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Exploring the Use of Metakaolin and Portland Pozzolana Cement for Concrete Sustainability

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A current challenge for the concrete industry is to add admixtures to produce concrete with improved strength. With this view, the present study explores compressive strength (fck) and flexural strength (fcr) for M40 grade of concrete with partial replacement Portland Pozzolana Cement (PPC) with metakaolin (Mk) in the range of 4% to 24 % by the weight of cement by adding ViscoFlux-2230+ as a superplasticizer to make the concrete workable. It was observed that up to 16% addition of metakaolin increased compressive and flexural strength by 27% and 15.78% respectively compared to ordinary concrete at 28 days. Similarly, for 7 days compressive and flexural strength was increased nearly by 20% and 13% respectively and for 90 days, it was observed to be nearly 15% and 16% respectively. A relationship between the compressive strength (fck) and flexural strength (fcr) of Mk concrete is developed. The early age compressive strength development was greater practically in all Mk concrete. Indirectly increasing the rate of metakaolin can lower the regularized CO_2 emission and resource consumption. From the results, concrete may be recognized as sustainable concrete.

Keywords: Compressive strength, Flexural Strength, Mk Concrete, Sustainability

1 Introduction

Nowadays after water, concrete is widely used in the world. The main constituent of concrete is cement and the cement industry is the major source of emission of CO_2, (a potent greenhouse gas) into the environment, Cement is the most expensive and important substance in the manufacturing of concrete, and it is an environmentally unfriendly material. In the recent era, it needs to produce concrete that is sustainable, preserves the environment, lowers the greenhouse effects in construction, and modifies its properties. With this view, many researchers are working hard to reduce the quantity of cement used in concrete. Undoubtedly, concrete is the most widely used, easily workable construction material around the globe. It is a crucial component of many structures, bridges, highways, and dams. It can be used for sidewalks, curbs, pipes, and drains in addition to structural applications. Despite vast global production and consumption, there has been much debate concerning the possibility that concrete may be a significant source of greenhouse gas emissions. In view of the present climate situation and the phenomenon of global warming, a "green revolution," or the implementation and introduction of materials (eco-friendly), is urgently required in the building industry and other sectors. Due to high cost, environmental sustainability, and green energy conservation, material admixtures with various proportions of cement are in great demand along with the building industry's growth. As all climatic factors have adversely impacted sustainability over the past few decades, we need the next generation to stop dramatic changes in the use of natural resources early on. Due to the addition of pozzolanic ingredients such as rice husk ash (RHA), silica fume, pulverized granular blast furnace slag, fly ash and MK, the situation surrounding the usage of concrete has significantly changed (MK). In high-strength concrete, cement partially replaces these elements[1-5]. These pozzolanic materials improve the performance of concrete with the aid of interacting with Portland cement's hydration product to produce C-S-H gel, which is the primary cause of the growth in concrete strength[6-8] . Researchers have been interested in the advantages, support, and use of metakaolin as a partial alternative for cement in some cases over the last 20 years. Metakaolin is made by calcining refined kaolinitic or a lump of pure clay at temperatures ranging from 650 to 850 °C, which is then ground to a

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fineness between 700 and 900 m^2/kg. A micron-sized powdered particle with innocuous contaminants has been thoroughly eliminated. Many researchers claim that concrete containing metakaolin performs exceptionally well concerning its mechanical and durability properties[9-13]. This strategy is advantageous and environmentally favorable in lots of tactics like minimizing the percentage of intake of Portland cement that is answerable for CO_2 emission to the surroundings. This paper focused on the enhancement of compressive strength and flexural strength with MK concrete. This paper also emphasized the use of MK in different proportions in the concrete mix and investigated its effect on fck and fcr at different days of curing to make it more sustainable.

2. Materials and Methods

2.1. Materials

The materials Portland pozzolana cement through for PPC identification (IS 1489: 1991) [14], MK, sand, and aggregates were used. MK improving pozzolan quality in amorphous powder form supplied by, Gujarat Company, 20 Micron Ltd. Table 1 and Table 2 provide the specifications of Portland pozzolana cement and metakaolin, respectively.

Nearby stream sand meeting the prerequisites of IS 383(2016)[15] Zone II as per IS 2386-1963 (I, II, and III) is utilized as fine aggregate and crushed natural stone to 20 mm and 10 mm in neighborhood quarries[16] is utilized as coarse aggregate. Freshwater, free from acids and organic matter, adjusting to IS: 456-2000[17] utilized to blend concrete samples. IS: 9103-1999 principles were utilized to acquire the extra properties expected to project all samples of the blend. Water-deducting agent, ViscoFlux-2230+ with specific gravity 1.1was added as a super plasticizer to the casting of concrete.

2.1 Mix Proportions

According to IS: 10262-1999[18] and ACI Committee 544[19], the concrete grade M40 was calculated according to the given norms, the concrete mixture ratio with the required productivity was (1:1.73:3.22), the required W/C ratio was 0.38. The total amount of the binder is 400 kg/m3. By adjusting the amount of super plasticizer workable concrete mixtures were prepared by keeping the slump between 50 and 70 mm. Mk was replaced by 4,8, 12,16,20, and 24, % of the total binder weight for all mixes. Experimental samples of a cube with a compressive strength of 150x150x150 mm and a prism with a flexural strength of 100x100x500 mm were molded. After 1 day of curing, demolding and then curing in water for the period of 7, 28, and 90 days. All samples were tested for compressive and flexural strength according to standards [20-21].

3 Results and Discussion

3.1 Setting time of cement

The time required for setting the cement was 130 minutes for the initial set and 315 minutes for the final set.

3.2 Workability of concrete

By adjusting the amount of superplasticizer, the slump value was between 50 and 70 mm for all concrete mixtures.

Table 1 — Standard specification of PPC

Sr. No.	Contents	Requirements as per IA 1489 (Part I): 1991	Results
1 Chemical composition			
1	Magnesia %	Not more than 6.0 %	1.1
2	Insoluble Residue %	[X+4.0 (100-X)/100] Max. (X is % Pozzolana in PPC)	27.0
3	Sulphur Calculated As SO3 %	Not more than 3.0 %	2.3
4	Loss On Ignition %	Not more than 5.0 %	2.0
5	Chloride %	–	0.022
2 Physical properties			
1	Fineness (m^3/Kg)	Not less than 300	369
2	Initial setting time (minutes)	Not more than 30	130
3	Final setting time (minutes)	Not more than 600	315
4	soundness	Not more than 10 mm	0.5
5	Drying shrinkage	Not more than 0.15 %	0.04

Table 2 — Chemical and physical characteristics of metakaolin (MK))

Sr. No.	Oxides	Metakaolin (% by mass)
I Chemical composition		
1	SiO_2	53
2	Al_2O_3	43
3	Fe_2O_3	1.2
4	CaO	0.5
5	Na_2O	0.12
6	MgO	0.4
7	K_2O	0.53
8	L.O.I.	0.4
9	TiO_2	2.27
II Physical properties		
1	Surface area (m^2/kg)	18,000
2	Specific gravity	2.6

3.3 Effect of Metakaolin on Compressive Strength cube specimen

Figure 1 depicts the compressive strength variation on concrete with varying percentages of in MPa for cube specimen testing in the laboratory with respect to curing age. Considerable enhancement in the percentage of compressive strength in concrete was observed in the range of 13% to 27% at 4%, 8%, 12%, and 16% MK replacement levels. The concrete showed significant improvement in the compressive strength at 16% MK replacement level at all ages of concrete curing. From the observations, the compressive strength with 16 % Mk at 28 days curing and 90 days curing was 52.4Mpa and 56.18Mpa respectively. This indicated that compressive strength increased marginally with the increasing days of curing.

Beyond 16% MK replacement, the compressive strength decreased. From the observations, it was revealed that 16% MK replacement is the optimum percentage that gave maximum Compressive Strength. In this investigation, the replacement level of 20 % and 24% were included best to look at the trend of the behaviour after the 16% stage. From the observations, it was revealed that when 4%, 8%, 12%, and 16% cement is replaced with metakaolin, the compressive strength of the cube increases by up to 27% when compared with normal concrete. It was found that the percentage gain in strength is more at the early age of concrete. The compressive strength at 16 % replacement of cement with MK was found to be 52.5MPa and 56.18MPa at 28 and 90 days respectively

3.4 Effect of MK on FS beam specimen

The flexural strength test was conducted on specific prismatic beam specimens under two-point loading over an effective span of 400 mm as per the IS 516:1959. The results of the effects of MK (different percentages) on average fcr are shown in Fig. 2.

The above Figure shows the average flexural strength of concrete with various percentages of MK at 7 days, 28 days, and 90 day age of curing and gives higher results at a 16% replacement level at all the ages of concrete. The improvement is about 16 % at 90 days compared to the flexural strength of cement concrete without metakaolin.

3.5 Compressive strength and flexural strength relationship

The graphical relation between the cube compressive strength v/s flexural strength of the beam (Figure 3) and their predicted mathematical model is shown in Table 3. Its coefficient value is found above 90% which was observed to be in a good linear relationship.

Taking into consideration the correlation between the fck and fcr values of all concrete mixtures, Figure 3 plots the fck and fcr of all concrete mixtures with a curing age of 7 days to 90 days. Table 3 displays the ultimate relationship between these two parameters. In line with the correlation coefficient (R^2), the relationship between fck and fcr values is linear.

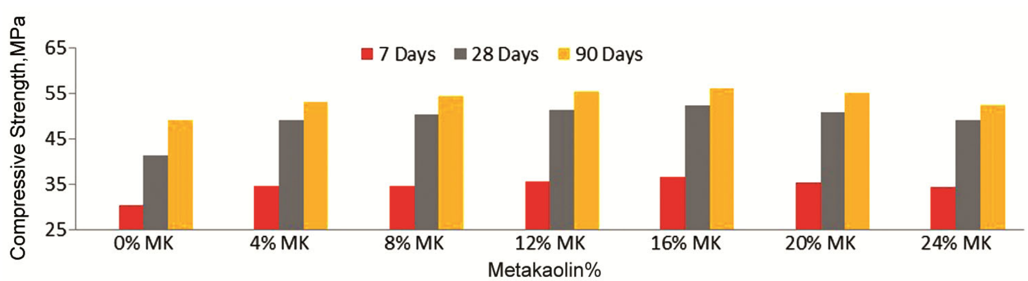

Fig. 1 — Compressive strength variation of concrete with Metakaolin percentage.

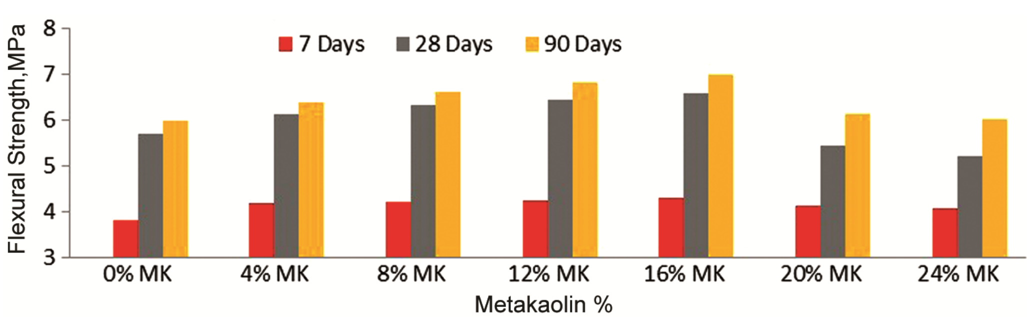

Fig. 2 — Average flexural strength of concrete with different percentages of MK.

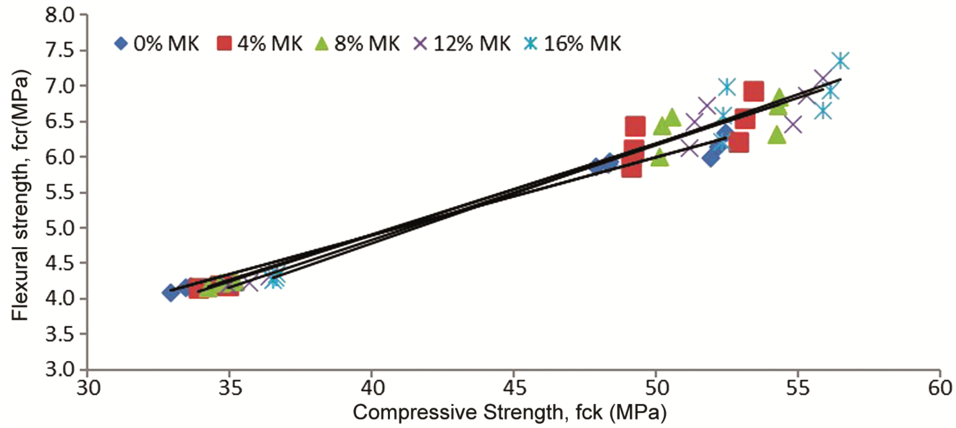

Fig. 3 — Relationship between compressive Strength and Flexural Strength of Concrete with MK replacement.

Table 3 — Model describing the link between the cube's compressive strength and the beam's flexural strength

Metakaolin %	Mathematical Model	
	Equation	R^2 Value
4	fcr = 0.129fck - 0.284	R^2 = 0.961
8	fcr = 0.127fck - 0.186	R^2 = 0.965
12	fcr = 0.133fck - 0.500	R^2 = 0.973
16	fcr = 0.139fck - 0.809	R^2 = 0.960

For individual models with partial cement replacement by MK at 4%, 8%, 12%, and 16%, a Direct relationship was also observed with the correlation portions 0.961, 0.965, 0.973, 0.987, and 0.960 independently.

4 Conclusion

Following are the conclusions based on the results.

- Using MK in place of cement improved the concrete's mechanical qualities. The addition of MK over standard concrete was a promise of an increase. In present study the result revealed that compressive and flexural strength increased by 27% and 15.78% when MK was 16% compared to ordinary concrete at 28 days.
- Similarly compressive and flexural strength increased nearly by 20% and 13% respectively for 7 days. For 90 days it was observed that compressive and flexural strength increased nearly by 15% and 16% respectively.
- A relationship between the compressive strength (fck) and flexural strength (fcr) of Mk concrete is developed for MK variation 4% to 16%. The most often required compressive strength can be calculated by the model for various percentages of MK concrete.
- The high fineness of MK created a significant demand for water. A superplasticizer was utilized to provide the requisite workability.

From the present study, concrete may be recognized as sustainable concrete.

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