Mechanical and Short-Term Durability Study of High-Performance Concrete using Mineral Admixtures and Optimized by Taguchi's Approach

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ABSTRACT: In the construction industry, while manufacturing higher grades of concrete such as M100, there is a possibility of more material wastage due to the number of trials carried out to achieve the desired strength. High performance concrete has been emerging as a promising alternative for conventional cement concrete. Generally, High performance concrete composes of alternative binding material to cement, which has similar properties, and the proportions were decided to provide strength, durability, and workability required for being sound in structural and environmental aspects. This study was conducted on an investigation of optimizing the mix design for high performance concrete with silica fume and alccofine as mineral admixtures in various ratios 5% &10%, 10% & 5%, and 7.5% & 7.5% for M100 grade of concrete and superplasticizer as a water-reducing chemical admixture. The mix design for M100 was obtained using American concrete institute code provisions with compressive strength as the parameter. Optimizing the mix design using Taguchi's method with four variables taken into consideration mineral admixture, water binder ratio, superplasticizer, and curing system on an orthogonal array. A comparison study ofcompressive strength on all the trails and the optimum resultsare taken. The durability study on acid resistance and rapid chloride penetration test on the optimum result.

KEYWORDS: Optimization, High-Performance concrete, Taguchi Method.

I. INTRODUCTION

Properly designing the concrete mix using many natural waste materials will directly increase the mechanical, flowability, and remaining other properties of concrete (F. De Larrard et al. 1994]) Silica fume is a low-density material having the high SiO_2 content than cement which indeed makes it play a major role in high performance concrete production (G.A. Rao 2003). Due to its lightweight and micro-sized, these materials have gained more flowability and it reaches the pores created by the water in between the aggregates (H. Vikan et al. 2007). The amount of formation of C-S-H gel is high when the quantity of cement content replaced with silica fume in an optimized percentage (K.L. Scrivener et al. 2004). These properties of silica fume can develop a bond between the aggregates which is resulting in the formation of CH crystals (X.H. Wang et al. 2009) and also changes the brittle phase to ductile when it is hardened (Z. Wu et al. 2016). Some researchers have used the replacement percentage of silica fume as 20% to 30% (H. G. Russell et al. 2013). In which the voids are lowered, the bond between the aggregates, compressive, and flexural strength is increased (Y.W. Chan et al. 2004). The replacement of 5% to 15% also been used by some authors, which are having the exact material characteristics (A.Arora et al. 2018). When silica fume material is added into the concrete with an increasing percentage indeed improves the flowability but, this will result in a decrease in density will directly affect the mechanical properties of the concrete (M. Li et al. 2013).

To overcome this issue an optimization technique is used to found out the maximum level of percentage to be added in the concrete to get maximum strength, durability, and other characteristics which can be evident in microstructure study (Z. Wu et al. 2017). The uniform dispersion of the particle added in the concrete is made by super plasticizers (C. Schröfl et al. 2012) which are used for reducing the water content of the concrete. Silica fume addition to the range 0 to 30% will possess some mechanical property which is not a constant value. It can also be decided based on the water-cement ratio used in the mix proportion (S. Bhanja et al. 2005).

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Some researchers have increased the performance of the concrete by the hybrid technique. Replacement of two or more different materials with the cement will also increase the performance of the concrete, which is made in this study. By replacing two different materials with cement, it is very hard to find the optimum percentage of replacement material. So some researchers have followed the approach which is made by Taguchi(Shyam Kumar Karna et al. 2012). With that approach, we can be able to find out the replacement material of an optimum percentage which should be added in the concrete to get high performance. In this study, both silica fume and alccofine material (Indu Lidoo et al. 2013) are used for achieving high performance in mechanical properties. This study deals with the high strength concrete with the use of two different replacement material and superplasticizer to obtain the M100 grade concrete. To achieve the higher compressive strength, direct tensile strength, and shear strength this concrete is designed.

II. Material Properties

The materials takenfor this study are Ordinary Portland Cement of grade 53, conventional coarse aggregate, M-sand as fine aggregate, and two replacement materials for cement are Alccofine and Silica Fume. The cement is tested for the Specific gravity under the codal provision ofIS:2386(part III) – 1983, and its value is 3.12, which is the allowable range. Then it is also taken for setting time test under the codal provision of IS 12269-2013 and it takes 36min for initial setting time and 522 min for final setting time. The cementitious material Alccofine and Silica fume tested for the specific gravity as per the codal provision ACI 226-1988 its values are 2.9 and 2.2, respectively. The specific gravity of coarse aggregate and fine aggregate is also tested and its results are 2.87 and 2.73, respectively. The high range water reducing agent is used in this study is AURAMIX 300, which is added 1% from the binder content. Then the concrete mix is tested for the flowability, and its slump achieved is a true slump.

III. Experimental method

This study is developed in such a way that it includesthe parameters which are having significant effects on the characteristics of a high performance concrete. Furthermore, it can also reduce the number of experiments. The experimental design method selected for this study is the Taguchi method using an orthogonal array [9], L9 (34) to run at once 4 (four) variables. Silica fume and Alccofine, Water binder ratio, Superplasticizer, and Curing method, These parameters are considered to have a significant effect over compressive strength.

Parameters		Unit	Levels		
			1	2	3
Silica Fume and Alccofine	A	%	5%+10%	10%+5%	7.5%+7.5%
Water Binder Ratio	B	-	0.25	0.27	0.30
Superplasticizer	C	%	1.2%	1%	0.8%
Curing System	D	-	Freshwater (FW)	Artificial Seawater (ASW)	Accelerated curing Tank (AC)

Table 1. Variables and levels

The level of variations considered parameters are shown in Table 1. Table 3, shows the variables and their levels that are aligned based L9 orthogonal array. After mixing, high performance concrete is filled in moulds and left undisturbed for 24 hours after that it is demoulded. Once thesample is hardened, it is cured by immersing them in three curing conditions, namely: freshwater, Artificial seawater, and accelerated curing tank for until 28 days except accelerate curing for 2 days. The temperature of curing is under a range of 27˚C to 32˚C for freshwater and artificial seawater curing whereas for accelerated curing the temperature is 100˚.The compressive strength of hardened high performance concrete specimens is to be determined. The concrete specimen for the compressive strength test is 100mm x 100mm x 100mm cube is made.

Table 2. Orthogonal Array (L9)

Experimental trails	Variables

	A	B	C	D
M1	1	1	1	1
M2	1	2	2	2
M3	1	3	3	3
M4	2	1	1	3
M5	2	2	2	1
M6	2	3	3	2
M7	3	1	1	2
M8	3	2	2	3
M9	3	3	3	1

Table 3, shows the composition of artificial seawater used for curing. The artificial seawater curing is considered because high strength concretes are mainly used in off shore structures. Hence knowing the performance of high strength concrete is important. The specimen is initially placed in fresh water for 7 days and later transferred into artificial seawater curing tank.

Table 3. Composition of artificial seawater curing

Components	Concentration(g/l)
NaCl	24.53
KCl	0.67
$CaCl_2$_$2H_2O$	1.36
$MgCl_2$_$6H_2O$	4.66
$MgSO_4$_7H2O	6.29
$NaHCO_3$	0.18

Table4. shows the detailed report of trail mixes in accordance with orthogonal array and level of variables. These mixes will be made to caste the cube, and the compressive strength test is conducted.The optimum percentage of replacement material is taken with their respective water binder ratio and curing technique.

Table 4.Optimization with Orthogonal array

Experimental trails	Variables			
	Silica fume and alccofine	Water binder ratio	Superplasticizer	Curing system
M1	5%+10%	0.25	1.2 %	FW
M2	5%+10%	0.27	1%	SW
M3	5%+10%	0.30	0.8%	AC
M4	10%+5%	0.25	1.2%	AC
M5	10%+5%	0.27	1%	FW
M6	10%+5%	0.30	0.8%	SW
M7	7.5%+7.5%	0.25	1.2 %	SW
M8	7.5%+7.5%	0.27	1 %	AC
M9	7.5%+7.5%	0.30	0.8 %	FW

3.1. Compressive Strength

The concrete is designed for M100 grade, and to achieve this grade, two types of replacement material for cement is used. The compression testing machine is used to test the concrete cubes. The compressive strength test is done for during the 7th, 14th, and 28th day of curing. The 7th-day test shows the strength of the concrete mixesatan early age. Whereas the 28th-day test shows the almost maximum strength of the mixes.

The compressive strength test results for various mix proportions in which the Alccofine and Silica Fume materials are replaced are represented in graphically in figure 1. The 28th-day test results show clearly that mix M3, M4, and M8 made for accelerated curing possess less strength when compared to the other mixes. Then the concrete cubes, which are made curing with the Air and Steam Curing, possess comparatively less strength than the cubes, which is cured with abundant water. The reason for the increase in strength is due to proper hydration made after the casting. The density is also high when the finer pores are filled with the microparticles in the Alccofine and Silica Fume, which directly improves the strength of the concrete. The optimized mixesare taken for further study is M1, M5, and M9, as shown in table 5. In that, the M9 mix shows the optimum results when compared to other mixes.

Table 5. Compressive strength results

Mix	Density(kg/m^3)	Compressive Strength(N/mm^2)		
		7th Day	14th Day	28th Day
M1	2764	72.4	96.5	112.4
M2	2624	65.5	86	95.3
M3	2653	*	*	105.16
M4	2692	*	*	109
M5	2725	64	88.9	105.7
M6	2632	62.3	82.3	94
M7	2664	73.8	97.2	103.1
M8	2728	*	*	108
M9	2773	84.6	102.5	118

* Not applicable due to accelerated curing.

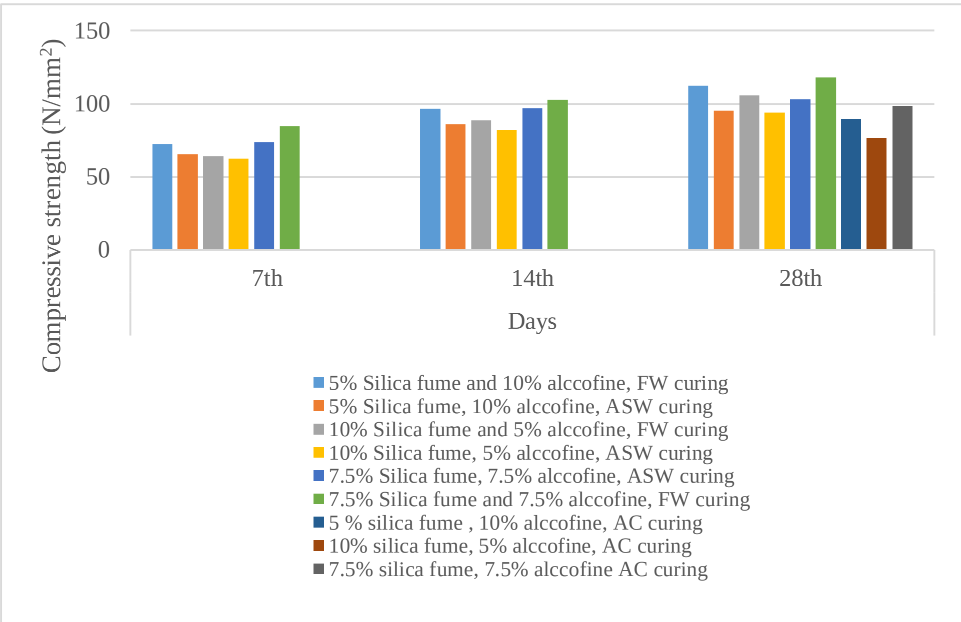

Figure1. Compression strength results

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1. Shear strength test

The concrete cylinder specimen is cast of dimensions 100mm diameter and 200mm height to test the shear strength of the high strength concrete. These concretes are cast after the optimization is made, and the three optimum results obtained from the compressive strength is taken for this casting of cylinders. The cylinder specimen is made for 28 days of curing, and then it is taken for shear strength testing. Whereas test was proceeded to check with shear strength test and obtained convincing results in shear strength aspects, as shown

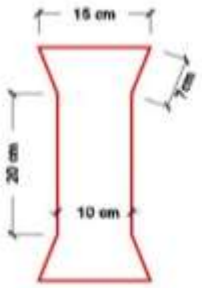

Figure 2. Dog bone shape specimen

Figure 3. Direct tension testing

in Table 6. The optimum shear strength result obtained wasfrom the M9 mix.

2. Direct tension test

The direct tensile strength of concrete is tested using a concrete prism, which is cast with the steel mould. The specimen is designed like the dog bone ends at either side as shown is figure 2, and the middle portion is designed like the rectangular shape. This test is made to test the bonding ability of the aggregates and binders in the concrete(P.R. Kannan Rajkumar et al. 2014). During a load is applied, the top anchorage will start to pull the specimen at the ultimate load; the concrete specimen will be split into two parts as shown in figure 3. The test specimens were casted based on the optimum results obtained. The result obtained for direct tension testing of M9 mix has achieved convincing results in tensile strength aspects as shown in table 5.

Table 6.Shear strength and Direct tension testing results

Mix	Specimen	Shear Strength	Direct Tensile Strength
		28 days	28 days
M1	1	8.4 N/mm^2	2.8 N/mm^2
M5	2	7.26 N/mm^2	2.576 N/mm^2
M9	3	8.59 N/mm^2	3.11 mm^2

3. Acid Test

In acid test, concentrated sulphuric acid of 500ml is diluted with 25 liters water, and then the cube specimen of 100mm x 100mm x 100mm is immersed and cured for 7 days with reference to the ACI 544 – 2R.The acidtest was conducted by measuring two weight of the specimen, one is the weight before it is taken for curing in diluted sulphuric acid, and the second weight is after curing of specimen with the acid up to 7, 14 and 28 days of curing. Table7, shows that the initial weight of the specimen is greater than the final weight. These variationsare less in comparisonwith conventional concrete specimens. The absorption is less due to the filling of micro sized particle inside the specimen which increases the density.

Table 7: Acid Test results

Mix	Specimen	Initial	Final weight (Kg)	Average reduction in

M9		weight (Kg)			weight (%)	
			14 days	28 days	14 days	28 days
7.5% Silica fume & 7.5% Alccofine, FW Curing	1	2.744	2.739	2.650	0.18	3.54
	2	2.764	2.757	2.652	0.25	4.22
	3	2.758	2.752	2.659	0.21	3.72

4. Rapid Chloride Penetration Test (RCPT)

The penetration of chloride is harmful to the durability of concrete.The specimen used for this test is the cylindrical disc of dimension 50mm long and 100mm diameter. The specimen immersed in sodium chloride solution made with 0.3 molarity starts penetrating into the core part of concrete while the subjected to the passing of charges. Table8 shows the charges passed in the specimen by coulombs. With reference to ASTM C 1202, the values of RCPT are shallow due toits high resistivity towards percolating chloride ions and thus highly durable.

Table 8: Results of the rapid chloride penetration test

Mix M9	Specimen	Charges passed (Coulombs)	
		28 days	56 days
7.5% Silica fume & 7.5% Alccofine, FW Curing	1	378	196
	2	329	207
	3	370	198

IV. Conclusion

The concrete with is casted using silica fume, and alccofine possesses the high performance concrete, which is studied according to the American Concrete Institute. There is an increase incompressive strength as the mineral admixtures content were in uniform mixture.The workability, mechanical property and durability were studied.It is known that silica fume(7.5%) and alccofine (7.5%) performed better in both freshwater, artificial seawater curing, and accelerated curing system. The reason for the increase in strength is due to proper hydration made after the casting. The density is also high since the finer pores are filled with the microparticles in the Alccofine and Silica Fume, which directly improves the strength of the concrete and Taguchi design helped in reducing the number of experiments. When further studied in durability aspects, the high-performance concrete of silica fume (7.5%) and alccofine (7.5%) has shown optimum results under acid test and rapid chloride penetration test because of tightly packed bonding between the binding materials

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