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Elimination of Greenhouse Gas Emissions by Utilization of Industrial Wastes in High Strength Concrete for Environmental Protection

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ABSTRACT

Greenhouse gases prevalence in the atmosphere is a primary reason for global warming. The cement manufacturing sectors are a significant producer of greenhouse gases, contributing one metric tonne of carbon dioxide into the environment for every metric tonne of cement produced. The heat of concrete is increased by several degrees during the pozzolanic reaction, and CO_2 is released. The development of binary and ternary cementitious systems has minimized the unfavorable reactions of conventional cementitious materials. Metakaolin and alccofine, two mineral admixtures derived as waste products from industries, were used as cement substitutes in this study. The compressive strength of alccofine was compared to a metakaolin-based high strength eco-friendly concrete mix of grade M50 in an experimental investigation. In the case of binary and ternary blended cementitious systems with alccofine and metakaolin, twelve alternative mix proportions were tested, ranging from 0 to 20% in 5% increments. Based on the observed mechanical characteristics of concrete, it was discovered that the optimum replacement of alccofine was 15% and metakaolin was 5% by volume of cement in the binary cementitious system. Similarly, in the ternary cementitious system, replacing 15% alccofine with 5% metakaolin in the cement mixture results in the greatest increase in compressive strength when compared to the other experiments. As a result, it is concluded that using extra cementitious materials in concrete with mineral admixtures such as alccofine and metakaolin results in significant cost and energy savings, as well as a notable reduction in environmental pollution.

INTRODUCTION

Concrete materials are used in the construction of community infrastructure. Because of the nature of concrete, cement is the only reactive component that blends and holds the materials together. When it comes to concrete's load-bearing capacity, the aggregates, which account for 75% to 80% of the entire concrete volume, carry the weight of the applied load. Due to numerous factors such as high strength, long-term strength, greater durability, economic, and environmental reasons, HSC has been more popular in recent decades all over the world, and has played an essential role in the construction of special structures and large infrastructures (Umamaheswaran et al. 2015, Suchithra & Malathy 2016). To address environmental challenges, the cement industry is working on a more sustainable method of production. The fact is that cost and intensive energy are not the only issues, the generation of large amounts of greenhouse gases that have a negative impact on the environment has now become the primary problem in the manufacturing of Portland cement. Several methods, replacements, and supplements were experimented with reducing the usage of Portland cement (Ushaa et al. 2015, Kothai & Malathy 2015). The use of mineral additives has been proven to improve the strength and durability of concrete. The use of supplementary cementitious materials in concrete with mineral admixtures such as alccofine and metakaolin results in significant cost and energy savings, as well as a notable reduction in environmental pollutants (Naik & Moriconi 2005, Chan et al. 2006, Kumar et al. 2016, Thangaraj & Thenmozhi 2013).

Metakaolin is a clay-based mineral with outstanding qualities for treating amorphous alumino-silicate, which makes concrete more responsive. Alccofine is a mineral additive that can be manufactured to the suitable fineness to get the desired characteristic in the concrete in which it is employed. Mineral admixtures such as metakaolin and alccofine, in addition to this approach, can be employed in the HSC to produce better compressive strength (Jaydeep et al. 2016, Saha et al. 2014, Annadurai & Ravichandran 2014, Raju et al. 2017).

Experimentally, replacing part of the cement in the concrete mix with varying percentages of fly-ash and metakaolin resulted in a significant reduction in the cost of the concrete and the eradication of green gas emissions (Lakshmi et al. 2016, Satyendra et al. 2015, Malagavelli et al. 2018, Surendra & Rajendra 2016).

Experimentations were performed with various percentages of metakaolin replaced with cement in M30 concrete and it was observed that the split-tensile, compressive strength, and flexural strength were optimal at 15% replacement. As a result of the findings encouraging the use of metakaolin, it can be used in large-scale buildings to offset the environmental and economic costs of traditional cement manufacturing and use (John 2013, Rao & Kumar 2016). When metakaolin was added, the workability was diminished, but this was corrected with the application of a superplasticizer (Narmatha & Felixkala 2016, Jagtap et al. 2017, Hemanth et al. 2017).

When cement is replaced with various percentages of metakaolin in an M30 concrete, the basic characteristics of the concrete are found to be highest at 15%, indicating that metakaolin can be used as a dependable pozzolanic material substitute for cement in high strength concrete. As a result, this new cementitious/pozzolanic substance will provide a solution to the environmental issues created by conventional cement consumption and production (Sood et al. 2014, Philip & Neeraja 2015, Chowdhury & Saha 2016).

Acid resistance, sulfate attack, and chloride attack tests were used to investigate the durability characteristics of alccofine in concrete (Gayathri et al. 2018). The researchers found that replacing 15% of the alccofine with 15% boosted the concrete's resistance to acid attacks. Similarly, the mechanical characteristic of alccofine has been studied by Kaviya et al. (2017). They concluded that cement is replaced by 15% alccofine, which increases compressive strength (Suganya & Lathamaheswari 2019). Cement replaced partially with alccofine reduces water demand for the same workability by developing a dense pore structure and thus helps to attain higher strength (Hermawana et al. 2015, Ansari et al. 2015, Puti et al. 2015).

A high-strength concrete mix of grade M50 was cast and tested with 0, 5%, 10%, 15%, and 20% alccofine substituting cement and metakaolin in 5% increments. After 7, 14, and 28 days of moist curing, compression tests were performed.

The objective of this project is to determine the optimum replacement percentage of alccofine and metakaolin for cement in concrete and to analyze the mechanical characteristics of concrete added with alccofine and metakaolin by its compressive strength.

MATERIALS AND METHODS

Binder

In this study, in the course of experimental investigation, the binder material used in the concrete is 53-grade OPC (IS 12269:1987). Preliminary tests were conducted for the cement used for the study and the characteristics listed in Table 1.

Fine Aggregate

The study (Zone II) uses river sand as a fine aggregate, verifying IS:383:1970's specific gravity of 2.6. The physical qualities of the sand utilized in this investigation, as well as the characteristics, are given in Table 2, were analyzed.

Coarse Aggregate

The coarse aggregate utilized in the study is 20mm in size and has a specific gravity of 2.8, according to IS: 383:1970. The physical parameters of the coarse aggregate employed in this investigation, as well as the characteristics, are given in Table 3, were assessed.

Water

Potable tap water was used for the concrete preparation and curing operations.

Chemical Admixture

Master Gelenium SKY 8233, a superplasticizer based on a new generation modified polycarboxylate ether, was employed.

Metakaolin

It is a clay-based mineral with outstanding qualities for handling amorphous alumino-silicate, which makes it receptive

Table 1: Physical properties of cement (53 grade).

Characteristics	Experimental Values
Initial setting time	50 min
Final setting time	320 min
Specific gravity	3.15
Consistency	32%
Soundness	1.2 mm
Compressive strength (MPa)	29.8 at 3 days 45.6 at 7 days 56.2 at 28 days

Table 2: Physical properties of fine aggregate.

Physical properties	Experimental Values
Fineness modulus	2.82
Density	1635
Specific gravity	2.6

to concrete. The metakaolin will react with the concrete ingredient's calcium hydroxide (Dubey et al. 2015). Pozzolanic materials, like other traditional alternatives, hydrate during the process of hydration.

Alccofine

Alccofine 1203, an ultrafine low calcium silicate product with high reactivity made by a controlled granulation technique, was used in this study (Fig. 1). Tables 4 and 5 show the physical and chemical compositions of Alccofine 1203 and Metakaolin (MK).

MATERIALS AND METHODS

Mix Design for M50 Grade Concrete

Mix proportioning: M50 grade mix concrete was created to meet the requirements of IS 10262:2009 code provision. The best dose of chemical admixture to be utilized in concrete is found based on several trail mixes with varying percentages of chemical admixture by the weight of cementitious material of 0.25%, 0.5%, 0.75%, and 1%. Table 6 shows the mixed design proportion.

Mix preparation: In a dry environment, the OPC, alccofine, metakaolin, coarse aggregate, and fine aggregate were completely combined with power mixers for 30 seconds. Water and superplasticizer are added in quantities as per the design mix to make the concrete mixes after the dry ingredients have been blended. The binary and ternary blended systems of mineral admixtures are shown in Tables 7 and 8, respectively.

Table 3: Physical properties of coarse aggregate.

Physical properties	Experimental Values
Fineness modulus	1.9
Impact value	14.2
Specific gravity	2.8

Fig. 1: Alccofine-1203.

Casting and Curing of Moulds

108 binary and ternary cementitious (alccofine and metakaolin) concrete specimens were cast in form of standard concrete cubes as per IS456:2000 with the prepared concrete mix. The concrete cube specimens are cured for various periods such as of 7, 14, and 28 days in the ambient temperature of 27±2°C in the curing tank. Fig. 2 shows the evidence of concrete specimens cast and cured.

Workability

Workability is a term used in concrete technology to describe the properties of concrete that make it easier to place, compact, and finish. The Slump cone test is commonly used to determine the workability of fresh concrete. The slump

Table 4: Chemical and physical composition of alccofine 1203.

Chemical Properties		Physical Properties	
Existing Mineral	Composition [%]	Physical Possessions	Outcomes
SiO_2	35.30	Partial Size Distribution (in micro meter)	
MgO	6.20	D10	1.8
Al_2O_3	21.40	D50	4.4
Fe_2O_3	1.20	D90	8.9
SO_3	0.13	Specific Gravity	2.7
SO_2	23.46	Bulk Density [$kg.m^{-3}$]	680
CaO	33	Specific Surface Area [$cm^2.gm^{-1}$]	12000

Table 5: Chemical and physical composition of metakaolin.

Chemical Properties		Physical Properties	
Existing Mineral	Composition [%]	Physical Possessions	Outcomes
SiO_2	52.5	Residue on Sieve [%]	
MgO	0.25	90 µm	1.00
Al_2O_3	42.20	45 µm	12.80
Fe_2O_3	0.34	Loss on ignition	0.50
SO_3	0.01	Pozzolanic Activities based on CaO Absorption [$mg.g^{-1}$]	25
SO_2	63.48	Specific Gravity	2.65
CaO	0.30	Bulk Density [$kg.m^{-3}$]	350
Na_2O	0.10	Specific Surface Area [$cm^2.gm^{-1}$]	18000
$K_2O + Na_2O$	0.05	Insoluble residue [%] HCl/ Na_2CO_3	63.45

Fig. 2: Casting and curing of concrete specimen.

characteristics of various combinations of concrete mixes developed in this investigation are shown in Tables 8.

RESULTS AND DISCUSSION

Table 9 and Table 10 show the average compression strength of concrete cubes tested after curing for 7 days, 14 days, and 28 days.

Compressive Strength

The compressive strength test results of Alccofine and Metakaolin replaced the binary blended cementitious system shown in Table 9 and Fig. 3.

In a binary blended system, concrete with 5%, 10%, and 15% alccofine replacement (AF5MK0, AF10MK0, AF15MK0) had compressive strengths that were 1%, 2.3%, and 18.8% greater than the control mix (AF0MK0) after 28 days of compression testing. However, replacing 20% of the alccofine mix with AF20MK0 resulted in a 3.9% lower compressive strength than the control mix (AF0MK0).

Similarly, metakaolin specimens with 5% metakaolin replacement (AF0MK5) had 19.8% better compressive strength than the control mix after 28 days of compression testing (AF0MK0). However, 10%, 15%, and 20% metakaolin replacement (AF0MK10, AF0MK15, AF0MK20), respectively, resulted in 12.3 percent, 20.9%, and 31.5% lower compressive strength than the control mix (AF0MK0).

At 28 days, concrete with 5% AF and 15% MK, and 10% of both AF and MK replacement (AF5MK15 & AF10MK10)

Table 6: Concrete mix proportion.

Mix Proportion for M-50 Grade of Concrete	
Materials	Target compressive strength [Mpa] 50
W/C ratio	0.35
Total Cement Content [kg.m^{-3}]	435
Fine Aggregate [kg.m^{-3}]	742
Coarse Aggregate [kg.m^{-3}]	1113
Water [kg.m^{-3}]	152
Mineral Admixture [kg.m^{-3}] Percentage of replacement of cementitious content – Binary blended system	5% - 20%
Mineral Admixture [kg.m^{-3}] Percentage of replacement of cementitious content – Ternary blended system	20%
Superplasticizer [kg.m^{-3}] By the weight of cementitious content in the concrete mix	0.25%

Table 7: Percentage of alccofine (AF) and metakaolin (MK), binary blended system.

Specimen Mix ID	Blending Material	Water Content [kg.m^{-3}]	Cement Content [kg.m^{-3}]	Workability [mm]
AF0MK0	Only OPC	152	435	74
AF5MK0	OPC + 5%AF	152	413.25	68
AF10MK0	OPC + 10%AF	152	391.50	75
AF15MK0	OPC + 15%AF	152	369.75	90
AF20MK0	OPC + 20%AF	152	348	110
AF0MK5	OPC + 5%MK	152	413.25	88
AF0MK10	OPC + 10% MK	152	391.50	65
AF0MK15	OPC + 15% MK	152	369.75	62
AF0MK20	OPC + 20% MK	152	348	60

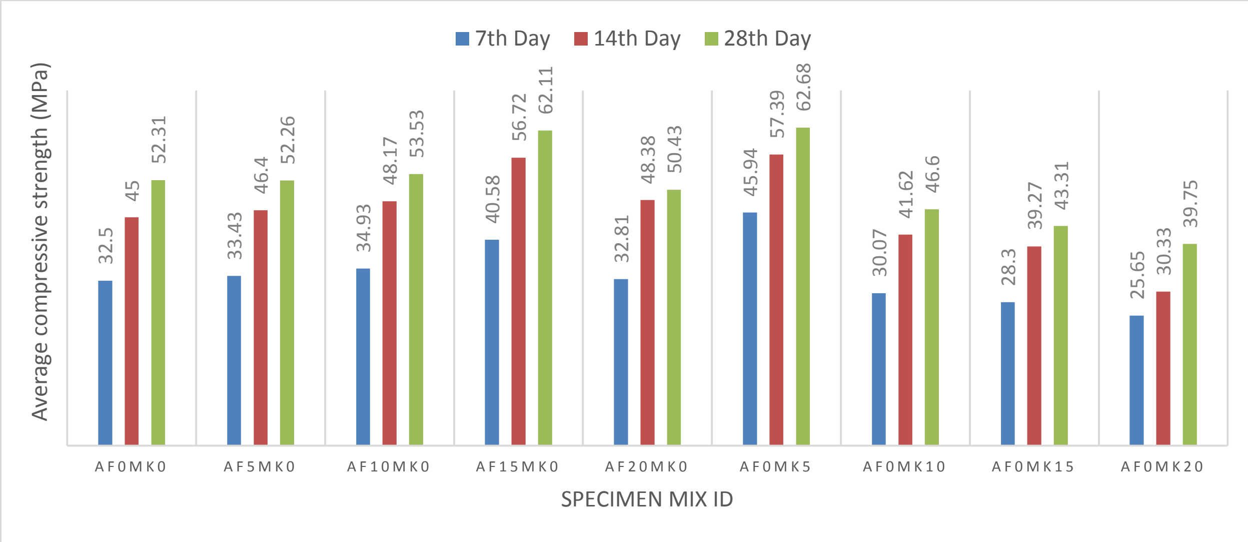

Fig 3: Comparison of compressive strength with binary blended system.

Table 8: Percentage of alccofine (AF) and metakaolin (MK), ternary blended system.

Mix ID	Blending Material	Water Content [$kg.m^{-3}$]	Cement Content [$kg.m^{-3}$]	Workability [mm]
AF5MK15	OPC + 5%AF+ 15% MK	152	391.50	90
AF10MK10	OPC + 10%AF+ 10%MK	152	348	88
AF15MK5	OPC + 15%AF+ 5%MK	152	304.50	70

Table 9: Compressive strength of binary blended system.

Specimen Mix ID	Average Compressive Strength [Mpa]			Percentage of variation in compressive strength when compared with control mix at 28 days.
	7^{th} Day	14^{th} Day	28^{th} Day	
AF0MK0	32.50	45.00	52.31	-
AF5MK0	33.43	46.40	52.78	+1%
AF10MK0	34.93	48.17	53.53	+ 2.3
AF15MK0	40.58	56.72	62.11	+18.8
AF20MK0	32.81	48.38	50.43	-3.9
AF0MK5	45.94	57.39	62.68	+19.8
AF0MK10	30.07	41.62	46.60	-12.3
AF0MK15	28.30	39.27	43.31	-20.9
AF0MK20	25.65	30.33	39.75	-31.5

had 14.8 percent and 7.9 percent lower compressive strength than the control mix in a ternary blended system (AF0MK0). However, concrete containing 15% AF and 5% MK (AF-15MK5) had a 3 percent better compressive strength than the control mix (AF0MK0). The compressive strength test findings of Alccofine and Metakaolin were used to replace the ternary blended cementitious system presented in Table 10 and Fig. 4 in the ternary blended system.

CONCLUSION

The results of an experimental investigation of alccofine with metakaolin mineral admixture in binary and ternary blended cementitious systems. According to a compressive strength investigation, the optimum percentage of cement by alccofine and metakaolin was 15% and 5% by volume, respectively. Similarly, the replacement of 15% alccofine and 5% metakaolin in the ternary blended system resulted in the

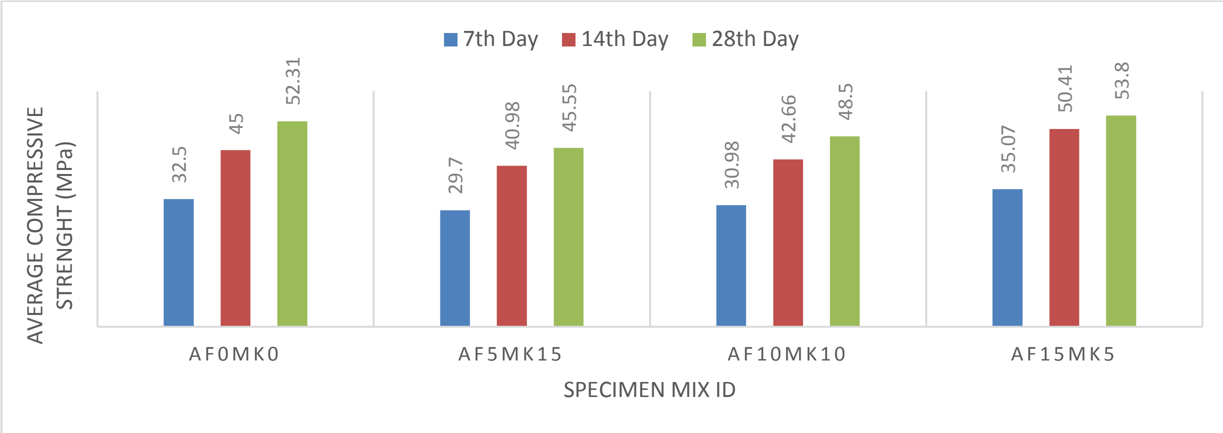

Fig 4: Comparison of Compressive strength with Ternary Blended System.

Table 10: Compressive strength of ternary blended system.

Specimen Mix ID	Average Compressive Strength (MPa)			Percentage of variation in compressive strength when compared with control mix at 28 days.
	7th Day	14th Day	28th Day	
AF0MK0	32.50	45.00	52.31	
AF5MK15	29.70	40.98	45.55	-14.8%
AF10MK10	30.98	42.66	48.50	-7.9%
AF15MK5	35.07	50.41	53.80	+ 3%

best compressive strength compared to all other combinations in the ternary blended system.

Metakaolin, a highly pozzolanic material with micro-filler properties, and alccofine, a higher specific surface area material with early strength acquiring properties, are combined to improve workability strength and chemical attack resistance by reducing porosity through C-S-H gel production.

Because the findings support the use of alccofine and metakaolin in large-scale buildings, they can be used to offset the environmental and economic costs of traditional cement manufacture and use. Finally, the binary and ternary blended systems led to significant concrete cost reductions and greenhouse gas emissions elimination.

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