MATHEMATICAL MODEL FOR COMPRESSIVE STRENGTH OF TRIPLE BLENDED SELF COMPACTING CONCRETE USING METAKAOLIN AND SILICA FUME

Kalp A. Shah[1], Aakash Suthar[2], Mili Shankhala[3]

[1]1P. G. Student, Department of Civil Engineering, L.J.I.E.T., Gujarat Technological University
[2]Assitant Professor, Department of Civil Engineering, L.J.I.E.T., Gujarat Technological University

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Abstract - *In the past few decades, extensive research has been conducted on concrete manufacturing technology worldwide to find alternative materials that can partially or completely replace conventional Portland cement (OPC) and meet the requirements of stability and durability. Part of the alternative materials tested to replace cement, strength, workability and durability of industrial by-products, such as fly ash, blast furnace slag, silica fume, metakaolin, rice husk ash, etc., are now called supplementary binders (CCM). Although the materials and technologies used to produce concrete have been extensively studied in the past few decades, concrete has certain shortcomings, such as: Cavity caused by improper mixing/compaction will affect Strength and durability. It is a solution to minimize these voids in concrete. Since self-compacting concrete has many advantages, such as easy installation, reduced noise pollution, and shortened pouring time, it has various uses in the field of construction. The study clearly shows that self-compacting concrete is required in the concrete area to avoid compaction by external influences. The dead weight on the corners of all formwork is also completely compacted with dense steel. SCC is a homogeneous and dense ternary mixed concrete composed of 5%, 10%, 15%, 20% and 25% metakaolin, 0%, 5%, 10%, 15% and 20% silica instead of cement and viscosity modifier. In order to study the compressibility of mortar, various building mixtures with variable cement-sand ratios were prepared and tested.*

***Key Words*: Triple blended concrete, self-compacting concrete, Metakaolin, Silica fume, mathematical model, compressive strength, concrete mix design, linear regression**

1. INTRODUCTION

In the past making concrete structures without vibration have been made for examples, placement of concrete under water is done by without vibration. Mass concrete and shaft concrete can be place without vibration. But above the examples of concrete are generally of lower strength. Modern application of self-compacting concrete is focus on high performance and better strength and workability. Recognizing the lack of uniformity and complete compaction of concrete by vibration research at the University Of Tokyo, Japan started in 1980 to develop self-compacting concrete. In the early 1990, Japan developed and use of self-compacting concrete does not required any vibration to achieve compaction by the year 2000 the self-compacting concrete has become popular in Japan for ready mix concrete. Several European countries conclude the significance and potential of self-compacting concrete was developed in Japan. During 1989 they founded European federation of natural trade association representing producer and applicators of specialist product (EFNARC). The use of self-compacting concrete started growing rapidly. EFNARC, making use of wide practical experience of all person of European federation with self-compacting concrete. It has drawn up specification and guideline to provide a framework for design and use of better quality self-compacting concrete during 2001. Most of information of test method given in this project is based on specification for self-compacting concrete. Self-compacting concrete is described as “the most revolutionary development in concrete construction for several decades” When compare two normal concrete to the blended concrete is very economical and having batter strength then normal concrete. Triple blended concrete is in corporate with three cementations material the suitable proportion of triple mixes impact the one of secondary material to adjust for its weakness of another. Such cement were found to display very good mechanical properties of concrete. This emerges from the decrease in for major and the refinement of the pore structure of the concrete glue and also from changes in properties of concrete in the past year the concrete having natural pozzolans which are in the form of rise husk ash, metakaolin, silica fume, zeolite, fly ash are largely use in the world. This are highly require in the place like nuclear structure power structure chimneys etc. concrete is the most use material and its computation is very high. Concrete has become popular due to its mouldability in to any complex size, strength, economy, availability of ingredients. Concrete is a mixture of cement, coarse aggregate, fine aggregate and water. The development of new admixtures has change the properties a concrete. There is many research in last few decades on concrete technologies. Concrete has certain problem like presence of void due to improper mixing it will a fact the strength and durability of self-compacting concrete is the solution of such void in concrete self compacting concrete has the many applications in the construction field some of are ease of placement, lase concreting time etc. The present study shows that the self-compacting concrete is very useful in concrete field to minimize the use of compaction. Self compacting concrete is settle under its own weight along the whole area even it get completely compacted in dense area. Self compacting concrete is homogeneous. It is dense. It has similar structure property of vibrated concrete. Self compacting concrete can cast in such way that there is no additional vibration is needed.

1.1 Significance of the work

In order to obtain SCC, the main criterion for developing the mixing ratio is to determine the physical properties of the concrete. Fresh SCC has better fluidity, self-sealing and anti-delamination. They help reduce cell problems in concrete. Therefore, SCC can greatly improve reliability and durability. It can meet the required axial compressive strength test. SCC material is the same as that of vibrating cement concrete. Contains cement, fine aggregate, coarse aggregate and water as well as additives. Some other modifications are required to maintain strength and other rheological properties (for example, fluidity requirements).The fine aggregate content can offset the other components of this type of special concrete by volume.

2. LITERATURE REVIEW

Anhad Singh Gill, Rafat Siddique [2018] [1]

This paper put the durability and micro structure properties of self-compacting concrete made up of metakaolin (MK) and rice husk ash (RHA). A total mixes include the control mix are design. Slump flow, L-box, U-box and V-funnel test are conducted with concrete. Testing of harden state is done at age of 7, 28, 90 and 365 days and is tested for compressive strength and durability properties like water assumption porosity and sulphate resistance test. One is the control mix (M1) and other three mix (M2, M3 and M4) are prepared by partial replacement of cement with metakaolin in proportion of 5%, 10% and 15% and fine aggregate is partially replace with rice husk ash with fix proportion of 10%.

Pawel Niewiadomski, Jerzy Hola, Andrzej Ćwirzeń [2018] [2]

The paper represent the result of the total 11 series of self-compacting concrete, which are made by different amount of the nanoparticles like: SiO_2, TiO_2 and Al_2O_3 and also there is one reference concrete without addition of nanoparticles. This study conclude the mechanical properties of a self-compacting concrete. A total of 11 self-compacting concrete mixes are made, with the reference (S1) without a nano-additive. Mixing of concrete is done by pan mixture. Test of physical properties are explain determination of the total air content and the content of micro pores. The also increase in strength with mixing of 2% of nano TiO_2 and nano Al_2O_3. The compressive strength result also obtain for 90 days. This studies show that the high chemical reactivity of nano particle is useful for creating additional place for the formation of C-S-H phase, it is responsible for the concrete strength.

S. Vijaya Kumar, B. Dean Kumar, and B. L. P. Swami [2019] [3]

This present study shows that the self-compacting concrete is necessary in concrete field for prevention of external compaction. Investigation for require design and self-compatibility methods had studied out to make good performance concrete. This study shows the presence of steel fiber percentage and expect ration on the strength and other properties of the concrete. In this study M40 grade is use for base concrete. The triple blending include the replacement of cement with fly ash at 15% and Silica fume at 10% by weight of cement. In this study the percentage of steel fiber is ranging from 0.20 to 0.80.The workability test, young's modulus and poison's ratio are evaluated. The mix design of M40 grade of concrete is done according to IS 10262-2009 by utilizing the materials. The admixture fly ash and CSF are use as a replacement of cement at 15% to 10% to achieve triple blending.

S. Madhava Reddy, M. Vani [2019] [4]

In this study, a mix design for high strength concrete of M60 grade is using by triple blending technique with the ground granulated blast furnace slag (GGBS) and Metakaolin (MK) as partial replacement of cement by weight between 0% - 30% with glass and steel fiber are added at 0.5%, 1%, 1.5% and 2% as a partial replacement of total fiber percentages. In this study of experimental investigation, a mix design of concrete having M60 grade is used by triple blended self-compacting concrete using MK and GGBS. The various proportion of fiber are added at 0.5%, 1%, 1.5% and 2 % by the total percentages of fiber. The result for various mix of concrete are studied and determine the optimum mix for maximum strength.

Srinivas Vasam, K. Jaganadha Rao, and M. V. Seshagiri Rao [2019] [5]

With regard to the consumption of natural resources and, to a certain extent, the disposal of construction and demolition waste, attention to recycled concrete aggregates has become increasingly important. The use of RCA (recycled concrete aggregate) in SCC combines the advantages of SCC and RCA Overall, the Concrete mix design is a process of trial and error using new materials such as RCA. In this article, we developed an empirical model to predict the compressive strength and other mechanical properties of SCC with RCA by performing multiple regression. The empirical equation of discovery development can be predicted Cinch's compressive strength SCC is about 90%. In this way, by using the hardness prediction equation derived from the reduced dough mix, a lot of energy, time and materials can be saved.

3. MATERIAL

Cement: ordinary Portland cement confirming to be IS: 12269-1987 with a design strength for a required days.

Coarse aggregates: course aggregates confirming to IS 383 were used. The maximum size of aggregates of 20mm are used.

Fine aggregates: Confirming to IS 383 has been used as fine aggregates. Zone II sand are used.

Water: potable water having PH=7.2 has been used for concrete as per clause 5.4 of IS 456-2000.

Metakaolin: Metakaolin are used as a proportion of 0%, 5%, 10%, 15%, and 20%.

Table -1: Physical properties of Metakaolin

Physical component	Metakaolin
Specific Gravity	2.40 to 2.60
Color	Off white
Physical form	Powder
Average plastic size	<2.5 µm
Brightness	80-82 Hunter L
BET	15 m^2/g
Specific surface	8-15 m2/g

Table -2: Chemical properties of Metakaolin

Chemical compositions	Metakaolin (%)
SiO_2	55.5
Al_2O_3	36.5
Fe_2O_3	2
TiO_2	1
K_2O	1.70
Na_2O	0.1
LoI	3.2
Density (g/cm^3)	2.58

Silica fume: Silica fume are used as a proportion of 0%, 5%, 10%, 15%, and 20%.

Table -3: Physical properties of Silica fume

Physical component	Silica fume
Specific Gravity	2.2
Color	Light to dark gray
Physical form	Powder
Mean grain size (µm)	0.15
Specific area (cm^2/gm)	150000-300000

Table -4: Chemical properties of Silica fume

Chemical compositions	Silica Fume
SiO_2	95
Al_2O_3	0.13
Fe_2O_3	4
CaO	0.39
MgO	0.21

4. RESEARCH GAP

According to the literature reviewed till now, following research gaps can be noted:

- It was found that none of the research paper used the combination of metakaolin, silica fume with cement.
- It was found that mathematical model for compressive strength of silica fume and metakaolin was not prepared.

- Stability of construction work is very much needed for that earlier strength is required.
- Concrete should have self-sufficient strength otherwise problem can take place.

5. OBJECTIVE

Objectives of the present study are as follows:

1. To increase the compressive strength of concrete.
2. To make the mathematical model for compressive strength of concrete.
3. To increase the workability and fluidity of concrete.
4. To study the presence of metakaolin, silica fume and viscosity modifying agent on the strength of the triple-blended self compacting concrete.
5. To minimize the damage related to vibration.
6. To fill the concrete even in dense reinforcement.
7. To reduce noise pollution by vibration used.
8. To improve segregation resistance of the mix without loss of workability.

6. EXPERIMENTAL SRUDY

6.1 Mixing and curing

The mix proportion of concrete are made according with the IS code (IS: 10262-2009). Grade of concrete is fixed. It is decided to M30 grade of concrete. Initially the sand, cement and aggregate are properly mix by mixture machine. After that the additive materials are added to the concrete which are metakaolin and silica fume. Viscosity modifying agent are also used to make self compacting concrete are more flowable. The two cementitious materials are metakaolin and silica fume are added in the concrete by weight of cement by partially replacement of cement content.

These material are added in the 5%, 10%, 15% and 20% of each to the concrete. And cubes are casted in mold of size 150mm x 150mm x 150mm. These cubes are curing properly and then after they were tested. The compressive strength of all mixes are recorded. The mathematical model are also made from the result data this will help to get compressive strength of any mixes by just putting values in the equation.

Mix proportion for concrete mix is shown below.

Cement: 412 kg/m^2
Water: 186 kg/m^2
Fine aggregate: 1100 kg/m^2
Coarse aggregate: 635 kg/m^2

6.2 Mix Proportion

Table -5: Mix Proportion of concrete

Mix	Cement	Metakaolin	Silica fume	Coarse aggregate	
				20 mm	10 mm
M0	85 %	10 %	5 %	70 %	30 %
M1	85 %	5 %	10 %	70 %	30 %
M2	80 %	10 %	10 %	70 %	30 %
M3	75 %	10 %	15 %	70 %	30 %
M4	75%	15 %	10 %	70 %	30 %
M5	90%	5%	5%	70 %	30 %
M6	80%	5%	15%	70 %	30 %
M7	75%	5%	20%	70 %	30 %
M8	70%	5%	25%	70 %	30 %
M9	70%	10%	20%	70 %	30 %
M10	65%	10%	25%	70 %	30 %
M11	80%	15%	5%	70 %	30 %
M12	70%	15%	15%	70 %	30 %
M13	65%	15%	20%	70 %	30 %
M14	75%	20%	5%	70 %	30 %
M15	70%	20%	10%	70 %	30 %

7. RESULTS AND DISCUSSION

7.1 Compressive strength test

For compressive strength measurement, cubes with different mix proportion of standard size are made of 15cm mold size and then tested on CTM. This separate test can be used to evaluate whether the pouring is performed correctly. The compressive strength of concrete in general construction projects is between 15 MPa and 30 MPa, which is higher in commercial and industrial structures.

Fig -1: Compressive testing

Table -6: Compressive strength result

Mix	Mix Proportion			Average 7 days compressive strength (N/mm2)	Average 28 days compressive strength (N/mm2)
	Cement (%)	MK (%)	SF (%)		
M0	85	10	5	26.78	39.73
M1	85	5	10	25.68	38.45
M2	80	10	10	26.52	40.26
M3	75	10	15	27.94	41.86
M4	75	15	10	29.63	43.53
M5	90	5	5	21.82	38.64
M6	80	5	15	22.38	40.58
M7	75	5	20	21.97	42.73
M8	70	5	25	23.57	43.68
M9	70	10	20	22.79	41.69
M10	65	10	25	24.63	44.93
M11	80	15	5	27.84	39.23
M12	70	15	15	28.70	42.86
M13	65	15	20	25.85	43.69
M14	75	20	5	28.13	39.82
M15	70	20	10	29.96	41.63

7.2 Slump flow Results

This is the ability of fresh concrete to flow under its own weight and fill all the spaces in the formwork. Perform a vertical flow test to check fluidity. The vertical flow value describes the fluidity of the fresh mixture under unrestricted conditions. This test can provide additional information about aggregation strength and regularity.

Fig -2: Flow of SCC

Table -7: Slump flow Results

Mix proportion	Slump Flow	Permissible value
M0	630	Slump flow For classes SF 1 : 550mm – 650mm SF 2 : 660mm – 750mm SF 3 : 760mm – 850mm
M1	635	
M2	680	
M3	590	
M4	625	

7.1 Mathematical Model

Multilinear regression determines the relationship between two or more independent variables and dependent variables by fitting a linear equation to the observed data. • According to the general form of multiple linear regression, each value of the independent variable refers to the value of the dependent variable expressed in the equation, as shown below:

$$y = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + a_4X_4 + ...$$

(Multi linear regression equation)

Here, 'y' is dependent variable; X_1, X_2, X_3 and X_4 are independent variables representing various parameters. We measure a quantity y for several values of parameters X_1, X_2, X_3 and X_4. The compressive strength of concrete after 28 days of hardening depends on the quality of the concrete. It also varies according to the percentage of metakaolin and silica fume aggregate mixed with concrete. Given the specific brand. Variable compressive strength of concrete after 7 days and 28 days. The functional relationship between curing and three variables: cement, silica fume, and metakaolin. The following formula is obtained.

Compressive Strength after 7 days

$$Y_7 = 13.7465 + 0.07117C + 0.4679MK + 0.00538SF$$

Compressive Strength after 28 days

$$Y_{28} = 62.9842 - 0.2691C - 0.1077MK - 0.0061SF$$

Where, C = % of Cement in concrete
MK = % of Metakaolin in concrete
SF = % of Silica Fume in concrete

Table -7: Compressive strength test result by mathematical model

Mix	Mix Proportion			Average 7 days compressive strength (N/mm2)	Average 28 days compressive strength (N/mm2)
	Cement	MK	SF		
M0	85	10	5	24.50	39.01
M1	85	5	10	22.18	39.51
M2	80	10	10	24.17	40.32
M3	75	10	15	23.84	41.63
M4	75	15	10	26.15	41.12
M5	90	5	5	22.52	38.19
M6	80	5	15	21.86	40.82
M7	75	5	20	21.53	42.14
M8	70	5	25	21.20	43.45
M9	70	10	20	23.51	42.95
M10	65	10	25	23.18	44.26
M11	80	15	5	26.48	39.80
M12	70	15	15	25.83	42.44
M13	65	15	20	25.50	43.75
M14	75	20	5	28.47	40.61
M15	70	20	10	28.14	41.93

Table -7: Comparison between experimental and mathematical result

Mix	Experimental compressive strength		Theoretical compressive strength		Percentage Error	
	7 Days	28 Days	7 Days	28 Days	7 Days	28 Days
M0	26.78	39.73	24.50	39.01	-9.29	-1.87
M1	25.68	38.45	22.18	39.51	-10.73	2.68
M2	26.52	40.26	24.17	40.32	-9.70	0.13
M3	27.94	41.86	23.84	41.63	-10.18	-0.55
M4	29.63	43.53	26.15	41.12	-11.24	-5.85
M5	21.82	38.64	22.52	38.19	3.10	-1.17
M6	22.38	40.58	21.86	40.82	-2.38	0.60
M7	21.97	42.73	21.53	42.14	-2.03	-1.40
M8	23.57	43.68	21.20	43.45	-9.17	-0.52
M9	22.79	41.69	23.51	42.95	3.08	2.93
M10	24.63	44.93	23.18	44.26	-6.23	-1.51
M11	27.84	39.23	26.48	39.80	-5.11	1.45
M12	28.70	42.86	25.83	42.44	-11.12	-0.99
M13	25.85	43.69	25.50	43.75	-1.37	0.14
M14	28.13	39.82	28.47	40.61	1.19	1.96

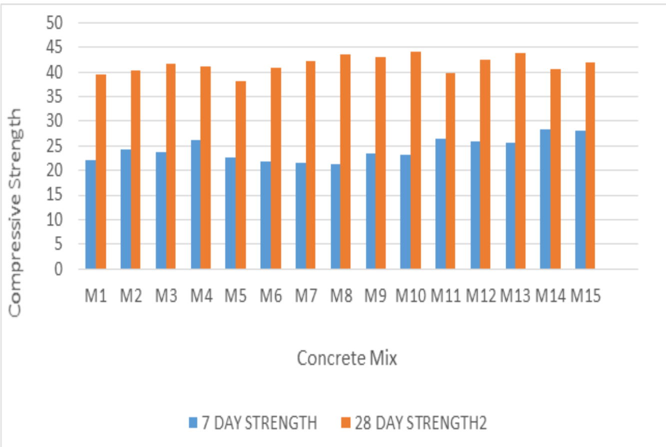

Chart -1: Graph of mathematical model result

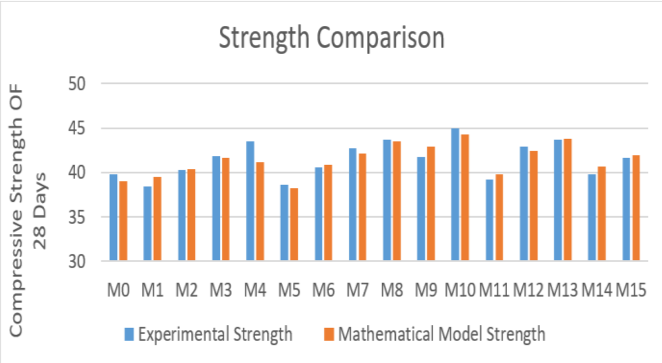

Chart -1: Experimental and predicted values of compressive strength

7. CONCLUSIONS

From the study, the some important points are noted which are listed below.

1. All the self-compacting concrete mix gets good slump flow maximum flow is 680 mm at M2 mix having 10% MK and 15%SF.
2. As the increase of metakaolin and Silica fume the value of flow is decreasing.
3. As the increasing the metakaolin the initial strength is increased.
4. The strength of self compacting concrete are increases with the mixes of silica fume.
5. At the 10% replacement of metakaolin and 25% replacement of silica fume get the maximum strength of concrete.

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