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Experimental Evaluation of Durability Properties of Concrete with Binary Cement Replacement by Metakaolin and Fly Ash

Bandi Upendra[1*], P. S Rama Chaitanya Kumar[2]

[1]*Civil Engineering Department, JNTUA College of Engineering, Anantapur, Andhra Pradesh, India*

[2]*Assistant Professor in Civil Engineering Department, ALTS, Andhra Pradesh, India*

[*]*Corresponding author*

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Abstract

The demand and use of concrete have led to a lot of research into improving its strength, workability, durability, and many more. Improving the Durability of concrete is paramount in the construction of basic infrastructure in a bid to make it sustainable. In this study, the influence of the partial replacement of cement by Metakaolin (MK) and FlyAsh (FA) was investigated and the effects on durability properties were determined. Namely, two types of pozzolans were opted for this study which are Metakaolin and Fly ash This was done in a bid to reduce the cost of cement which is one of the most expensive components of concrete production, and to improve sustainability in the construction industry. In this study partial replacement of cement has been done at 0%,5%,10%,15%,20% with MK (Metakaolin) and 0%,5%,10%,15%(constant) with FA (Fly ash). The compressive strength of concrete made with MK-FA has been compared with High strength concrete i.e., M60 grade of concrete. The optimized strength value of concrete will be achieved for compressive strength. In this study, we determined the Durability properties at 30, 90, and 120 days.

Keywords: Metakaolin; Flyash; Compressive strength, Durability

1. Introduction

1.1General:

High-strength and high-performance concrete now demand the application of supplement cementing materials, as they have for the past ten years. Natural resources, industrial wastes, byproducts, and materials with lower energy and production times can all be considered. Using fine pozzolanic materials reduces the amount of crystalline compounds in high-strength concrete, especially calcium hydroxide. As a result, the thickness of the interfacial transition zone in high-strength concrete is reduced. In ultra-high strength concrete, where the matrix is extremely dense, a weak aggregate may become the weak link in the strength of the concrete due to the densification of the interfacial transition zone, which enables efficient load transfer between the cement mortar and the coarse aggregate. In recent years, high- strength concrete has been developed with pozzolanic materials like Ground Granulated Blast Furnace Slag, Silica Fume, Fly ash, metakaolin, and rice husk ash. The HSC can be enhanced with workability and strength and results in the decrement of permeability. In this work, we used Metakaolin (MK) and Fly Ash (FA) as pozzolanic material, by using a combination of MK and FA the mechanical properties of concrete were increased.

1.2 Objectives of Research:

The following tests are proposed to be conducted to evaluate the strength and durability properties of Metakaolin and Fly Ash in concrete. The test results are compared with equivalent grade control concrete.

1. To investigate the Compressive Strength acquired by the mix after the 30, 90 and 120 days of curing period respectively.
2. Ability to test the durability properties of the concrete to resist weathering action, chemical attack, abrasion, and other conditions of service.
3. To use solid wastes to lessen pollution in the environment.
4. To create a concrete mix that is environmentally friendly.
5. To determine which strength has increased in relation to the ideal replacement percentage.

2. Review of Literature

S. Yeswanth Sai Krishna, B Ajitha (2023), stated that they had totally replaced the fine aggregate with slag sand and that they had evaluated the strength of the concrete by replacing cement with Nano silica in a range of 5%, 10%, 15%, and 20%. The mix was M60. Standard cubic specimens measuring 150 mm by 150 mm by 150 mm were used for the replacement studies. The results showed that using 100% slag sand in place of fine aggregate and 15% Nano silica in place of cement produced better results. When nano-silica content in concrete surpasses 15%, the material's strength declines. Using Nano silica not only creates green concrete but also safeguards the environment.

Shaik Sony Sulthana, B Ajitha (2023), reported that to determine and compare the strength and durability properties of High strength concrete containing Metakaolin (MK) and Marble Dust with cement replacement and fine aggregate is fully replaced with slag sand. For this purpose, concrete mixtures were produced by substituting cement with 5%-15% of the Metakaolin and 10%-20% of the marble dust by weight. The amount of binder material for the concrete mixtures was 300 and 400 kg/m3 with a constant water-to-cement ratio of 0.36. In this investigation Compressive strength of concrete was determined after 28, 30, 90 and 120 days of water, acid and base curing methods.

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 M60mix.Thereplacementstudieswereconducted 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 inplace offine aggregate. The strength of the concrete decreases when the percentage of Metakaolin exceeds 15%. In addition to produce green concrete, the use of metakaolin protects the environment.

Vijay Shankar and Suji (2014) investigated the optimum percentage (0, 2.5, 5, 7.5, 10, 12.5 & 15%) of Metakaolin as a partial replacement for cement together with partial replacement of natural river sand with quarry dust at (0, 10, 20, 30 & 40), results in the production M40 grade mixes. From the experimental results it is proved that Quarry Dust can be used as an alternative material for the fine aggregate (sand). Metakaolin can be used as one of the alternative materials for the cement used for producing HPC. Based on the results the compressive and split tensile strengths are increased by mixing of Metakaolin with Quarry Dust. The compressive strengths are 16%,16% 10%,10%,10%, and 10% at the period of7,14,28,56, 90, and 120days and the increase in the split tensile strength is 16% and 12%at the period of 28 & 56 days.

A.N.Swaminathen, S.Robert Ravi, their work " Strength Characteristics of Concrete with Indian Metakaolin and Rice Husk Ash." In this research, MK and RHA are studied as a replacement for cement in the following proportions: 0+0%, 5+10%, 7.5+10%, 10+10%, 5+12.5%, 10+12.5%,

5+15%, 7.5+15% and 10+15% for high strength. It was found that a 7.5% replacement of metakaolin and 12.5% replacement of rice husk ash appear to be the optimum replacement which exhibited more strength.

Chepuri Jaswanthi Yoga, B Ajitha, they noted that Metakaolin and marble dust strength tests ranged from 0% to 20% and fine aggregate was fully replaced with slag sand and that they were done. The mix used was M60. The replacement experiments were carried out using 99 conventional cubic specimens of size 150mm*150mm*150mm, as well as 99 cylinders of 15cm and 20cm in height. The results showed that the replacement of cement with 15% Metakaolin and 10% Marble powder gave better results. When the percentage of Metakaolin is above 15% and by not altering the percentage of Marble powder to 10% there is a reduction in the strength of the concrete. The use of Metakaolin with marble powder saves the environment and produces green concrete. The ideal proportion for Metakaolin is 15%, while for Marble powder it is 10%.

3. Experimental Work

3.1Materials:

A. Cement: In this research work, the cement used was Ordinary Portland Cement (OPC) 53-grade Sri chakra cement with specific gravity 3.11 which is easily available in the market. The properties of cement were determined in accordance with IS – 8112:1989 were: Fineness – 5% (⩽10%); Consistency – 29%; Initial setting time -65 minutes (⩾30minutes); Final setting time 550 minutes (⩽600 minutes).

B. Fine Aggregate: A better quality of river sand was used as fine aggregate by sieving through a 4.75mm sieve. The tests such as specific gravity, bulk density, and fineness modulus, water absorption were obtained as 2.64, 1890.81kg/m3, and 2.52, 1% respectively.

C. Coarse Aggregate: The coarse materials utilized in this research are 20 mm natural stone coarse aggregates that are locally available. Laboratory tests on coarse aggregate were performed as per IS: 2386 (part III)- 1963 to determine different characteristics like specific gravity, and water absorption were obtained as 2.77, and 0.5% respectively.

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.

3.2Mineral admixtures

A. FlyAsh: From the combustion of pulverized coal and transported by the flue gases of boilers by pulverized coal, Fly Ash is produced. It was transported from Sri Damodaran Sanjeevaiah Thermal Power Station Nellore, dried, and subsequently used. Likewise, the specific gravity of Fly Ash is 2.5

B. Metakaolin: Metakaolin is a relatively new material in the concrete industry and it is effective in increasing strength, reducing sulfate attack, and improving air-void network. Pozzolanic reactions change the microstructure of concrete and the chemistry of hydration products by consuming the released Calcium Hydroxide (CH) and producing additional Calcium Silicate Hydrate (C-S-H), resulting in an increased strength and reduced porosity and therefore improved durability. 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, FA, and OPC are presented in the table.

Table1: Physical and Chemical Properties of MK and RHA

Properties	OPC53grade	MK
Physical Properties		
Specific gravity	3.11	2.6
Average particle size	20µm	2.5µm
Specific area m^2/kg	325	13000
Color	Grey	Off-white
Chemical Properties		
PH	12	5.5
SiO2	21.54	52
Al2O3	4.68	46
Fe2O3	2.46	0.60
TiO2	-	0.65

3.3 Chemical Admixture:

A. Super Plasticizer: Super Plasticizers are to be added to cement concrete at the time of mixing so as to achieve the desired property in concrete, in the plastic or hardened state. Poly-carboxylate Ether Superplasticizer obtained from Chemcon tech SYS was used. It conforms to IS: 9103 – 1999 and its specific gravity was 1.2.

3.4 Mixproportions: ToattainM60gradestrength, the concrete was designed in accordance with IS 10262-2009, and a water-to-cement ratio of 0.38 was employed. Distinct mixes of cement by varying proportions of 0%,5%,10%,15%,20% with MK (Metakaolin) and 0%,5%,10%,15%(constant) with FA (Fly ash) were tested to analyze the strength characteristics in terms of Compressive Strength. Nine cubes are cast for each mix and tested for Compressive Strength.

3.5Testing methods

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

3.5.2 Compression test: The test program considered the cast and testing of concrete specimens of the cube (150mm) and (150 x 150 mm). The specimen was cast M60 grade concrete using OPC, Natural River sand, coarse aggregate (20mm to 4.75mm), and Metakaolin. Each three numbers of specimens are made to take the average value. The Specimens were removed from the cube after 24 hours. The specimens were allowed to the curing periods of 30, 90 and 120 days. Tests were conducted to ascertain the strength criteria in concrete are described below in detail.

3.5.3 Durability: The durability is the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties. Due to the denser binder matrix and the reduced chemical and physical deterioration the durability of cementitious systems is greatly increased. Depending on the application an engineer must design concrete of different degrees of durability and properties which depend on the exposure given by the environment, e.g. water salt water, etc With metakaolin and Fly ash the durability can be improved to the needed levels to find the suitable durability to extend the life time of a concrete. The durability of concrete may be defined as the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties. Different concretes require different degrees of durability depending on the exposure environment and properties desired. For example, concrete exposed to tidal seawater will have different requirements than an indoor concrete floor. Concrete ingredients, their proportioning, interactions between them, placing and curing practices, and the service environment determine the ultimate durability and life of concrete. Tests were conducted to ascertain the resistance of developed concrete to sulphate and hydroxide attack, Temperature attack, etc.

4. Test Results and Discussions

4.1. Workability:

The workability of the control mix and MK-FA mixed concrete was measured according to IS Standards. At different levels of replacement of MK-FA, the workability of concrete is illustrated in Fig. 1. It is clearly depicted from the results that the control mix has a higher slump value as compared to MK-FA concrete blends.

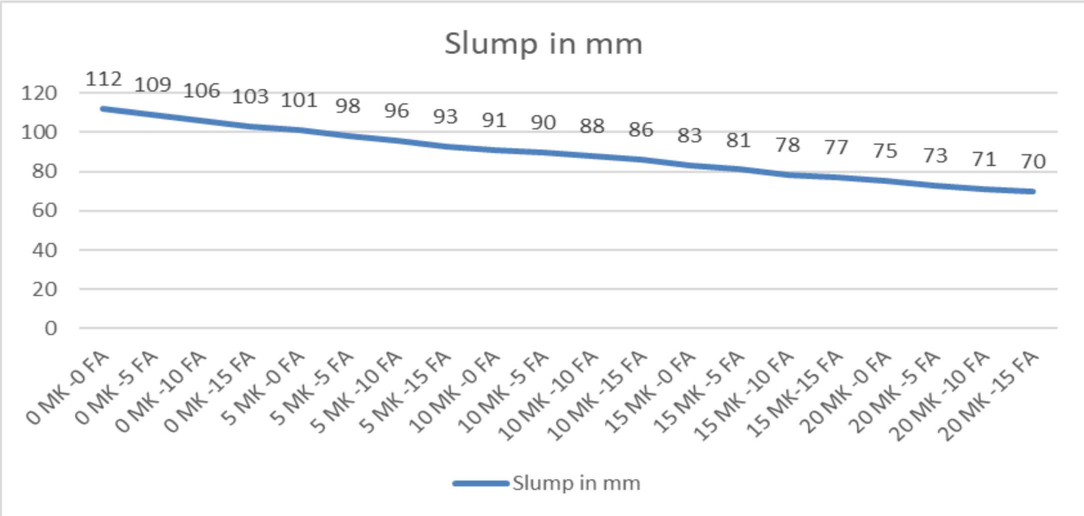

Figure1:Slump with different mixed proportions of MK-FA.

4.2. Casting of specimens:

The moulds that were used to cast cubes were carefully cleaned. A thin layer of oil was applied to the interior surface of the molds to prevent concrete adherence and leakage. Then, using a tamping rod, the concrete was poured into the greased molds (cubes, beams and cylinders). Tests were conducted at 30,90 and 120 days of age.

4.3Methods of curing:

Curing is the most important & sensitive factor that plays an important role in strength development and durability of concrete. Properly cured concrete has an adequate amount of moisture for continued hydration and development of strength, volume stability and resistance to freezing and thawing. This research work has been carried out to study the effect of acidic curing on the strength and durability of hardened concrete. So, this experimental work was carried out in the following curing conditions

(i) Normal water curing (ii) Acidic curing iii) Base curing.

4.3.1 Normal water curing: Water unsuitable for drinking is generally considered unsuitable for curing concrete as well. The water used for normal water curing of concrete samples was taken from the concrete technology laboratory, JNTUA. The concrete samples were tested after 30,90 and 120 days of proper curing. to acids and most acids disintegrate the cement slowly or rapidly depending upon the type of pH value of acidic water. The solution used for acidic curing of concrete samples was prepared using concentrated $MgSO_4$, which was diluted to obtain a pH of 4.5. The concrete samples were tested after 30,90 and 120 days of proper acidic curing.

4.3.2 Acidic curing:

Concrete is not fully resistant to acids and most acids disintegrate the cement slowly or rapidly depending upon the type of pH value of acidic water. The solution used for acidic curing of concrete samples was

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prepared using concentrated MgSO4, which was diluted to obtain a pH of 4.5. The concrete samples were tested after 30,90 and 120 days of proper acidic curing.

4.3.3 Base Curing: Base during curing, the rate and amount of moisture loss from concrete while it hydrates are managed. As the name implies, this curing method involves keeping the exposed surface constantly wet to prevent it from drying out. Common techniques for achieving this goal include ponding water or spraying water over the top of the surface. But in this study Sodium hydroxide (NaOH) is used for base curing after 30, 90 and 120 days of proper Base curing.

4.4 Compressive strength (Acid and Base Curing): The uniaxial compressive test after acid and Base curing results are depicted in Fig.2 and Fig.3. In comparison to the control mix, the compressive strength of MK and FA steadily increased up to 5.04% after 120 days of Acid curing and 4.82%after 120 days of Base curing and subsequently dropped. This study determined that 10%MK+10%FAwasthebestcombination.

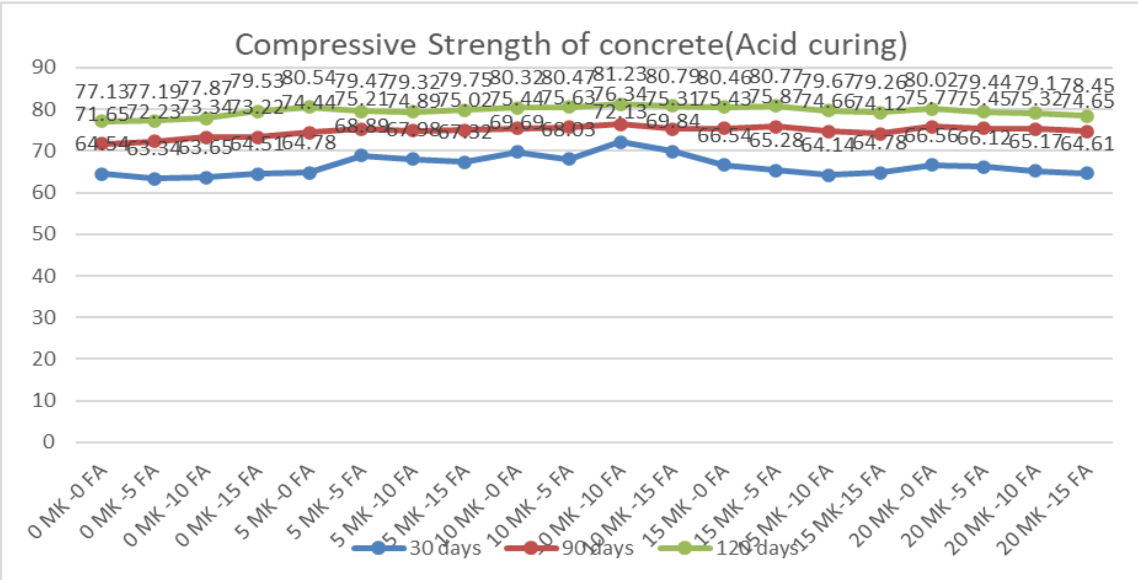

Figure2: Compressive strength with different mixed proportions of MK-FA after Acid curing.

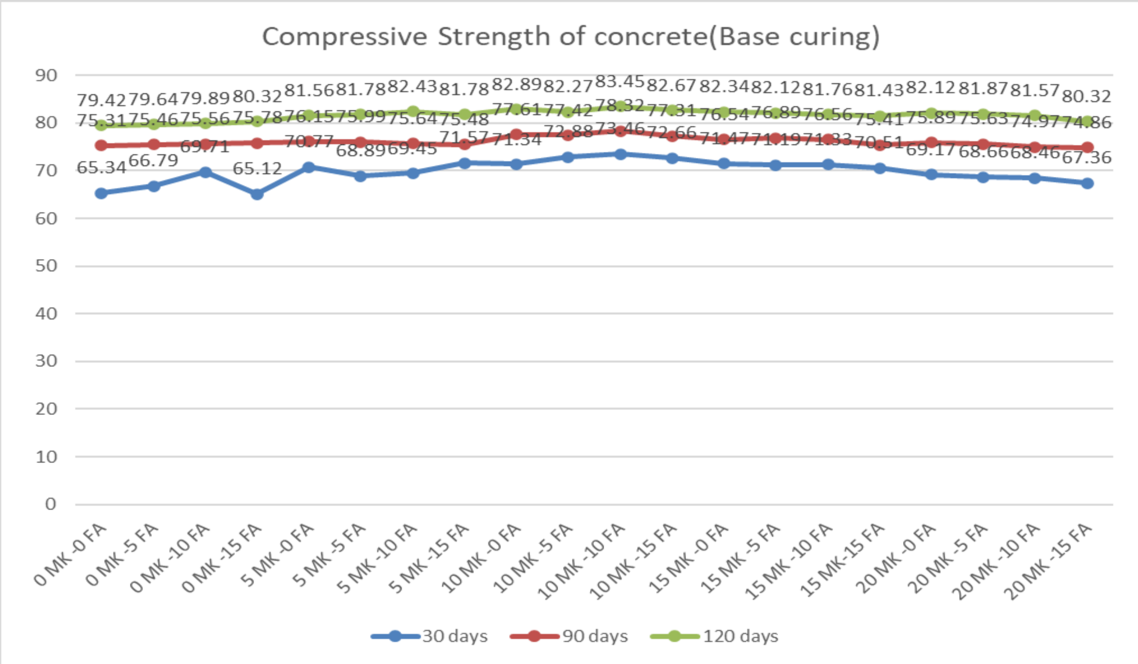

Figure3: Compressive strength with different mixed proportions of MK-FA after Base curing.

5. Conclusion

Based on the investigation conducted on the strength and durability characteristics of Metakaolin and Fly Ash as the replacement materials blended with a high percentage of metakaolin and FA with the water demand will be more. Because of the greater fineness of Metakaolin and FA to maintain constant workability, the use of plasticizer becomes necessary. An optimum of 10% of metakaolin and 10% of FlyAsh gives better strength. The gain in Strength of metakaolin concrete with age is normal compared to that of ordinary concrete. Metakaolin and FlyAsh help concrete in having better sulphate resistance.

i. Metakaolin and Fly Ash can be recommended as a useful replacement to enhance the durability of concrete in an aggressive environment consisting of sulphates.

ii. Cement replacement up to 10% with metakaolin and Fly Ash leads to an increase in compressive strength, for the M60 grade ofconcrete.After10%thereisadecreasein compressive strength for 30, 90 & 120 days in both the Acid and Base curing period. The maximum replacement level of metakaolin is 10% and Fly Ash is 10% for M60-grade concrete.

iii. The optimum replacement level of OPC by MK was 10 %, which gave the highest compressive strength in comparison to that of other replacement levels; this was due to the dilution effect of partial cement replacement.

iv. As far as the durability properties are concerned, local MK and FA were found to reduce water permeability, absorption, and chloride permeability as the replacement percentage increases. This may be due to the filler effect of MK and FA particles which has substantially reduced the permeability or porosity of the concrete.

v. Consistency of concrete was decreased with the increase in Metakaolin and FA without affecting the compaction of concrete. Metakaolin and FA act as accelerating admixture in promoting cement hydration in concrete. Relatively finer and highly pozzolanic metakaolin as a partial replacement of cement produces pore structure modification and reduces porosity and pore size refinement in the hardening pastes and concretes.

vi. Metakaolin and Fly Ash contribute through the filler effect and act as an accelerating admixture to enhance cement hydration at early ages. At later ages, through pozzolanic reactivity, Metakaolin and Flyash contribute to the improvement in the properties of hardened concrete. Partial cement replacement with Metakaolin significantly increases the compressive strength and the degree of strength enhancement increases with the increase of Metakaolin content and w/c ratio. It was generally found to reduce with the increase of age.

vii. While chloride permeability, resistance to ASR, and sulfate attack are reduced in Metakaolin concrete, the carbonation depth is increased. 10% of MK and 10% of FA by replacement of cement is sufficient to control ASR-related expansion and sulphate attack.

Declaration of Conflicting Interests

The authors declare no potential conflicts of interest with respect to the research, authorship and publication of this article.

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