EXPERIMENTAL STUDY ON PARTIAL REPLACEMENT OF CEMENT BY METAKAOLIN AND EGGSHELL POWDER

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ABSTRACT: The most expensive and essential ingredient in concrete is cement. Additionally, the world's second-largest industrial emitter of CO2 is from the manufacture of cement. The demand and use of concrete have led to a lot of research in improving its strength, workability and many more. Concrete's strength can be increased by decreasing cement content and replacing it, using substitutes in the making of concrete to cut down on the consumption of cement. Our emphasis is on the limited replacement of cement in the manufacturing of concrete with cementitious materials. Such a substitute material is Eggshell powder (ES) and Metakaolin (MK). The study begins with an investigation of the chemical composition of Metakaolin (MK) and Eggshell powder (ES), emphasizing its potential as an additive material. The influence of partial replacement of cement by Metakaolin (MK) and Eggshell powder (ES). This was done to reduce the amount of cement being one of the harmful components of concrete production and replaced by natural materials, so to improve the sustainability of the construction. In this study, the mix proportioning involves systematically replacement of cement by Metakaolin (MK) range as 5% (constant) and 5%, 10%, 15%, 20% of Eggshell powder (ES). An experimental study demonstrates the mechanical properties of Metakaolin and Eggshell based concrete will be investigated. Compressive strength of concrete made with Metakaolin and Eggshell powder i.e.; M60 grade of concrete. The optimized strength value of concrete will be attained by split tensile strength, compressive strength, Flexural Strengthproperties at 3, 7 and 28 days.

Keywords: Metakaolin (MK), Eggshell (ES), Compressive Strength, Split Tensile Strength, Flexural Strength, High Strength Concrete.

INTRODUCTION

Cement, water, and Aggregates, both fine and coarse, are the ingredients that go into making concrete. Fly ash and other mineral admixtures are used in concrete to increase its strength. silica fumes, rice husk ash, metakaolin, and GGBS are commonly utilized. Recently, there has been a growing exploration of incorporating agricultural products to enhance concrete for sustainable construction, among which are eggs. Statistics from the Food and Agriculture Organization (FAOSTAT) reveal that India is currently the world's third-largest egg producer and the second-largest poultry market, showing an annual growth rate of over 14% and contributing to 61 million tonnes, or 3.6% of the world's total egg production. Egg production's annual growth rate ranges between 5-8%, and the poultry industry's total value is estimated to be around Rs 3,500 billion. Notably, the food industry alone generates approximately 250,000 tonnes of eggshell residue annually, with main frame and egg producers estimated to produce 10,000-11,000 tonnes of eggshell waste each year. Unfortunately, much of this waste is sent to landfills without any pretreatment, leading to significant environmental concerns. Consequently, there is an urgent need for viable alternatives to reduce waste.

Addressing the treatment and utilization of biowaste from an environmental and economic standpoint has become a focal point in our society. Specifically, research has indicated that eggshells, primarily composed of calcium in the form of CaO, can be used as an additive. Additionally, Eggshells are rich in iron, manganese, zinc, potassium, magnesium, and phosphorus. This waste can also be repurposed for practical use. Metakaolin, the anhydrous-calcined form mineral kaolinite found in clay, serves as a pozzolanic additive with various specific properties. Its purity determines the binding capacity or free lime and it is commonly used as an additive to concrete and/or cement.

Previous studies have shown that 8% to 20% (by weight) of Portland cement can be replaced with metakaolin. As part of a preliminary study, metakaolin and eggshell powder underwent physical and chemical analysis to evaluate their suitabilityfor standard applications.Theexperimental investigationaimed to assess thepotential of metakaolin and eggshell powder as a component replacementsfor cement within M60 grade concrete, usinga constant level of metakaolin replacement and varying levels of eggshell powder.

LITERATUREREVIEW

Pinnam Mahesh, B.Ajitha et al. (2021) In this investigation, MK (Metakaolin) was used to partially substitute cement at 0 percent, 0%,5%, 10%, 15 %,20% and 0%, 5%,10%,15%,20% (constant) with Marble dust. Concrete constructed with MK-Marble dust was compared to ordinary concrete of grade M40 in expressions of compressive, tensile and flexural strength. With the inclusion of MK and Marble dust, the result demonstrates an increase in strength. At10% MK and 10%Marble dust, the optimal the compressive, split tensile, and flexural strength values of the concrete were all reached.

AmarnathYerramala et al. (2014) studied behavior of concrete with egg outer shell dust as cement substitution. Research work depicts investigation into exploitation of poultry unproductive in concrete by means of an improvement of cement fusing eggshell powder (ESP). By substituting 5–15% of ESP for concrete, several ESP cements were produced. Results showed that ESP might be used to replace some of the cement in concrete in a useful way. Strengthening the improvement and gearbox features are the specifics that have been introduced. As for based on outcomes, at 5% egg outer shell dust substitution the strengths were prominent than basic concrete and shows that 5% egg outer shell dust is an absolute substance for the greatest strength. The exhibition of egg outer shell dust cements was practically identical up to 10% egg outer shell dust substitution as far as transition behavior with base concrete. Results additionally demonstrate the value of increasing fly ash in addition to ESP for improved concrete execution.

Dinakar, P.Pradosh, K.Sahoo, G.Sairam et al. (2019**)** It is an experimental investigation conducted to understand how stable concrete's qualities are affected by the degree of metakaolin. Combinations of metakaolin with binder substitutes at5%,10%, and 15% were created with a target strength of 90 MPa. The water binder ratio is 0.3. The compressive strength was observed 106MPa at 10% substitution of MK. Even tensile strength, durability and resistance were as well followed the same trend. The metakaolin is useful in preparation of high strength concrete.

Sunny A. Jagtap, Mohan N. Shirsath, Sambhaji L. Karpe et al. (2017) They conducted examine to understand the impact of metakaolin on properties of sample. They partially replaced cement by metakaolin with 5 - 20% by lump of cement. M35 grade concrete design is adopted with a mix proportion of 1:1.69:2.28 for 0.42 water binder ratio. For seven and twenty-eight days, both compression and flexural tests were conducted. Obtained results concluded that the strength properties increase up to 15% supplant of MK.

DohShuIng et al. (2014) researched on the possibility of eggshell powder being addictive when mixed with concrete. Different percentages of cement are substituted with eggshell powder. It employs the grade M25 concrete mix. The compressive strength and maximal strength improve after a 10% substitution of eggshell powder. Water absorption, bending failure, and flexural strength all increased as well.

Keramat khan, Dr K U Muthu et al. (2017) Investigated on the effect of metakaolin, Rice husk ash and egg crust dust by partial replacement of cement and keeping same W/C ratio to ordinary concrete and metakaolin, RHA & ESP. The concrete mixes has 0%,5%,10%,15% and 20% of metakaolin, RHA with 5% ESP, replacing cement partially and compressive, spit tensile and flexural tests are conducted. From this research the results are much better as compare to conventional concrete.

Nisar Ahmed Gabol, in 2019, Zaheer H. Zardari, Mian Jawaduddin, Fareed Ahmed Memon, and others They replaced the binder in this study with dust from egg shells. The major goal is to calculate the mechanical characteristics and workability using different percentages of ESP by cement weight, such as 0%, 2.5%, 5%, 7.5%, and 10%. A total of 120 samples of concrete were completed, consisting of 60 cumecs, 30 cylinders, and 30 prisms, with an object strength of 28 N/mm2..The compressive strength, cylindrical specimens, bending strength are tested at

3,7 and 28 days. The dimensions of cube used is 100x100x100, for cylinders 200x100 and for prisms 100x100x500.During the test the results are i.e., Tensile strength rose by 9.6% and reached a high of 8% after 28 days of cure when eggshell powder was used at a 7.5% concentration. As portion of egg outer shell dust increases the working capability of fresh concrete decreases.

Ayobami Busari, Joseph Akinmusuru, et al. (2019) The investigation on strength and durable features of sample using metakaolin as a sustainable material gave the result that an increase in the percentage of metakaolin reduces the workability and hence the enhancing the admixtures. The mechanical properties of concrete improved when added at about 10 to 25% of metakaolin. The heat of hydration increases with increase in the amount of metakaolin.

Dr. T. Felixkala, M. Narmatha et al. (2016) The specimen was casted for M60 grade of concrete with 5- 20% supplant of cement by metakaolin with even water binder ratio of 0.32. OPC of 53 grade cement, crushed stones of maximum size 20mm coarse aggregate and river sand passing IS sieve 4.75mm fine aggregate are used in the investigation. As a result of this investigation, the maximum strengths are occurred at 15% replacement by MK. At MK 15%, the increase in compressive and flexural strengths at 28 days is 17.45% and 14.28% respectively.

Gowsika et al. (2014) To find its chemical makeup and compressive strength, it was studied if eggshell powder could be partially substituted for cement concrete in a 1:3 cement mortar mixture. The cement is partially replaced with eggshell powder as 5%, 10%, 15%, 20%, 25% and 30% by weight of cement. The 28th day of life was used to test the strength at compression. The substitution of eggshell powder with microsilica results in varying strengths.

MATERIALS

Within this investigation, materials used for getting ready M60 quality concrete include Cement (OPC 53grade), Eggshell Powder, Metakaolin, Super plasticiser, water, coarse and fine aggregate.

Cement

Cement serves as a binder and is one among the primary components of concrete.During the project's duration, In this investigation, the use of finely powdered cement reduced the number of pores in the concrete. CMP grade 53, commonly known as Ordinary Portland Cement. Physical specifications for the purchased cement were tested in accordance with IS: 12269-1987. Here are a few of the physical attributes: Table 1.

Table1 Physical properties of Cement OPC 53grade

Material Property	Test Value
Specific Gravity of Cement	3.14
Consistency of Cement	34%
Initial Setting Time of Cement	35minutes

Eggshell Powder (ES)

In the poultry industry, waste eggshells are gaining attention because of their recyclability. Waste eggshells are available in huge quantities for breaking eggs, preparing food, and shade applications. In The food waste sector research is needed to find alternative ways to recycle and use waste eggshells in an environmentally friendly manner. A low-cost solution must be found. Eggshell waste disposal is usually a cost center rather than a profit center. Therefore, it is most necessary to remove it at the lowest cost. A thorough analysis of a few of the remaining possibilities and consideration of the most economical recycling strategy are necessary. A thorough breakdown of eggshell composition is provided in table 2.

Table-2: Chemical composition of the Eggshell power

OxideContents	Units	Result
CaO	%	57.8
Iron	ppm	12.2
Magnesiumand alkali metals	%	0.0009
Moisture	%	0.29
BulkDensity	g/mL	1.23
Particlesize	µm	80.2
Heat loss	%	0.31

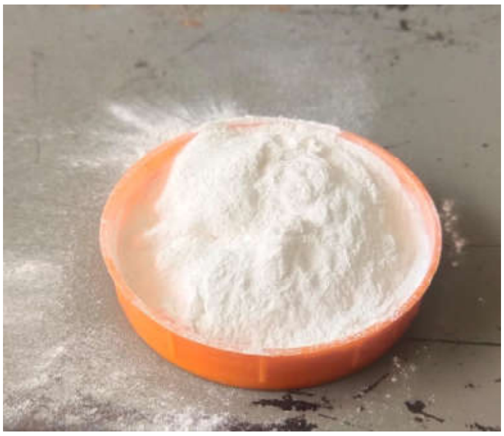


Fig1:EggshellPowder

Metakaolin (MK)

Anhydrous kaolinite clay minerals can be calcined to produce metakaolin. Ceramics have historically been made from kaolin-rich rocks, also referred to as kaolinite or kaolinite. The quality and reactivity of Metakaolin vary greatly depending on the characteristics of the raw materials used. It is produced by heating pure and refined kaolin clay to between 6500 and 8500 degrees Celsius, then grinding it until it is as fine as 700–900 m2/kg. It is a high-quality pozzolanic material that improves the durability of concrete when mixed with cement.
Metakaolin is composed of activated silica, alumina and other mineral additives, and forms calcium silicate hydrate, or C-S-H gel when it interacts with calcium hydroxide, which occurs at ambient temperature and lowers porosity while raising concrete's density. The precise chemical makeup of metakaolin is provided in Table 3 below.

Table-3: Chemical composition of the Metakaolin

Oxide Contents	Units	Result
Silica	%	53.4
Alumina	%	36.4
Ferric Oxide	%	4.2
CaO	%	0.3
MgO	%	0.05
Particlesize	µm	2.5

Fig2: Metakaolin

Manufacturing process of Metakaolin

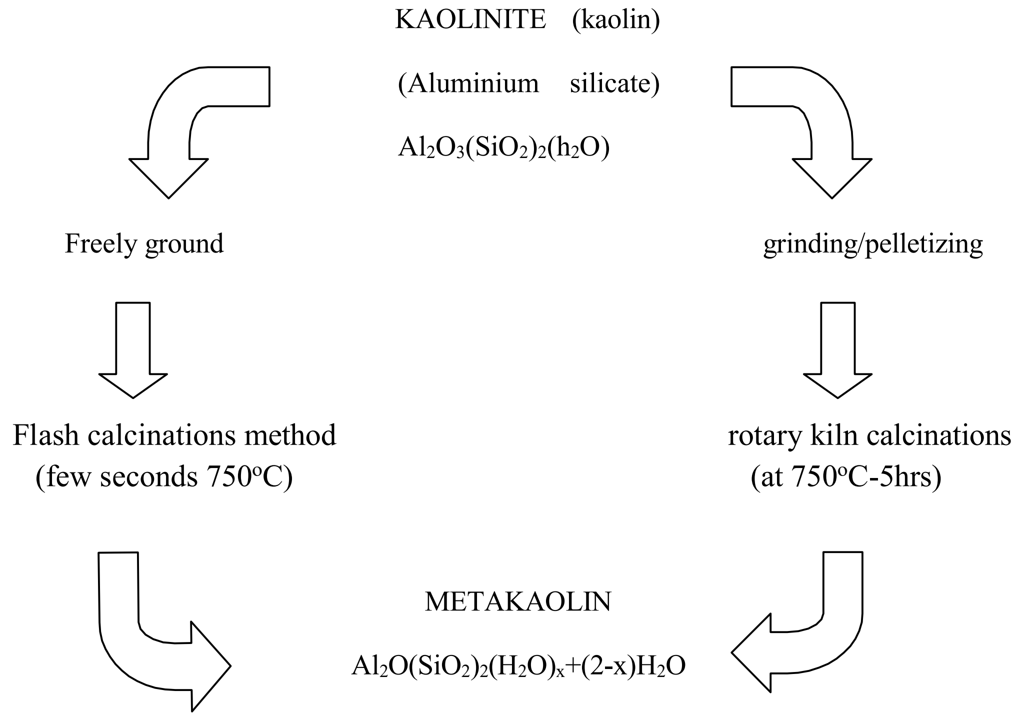


Fig:3 Metakaolin Flowchart

Fine Aggregate

The 4.75 mm IS sieve, which complies with IS383-1970's grading zone-II, was used to filter locally accessible River sand. Specific gravity of fine aggregate was 2.64.

Coarse Aggregate

Crushed metal was used in sizes up to 20mm and 12 mm from local sources with specific gravity of 2.75 as per IS383-1970.

Water

The cheapest and most crucial ingredient in concrete is water. Oil and fresh drinking water free of organic materials are added to the concrete mixture. The concrete is mixed with the necessary amount of water in a measuring container.

Super Plasticizer (Fosroc ConplastSP430)

Conplast SP430 is a superplasticizer for concrete that does not contain chloride. It is available as a brown solution that is readily dispersed in water. Conplast SP430 acts as a dispersant and reduces the moisture content by approximately 30%. Adding a superplasticizer to concrete releases the water trapped between the cement particles. Improved workability and strength can be achieved by utilizing a superplasticizer using a low water-to-cement ratio.

EXPERIMENTALPROGRAM

In this study, the proportions According to IS 10262:2009, concrete mixes of M60 grade were obtained. Several test mixtures were carried out without adding high performance reducing agent, and it was observed that the mixture was stiff and difficult to work. Trial mixes were created figuring out how much is needed to improve the workability of concrete. High performance reducing agent. For all the mixes, high performance reducing agent was added in the amount of 1.2% based on the weight of cement. The quantities of the resultant mix are provided in Table 4.

Table 4 Mix proportion for M60 Concrete

CEMENT	FINEAGGREGATE	COARSEAGGREGATE	W/CRATIO
1	1.47	2.81	0.33

For investigation of M60 concrete's workability and strength through experimentation, five mixtures were prepared using different proportions of eggshell 0%, 5%, 10%, 15% and 20% and metakaolin 5% as constant to partially replacement. Workability is studied by conducting cone slump test as per IS 1199(1959). Strength of concrete is checked by tests as per IS 516 (1959) and IS 5816 (1999).

Casting of Specimens: Before concrete is poured into the cast iron moulds, they are thoroughly cleansed of dust and polished with petroleum jelly on both sides. The table vibrating machine is used to set the moulds on its level platform. Three layers of concrete are poured into the moulds, and each layer is filled before being vibrated. After smoothing and levelling the top surface to the mould, any extra marble is taken out with a trowel. 150 mm by 150 mm by 150 mm cast cube specimens are used to assess compressive strength. To determine the split tensile strength, cylindrical specimens measuring 150 mm by 300 mm are cast. For flexural strength calculations, 500 x 100 x 100 mm cast beams are used.

Curing of Specimens: Once the sample is poured, let it sit at the ambient temperature for about a day without moving.The sample should be taken out of the mould and put right into a number of new water-filled curing tanks.

RESULTS AND DISCUSSIONS

The Table 5 displays the workability outcomes the slump cone experiment. Tables 6, 7, and 8 present the outcomes of the strength property tests for compressive, flexural, and tensile strength. The average value was given at each strength test, which involved testing a minimum of three specimens for each curing period.

Graphs 1 through 3 show the results of the tests for compressive, split tensile, and flexural strength for all percentages of cement replacement with ES and MK. Ordinate shows the test's strength value, whereas Abscissa shows the amount for ES and MK content.

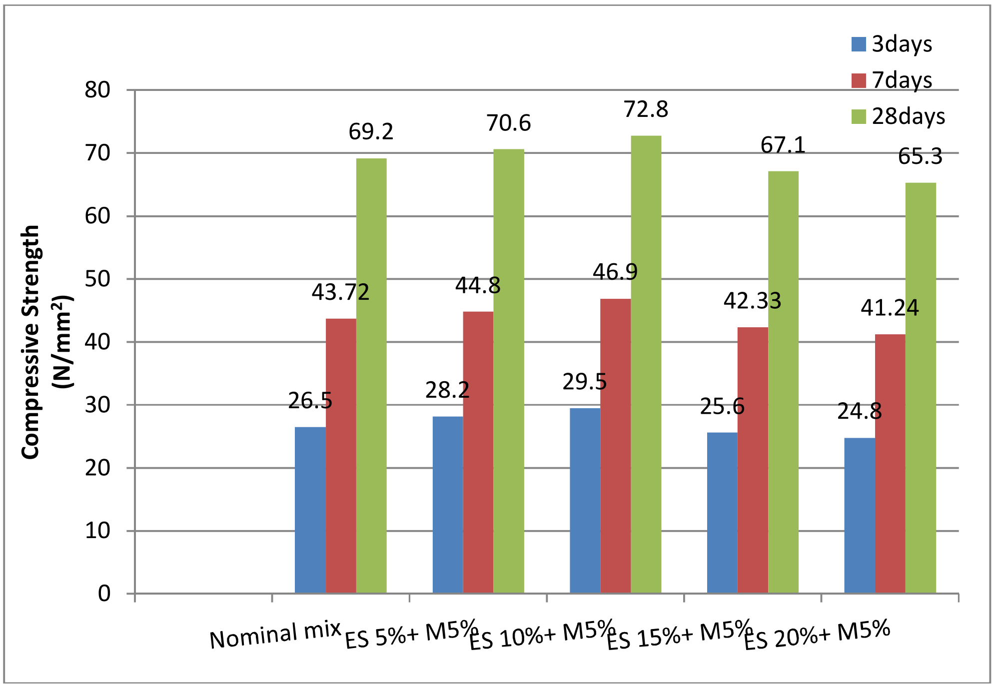
Table5 Results of concrete's workability test

S.No	Mix	Slump Value(mm)
1	NominalMix	100
2	MK(5%)+ES(5%)	75
3	MK(5%)+ES(10%)	60
4	MK(5%)+ES(15%)	50
5	MK(5%)+ES(5%)	38

From Table 5, it is evident that the values derived from slump tests decline as the proportion of MK and ES. MK and ES having a high specific surface area, act as filler material. Workability decreases as a result of the reduction in particle mobility caused by the rise in their content in the concrete mix. The water/cement (w/c) remains constant at 0.33 for all replacement percentages. According to the test results, workability can be enhanced by raising the w/c ratio after each replacement.

Table 6 Results of concrete's compressive strength test

Eggshell%+ Metakaolin%	3days (N/mm^2)	7days (N/mm^2)	28days (N/mm^2)
Nominalmix	26.5	43.72	69.2
ES5%+MK5%	28.2	44.8	70.6
ES10%+MK5%	29.5	46.9	72.8
ES15%+MK5%	25.6	42.33	67.1
ES20%+MK5%	24.8	41.24	65.3



Graph1: Effect of Eggshell and Metakaolin content on compressive strength of concrete

Figure: 3 Cube testing

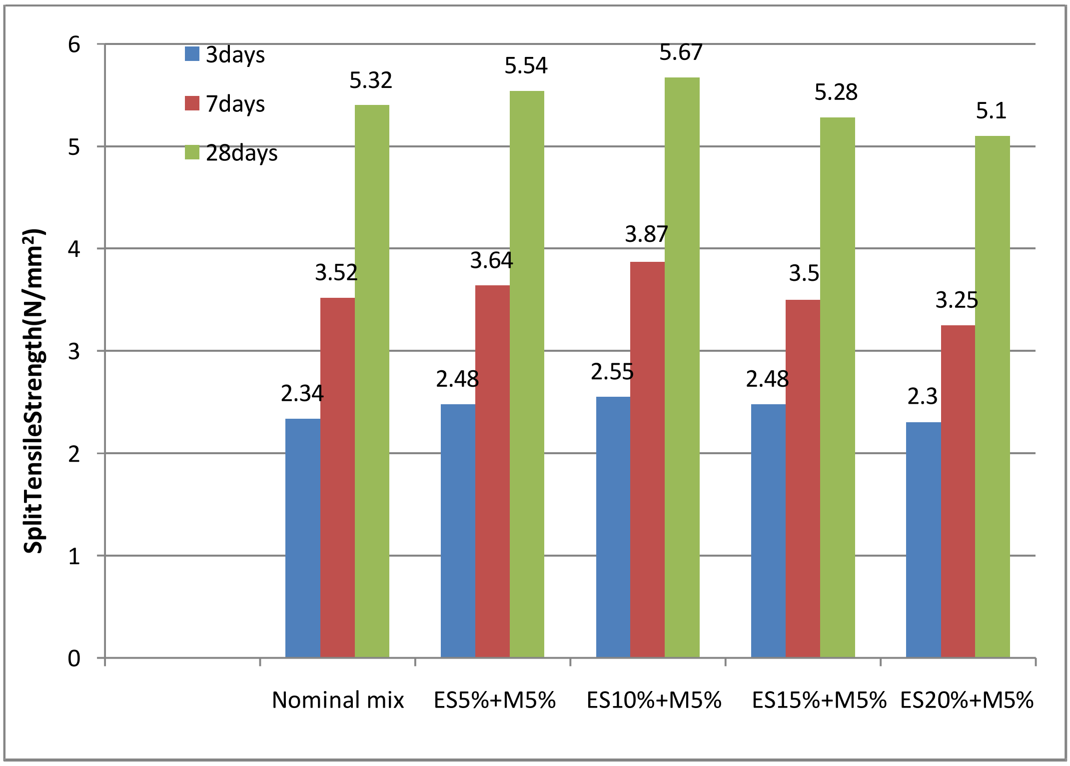
Figure:4 Cylinder testing

Figure: 5 Beam testing

From Table 6, it becomes evident that the compressible strength at each replacement percentage 7 days is around 2% to 7% higher than the 7-day strength of 43.72 N/mm2 of conventional M60 concrete. Similarly, at 28 days, thereis around a 5% increase compared to the conventional 28-day strength of 69.2 N/mm2 of M60 concrete, except for M60 with 15% ES and 5% MK and 20% ES and 5% MK content. The maximum values for all curing periods are achieved at 10% ES and 5% MK replacement of cement. Hence, the optimal content in cement concrete of M60 grade is 10% ES and 5% MK. The concrete of grade M60's compressive strength with 10% ES and 5% MK content is 5% higher than that of M60 conventional concrete. Strength decreases as ES and MK replace more cement in the same amount of time.

Table 7 Results of the concrete split tensile strength test

Eggshell%+ Metakaolin%	3days (N/mm^2)	7days (N/mm^2)	28days (N/mm^2)
Nominalmix	2.34	3.52	5.32
ES5%+MK5%	2.48	3.64	5.54
ES10%+MK5%	2.55	3.87	5.67
ES15%+MK5%	2.48	3.5	5.28
ES20%+MK5%	2.3	3.25	5.1

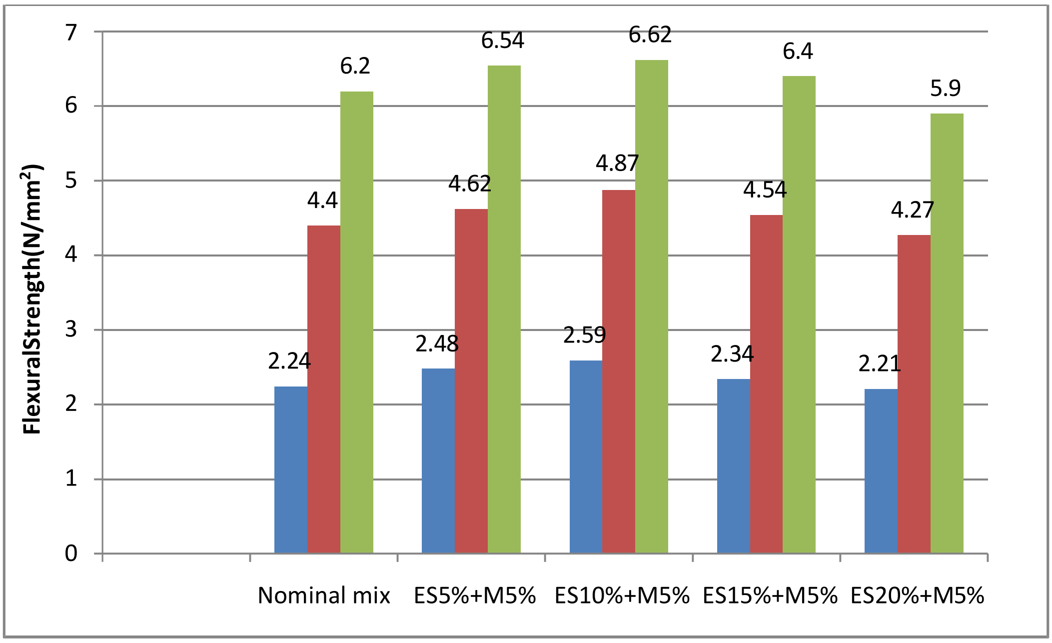


Graph 2: Effect of Eggshell and Metakaolin content on split tensile strength of concrete

Table 7 illustrates that M60 concrete's tensile strength containing 15% ES and 5% MK at all replacement ratios is 6% greater than that of conventional M60 concrete. And the strength decreased as the replacement of cement with ES and MK increased further.

Table 8 Concrete test results for flexural strength

Eggshell% +Metakaolin%	3days (N/mm^2)	7days (N/mm^2)	28days (N/mm^2)
Nominalmix	2.24	4.4	6.2
ES5%+MK5%	2.48	4.62	6.54
ES10%+MK5%	2.59	4.87	6.62
ES15%+MK5%	2.34	4.54	6.4
ES20%+MK5%	2.21	4.27	5.9



Graph 3: Eggshell and Metakaolin content's impact on concrete's flexural strength

From Table 8 It is clear that the M60 flexural strength of the concrete grade contains 15% ES and 5% MK at all replacement ratiosis 5% greater thanthat ofordinaryconcrete grade M60. And withfurther increase in cement replacement coupled with ES and MK, the strength decreased.

CONCLUSIONS

After experimental investigation, we came to the following conclusion:

1. Workability of the ES and MK concrete is reduced when compare with the normal concrete
2. The increase in percentage of ES and MK increases the powder content in concrete, which reduced free movement of particles.
3. The bond between the matrixes is very higher than the normal concrete.
4. The cube shows the highest compression strength when mixed with 10%ES and 5%MK. The potency of this blend was approximately 6% greater than the standard blend at 28 days. After increase in Es and MK content, the results gradually decreased.
5. The High Strength concrete displayed a consistent augmentation of split tensile strength, reaching up to 5%at28 days. After increase in ES and MK content, the results gradually decreased This research found that the optimal condition 10%ES and 5%MK.
6. The High Strength concrete displayed a consistent increase in Flexural strength, reaching up to 7% at 28 days. After increase in ES and MK content, the results gradually decreased. This research found that the optimal content 10%ES and 5%MK.

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