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TECHNICAL NOTE

Effect of Alccofine on Mechanical and Durability Index Properties of Green Concrete

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ABSTRACT

In the modern era, many research works are being carried out throughout the world for finding out a suitable cementitious material for the replacement of cement. The supplementary cementitious materials (SCM) can be used as a replacement of cement in the construction industry to minimize the carbon dioxide emission which is implicated in global warming and climatic changes in the environment. This paper presents the mechanical and durability index properties for M30 grade normal concrete (NM) and green concrete (GC). From the experimental results, it was clearly observed that the use of alccofine has resulted in attainment of higher strengths at early ages in concrete. Green concrete mix with 20% alccofine replacement of cement has achieved higher mechanical and durability index properties as compared to all other mixes. Response surface methodology was adopted to optimize the experimental data set in which regression equation was developed by relating response variable to input variable. This method helped to predict the experimental values within an acceptable error range. The predicted values were cross validated by employing coefficient of determination (R^2) and residual sum of squares (RSS) which showed a good fit.

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1. INTRODUCTION

Nowadays cement has become a dominant raw material in the manufacture of concrete [1]. The demand for cement is increasing worldwide with a consumption rate of nearly 4.3 billion tonnes per year. For the production of cement, a large amount of energy is consumed and it is one of the largest sources of CO_2 gas emission [2]. About 13500 million tonnes of CO_2 gas is released during the production of cement [3]. Therefore, researchers are interested in finding an alternative cementitious materials which can give better performance in all aspects such as fresh and hardened state properties along with durability properties in order to minimize the use of cement in concrete. According to available literature, the replacement of cement by industrial by-products which possess pozzolanic nature such as fly ash (FA), Metakaoline (MK), granulated blast furnace slag (GGBS), rice-husk ash (RHS), mine waste (MW), silica-fume (SF), red mud (RM) etc., have shown improved strength than the conventional concrete in terms of fresh, mechanical and durability properties [4]. Recently some of the researchers have reported that the microfine material namely Alccofine (ALC), obtained as a by-product from iron ore industry in India also possess pozzolanic nature, can be used as a partial replacement of cement in concrete [5]. By using alccofine as an admixture a significant improvement in workability and mechanical properties of concrete was observed [6,7]. Due to the ultrafine particle size, alccofine significantly improves the micro pore filling ability and create resistance to segregation which helps in enhancing fresh, mechanical and durability properties of concrete. It is much economical than all other micro pozzolanic materials like SF, MK. However, very little work has been reported on the use of ALC in concrete and mortars [8]. Mohan and. Mini [9] conducted experimental research on replacement of cement with GGBS and Alccofine to enhance the rheological and mechanical properties of self-compacting concrete. They have observed strength enhancements at 40% replacement (30% GGBS & 10% Alccofine) of cement and the optimum strength values in compressive, splitting tensile and flexural strengths were 42.3, 7.9 and 8.3MPa,

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respectively. Ansari et al. [10] conducted research on the performance of concrete with partial replacement of cement with alccofine for M30 grade concrete. They observed improvement in the strength of concrete at 15% replacement of cement by alccofine. Upadhyay et al. [8] have worked on an experimental investigation on high-performance concrete with the replacement of sand by M-sand and partial replacement of cement by alccofine and fly ash for M60 grade of concrete. From the investigation, they observed that the strength improvement in concrete with alccofine is higher than that of fly ash. As of now researchers have replaced up to 15% of cement by Alccofine and with combination of fly ash (30%) in concrete.

2. PROBLEM DEFINITION

The Ordinary Portland Cement which is a major constituent of conventional concrete plays a significantly important role in attaining the strength properties. But nowadays cement has become a major source for pollution which has propelled the researchers to replace cement by some alternative pozzolanic materials which can provide the desired mechanical and durability properties to concrete as well as address the pollution menace. Previous researchers focused on the use of Fly Ash, Metakaolin and Nano silica in concrete mix to improve the properties of concrete. In the present study, an attempt has been made to study the effect of different pozzolanic material like Alccofine as partial replacement of cement on mechanical properties and durability index of concrete so that the scope to address environmental pollution can be explored.

3. OBJECTIVES

In the present paper, an investigation was carried out to develop a green concrete (GC) by replacing cement with various percentages of alccofine (10, 20, and 30%). The current study highlights the result outcomes of the mechanical and durability index tests performed on all concrete mixes. The paper moreover focuses on the effects of using of alccofine on initial stage strength and long-time properties of green concrete. Hence the efforts are to observe the improvement in green concrete and examine some of the mechanical and durability index properties which lead to a sustainable construction.

4. MATERIALS

4. 1. Cement Ordinary Portland Cement (OPC) of 43 grade was used for the preparation of various mixes [11] and it was tested as per Indian specification.

4. 2. Fine Aggregate Locally available river sand passing through 4.75 mm sieve with fineness modulus of 2.71%, falling under Grading Zone II conforming to BIS: 383 - 2016 was used as fine aggregate.

4. 3. Coarse Aggregate Locally available crushed rocks passing through 20 mm sieve conforming to BIS: 383 - 1970 was used as coarse aggregate.

4. 4. Alccofine Alccofine is a specially processed slag based secondary cementitious material with high glass content having higher reactivity and lower silicate content obtained from controlled granulation. ALC 1203 was acquired from Ambuja Cement Ltd, Goa conforming to ASTM C989 - 1999**.** Tables 1 and 2 show the properties of alccofine.

5. RESEARCH METHODOLOGY

5. 1. Mix Proportions In the present investigation, M30 grade concrete mix design was carried out according to BIS: 10262 – 2009 [12]. Cement was partially replaced with alccofine. Alccofine was added upto 10, 20 and 30% by weight of cement content. The effects of alccofine on the mechanical and durability index properties of green concrete were evaluated. The water/binder ratio of 0.45 was used throughout the mix design. The mix proportions for the conventional concrete (CM) and green concrete mixes are shown in Table 3.

TABLE 1. Physical properties of Alccofine

Characteristics	Test Results
Specific gravity	2.9
Specific surface area [m^2/kg]	1200
Bulk density [kg/m^3]	680
Particle Size in Micron	
D10	1.5
D50	5
D90	9

TABLE 2. Chemical properties of Alccofine (%)

CaO	SiO_2	Al_2O_3	Fe_2O_3	SO_3	MgO
61-64	21-23	5-5.6	3.8-4.4	2-2.4	0.8-1.4

TABLE 3. Mix proportions of the concrete mixes

Mix ID	C (%)	ALC (%)
CM	100	0
AFC1	90	10
AFC2	80	20
AFC3	70	30

5. 2. Test Performance Procedure

5. 2. 1. Mechanical Tests Specimens for mechanical properties of different mixtures were prepared with partial replacement of cement with alccofine (i.e. 0, 10, 20 and 30%). Cubic specimens of 150 mm * 150 mm * 150 mm, cylindrical specimen (d x h) of 150 mm * 130 mm and prism specimens of 100 mm * 100 mm * 500 mm were casted to find the variation of compressive strength, splitting tensile strength and flexural strength, respectively. The specimens were demoulded after 24 hours and cured until the test date as per IS 516-1959 specification. The compressive strength tests were carried out for three samples for every single mix at 7 and 28 days as per IS 516-1959 specification. The splitting tensile tests were carried out at 7 and 28 days as per IS 5816-1999 specification [13] and flexural strengths were evaluated as per IS 516-1959 specification.

5. 2. 2. Water absorption Test The water absorption test was performed according to ASTM C642-2013 [14]. Water absorption tests were conducted on cube samples for 7 and 28 Days curing period. The samples were allowed to complete the curing period under room temperature and allowed to dry in open sky for 2 – 3 hours so that the surface moisture content will get evaporated. Now the specimens were kept in an oven at 110°C. After 24 hours the samples were removed from the oven and allowed to cool off to room temperature [14]. Weights of samples (A) were measured after cooling of samples up to room temperature. After measuring the weight A, samples were again immersed in water. After 48 hours the samples were removed from the water and they were weighed as weight B. The water absorption percentage of samples was calculated by following Equation (1).

$$\text{Water absorption (\%)} = \frac{B-A}{A} \text{ X } 100 \quad (1)$$

A= Weight of the oven dried sample at 110□ C for 24 hours,
B= Weight of the sample after 48 hours of immersion in water.

6. RESULTS AND DISCUSSION

6. 1. Effect of Alccofine on Compressive Strength

From the results, it was clearly observed that the green concrete mixtures made with alccofine showed higher compressive strength than the conventional concrete mix. The early age (7 days) compressive strength of mixtures AFC1, AFC2 and AFC3 was improved by 20.88, 28.38 and 7.04%, respectively. Data for comparison to the conventional concrete mix are shown in Figure 1. The improvement in early age compressive strength of green concrete was due to the accelerated hydration reaction on the addition of alccofine [15,16]. Similar data were observed at the age of 28 days. The mixes with Alccofine i.e. AFC1, AFC2 and AFC3 showed an improvement in compressive strength by 7.78, 8.70 and 1.20%, respectively; with respect to the conventional concrete mix. From the above results, it was observed that the percentage strength gain is higher at 7 days of curing when compared with other ages of curing. Therefore, it can be concluded that the rapid development of the compressive strength of green concrete at an early age showed that the alccofine not only serves as a filler to increase the density of the micro and nanostructure of concrete but also serves as an activator in the hydration process. A decrease in strength on an addition of alccofine beyond 20% is attributed to the reason that the quantity of alccofine particles is higher than of liberated lime quantity in hydration process resulting in leaching out that leads to decrease in pore bonding strength.

6. 2. Effect of Alccofine on Split Tensile Strength

From Figure 2, it was clearly observed that the green concrete mixes made with alccofine showed higher split tensile strength than the conventional concrete mix. The early age (7 days) split tensile strength of mixes AFC1, AFC2 and AFC3 were improved by 9.31, 14.63 and 3.44%, respectively; in comparison to the conventional concrete mix. Similar types of results were observed at the age of 28 days. The mixes with alccofine i.e. AFC1, AFC2 and AFC3 showed an improvement in split tensile strength by 8.4, 11.11 and 1.30%, respectively; compared to conventional concrete mix for 28 days curing period. This increase in tensile strength may be attributed to the improved properties of the concrete matrix and the strong inter-phase bond between the binders (i.e. between cement and alccofine) and the aggregates. The interfacial transition zone (ITZ) plays a key role in the development of split tensile strength. By utilizing micro particles like Alccofine, the ITZ becomes denser resulting in improvement of split tensile strength.

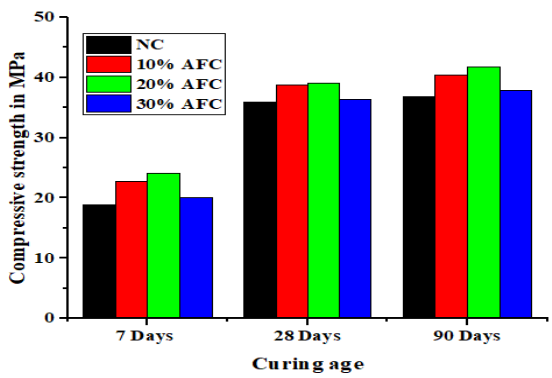

Figure 1. Graphical representation for compressive strength of Green Concrete mixes

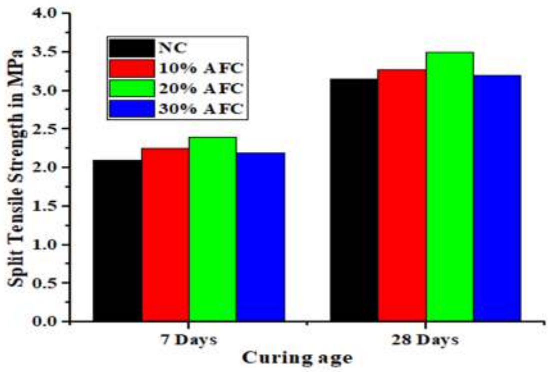

Figure 2. Graphical representation for split tensile strength of Green Concrete mixes

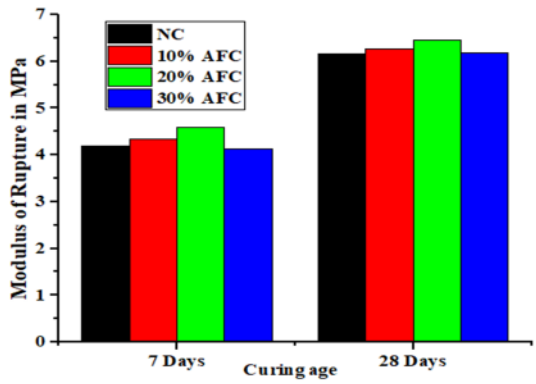

Figure 3. Graphical representation for modulus of rupture

It was also noticed that the split tensile strength of green concrete samples was enhanced when cement content was replaced up to 20% AFC and declined slightly on increasing the alccofine content. The decrease in tensile strength with greater than 20% AFC replacement is attributed to the reason that the quantity of alccofine particles is higher than the of liberated lime quantity in the hydration process resulting in leaching out that leads to decrease in strength.

6. 3. Effect of Alccofine on Modulus of Rupture

From the results, it was clearly observed that the green Concrete mixes made with alccofine showed higher modulus of rupture than the conventional concrete mix. The early age (7 days) flexural strength of mixes AFC1, AFC2 and AFC3 were improved by 4.85, 8.57 and 3.19%, respectively; in comparison to the conventional concrete mix as shown in Figure 3. Similar types of results were observed at the age of 28 days. The mixes with alccofine i.e. AFC1, AFC2 and AFC3 showed an improvement in flexural strength by 2.9, 4.9 and 0.32%, respectively with respect to the conventional concrete mix for 28 days curing period [17]. It was also noticed that the modulus of rupture of green concrete samples was enhanced when cement content was replaced up to 20% AFC and declined slightly on increasing the alccofine content.

6. 4. Effect of Alccofine on Water Absorption

From Figure 4, it was clearly observed that the green concrete mixes made with alccofine showed lower water absorption percentage than the conventional concrete mix. The early age (7th day) water absorption percentage was decreased by 7.59, 5 and 5.87%, respectively; for AFC1, AFC2 and AFC3 compared to the conventional concrete mix. Similar results were observed at the age of 28 days. The mixes with alccofine i.e. AFC1, AFC2 and AFC3 showed decrease in water absorption percentage of 5.41, 4.41 and 5.64%, respectively; with respect to the conventional concrete mix for 28 days. The low water absorption percentage results in green concrete mixes

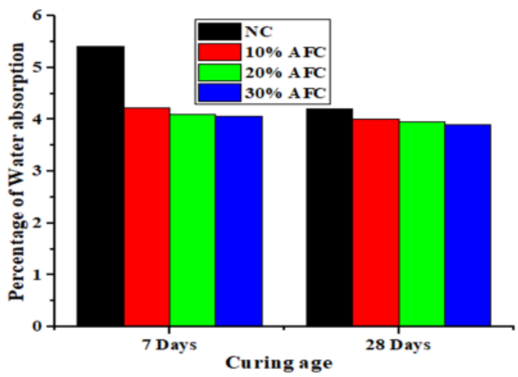

Figure 4. Graphical representation of the percentage of water absorption

was due to the occurrence of higher pozzolanic effect by alccofine due to their micro-particle size which made the concrete more denser, more compacted and also improved the pore structure of the concrete which helped to reduces the water absorption percentage.

7. DESIGN OF EXPERIMENTS

In the current research statistical approach using DOE has been used. In the design of experiments, a response variable and two independent variables are required. In this paper, 'strength of concrete in compression' as the response and the selected independent variables are 'age' and 'weight of alccofine' [18].

Experimental investigation carried out based on two variables are shown in Table 4. The experimental results presented in Table 4 have been used to predict the strength of concrete in compression depending on alccofine and age. The strength of concrete in compression model has been analyzed with the second-degree polynomial by using response surface regression equation given below (2).

$$A = B_0 + B_1Y_1 + B_2Y_2 + B_{11}Y_1^2 + B_{12}Y_1Y_2 + B_{22}Y_2^2 \quad (2)$$

where, Y_1= Alccofine, Y_2= Age, A= compressive strength
The obtained polynomial equation as shown in the Equation (3).

$$\text{Compressive strength} = 12.013 + 0.1275^*\text{Alccofine} + 1.0809^*\text{Curing Age} - 0.000905^*\text{Alccofine}^*\text{Alccofine} - 0.008946^*\text{Curing Age}^*\text{Curing Age} + 0.000011^*\text{Alccofine}^*\text{Curing Age} \quad (3)$$

The residual error is shown in Table 4. The percentage of error less than 5% has been observed such that obtained results are within in the range of 95% confidence level. From Figure 5 shows the actual values of compressive strength and predicted values of compressive strength.

8. CROSS-VALIDATION

8. 1. Coefficient of Determination

The COD is a valuable metric for showing accuricy. Let $\widehat{Y_j}$ be an approximation of the response to the k parametric mechanical model Y_j. The coefficient of determination is obtained by utilizing the relation in Equation (4).

TABLE 4. Predicted and experimental values by using regression expression

Alccofine	Age	Z experimental	Z predicted	Residual
0.00000	90	36.7850	35.2651	0.722540
43.8130	90	40.3570	39.1252	-0.335164
87.6260	90	41.7360	39.5095	-0.389452
131.439	90	37.8940	36.4179	0.002076
0.00000	28	35.9876	36.8333	-0.048280
43.8130	28	38.7900	40.7236	-0.366638
87.6260	28	39.1200	41.1382	0.597821
131.439	28	36.4200	38.0769	-0.182903
0.00000	07	18.7915	19.1414	-0.349905
43.8130	07	22.7200	22.9913	-0.271263
87.6260	07	24.1300	23.3653	0.764696
131.439	07	20.1200	20.2635	-0.143529

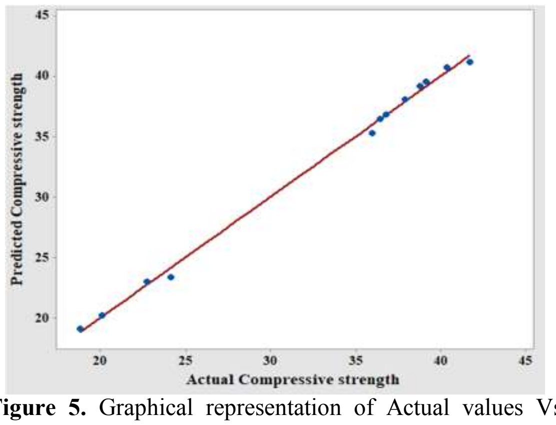

Figure 5. Graphical representation of Actual values Vs Predicted values

$$R^2 = 1 - \frac{\sum_{j=1}^{N}(Y_j - \widehat{Y_j})^2}{\sum_{j=1}^{N}(Y_j - \widehat{Y})^2} \quad (4)$$

Where Y_j = Experimental value and $\widehat{Y_j}$ = Predicted value from the regression model.

8. 2. Residual Sum of Squares

The residual sum of squares is a standout amongst the most well-known measures for the goodness of fit of a regression curve to aplot. Lower estimations of RSS shows better fit which demonstrates the model has a little arbitrary blunder part and the fit will be more valuble for prediction. The residual sum of squares is obtained by utilizing the relation in Equation (6):

$$\text{RSS} = \sum_{j=1}^{N}(Y_j - \widehat{Y_j})^2 \quad (5)$$

The Value of COD (R^2=0.997) obtained confirms the appropriate fit of the model as the discrepancy of total variation is found to be 0.0027% which is an acceptable range of error. The large R^2 values prove that there are no notable discrepancies between the estimated values.

The values of the RSS (i.e. 2.115) obtained confirms the appropriate fit of the model. Figure 5 Shows the predicted values and actual values by regression expression for compressive strength [19-21].

TABLE 5. Cross validation of response surface model

Y_j	$\widehat{Y_j}$	$\widehat{Y}$	R^2	RSS
36.785	36.83328	32.73759		
40.357	40.72364	32.73759		
41.736	41.13818	32.73759		
37.894	38.0769	32.73759		
35.9876	35.26506	32.73759		
38.79	39.12516	32.73759	0.9973	2.115
39.12	39.50945	32.73759		
36.42	36.41792	32.73759		
18.7915	19.1414	32.73759		
22.72	22.99126	32.73759		
24.13	23.3653	32.73759		
20.12	20.26353	32.73759		

8. CONCLUSION

Based on the experimental investigation carried out on CC and GC mixes, the following conclusions are drawn:

- By using alccofine, improvement in the particle pac king and pore structure results in enhancement of m echanical and water absorption properties of the gre en concrete.

- The incorporation of alccofine in green concrete inc reases the mechanical strength and decreases the wa ter absorption properties when compared with the c onventional concrete mix at all ages. The strength in creased up to 20% alccofine replacement.
- The compressive, splitting tensile and flexural stren gth of green concrete improves upto 20% of cement replaced by alccofine due to the higher specific surf ace area and high pozzolanic activity of alccofine re sulting in high production of C-S-H gel and helps in the formation of compact structure in the concrete th at helps in improving the early strength gaining cap acity of concrete.
- Water absorption percentage of Green Concrete reduces due to the action of pore filling effect and acceleration of hydration of alccofine particles making the concrete denser and compacted.

The experimental data has been verified by using the response surface method, and the error is found to be an acceptable range.

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چکیده

در عصر مدرن، بسیاری از کارهای تحقیقاتی در سراسر جهان برای پیدا کردن مواد سیمان مناسب برای جایگزینی سیمان انجام شده است. مواد سیمانی اضافی (SCM) می تواند به عنوان جایگزینی سیمان در صنعت ساخت و ساز به منظور کاهش انتشار دی اکسید کربن مورد استفاده در گرمایش جهانی و تغییرات اقلیمی در محیط زیست مورد استفاده قرار گیرد. این مقاله خواص شاخص مکانیکی و دوام را برای بتن معمولی M30 (NM) و بتن سبز(GC) ارائه می دهد. از نتایج تجربی، به وضوح مشاهده شد که استفاده از آلکوفین منجر به رسیدن به نقاط قوت بالاتر در بتن های زود هنگام است. ترکیب بتن سبز با جایگزینی ۲۰ درصد آلکوفین سیمان با خواص شاخص مکانیکی و دوام بیشتر نسبت به سایر مخلوط ها به دست می آید. به منظور بهینه سازی داده های آزمایشی که در آن معادله رگرسیون با مرتبط کردن متغیر پاسخ به متغیر ورودی، توسعه داده شد، روش پاسخ پاسخ داده شد. این روش به پیش بینی ارزش های تجربی در یک حد خطای قابل قبول کمک می کند. مقادیر پیش بینی شده با استفاده از ضریب تعیین (R^2) و مجموع مجموع مربعات (RSS) که با مناسب بودن آنها نشان داده شد، اعتبارسنجی گردیدند.

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