of thousands of D-glucose molecules bonded together in a linear chain (straight chain).

Table 3 Jute Fiber (JF) chemical-composition

S. No	Parameters	Values
1	Cellulose (%)	57-65
2	Hemi-Cellulose (%)	20 -24
3	Wax and Fat(%)	0.32
4	H20soluble material (%)	1.21
5	Lignin (%)	17.2

Table 4 Jute Fiber (JF) physical properties

S. No	Parameters	Values
1	Jute fiber length	150-300 cm
2	Jute color	White, yellow grey, brown
3	Strength of jute	3.5-5G/Den
4	Dimension stability of jute	Good on Average
5	Specific gravity	1.48

Fig.2 Jute Fiber (JF)

3.4 Aggregates

Aggregates are classified into two categories based on their size: fine and coarse aggregates. Sand is used in the concrete as fine aggregate. Sieve analysis is performed to investigate the characteristics of fine aggregate. IS: 2386 (Part-1) –1963 was used to perform the tests. The aggregate which passes through the 4.75mm sieve is termed fine aggregate. Fine aggregate properties are maintained to obtain maximum size of aggregate between 4.75, 2.36 and 1.18mm, 600µm, 300µm, 150µm, and 75µm.

Table 5 Fine Aggregates (FA)

S. No	Parameters	Values
1	Specific gravity(sg)	2.6
2	Water Absorption (%)	0.82

Coarse aggregates, which constitute 70 to 85 percent of the weight and 60 to 80 percent of the volume of concrete, are usually referred to as inert filler. The maximum aggregate size has an impact on concrete workability and strength. Natural coarse aggregates, obtained from a nearby quarry, were employed in this investigation. In experiment aggregates with a size of 20 mm passed and 12.5 mm retained that are clean and devoid of harmful elements are used.

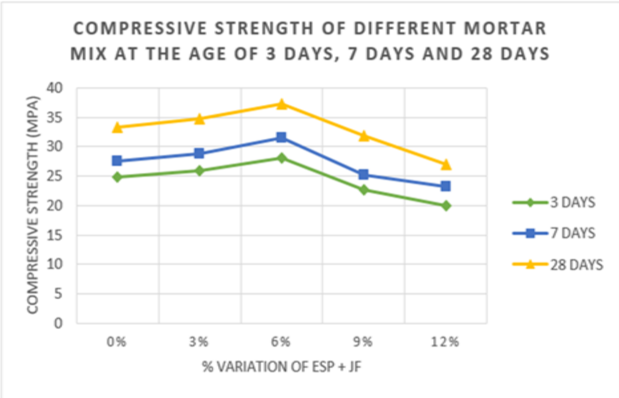
Table 6 Coarse Aggregate (CA)

S. No	Parameters	Values
1	Specific gravity(sg)	2.65
2	Water Absorption (%)	0.3
3	Type	Crushed stone
4	Impact Value	12.96

4. Results and Discussion

4.1 Compressive-Strength

Compressive strength test of cement, concrete is conducted as per IS:516-1959 for testing the mortar cube specimens with different contents of ESP along with JF for different ages such as 3-days, 7-days, and 28-days. The rate of loading adapted for carrying out the compressive strength test was 70 kN/min. The results of the compressive strength test for different curing periods are as shown in the chart and table.



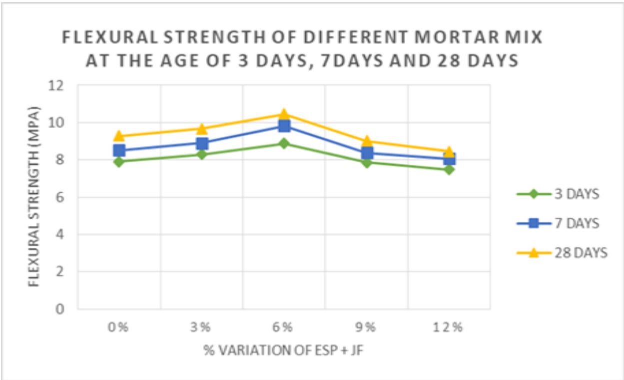
Graph.1 Compressive strength of (ESP+JF) cement mortar

Table 7 Compressive-Strength values

S. No	Mix	Jute Fiber (%)	ESP (%)	Compressive-strength(MPa)		
				Day-3	Day-7	Day-28
1	M_0	1.0%	0.0%	24.780	27.611	33.272
2	M_3	1.0%	3.0%	25.972	28.809	34.778
3	M_6	1.0%	6.0%	28.159	31.417	37.357
4	M_9	1.0%	9.0%	22.635	25.124	31.918
5	M_{12}	1.0%	12.0%	19.970	23.126	27.060

4.2 Flexural-Strength

Flexural strength test of cement, concrete is conducted as per IS:516-1959 for testing the mortar beam specimens with different contents of ESP along with JF for different ages such as 3-days, 7-days, and 28-days. The flexural-strength test is performed on mortar beams under two-point loading. It is usually the measure of modulus of rupture, maximum tensile stress that the concrete can take in bending without cracking.



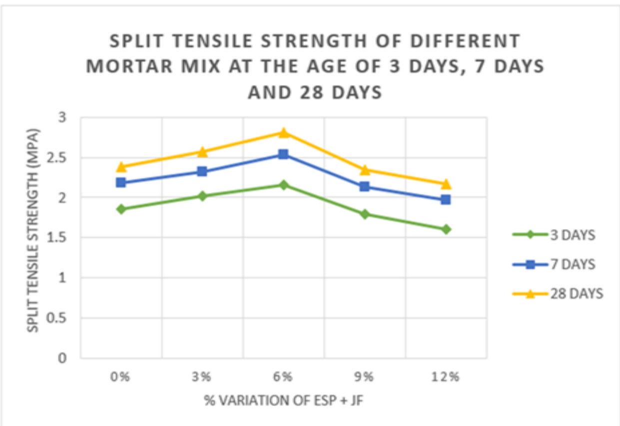
Graph.2 Flexural strength of (ESP+JF) cement mortar

Table 8 Flexural-Strength values

S. No	Mix	Jute Fiber (%)	ESP (%)	Flexural-strength(MPa)		
				Day-3	Day-7	Day-28
1	M_0	1.0%	0.0%	7.93	8.514	9.28
2	M_3	1.0%	3.0%	8.29	8.9	9.66
3	M_6	1.0%	6.0%	8.88	9.83	10.45
4	M_9	1.0%	9.0%	7.87	8.39	9.02
5	M_{12}	1.0%	12.0%	7.49	8.07	8.46

4.3 Split-Tensile-Strength

Split-Tensile strength test of concrete is conducted as per IS:5816-1999 for testing the mortar cube specimens with different contents of ESP along with JF for different ages such as 3-days, 7-days, and 28-days.

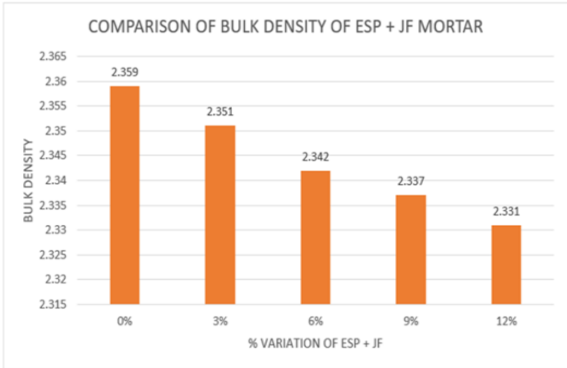


Graph.3 Split-tensile strength of (ESP+JF) cement mortar

Table 9 Split-Tensile-Strength values

S. No	Mix	Jute Fiber (%)	ESP (%)	Split-tensile-strength(MPa)		
				Day-3	Day-7	Day-28
1	M_0	1.0%	0.0%	1.855	2.183	2.384
2	M_3	1.0%	3.0%	2.013	2.313	2.571
3	M_6	1.0%	6.0%	2.151	2.531	2.811
4	M_9	1.0%	9.0%	1.798	2.134	2.339
5	M_{12}	1.0%	12.0%	1.606	1.97	2.165

4.4 Bulk Density

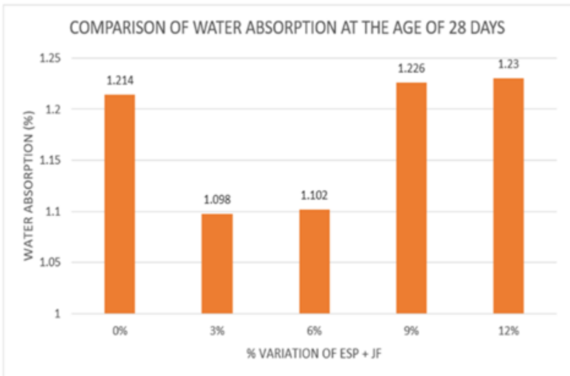


Graph.4 Bulk Density of (ESP+JF) cement mortar

Table 10 Bulk Density of various mixes

S. No	Mix	Bulk Density (gm/cc)
1	M_0	2.359
2	M_3	2.351
3	M_6	2.342
4	M_9	2.337
5	M_{12}	2.331

4.5 Water Absorption



Graph.5 Water Absorption of (ESP+JF) cement mortar

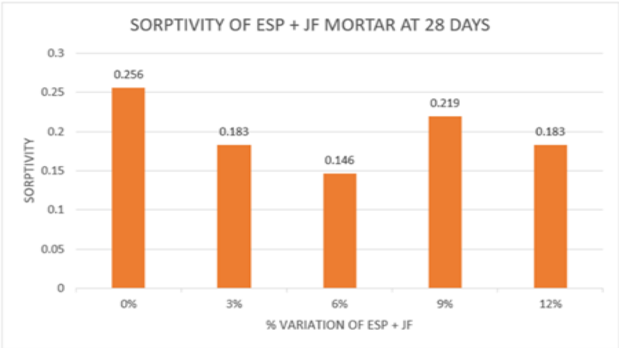
Table 11 Water Absorption of various mixes

S. No	Mix	Water Absorption (%)
1	M_0	1.214
2	M_3	1.098
3	M_6	1.102
4	M_9	1.226
5	M_{12}	1.23

4.6 Sorptivity

John Philip coined the term sorptivity in 1957, describing it as a measure of a medium's ability to absorb or desorb liquid by capillary action.

$$S = \frac{I}{t^{0.5}}$$



Graph.6 Sorptivity of (ESP+JF) cement mortar

Table 12 Sorptivity of various mixes

S. No	Mix	Sorptivity (mm/min$^{0.5}$)
1	M_0	0.256
2	M_3	0.183
3	M_6	0.146
4	M_9	0.219
5	M_{12}	0.183

Conclusions

With increase in the amount of ESP and JF the split-tensile, compressive and flexural strength of cement mortar increases up to an optimized value and beyond that of we further increases the quantity of ESP and JF then strength starts reducing. In our studies the optimized value of (ESP+JF) was 6% for the split-tensile, compressive and flexural strength. Maximum split-tensile, compressive and flexural strength of 2.811 MPa, 37.35 MPa and 10.45 MPa respectively were obtained at day-28. By replacing cement with 9% and 12% of (ESP+JF) 4.06% and 18.67% reduction in compressive-strength was observed at day-28. With 6% replacement of (ESP+JF), 12.27% increase in compressive-strength was noticed at day-28 and below this age near about 13.80% increase in strength was noticed.

The 3 days flexural strength increased by 12.12%, 7 day increased by 15.45% and 28 days increased by 12.60% at optimum dose. The addition of more percentage that is 12% of (ESP+JF) in cement mortar reduces the 3 days flexural strength by 5.42%, 7 days by 5.21% and 28 days by 8.83%. At day-3 the Split-tensile strength was increased by 15.95%, day-7 strength increased by 15.94%, and at day-28 the strength was increased by 17.91% at optimal dose. At 12% replacement the split-tensile strength was reduced by 13.42%, 9.75% and 9.18% at the age of day-3, day-7 and day-28 respectively.

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