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Experimental Investigation of the Mechanical Properties of Blended Concrete Incorporating Metakaolin, Fly Ash, And Rice Husk Ash as Partial Cement Replacements: A Strategy for Sustainable Technology

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KEYWORDS

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Blending,
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Mechanical properties,
Compressive Strength

ABSTRACT:

Introduction: Concrete is a crucial and extensively utilized material in the construction industry. The utilization of SCMs has garnered significant interest due to their capacity to tackle sustainability and environmental issues.

Objectives: The purpose of this work is to provide a description of an experimental study that was carried out in order to analyse the mechanical properties of binder concrete that was produced using a mixture of three distinct blending materials for M25 grade and a composition of 0.45 water to binder.

Methods: There were a total of 39 combinations that were produced, and each of them contained varying amounts of Metakaolin (6%, 7%, and 8%), Fly Ash (5%, 10%, and 15%), and Rice Husk Ash (5%, 10%, 15%, and 20%).

Results: The workability of ternary blended concrete mixes fluctuates based on the proportion of Rice Husk Ash, which ranges from 5% to 20%. The control mix attained a maximum slump of 188 mm; however, the slump continually diminishes with increasing percentage replacement. The slump achieved for the optimal replacement percentage was 108 mm, which was satisfactory and somewhat beyond the necessary range. The maximum blending level of 28 percent (8% MK, 10% FA, and 10% RHA) yielded ideal strength parameter values. The compressive strength values recorded after 7, 28, and 56 days of replacement were 30.8 MPa, 38.9 MPa, and 42.6 MPa, respectively. The flexural strength was measured at 15 MPa, whereas the split tensile strength was recorded at 2.5 MPa.

Conclusions: The test results demonstrated a significant improvement in the mechanical properties of blended concrete relative to the control mix.

1. Introduction

Cement is a fundamental component in any engineering construction endeavours that utilise concrete. The worldwide production of concrete has experienced significant expansion since 1990. Concrete is a crucial material that is extensively manufactured globally (Huntzinger & Eatmon, 2009). Cement manufacture causes considerable environmental contamination through the emission of carbon dioxide (Aiswarya et al., 2013). Sharma & Khan (2016) assert that the transportation of each tonne of cement generates approximately 1 tonne of carbon dioxide emissions. Moreover, the cement sector constitutes around 5% of global industrial energy use. The expense of cement production is escalating rapidly, but the natural resources utilised as raw components for its manufacture are diminishing (Sundar & Manivel, 2015). The concrete sector is a major contributor to CO2 emissions. It originates from the calcination of limestone and the combustion of fuels in a kiln. Worrell et al. (2001) assessed that roughly 50% of CO2 emissions originate from fuel combustion, whereas the remaining 50% arise

from the decarbonisation of raw materials. The production of cement generates significant greenhouse gas emissions, contributing to global warming. Cement manufacture is an energy-intensive process that emits greenhouse gases, adversely affecting the environment (Sundar & Manivel, 2015).

Comprehensive research has definitively demonstrated that the optimal solution to the challenges of reinforced concrete durability is the use of finely divided siliceous materials into the concrete mix. This method is both technically robust and economically beneficial. These supplemental cementing ingredients, including Fly Ash (FA), Ground Granulated Blast-Furnace Slag (GGBFS), Silica Fume (SF), Rice Husk Ash (RHA), Metakaolin (MK), Natural Pozzolans (NP), and Volcanic Ash (VA), are classified as either pozzolanic or cementitious and pozzolanic substances. This renders them highly compatible for usage with Portland Cement (PC). Portland cement serves as the most efficient chemical activator for siliceous admixtures, enabling a durable and consistent interaction between PC, FA, GGBFS, and/or SF that remains intact without adverse effects (Lynsdale et al., 2000; Malolepszy et al., 2000). The combination of PC, FA, MK, and SF will produce excellent concrete with intrinsic properties for extraordinary durability, resulting in considerable social benefits regarding resources, energy, and the environment. This amalgamation represents the sole feasible route to attaining sustainable growth.

The incorporation of industrial by-products, including Fly Ash, Metakaolin, and Silica Fume, into concrete significantly enhances its essential properties in both fresh and hardened states (Lynsdale et al., 2000; Malolepszy et al., 2000). These substances not only enhance the flow properties and prevent the segregation of fresh concrete but also substantially improve its durability by controlling heat distribution, refining pore structure, minimising alkali content from cement, safeguarding against chloride and sulphate ingress, and facilitating continuous microstructural development through prolonged hydration and pozzolanic reactions (Menendez et al., 2003; Malhotra, 1986; Sivasundaram et al., 2004). Chemical binding in concrete can efficiently encapsulate harmful materials included in industrial waste, ensuring a secure containment environment. Moreover, mineral admixtures in concrete have demonstrated efficacy in alleviating durability problems associated with delayed ettringite and thaumasite development.

Supplementary cementitious materials (SCMs) can originate from natural sources, such as pozzolana, limestone, and metakaolin, or from industrial by-products, including fly ash, slag, silica fume, and rice husk ash. Menendez et al. (2003); Malhotra (1986); Sivasundaram et al. (2004). Binary cements, including Portland slag cement, pozzolanic cements, and limestone-Portland cements, are standardised in accordance with rules such as ASTM C 595, EN 197, and BS 146. Furthermore, the benefits derived from the incorporation of active supplementary cementitious materials and fillers in Portland cement have been thoroughly shown (Malhotra, 1986; Jones et al., 1997).

However, employing a singular supplementary cementitious material (SCM) to improve a certain durability attribute of concrete is constrained by distinct restrictions, contingent upon the SCM utilised. The limitations encompass diminished strength at an initial phase, extended curing duration, heightened reliance on admixtures, an elevated incidence of plastic shrinkage cracking, and vulnerability to freeze/thaw scaling upon exposure to deicer salts (Menendez et al., 2003; Sivasundaram et al., 2004). Utilising a singular supply chain management approach to address a certain durability concern may result in a failure in another dimension. The substitution threshold of a single SCM necessary to prevent Alkali Silica Reaction (ASR) expansion may introduce other issues or concerns. To ensure adequate protection against ASR, it is essential to incorporate a minimum of 50% slag or above 20% fly ash. Nonetheless, this may lead to diminished resistance to deicer salt scaling, as shown by Hogan (1985), Thomas & Establishment (1996), and Mehta (1989). or diminished early-stage strength.

A further example of material incompatibility arises when silica fume is incorporated in quantities beyond 10% of the cement's mass. These replacement levels are crucial to inhibit ASR expansion, as articulated by Thomas & Bleszynski (2000) and Boddy et al. (2000). Nonetheless, they frequently lead to complications regarding the workability of fresh concrete and difficulties in the efficient dispersion of silica fume, as emphasised by Hooton et al. (1998).

Moreover, binary cements often present additional disadvantages, such as the necessity for extended moist curing, increased dependence on chemical admixtures, diminished early-age strength, greater vulnerability to cracking from drying shrinkage, and problems with scaling due to de-icing salts. Consequently, it is essential to investigate if multi-component (ternary or quaternary) cements might be improved through synergistic effects, wherein the components collaborate to mitigate their respective shortcomings. An efficient strategy is to employ a high-performance multi-blended cement concrete that integrates moderate quantities (15 to 35%) of fly ash or natural pozzolana, in conjunction with a reduced level (<7% by mass) of silica fume. Furthermore, any industrial waste materials (15 to 20%) including Bag House Dust (BHD), Cement Kiln Dust (CKD), Clay, Limestone Powder (LSP), and Pulverised Steel Slag (PSS) may be used. Ternary blends facilitate the use of one supplemental cementitious material (SCM) to compensate for the intrinsic shortcomings of another SCM. These particular materials are acknowledged for their outstanding attributes regarding freshness and mechanical performance. The suitability of mixtures depends on specific performance standards, curing conditions, environmental exposure, material accessibility, and economical manufacture.

The present study offers a succinct summary of the effects of different additives, including Metakaolin, Fly Ash, and Rice Husk Ash. The research will focus on optimising the ratio of each aforementioned waste resource when integrated to produce high-quality concrete. Numerous studies have been undertaken to assess the effects of various industrial waste materials, including Metakaolin (Sabir et al., 2001; Murali & Sruthee, 2012), Fly ash (Patil et al., 2012; Atadero et al., 2009; Kiran & Ratnam, 2014), and rice husk ash (Kishore et al., 2011; Habeeb & Mahmud, 2010; Chandraul et al., 2015; Krishna et al., 2016), utilised as a singular blending material. Nadeem et al. (2008) employed a binary mix of Metakaolin and fly ash as substitute materials in their study. The study aimed to investigate the effect of these materials on the durability of high-strength concrete. Bai & Gailius (2009), and Torgal et al. (2011) sought to assess the effects of its use when replaced at designated ratios. Kannan & Ganesan (2012) investigated the effects of employing rice husk ash, metakaolin, and their mixtures as alternative blending materials in cement. Katroliya & Tiwari (2013) recorded the use of fly ash and rice husk ash in assessing the compressive strength of the resultant concrete.

Patel & Sheth (2014) and Manju & Premalatha (2016) investigated the influence of pozzolanic binders and filler materials on the characteristics of self-compacting concrete, with particular emphasis on binary, ternary, and quaternary interactions. Nonetheless, there is a dearth of study in the literature examining the ternary or quaternary mixing of waste materials, particularly fly ash, Metakaolin, and Rice Husk Ash.

2. Materials and methods

2.1 Materials

2.1.1 Cement

A cement of the OPC 43 grade was used, and it was manufactured in accordance with the Indian specification IS: 8112 – 1989. Cement possesses the following physical qualities, which are as follows: 2.74% is the fineness modulus, 29% is the normal consistency, 3.15 is the specific gravity, 90 minutes is the first setting time, and 220 minutes is the ultimate setting time. Furthermore, the initial setting time is 90 minutes. At three days, 28 days, and 56 days, the compressive strength was measured to be 32.5 MPa, 42.5 MPa, and 56.5 MPa, respectively. These values were determined by laboratory testing. The chemical parameters of OPC, which include the Lime saturation factor, the ratio of alumina to iron oxide, the insoluble residue, the magnesium oxide, the loss on ignition, and the total chloride, have the following values: 0.85, 1.13%, 1.69%, 3.02%, 2.43%, and 0.018% correspondingly.

2.1.2 Aggregate

By adhering to the grading standards of Zone II, which are defined in IS: 383 – 1970, the fine aggregate that was utilised in this experimental study was obtained from river sand that was collected from our immediate vicinity. For the purpose of determining the fineness modulus, specific gravity, and water absorption of the fine aggregate, a sieve examination was carried out. As a result, the following findings were obtained: According to the measurements, the fineness modulus was 2.75, the specific gravity was 2.62, and the water absorption was 1.3%. In an alternative method, crushed stone with dimensions of 20 mm and 12.5 mm was utilised. In terms

of fineness modulus, specific gravity, and water absorption, the coarse aggregate with a diameter of 20 millimetres had values of 8.22%, 2.63, and 0.42%, respectively. Similarly, the values for the coarse aggregate with a size of 12.5 millimetres were 7.7%, 2.73, and 0.54% correspondingly.

2.1.3 Water used and Super plasticizer

The FOSROC brand's Auramix 400, which is a water-reducing admixture with a great range of effectiveness, was utilised in the experimental study. In accordance with the specifications IS: 9103–1999 (2007) and ASTM C494 type G, this product is in compliance. Auramix 400 is a unique combination of cutting-edge super plasticisers that was created by utilising a poly-carboxylic ether polymer that possesses elongated lateral chains. The production of concrete that possesses extraordinary performance and good workability is made possible by the use of Auramix 400. A consistent dosage of 0.8% (by weight of cement) was added to the concrete in order to increase its workability. This was done before the concrete was used. For both the casting and curing processes of all of the concrete specimens, potable water was utilised. Regarding the design of the concrete mix, a water-to-cement ratio (w/c) of 0.45 is utilised.

2.1.5 *Mineral Admixtures*

Metakaolin (MK), Fly Ash (FA), and Rice Husk Ash (RHA) were the three different admixtures that were utilised for the purpose of this experimental study. This article provides an overview of the physical and chemical features of these admixtures, which may be found in Tables 1 and 2.

Table 1 Physical Property of Mineral Admixtures

Physical Properties	Metakaolin	Fly Ash	Rice Husk Ash
Physical State	Micronized Powder	Powder form	Powder
Odour	Odourless	Odourless	Odourless
Appearance	White Colour Powder	Grey White Powder	Grey/off white Powder
Colour	White	Grey	Off white
Pack Density	0.5 gm/cc	0.9 gm/cc	9.94 gm/cc
Bulk Density (Loose)	-	-	0.37 gm/cc
PH of 5% Solution	-	-	7.3
Specific Gravity	2.64	2.10	2.26
Water Absorption	66.80 ml/100 gm	58.60 ml/100 gm	0.12%
Oil Absorption	64 ml/100 gm	-	97.70%

Table 2 Chemical Properties of Mineral Admixtures

Chemical Properties	Metakaolin	Fly Ash	Rice Husk Ash
Silica (SiO_2)	52.86%	58.72%	88.90%
Alumina (Al_2O_3)	44.10%	42.25%	2.60%
Ferric Oxide (Fe_2O_3)	0.45%	4.6%	2.23%
Titanium Oxide (TiO_2)	0.36%	0.56%	-
Calcium Oxide (CaO)	0.28%	0.38%	0.21%
Magnesium Oxide (MgO)	0.21%	0.20%	-
Pottasium Oxide (K_2O)	0.20%	0.45%	0.33

Sodium Oxide (Na_2O)	0.25%	0.35%	0.36
Loss on Ignition	0.85%	3.2%	4.03%

2.2 Methods

The concrete mixtures were designed with the absolute volume approach for M25 grade concrete, as outlined in IS: 10262 - 2009. The materials were allocated according to their weight. All concrete mixtures were formulated with cementitious materials with a density of 350 kg/m^3, a water to cementitious materials ratio of 0.45, and a coarse to total aggregate ratio of 0.60. The objective was to attain the requisite workability by establishing a superplasticizer dosage that allows a slump value variation within the range of 100 ± 25 mm. The control mix, consisting solely of Ordinary Portland Cement (OPC), is designated as M0. The comprehensive combinations of ternary blended concrete mixtures have been categorised into three classifications: (i) Group - I: The specimens in this category were formulated by substituting 6-41% of the cement with 6% Metakaolin, 5-15% Fly Ash, and 5-20% Rice Husk Ash. The specimens are designated as M1 through M13. (ii) Group - II: The specimens in this category were created by substituting 7-42% of the cement with 7% Metakaolin, 5-15% Fly Ash, and 5-20% Rice Husk Ash. The specimens are designated as M14 to M26. (iii) Group - III: The specimens in this category were formulated by substituting 8-43% of the cement with 8% Metakaolin, 5-15% Fly Ash, and 5-20% Rice Husk Ash. The specimens are designated as M27 through M39. The volume of one batch, comprising 9 cubes, 3 cylinders, and 1 beam, was determined to be 0.044 m^3, factoring in a wastage of 20%. Table 3 enumerates the quantities of various elements for distinct mixtures.

Table 3 Quantities of several ingredients for different mixes per unit volume (kg/m^3)

Mix [M]	**Materials (kg)**				**FA (kg)**	**CA (kg)**	
	OPC	**MK**	**FA**	**RHA**		**12.5 mm**	**20 mm**
M0	350	0	0	0	771.31	481.81	687.33
M1	329	21	0	0	769.94	480.95	686.11
M2	294	21	17.5	17.5	764.68	477.67	681.43
M3	276.5	21	17.5	35	762.35	476.21	679.35
M4	259	21	17.5	52.5	760.02	474.76	677.27
M5	241.5	21	17.5	70	757.68	473.30	675.19
M6	276.5	21	35	17.5	761.76	475.85	678.82
M7	259	21	35	35	759.43	474.39	676.74
M8	241.5	21	35	52.5	757.09	472.93	674.66
M9	224	21	35	70	754.76	471.47	672.59
M10	259	21	52.5	17.5	758.84	474.02	676.22
M11	241.5	21	52.5	35	756.51	472.56	674.14
M12	224	21	52.5	52.5	754.17	471.11	672.06
M13	206.5	21	52.5	70	751.84	469.65	669.98
M14	325.5	24.5	0	0	769.71	480.81	685.91
M15	290.5	24.5	17.5	17.5	764.46	477.53	681.22

M16	273	24.5	17.5	35	762.12	476.07	679.14
M17	255.5	24.5	17.5	52.5	759.79	474.61	677.06
M18	238	24.5	17.5	70	757.45	473.15	674.99
M19	273	24.5	35	17.5	761.53	475.70	678.62
M20	255.5	24.5	35	35	759.20	474.25	676.54
M21	238	24.5	35	52.5	756.87	472.79	674.46
M22	220.5	24.5	35	70	754.53	471.33	672.38
M23	255.5	24.5	52.5	17.5	758.61	473.88	676.02
M24	238	24.5	52.5	35	756.28	472.42	673.94
M25	220.5	24.5	52.5	52.5	753.94	470.96	671.86
M26	203	24.5	52.5	70	751.61	469.50	669.78
M27	322	28	0	0	769.48	480.67	685.70
M28	287	28	17.5	17.5	764.23	477.39	681.02
M29	269.5	28	17.5	35	761.89	475.93	678.94
M30	252	28	17.5	52.5	759.56	474.47	676.86
M31	234.5	28	17.5	70	757.23	473.01	674.78
M32	269.5	28	35	17.5	761.30	475.56	678.42
M33	252	28	35	35	758.97	474.10	676.34
M34	234.5	28	35	52.5	756.64	472.64	674.26
M35	217	28	35	70	754.30	471.19	672.18
M36	252	28	52.5	17.5	758.38	437.37	675.81
M37	234.5	28	52.5	35	756.05	472.28	673.73
M38	217	28	52.5	52.5	753.72	470.82	671.65
M39	199.5	28	52.5	70	751.38	469.36	669.57
Note: Quantity of super plasticizer was calculated as 2.8 kg/m^3 for all mixes							

3. Testing of Concrete Specimens

The workability of concrete denotes its capacity for efficient mixing, placement, consolidation, and finishing. The quality of freshly mixed concrete significantly influences its ease and homogeneity during these operations. The workability of concrete was evaluated utilising a slump cone measuring 100×200×300 mm, in compliance with the IS: 1199-1959 standard. The slump test is performed between batches to evaluate the uniform quality of concrete throughout the construction process.

The compressive strength of a material denotes the greatest force it can endure prior to complete failure. The compressive strength was calculated by dividing the failure force by the cross-sectional area that bore the load. The compressive strength of 150 mm cube specimens was assessed in accordance with IS:516 – 1959 via a digital compression testing machine after 7, 28, and 56 days of curing.

The split tensile strength of (75 × 150) mm cylinder specimens was measured in accordance with IS:516 – 1959. The split tensile strength was determined by applying the formula $T = 2 \times P/(\pi \times D \times L)$.

However, the flexural strength was assessed using beam specimens of 100×100×500 mm, in accordance with IS:516 – 1959, which is commonly referred to as four-point loading. The flexure strength was determined by applying the formula $F_b = PL/bd^2$, where F_b represents the flexure strength, P is the applied load, L is the length, b is the width, and d is the thickness of the material. This calculation was used because the shear span (a) is less than 110 mm.

5. Results and discussion

5.1 Fresh properties of concrete

The workability of concrete is generally employed to assess its fresh characteristics. Four categories have been established based on the workability findings of the concrete. (i) Group-I: ternary blended concrete produced by replacing 6-8% of the cement with Metakaolin (MK), i.e. (ii) Group-II: ternary mixed concrete incorporating 6% Metakaolin (MK), 5–15% Fly Ash (FA), and 5-20% Rice Husk Ash (RHA) as substitutes for cement in M1, M14, and M27. M2-M13; (iii) Group-III: ternary mixed concrete using 7% Metakaolin (MK), 5–15% Fly Ash (FA), and 5–20% Rice Husk Ash (RHA) as substitutes for 17–42% of the cement content in the mixture. Combine 15–26 (M15–M26); (iv) Group IV: ternary mixed concrete produced by replacing 8% Metakaolin (MK), 5–15% Fly Ash (FA), and 5–20% Rice Husk Ash (RHA) for 18–43% of cement, corresponding to grades M28–M39. The optimal depiction of these configurations, illustrating diverse category outcomes, is located in Figures 1 to 4.

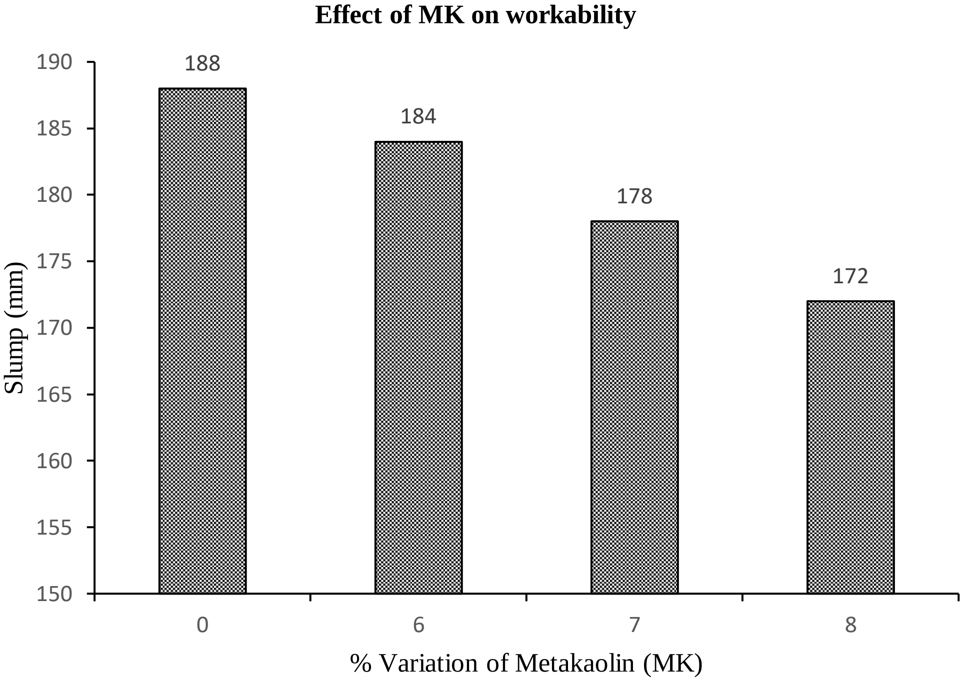

Fig. 1 Workability of Group I ternary blended concrete specimens using 6-8% MK

Analysis of Fig. 1 reveals that the incorporation of MK into regular cement concrete led to a reduction in workability. Nonetheless, the incorporation of differing quantities of MK in the concrete production process has led to a notable decrease in workability. The control mixture demonstrates a greater slump value than all other mixtures

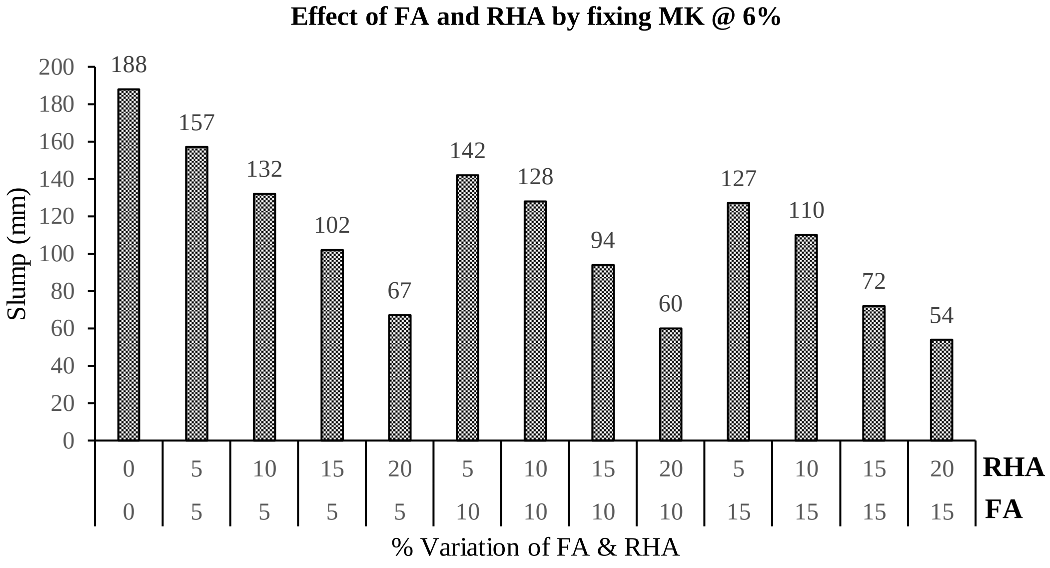

Fig. 2 Workability of Group II ternary blended concrete specimens

Continuing with Fig. 2 for Group II ternary blended concrete mixtures, the MK content is set at 6%, while the proportions of other waste components remain same (i.e., 5-15% FA and 5-20% RHA). The workability of the mixture demonstrated a steady decrease as the replacement ratio rose, irrespective of other mixtures. The control mixture demonstrates a greater slump value than all other mixtures.

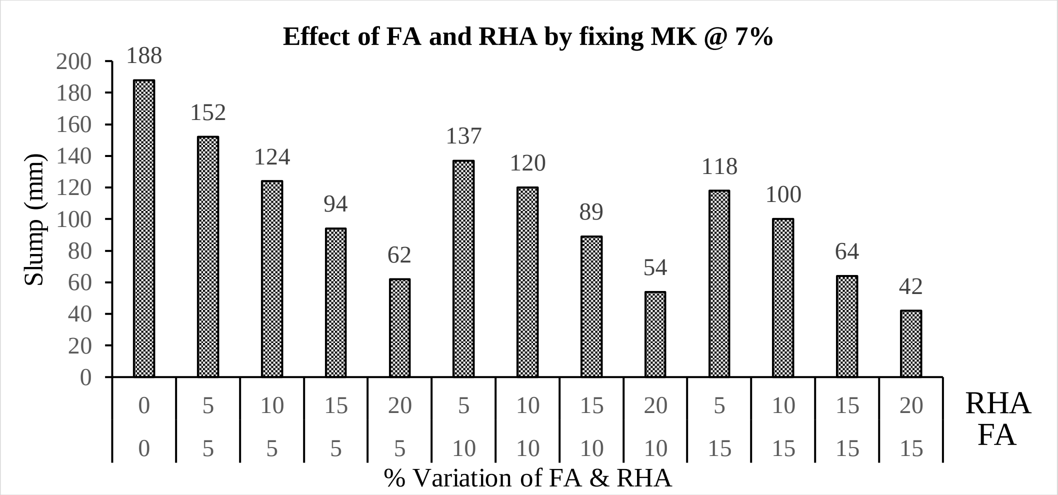

Fig. 3 Slump variation of Group III ternary blended concrete mixes

Likewise, Figure 3 pertains to Group III. The ternary blended concrete mixes are formulated by modifying the MK content to 7%, while preserving the same proportions of other waste constituents as in prior instances (i.e., 5-15% FA and 5-20% RHA). The workability of the mixture demonstrated a decreasing trend as the replacement percentage rose, irrespective of other mixtures. The control mixture demonstrates a greater slump value than all other mixtures.

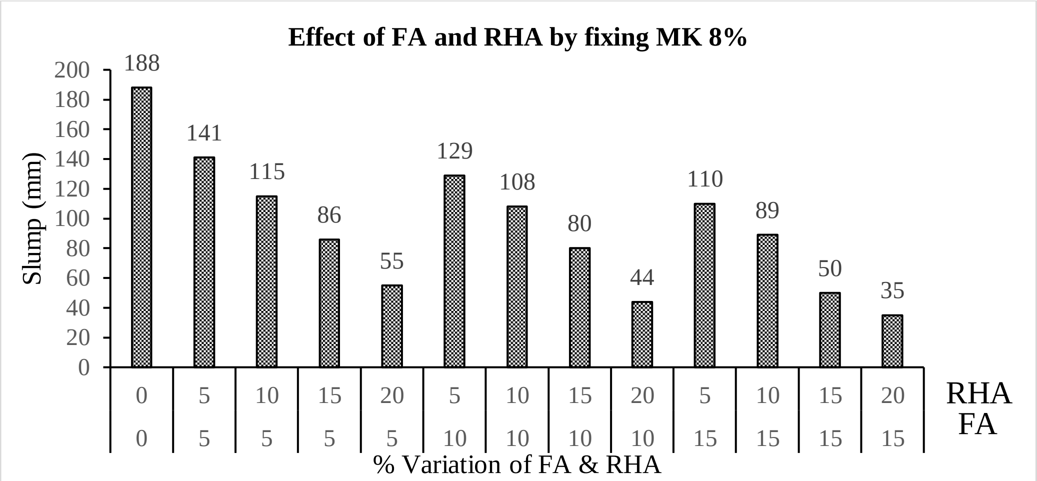

Fig. 4 Slump variation of Group IV ternary blended concrete mixes

Figure 4 illustrates the outcomes of Group IV ternary blended concrete mixtures, whereby the MK content is set at 8%, but the proportions of the other waste constituents remain constant with prior situations (i.e., 5-15% FA and 5-20% RHA). The workability of the mixture demonstrated a decreasing trend as the replacement percentage rose, irrespective of other mix variables. The control mix demonstrates a greater slump value relative to the other mixes.

5.2 Mechanical strength of concrete

5.2.1 Compressive Strength

The average compressive strength of concrete specimens, assessed after 7, 28, and 56 days of water curing, is presented. The outcomes have been classified into three separate categories: Group-I comprises ternary mixed concrete specimens in which 6-41% of the cement is substituted with 6% Metakaolin (MK), 5-15% Fly Ash (FA), and 5-20% Rice Husk Ash (RHA). The specimens are designated as M1 through M13. Group-II comprises ternary blended concrete specimens in which 7-42% of the cement is substituted with 7% metakaolin, 5-15% fly ash, and 5-20% rice husk ash. The specimens are designated as M14-M26. Group-III comprises ternary blended concrete specimens in which 8-43% of the cement is substituted with 8% metakaolin, 5-15% fly ash, and 5-20% rice husk ash. The specimens are designated as M27-M39. Each category has been further broken into many forms to demonstrate the trend behaviour of RHA, while maintaining the content of MK and FA constant. Figure 6 offers the most precise depiction of standard values for compressive strength.

The advancement of compressive strength in Group-I ternary blended concrete specimens, which incorporate a specific percentage of cement substituted with 6% MK, 5% FA, and 5-20% RHA, alongside a control mix, is illustrated in Fig. 5. The compressive strength shown a positive connection with the duration across all mixes. Figure 5 illustrates that the incorporation of MK in ordinary cement concrete led to a reduction in compressive strength. After 56 days of curing, the compressive strength was recorded at 35.32 MPa when ordinary concrete was combined with 6% MK. Comparable decreases in compressive strength were noted in other mixes where cement was substituted. Nonetheless, when concrete is formulated by incorporating varying proportions of RHA with a constant composition of 6% MK and 5% FA, a notable enhancement in compressive strength has been recorded for a 10% RHA mixture (M3) after 7, 28, and 56 days of curing. This enhancement in strength parallels that seen when using 6% MK only (i.e., M1). The optimal replacement ratio for Group-I concrete specimens was established as 6% MK + 10% FA + 10% RHA, referred to as M7.

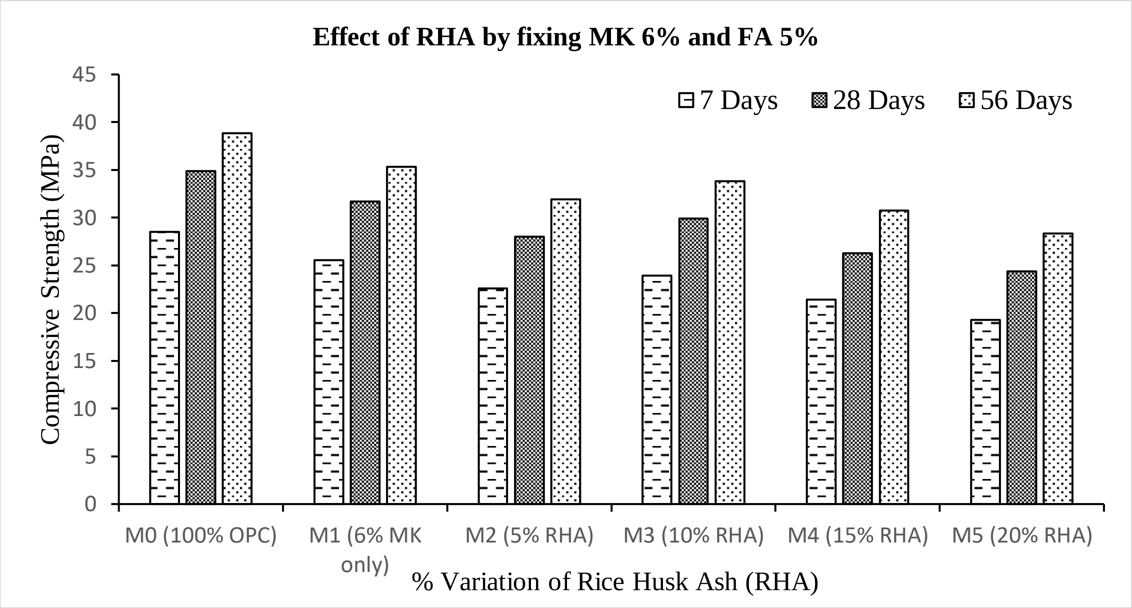

Fig. 5 Typical results for Compressive strength of Group-I ternary blended concrete mixes

On the other hand, the results for the development of compressive strength in Group-II ternary blended concrete mixes are given in Figure 6. These mixes contain a certain percentage of cement that is replaced with 7% Metakaolin (MK), 5% Fly Ash (FA), and 5-20% Rice Husk Ash (RHA), in addition to one control mix. All of the combinations showed a positive association between the compressive strength and the amount of time that had passed within the mixture. The increase in compressive strength that occurred as a consequence of the incorporation of MK into plain cement concrete is demonstrated by the data that is presented in Figure 6. For instance, the compressive strength values were recorded as 27.76, 33.84, and 38.43 MPa respectively after 7, 28, and 56 days of curing when the plain concrete was mixed with 7% MK entirely. These values were reported after the concrete had been cured for 7, 28, and 56 days. Furthermore, when the concrete is created with the presence of 7% MK, along with 5% FA and 5-10% RHA, the strength of the concrete is shown to decrease in comparison to the control mix. This is observed in other mixes, including M15-M18. When the concrete is formed by combining different amounts of RHA with a fixed content of 7% MK and 5% FA, however, a considerable improvement in compressive strength has been reported for the concrete with 10% RHA (M16) after 7, 28, and 56 days of curing. This was noticed after the concrete had been cured for 7, 28, and 56 days. This pattern is comparable to what was seen in the concrete that was mixed with only 7% MK according to the M14 formula. It was discovered that the appropriate replacement percentage for Group-II concrete specimens is 7% MK plus 10% FA plus 10% RHA, which is equivalent to the M20 mix.

The compressive strength progression of Group-III ternary blended concrete specimens, comprising 8% cement substitution with MK, 5% with FA, and 5-20% with RHA, alongside a control mix, is illustrated in Fig. 7. The compressive strength shown a positive connection with the duration across all mixes. Observations from Figure 7 indicate that the incorporation of MK into plain cement concrete improves its compressive strength. Curing the concrete for 7, 28, and 56 days yields compressive strength values of 30.18, 37.24, and 41.76 MPa, respectively, when mixed with 8% MK alone. A significant improvement in compressive strength at 7-, 28-, and 56-days post-curing is observed with an increase in MK content to 8%. Additionally, a reduction in strength, akin to the control mix, is noted in other mixes (namely M28-M31) when the concrete is produced with 8% MK alongside 5% FA and 5-10% RHA. Nevertheless, when concrete is produced by combining different proportions of RHA with a constant composition of 8% MK and 5% FA, a notable enhancement in compressive strength has been recorded for the concrete containing 10% RHA blending (M29) after 7, 28, and 56 days of curing. The compressive strength of the Group-III ternary blended concrete specimens was very low; nevertheless, notable strength development occurred after 56 days of curing. The optimal replacement proportion for Group-III concrete specimens, as well as throughout all 39 combinations, was established as 8% MK + 10% FA + 10% RHA, corresponding to the M33 mix.

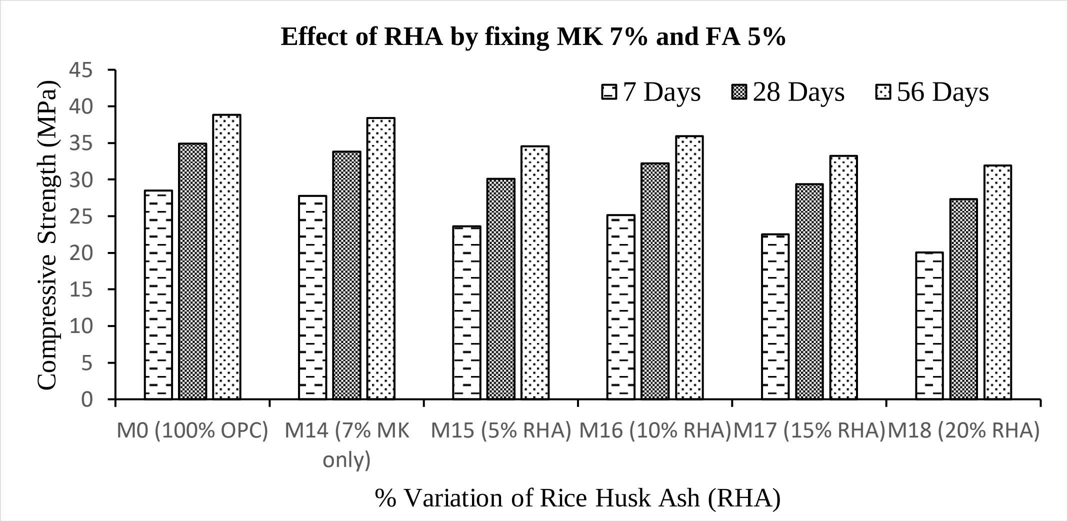

Fig. 6 Typical results for Compressive strength of Group-II ternary blended concrete mixes

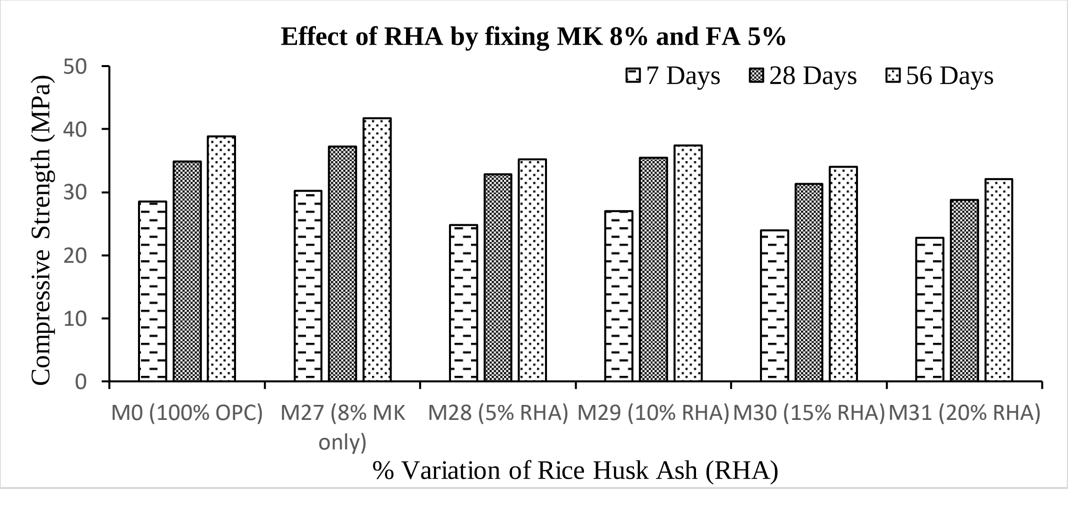

Fig. 7 Typical results for Compressive strength of Group-III ternary blended concrete mixes

5.1.1 Flexure Strength

The mean flexural strength of concrete specimens, assessed following 28 days of water curing, is documented. Figure 8 demonstrates the particular effect of Metakaolin on flexural strength. According to the data illustrated in Fig. 8, the incorporation of MK into plain cement concrete led to a reduction in flexural strength. After 28 days of cure, the flexural strength of ordinary concrete incorporating 6% MK was recorded at 12.75 MPa. The use of varying quantities of MK throughout the concrete mixing process has led to a notable enhancement in flexural strength. A blend containing 8% MK (designated as M27) has demonstrated a significant enhancement in flexural strength following 28 days of curing.

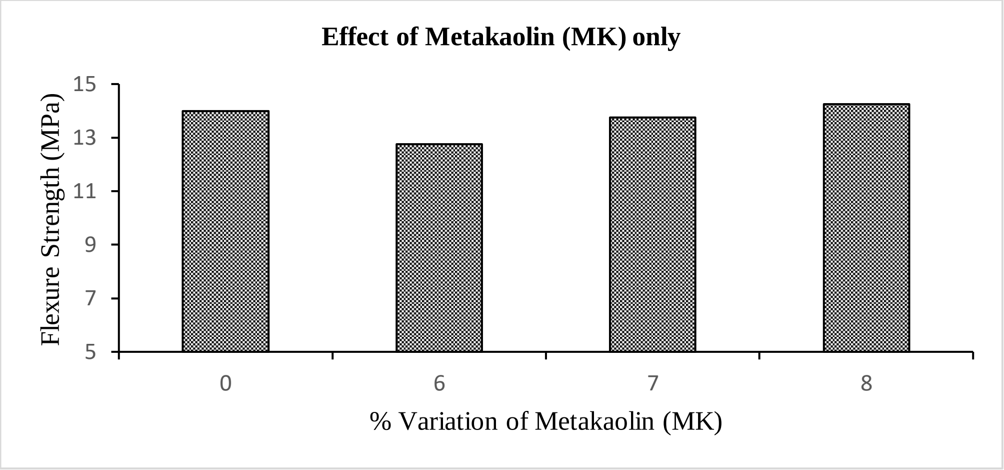

Fig. 8 Flexure strength of ternary blended concrete mixes using 6-8% MK only

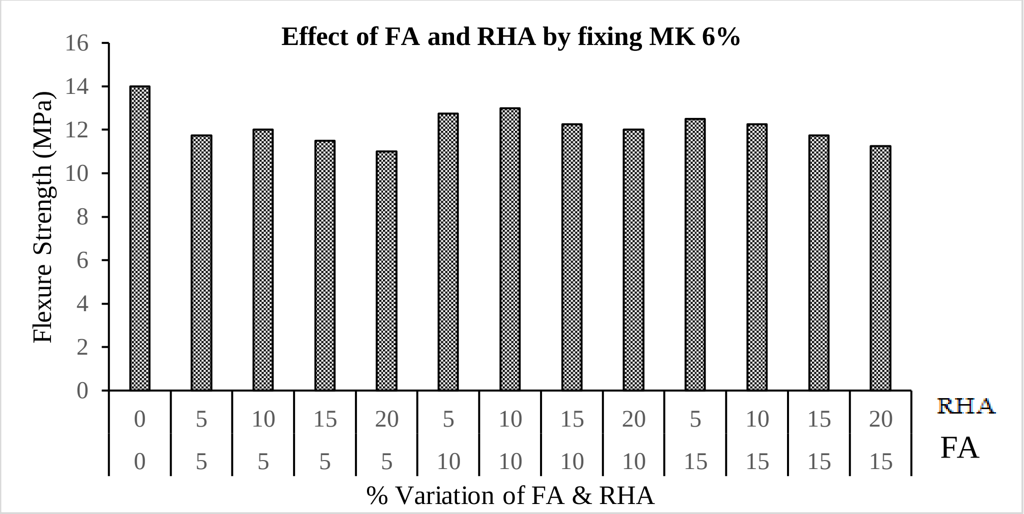

Fig. 9 Typical results for flexure strength of ternary blended concrete mixes at 28 days curing

The evolution of flexural strength in ternary blended concrete mixes, with 6% MK, 5-15% FA, and 5-20% RHA replacing cement, is illustrated in Fig. 9. The quantity is ten. As per the illustration. It has been noted that the incorporation of varying percentages of RHA, with a constant 6% MK and 5% FA, results in a considerable enhancement in flexural strength when 10% RHA is utilised (M3) after 28 days of curing. This rise parallels the trend noted when combining alone with 6% MK. Further investigation indicates similar variations for 10% and 15% FA, alongside a range of 5-20% RHA and 6% MK.

Figure 9 indicates that the mixture including 74% OPC, 6% MK, 10% FA, and 10% RHA (designated as M7) exhibits a marginally reduced flexural strength relative to the control mixture (M0) following 28 days of curing. Moreover, the predominance of FA's behaviour is evident in the M6-M9 mixture, especially in contrast to the M2-M5 mixture, particularly with the addition of 10% FA. The ideal blending combination that produces

the maximum flexural strength for all mixes is identified as 8% MK + 10% FA + 10% RHA (designated M33) for ternary blending, and 8% MK (designated M27) for single blending.

5.1.1 *Split Tensile Strength*

The average split tensile strength of concrete specimens, assessed following 28 days of water curing, is documented. Figure 10 demonstrates the distinct effect of Metakaolin on split tensile strength. According to the data illustrated in Fig. 10, the incorporation of MK in plain cement concrete initially leads to a declining trend. At a subsequent stage, particularly when 8% of MK is utilised as a substitution, the split tensile strength value exhibits a slight increase relative to the control mix. Research indicates that the incorporation of varying percentages of MK into concrete results in a notable enhancement in split tensile strength when 8% MS is blended (designated as M27) and cured for 28 days

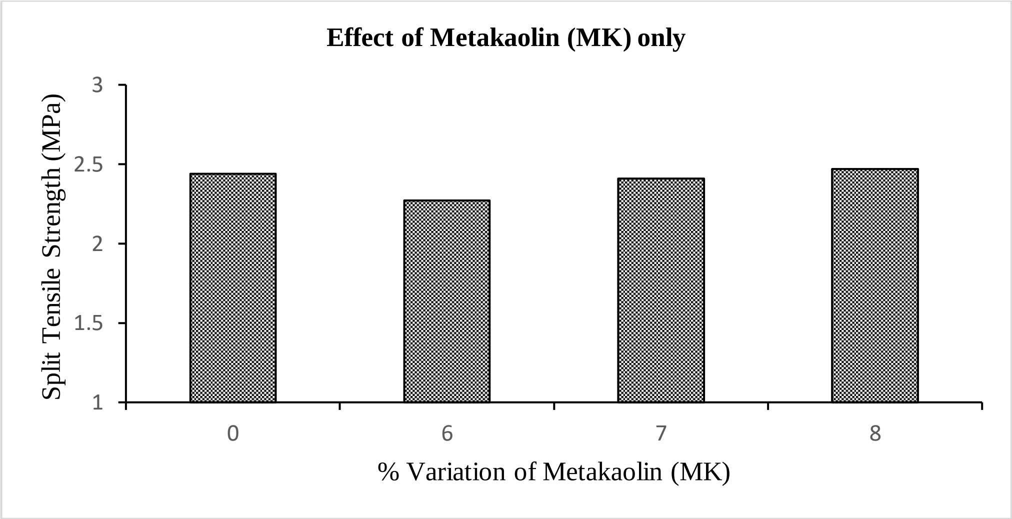

Fig. 10 Split tensile strength of ternary blended concrete mixes using 6-8% MK only

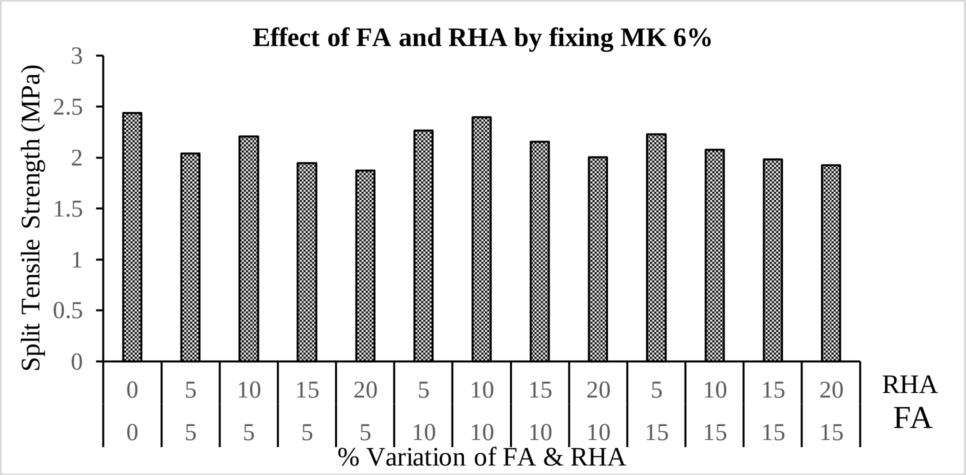

Fig. 11 Typical results for split tensile strength of ternary blended concrete mixes at 28 days curing

Figure 11 depicts the typical results of split tensile strength development in ternary blended concrete mixtures, whereby a certain amount of cement is substituted with 6% MK, 5-15% FA, and 5-20% RHA,

in addition to one control mixture. The results in Fig. 11 clearly indicate that the split tensile strength of concrete markedly improves with varying quantities of RHA combined with a constant content of 6% MK and 5% FA. A significant increase in split tensile strength is observed when 10% RHA is incorporated (designated as M3) and the concrete is cured for 28 days. Further investigation indicates similar variations for 10% and 15% FA about the range of 5-20% RHA and 6% MK. The impact of FA is more significant in mixtures M6-M9 than in mixtures M2-M5, especially when FA is incorporated at a 10% level.

Figure 11 indicates that the values of M10 exceed those of other mixtures (M11, M12, and M13), although remain inferior to the control mix and the combinations utilised for M6-M9. Figure 11 illustrates that the strength values enhance when the FA concentration rises from 5% to 10%. Nonetheless, the tendency shifts in M10-M13 when the FA fraction is elevated from 10% to 15%. The data unequivocally demonstrates that the optimal proportion of FA in these mixes is 10%. Fig. 11 demonstrates that the optimal result is attained by the use of a combination of all admixtures, namely 6% MK, 10% FA, and 10% RHA. Although the incorporation of MK in plain cement concrete led to a decrease in split tensile strength, the reduction was not significant. The ideal blending combination that produces the maximum split tensile strength across all combinations is identified as 8% MK + 10% FA + 10% RHA (designated M33) for ternary blending, and 8% MK (designated M27) for single blending.

6 Conclusion

This study investigated the effects of several pozzolanic elements on the properties of blended concrete in its fresh and hardened forms. The ternary blended concrete mixtures were prepared by substituting a proportion of Ordinary Portland Cement (OPC) with 6 to 8% Metakaolin (MK), 5 to 15% Fly Ash (FA), and 5 to 20% Rice Husk Ash (RHA). An innovative method was presented to assess the cumulative effect of MK, FA, and RHA on the development of compressive strength in concrete. This was accomplished by the utilisation of a ternary blending concrete method. This section presents a succinct summary of the conclusions drawn from this enquiry.

- The workability of ternary blended concrete mixes fluctuates based on the proportion of Rice Husk Ash (RHA), which ranges from 5-20%, while consistently including 6-8% Metakaolin (MK) and 5-15% Fly Ash (FA). An unfavourable correlation was seen between workability and the concurrent increase in the blending of FA and RHA. The control mix attained a maximum slump of 188 mm; however, the slump constantly diminishes with an increase in the amount of replacement. The slump achieved for the optimal replacement percentage was 108 mm, which was satisfactory and somewhat exceeded the specified range.
- The optimal strength parameters were achieved using a mixture of 8% MK, 10% FA, and 10% RHA. The inclusion of supplementary percentages produced advantageous results relative to the control combination. The compressive strength values recorded after 7, 28, and 56 days of replacement were 30.8 MPa, 38.9 MPa, and 42.6 MPa, respectively. The flexural strength was measured at 15 MPa, whereas the split tensile strength was recorded at 2.5 MPa.

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References

2. Huntzinger D.N., Eatmon T.D., 2009. A life-cycle assessment of Portland cement manufacturing: comparing the traditional process with alternative technologies. Journal of Cleaner Production 17, 668-675.
3. Aiswarya S., Arulraj G.P., Dilip C., 2013. A Review on use of Metakaolin in Concrete. Engineering Science and Technology: An

International Journal (ESTIJ) 3, 592-597 0–1416.

4. Sundar J., Manivel S., 2015. A Study on Mechanical Properties of Concrete with Multi-Component Composite Cement. International Conference on Engineering Trends and Science & Humanities (ICETSH) 22-25.
5. Sharma R., Rizwan A., Khan., 2016. Effect of Different Supplementary Cementitious Materials on Mechanical and Durability Properties of Concrete. Journal of Materials and Engineering Structures 129-147.
6. Lynsdale C.J., Khan M.I., 2000. Chloride and oxygen permeability of concrete incorporating fly ash and silica fume in ternary systems. In: Malhotra VM, editor. CANMET/ACI. International conference on durability of concrete, 5th, Barcelona. Proceedings. Detroit: American Concrete Institute. 739–53 [SP 192–45].
7. Małolepszy J., Pytel Z., 2000. Effect of Metakaolinite on Strength and Chemical Resistance of Cement Mortars, CANMET/ACI 2000, Fifth International Conference Durability of Concrete, Barcelona, Spain, Vol. I, 192-204.
8. Menendez G.V., Bonavetti E.F., Irassar., 2003. Strength development of ternary blended cement with limestone filler and blast-furnace slag. Cement and Concrete Composites 25(1), 61-67.
9. Malhotra V.M.E., 1986. Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete. Proceedings 2nd International Conference, ACI SP 91.
10. Sivasundaram V., Bouzoubaa N., Bilodeau A., Fournier B., Golden D.M., 2004. Development of Ternary Blends for High-Performance Concrete. ACI Materials Journal 101,19-29.
11. Jones M.R., Dhir R.K., Magee B.J., 1997. Concrete containing ternary blended binders: Resistance to chloride ingress and carbonation. Cement and Concrete Research 27(6), 825-831.
12. Hogan F.J., 1985. The effect of blast furnace slag cement on alkali aggregate reactivity: A literature review. Cement, Concrete and Aggregates, CCAGDP (7)2, 100-107.
13. Thomas D.A., Establishment B.R., 1996. Review of the Effect of Fly Ash and Slag on Alkali-aggregate Reaction in Concrete. Building Research Establishment.
14. Mehta P.K., 1989. Pozzolanic and Cementitious Byproducts in Concrete- Another Look. ACI 1 (114), 1-43.
15. Thomas M.D.A., Bleszynski R.F., 2000. The use of silica fume to control expansion due to alkali-aggregate reactivity in concrete-a review. *Materials Science of Concrete* (Edited by Skalny and Mindess) Vol. 6, American Ceramic Society.
16. Boddy A.M., Hooton R.D., Thomas M.D.A., 2000. The effect of product form of silica fume on its ability to control alkali-silica reaction. Cement and Concrete Research (30), 1139-1150.
17. Hooton R.D., Bleszynski R.F., Boddy A., 1998. Issues related to silica fume dispersion in concrete, Materials Science of Concrete: The Sidney Diamond Symposium (Ed. M. Cohen, S. Mindess, J. Skalny) 435-446.
18. Sabir B.B., Wild S., Bai J., 2001. Metakaolin and calcined clay as pozzolans for concrete :a review. Cement and concrete composite 23, 441-454.
19. Murali G., Sruthee P., 2012. Experimental study of concrete with metakaolin as partial replacement of cement. International journal emerging trends in engineering and development 4(2), 344-348.
20. Kishore R., Bhikshma V., Prakash P.J., 2011. Study on strength characteristics of high strength rice husk ash concrete. Procedia Engineering 14, 2666-2672.
21. Chandraul K., Singh M.K., Saxena A.K., Arora T.R., 2015. Experimental study of RHA concrete. International Journal for Research in Applied Science & Engineering 3(2), 77-82.
22. Habeeb G.A., Mahmud H.B., 2010. Study on properties of rice husk ash and its use as cement replacement material. 13, 185-190.
23. Krishna N.K., Sandeep S., Mini K.M., 2016. Materials Science and Engineering. IOP conference series 1-11.

24. Nadeem A., Johnny Y.N., Mok S.A., Brian H.Y., Leung G.K.W., 2008. Comparison of chloride permeability of metakaolin and fly ash concretes and mortars under elevated temperatures. Singapore: 33rd Conference on our world in concrete & structures, Singapore.
25. Bai J., Gailius A., 2009. Consistency of fly ash and metakaolin concrete. Journal of civil engineering and management 15(2), 131-135.
26. Pacheco Torgal F., Shasavandi A., Jalali S., 2011. Using metakaolin to improve the compressive strength and the durability of fly ash based concrete. Morocco: International seminar, innovation & valorization in civil engineering & construction materials. 23-25.
27. Kannan V., Ganesan K., 2012. Strength and water absorption properties of ternary blended cement mortar using rice husk ash and metakaolin. Scholarly Journal of Engineering Research 1(4), 51-59.
28. Katroliya A., Tiwari A., 2013. The Effect of Rice Husk Ash and Fly Ash Used as Supplementary Cementing Material on Strength of Mortar and concrete. International Journal of Engineering Research & Technology 2, 1-12.
29. Patel J.D., Sheth A.J., 2014. High performance concrete using quaternary blended. International Journal of Innovative Research in Advanced Engineering 15, 133-137.
30. Manju R., Premalatha J., 2016. Binary, ternary and quaternary effect of pozzolanic binders and filler materials on the properties of self compacting concrete. International Journal of Advanced Engineering Technology 7(2), 674-683.