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Performance Improvement Studies of Cement with GGBS, Metakaolin and Coarse Aggregate with Various Types of Seashells

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ABSTRACT:
Concrete is the most extensively used construction material around the world and its properties have been changing technological advancements. Varieties of concrete have been developed to enhance the different properties of concrete. An investigation into the potential use of partial replacement of mineral admixture in concrete-strength has been carried out. The engineering properties of fresh and hardened concrete are obtained by conducting tests on the slump, and compressive strength at 7 and 28 days of the curing period, in this research partial replacement of cement with 10% metakaolin and GGBS (Ground Granulated Blast-furnace Slag). Also, Coarse aggregate was replaced with 10% and 20% of different seashells like clam, gastropod, and cockle sea shells in the concrete. The compressive strength of concrete made with MK-GGBS has been compared with concrete-strength i.e.; M20 grade of concrete. It has been concluded that the strength development of Sea shell concrete blended with metakaolin and GGBS was enhanced. It was found that a 10% replacement of metakaolin and a 10% replacement of GGBS appeared to be the optimum replacement which exhibited more strength. This investigation has proved that the 10%MK and 10% GGBS concrete can be used as structural concrete as a suitable replacement.

1. Introduction

1.1 General:

In the last decade, the use of supplementary cementing materials has become an integral part of Concrete-strength and high-performance concrete. These can be natural materials, by-products industrial wastes, or the ones that require less energy and time to produce. The utilization of fine pozzolanic materials in Concrete-strength leads to a reduction of the crystalline compounds, particularly, calcium hydroxide; consequently, there is a reduction of the thickness of the interfacial transition zone in concrete-strength. The densification of the interfacial transition zone allows for efficient load transfer between the cement mortar and the coarse aggregate contributing to the strength of the concrete, for concrete strength where the matrix is extremely dense, a weak aggregate may become the weak link in concrete strength. In recent years, the strength of concrete has been developed with pozzolanic materials like Ground Granulated Blast Furnace Slag, Silica Fume, Fly ash, metakaolin, and rice hush ash.

A Seashell is a hard, protective layer, a calcareous exoskeleton that encloses, supports, and protects the soft parts of an animal (Mollusca). As they grow, the shells increase in size which becomes a strong compact casing for the Mollusca inside. The major molluscan seashell includes bivalves such as clams, scallops, and cockle. The hard shells are regarded as waste, which is accumulated in many parts of the country when dumped and left untreated may cause an unpleasant odour and disturbing view to the surrounding. Also, the aggregate surface texture influences the bond between aggregate and cement paste in hardened concrete. Thus, it opens an investigation into its potential as a partial replacement of coarse aggregate.

In this work, we used Metakaolin (MK) and GGBS as pozzolanic material with the replacement of cement, and different sea shells with coarse aggregate, by using a combination of MK, GGBS, and sea shells the mechanical properties of concrete were increased.

1.2 Objectives of Research:

The objective of the research proposal is to study the influence of the percentage of a seashell as a partial replacement of coarse aggregate and the percentage of MK and GGBS as a partial replacement of cement on the mechanical properties of concrete to establish the optimum percentage of seashell and MK and GGBS, for the chosen size and type of seashell aggregate especially in coastal and riverine areas. The detailed objectives of the study are summarized below:

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i. Conducting experimental studies of mechanical properties of seashell coarse aggregate.
ii. Experimenting with the concrete mixes containing 10% of MK & GGBS with cement and 10% of different seashells as partial replacement of coarse aggregate.
iii. to evaluate the mechanical properties of concrete such as compressive strength, and tensile splitting strength characteristics.
iv. Analyzing and studying the effect of varying percentages of seashell and MK & GGBS and comparing the results with normal concrete without any replacements.
v. Performing the slump test and analyzing the variation of a slump for different percentages of a seashell to obtain the workability characteristics of the concrete with partially replaced seashell as coarse aggregate.
vi. Obtaining the optimum percentage of seashells and MK & GGBS based on the test results.

2. Review of Literature

Vineeth Kumar, Akash Prakash, objective was to find the compressive and split tensile strength at 7 and 28 Days by partially replacing cement with Metakaolin and marble powder First M30 mix was prepared, and then in each successive trail Metakaolin and marble dust were replaced. The proportions are replaced 5% MK+5% MP,10% MK+10% MP,12.5% MK+12.5% MP, and 15% MK+15% MP. Results showed that the compressive strength and split tensile strength of concrete is higher at 10% MP+10% MK.

M Praneeth Kumar, B Ajitha (2021), Reported that they had tested the strength of the concrete by substituting metakaolin for cement in a range of 0% to 20% and that they had completely replaced the fine aggregate with steel slag sand. It was an M60 mix. The replacement studies were conducted with standard 150 mm x 150 mm x 150 mm cubic specimens. The outcomes demonstrated that superior outcomes were obtained when 15% Metakaolin was substituted for cement and 100% steel slag sand was used in place of fine aggregate. The strength of the concrete decreases when the percentage of Metakaolin exceeds 15%. In addition to producing green concrete, the use of metakaolin protects the environment.

Dr. Vaishali G. Ghorpade and Syed Talha Zaid (2014) conducted research on the subject of "Experimental Investigation of Snail Shell Ash (SSA) as Partial Replacement of Ordinary Portland Cement in Concrete". In this work, SSA proportions of 0%, 5%, 10%, 15%, and 20% were used in place of OPC. They come to the conclusion that a 5% replacement of OPC with SSA is ideal after observing increases in compressive strength of 7.50% and split tensile strength of 3.54% during a 28-days curing period. They also came to the conclusion that the workability of concrete is also impacted.

B. Ramakrishna and A. Sateesh (2016) have published a paper on the topic of Exploratory study on the use of cockle shells as partial coarse and fine aggregate replacement in concrete, by using the cockle shells to replace a proportion of the coarse and fine aggregates, which might minimize consumption of natural fine aggregate usage. For this research, seven different mix percentages of shells were employed to make various types of the concrete mix: 0%, 5%, 10%, 15%, 20%, 25%, and 30%. In this work, Tests for fresh and hardened properties were performed as per Indian standard code specifications. They came to the conclusion that adding crushed cockle shells to fine aggregate at a level of 10% and replacing natural coarse material at a level of 25% increased compressive strength. However, this substitution affected the workability of the concrete.

Khawaja Adeel Tariq, Muhammad Sohaib, and Mirza Awais Baig (2021), conducted research on the subject of "Effect of partial replacement of cement with rice husk ash on concrete properties". Cement was substituted for Rica Husk ash at percentages 6%, 12%, and 18%. The optimum results are achieved with a 6% replacement of cement with rice husk ash.

3. Experimental Work

3.1 Materials:

A. Cement: Cement is a crucial building material used in construction for making concrete and mortar. It's a fine powder that, when mixed with water, forms a paste that binds sand and aggregates to create a solid structure. In this work, locally available Ordinary Portland Cement (OPC) 53-grade Sri chakra cement has been used.

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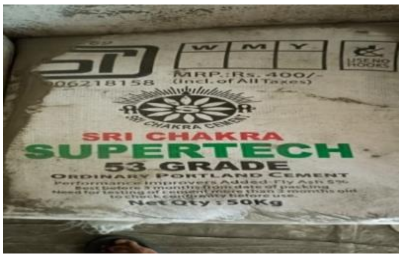

Figure 1: Portland Cement (OPC)

B. Fine Aggregate: In RCC, the quantity of fine aggregate is critical. In general, RCC uses more fine aggregate than ordinary concrete. However, as fine aggregate requires a disproportionately higher amount of water than coarse aggregate, care must be taken to include the ideal proportion of fine aggregate in the mix. By passing the river sand through a 4.75mm sieve, higher-quality river sand was utilized as fine aggregate.

Figure 2: Fine Aggregate.

C. Coarse Aggregate: Locally accessible 20 mm natural stone coarse aggregates were used as the coarse materials in this study. According to IS: 2386 (part III)-1963, laboratory tests were conducted on coarse aggregate to ascertain various properties.

Figure 3. Coarse Aggregate.

D. Water: Concrete must be mixed with clean water that has no dangerous quantities of oils. acids, alkalis, organic compounds, or other deleterious chemicals. In this investigation, we used portable tap water from the college campus water plant that met the IS456-2000 standards for casting concrete and curing the specimens.

Figure 4. Water.

E. Sea shells: For this study, sea shells were transported from Thiruvalluvar Nagar beach, Chennai, and contained slightly more $CaCO_3$ (90.18%) than limestone. Physical properties of sea shells include a specific gravity of 2.36 and water absorption (0.60%), sea shells were formed as the result of the disintegration of dead animals. Seashell consists of three layers outer, intermediate, and inner layer. The outer layer is made up of calcite material whereas the inner layer is otherwise known as nacre which is made up of calcium carbonate. Since 95% of calcium carbonate is present in seashells, it has a strength nearly equal to coarse aggregate.

Figure 5. Sea shells.

3.2 Mineral admixtures

A. GGBS: GGBS is a granular material formed when molten iron blast furnace slag is rapidly chilled by immersion of water. It is a granular product with very limited crystal formation, is highly cementations in nature, has ground-to-cement fines.

Figure 6. GGBS

B. Metakaolin: Metakaolin for the present research work was obtained from Astra Chemicals Chennai, the metakaolin was sieved and a fraction passing 100µ sieve was used in the experiments. The chemical and physical properties of MK, GGBS, and OPC are presented in the table.

Figure 7. Metakaolin.

3.3 Mix proportions: To attain M20 grade strength, the concrete was designed by IS 10262-2009, and a water-to-cement ratio of 0.5 was employed. Distinct mixes of cement by 10% of MK&GGBS and 10% and 20% of calm, gastropod, and cockle shells were replaced with Coarse aggregate and were tested to analyze the strength characteristics in terms of Compressive and split tensile strength after 7 and 28 days of curing period. Six cubes are cast for each mix and tested for hardened properties.

3.4 Tests On Cement

3.4.1 Test in the field:

A field test usually refers to a variety of on-site tests carried out to evaluate the qualities and characteristics of cement in actual conditions.

3.4.2 Laboratory tests:

Laboratory tests on cement evaluate its quality and characteristics, ensuring compliance with IS Standards for construction applications.

3.4.3 Setting time tests:

The normal consistency of a cement paste determines the amount of water needed for the Vicat plunger to penetrate 5-7 mm from the bottom of the Vicat Mold, crucial for determining initial and final setting times.

3.4.4 Fineness of Cement

The fineness of cement is essentially informing you of the size of the cement particles present in a particular cement sample.

3.4.5 Specific gravity of cement

The specific gravity of cement serves as a measure of its quality. The specific gravity of cement is determined using kerosene that does not react with cement.

3.5 Tests on Fine Aggregate

3.5.1 Particle Size Distribution

Particle size distribution is conducted to evaluate the particle size distribution in an aggregate sample, referred to as gradation.

3.5.2 Specific gravity of fine aggregate

It is an important property that can be used to evaluate the consistency and quality of fine aggregate. The specific gravity of the material is usually measured using a pycnometer bottle as part of the quality control procedure.

3.6 Tests on Coarse Aggregate

3.6.1 Specific gravity and water absorption test

The specific gravity of an aggregate serves as a measure of material quality. Lower specific gravity values typically indicate weaker characteristics, whereas higher specific gravity values suggest stronger characteristics in aggregates. Water absorption in aggregates or saturated aggregates enhances the strength of rocks. However, stones with higher water absorption rates are typically considered unsuitable.

3.6.2 Flakiness Index

The flakiness index of an aggregate is the percentage by weight of particles, The particle shape and surface texture influence the properties of freshly mixed concrete is more than the properties of hardened concrete.

3.6.3 Elongation index

The elongation index is an experimental method to measure the length of the coarse aggregate, presence of more elongated particles disturbs the packing of the concrete.

3.6.4 Particle Size Analysis

Particle Size analysis is a method used to determine the particle size distribution of coarse aggregates such as gravel and crushed stone to classify them into different size ranges as per IS sieve This information is essential for designing concrete mixes and other construction materials.

3.7 Testing of Fresh and Hardened Concrete

3.7.1. Workability test: The workability of the concrete is checked through slump value. A slump test was performed for all mixes.

3.7.2. Compression test: The specimens of size 150x150x150 mm were tested. The compression test was performed for curing ages of 7 and 28 days by a 1000 KN capacity machine. The purpose of these tests was to determine the compressional behaviour of the test specimens at specified ages.

3.7.3 Split Tensile Test: The test program considered the cast and testing of concrete specimens of cylinders 100mm in diameter and 300mm in height. The specimen was cast M20 grade concrete using OPC, Natural River sand, coarse aggregate (20mm to 4.75mm), MK, GGBS and Sea shell aggregates. Each

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three numbers of specimens are made to take the average value. The Specimens were removed from the cylinder after 24 hours. The specimens were allowed to the curing periods of 7, and 28 days. Tests were conducted to ascertain the strength criteria in concrete are described below in detail.

4. Test Result and Discussions

4.1 Experimental Tests on Cement

In this study, Grade 53 ordinary Portland cement, as per, IS: 12269-1987, was utilized in this investigation. Throughout the investigation, the cement utilized was locally available Sri Chakra brand 53 Grade Ordinary Portland cement. It had no lumps and was fresh. The cement's physical characteristics as determined by different tests in accordance with Indian standard IS12269:1987. As indicated in the table, the various tests performed on cement include initial and ultimate setting time, as well as specific gravity.

Table 1: Cement's Physical Characteristics

S.no	Property	Test result
1	Specific gravity	2.7
2	Water absorption	0.47%
3	Elongation Index	9%
4	Flakiness	11.3%
5	Particle size Distribution	6.2

4.2 Experimental Tests on Fine Aggregate

As per experiments, the fineness modulus (FM) of fine aggregate ranged from 2.4 to 2.8, with the saturated surface dry (SSD) density ranging from 2.54 to 2.66. The fine aggregate amount ranged from 600 to 900 kg/m3. Fine aggregate has the physical qualities mentioned in the table and can be carried from local suppliers.

Table 2: Physical properties of Fine aggregate.

S.no	Property	Test result
1	Specific gravity	2.66
2	Fineness modulus	2.96
3	Zone	II
4	Water absorption	1.6%

4.3 Experimental Tests on Coarse Aggregate

The aggregates were tested in accordance with IS: 383-1970. The physical parameters of coarse aggregates were measured and are given in the table.

Table 3: Physical properties of Coarse aggregate.

S.no	Pro perty	Test result
1	Normal consistency	29%
2	Specific gravity	3.14
3	Initial setting time	54min
4	Final setting time	385min
5	Soundness	3mm
6	Fineness (sieve)	98.20%

4.4 Experimental Tests on Sea Shells

For this study, sea shells were transported from Thiruvalluvar Nagar beach, Chennai, and contained slightly more $CaCO_3$ (90.18%) than limestone. Physical properties of sea shells include specific gravity of 2.36 and water absorption (0.60%).

4.5 Experimental Tests on MK and GGBS

Metakaolin and GGBS were considered a good alternative to cement, because of its physical and chemical characteristics. To conduct the experimental investigation, the Metakaolin and GGBS capable of passing through a 90μm sieve of 50 kgs was transported from Astrra Chemicals in Chennai.

Table 4: Physical and Chemical Properties of MK and FA.

Properties	OPC 53grade	MK	GGBS
Physical			
Specific gravity	3.11	2.6	2.5
Average particle size	20μm	2.5μm	7μm
Specific area m^2/kg	325	13000	11250
Color	Grey	Off- white	Grey
PH	12	5.5	8
Chemical Composition %			
SiO2	21.54	52	40
Al2O3	4.68	46	17
Fe2O3	2.46	0.60	6
TiO2	-	0.65	0.01
CaO	62.58	0.09	24
MgO	1.08	0.03	1.6
Na2O	0.24	0.10	1.8
K2O	0.87	0.03	1.21
Loss on ignition	2.58	1.00	0.4%

The chemical analysis was carried out at Astrra Chemicals Limited in Chennai in accordance with standard procedures, and the lab reports were sent together with the Metakaolin and GGBS bag. The physical and chemical composition of Metakaolin and GGBS were shown in Table 4.

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4.5 Experimental Tests on Fresh Concrete

Workability is tested in terms of slump cone and compaction factor test, which decrease as sea shells are replaced with coarse aggregate and MK & GGBS are replaced with cement, respectively. The slump cone and compaction factor test with % replacement is depicted in the graph below.

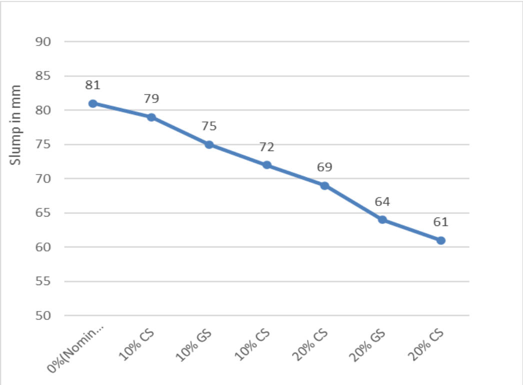

Figure 8: Slump with different mixed proportions of SS, MK and GGBS.

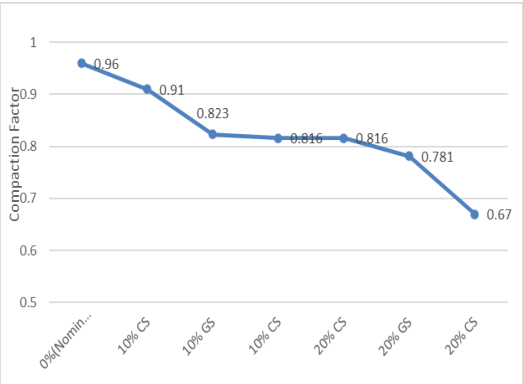

Figure 9: Compaction factor with different mixed proportions of SS, MK, and GGBS.

The workability test results show that the workability decreases as the percentage of Seashells and MK&GGBS increases. The slump value for the nominal mix was around 81 mm, and it steadily dropped to 72 mm. In terms of the compacting factor, the nominal mix demonstrated the highest workability. The dropping of workability is mainly due to the uneven form and surface structure or texture of sea shells. Furthermore, because the surface hydration of MK&GGBS is slightly slower than that of cement, the water needed for mixing is not instantly wasted. However, even with the use of sea shells, the workability obtained is sufficient for normal concrete works.

4.6 Casting of specimens:

The moulds that were used to cast cubes, and cylinders were carefully cleaned. A thin layer of oil was applied to the interior surface of the moulds to prevent concrete adherence and leakage. Then, using a tamping rod, the concrete was poured into the greased moulds (cubes, and cylinders). Tests were conducted at 7 and 28 days of age.

4.7 Curing: Curing is the process of creating an atmosphere conducive to the setting and hardening of concrete. From the time the specimens leave their molds until they are shipped to the testing laboratory, the specimens are completely immersed in a pond of water with 50 mm of water over them. If possible, keep the temperature between 10°C and 25°C.

4.9 Experimental Tests on Hardened Concrete

4.9.1 Compressive strength: To investigate the progress of stability in old age, the compression quality of cubes measuring 150mmx150mmx150mm for 7 days and 28 days of curing as per IS 516-1959 were used. The tests were performed using a 2000 KN testing machine with a loading rate of 140 kg/cm/m2. Cubes were cast in 10% and 20% proportions of sea shells like calm shells. gastropod shells and cockle shells. Find the optimal proportion of sea shells in concrete and keep it at that level. Cubes were now cast in 10% amount of MK&GGBS. Three cubes were cast for each percentage, and the surface of the cubes was allowed to cure for 24 hours in a saturated state. The cubes were cured for 7 and 28 days. After the appropriate curing times of 7 and 28 days, the samples were removed from the curing container and dried on their surfaces.

Table 5: Compressive strength of concrete on 7 and 28 days of curing.

Mix.ID	7 Days strength (N/mm²)	28 Days strength (N/mm²)
Nominal Concrete	13.5	21.9
10% CS+10% MK+10% GG	15	24.85
10% GS+10% MK+10% GG	14	23.95
10% CS+10% MK+10% GG	13.25	23.35
20% CS+10% MK+10% GG	12.1	24.9
20% GS+10% MK+10% GG	11.4	23.4
20% CS+10% MK+10% GG	11.3	23.6

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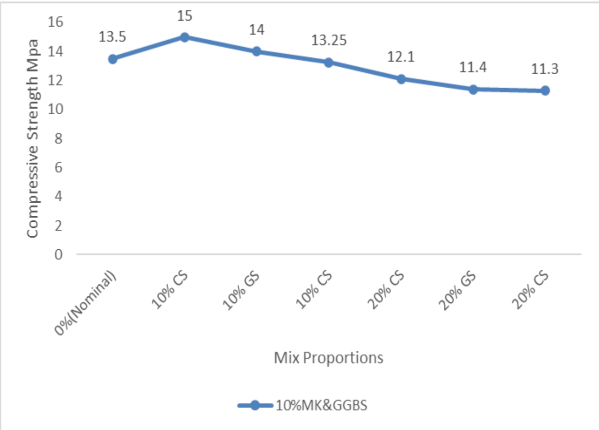

Figure 10: Compressive strength with different mixed proportions of MK, GGBS & SS at 7 days.

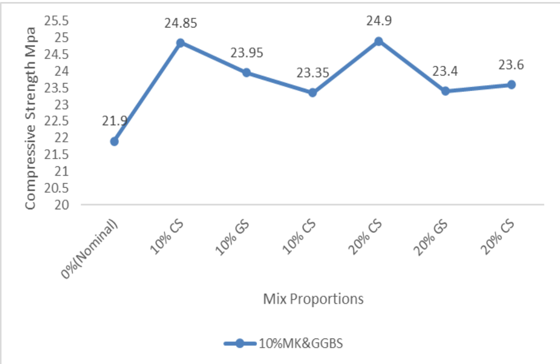

Figure 11: Compressive strength with different mixed proportions of MK, GGBS & SS at 28 days.

The comparison of uniaxial compressive test results is depicted in Fig.12. In comparison to the control mix, the compressive strength of MK, GGBS, and different types of sea shells steadily increased up to 10% after 7 days of curing period and 11.87% after the 28 days of curing period and then subsequently dropped. This study determined that 10% MK+10% GGBS+20% calm Shells was the best combination.

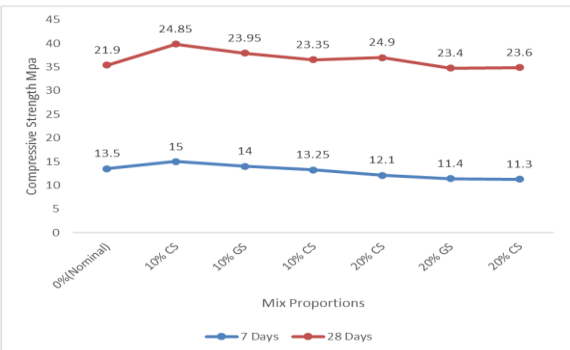

Figure 12: Comparison of Compressive strength with different mixed proportions of MK-GGBS at 7 and 28 days.

4.5 Split tensile Strength test: The tensile strength of concrete can be determined by this indirect test. Concrete specimens were tested for splitting tensile strength on cylinders 150 mm in diameter and 300 mm in height after 7 and 28 days of water curing. IS 5816-1999 was used to conduct the test. A splitting tensile strength test was conducted on cylindrical specimens positioned horizontally on the compression testing machine. The load was applied till failure, and the splitting tensile strength values are graphed in the below Figure.

Table 6: Split Tensile strength of concrete on 7 and 28 days of curing

Mix.ID	7 Days strength (N/mm^2)	28 Days strength (N/mm^2)
Nominal Concrete	3	4.13
10%CS+10%MK+10%GG	3.5	4.57
10%GS+10%MK+10%GG	2.13	3.87
10%CS+10%MK+10%GG	2.04	2.94
20%CS+10%MK+10%GG	2.4	2.93
20%GS+10%MK+10%GG	1.82	2.12
20%CS+10%MK+10%GG	1.74	2.05

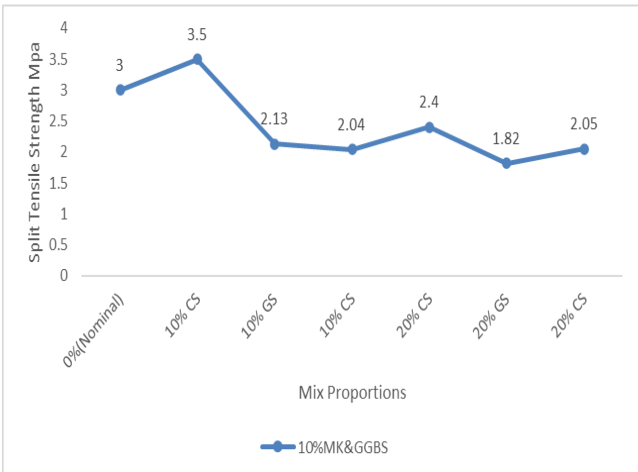

Figure 13: Split Tensile strength with different mixed proportions of MK-GGBS at 7 days.

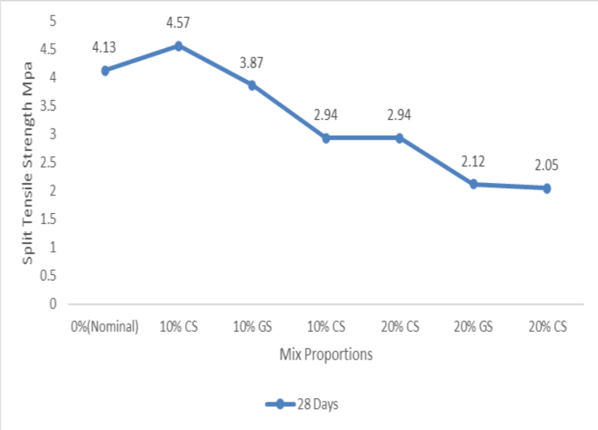

Figure 14: Split Tensile strength with different mixed proportions of MK-GGBS at 28 days.

The Comparison of results depicted below that the cylinder's splitting tensile strength was optimum at 10% of MK, 10% of GGBS and 10% of calm sea shell replacement. The percentage increase in strength exceeds the nominal mix by 14.28 % and 9.62% after 7- and 28-day curing periods respectively. The percentage strength was increased up to 10%MK+10%GGBS+10% Calm Shells, but then reduced due to a greater void space ratio in the specimens, resulting in a weaker bond between the concrete.

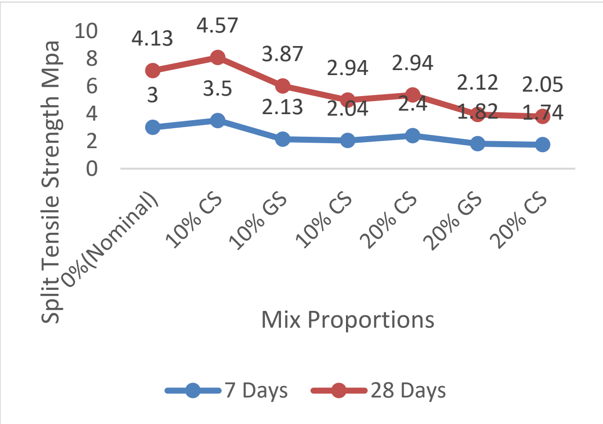

Figure 15: Split Tensile strength with different mixed proportions of MK-GGBS 7 and 28 days.

5. Conclusion

In this research work M20 grade concrete was designed. About 24 cubes and 24 cylinders were cast to test the compressive strength and split tensile strength of concrete. On the arrival of results, the following conclusions were obtained.

1. The workability of the concrete as measured by the slump reveals that as MK, GGBS, and sea shell replacement increases, the slump decreases, and the findings are within the typical range of concrete.
2. Metakaolin and GGBS concrete gain strength over some time, the compressive strength of Sea shell concrete with MK and GGBS is more than conventional concrete.
3. Splitting tensile strength was optimum at 10% of MK, 10% of GGBS, and 10% of calm sea shell replacement. The percentage increase in strength exceeds the nominal mix by 14.28 % and 9.62% after 7- and 28-day curing periods respectively
4. The optimum replacement of cement with MK and GGBS is 10% and 10%. Also, 10% calm shell replacement with coarse aggregate gives more strength.
5. The addition of MK and GGBS shows an increased water absorption compared with OPC concrete.
6. As per the experimental results it is concluded that the optimum concrete mixes can be arrived at by blending cement With MK and GGBS.

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