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Procedia Engineering 51 (2013) 65 – 74

Procedia Engineering

www.elsevier.com/locate/procedia

Chemical, Civil and Mechanical Engineering Tracks of 3rd Nirma University International Conference (NUiCONE 2012)

Evaluation and mix design for ternary blended high strength concrete

R Rathan Raj[a]*, E B Perumal Pillai[b], A R Santhakumar[c]

[a]*Assistant Professor, Department of Civil Engineering, Sathyabama University, Chennai – 600 119, Tamilnadu, India.*
[b]*Professor & Registrar, Anna University of Technology Madurai, Madurai – 625 002, Tamilnadu, India.*
[c]*Professor & Consultant, CDMM, College of Engineering, Guindy, Anna University, Chennai – 600 025, Tamilnadu, India.*

Abstract

Concrete has been the most widely used construction material for several years. Though conventional concrete (CC) performs very well under normal conditions, in special situations a very high compressive strength of concrete together with sustainability to aggressive environments is necessary. Hence, higher compressive strength of range more than 60 MPa is essential. So far, concrete mixes were designed only for strength and workability requirements. For the performance of long satisfactory life, the designed mixes should be checked and proved for their durability properties such as low permeability, high corrosion resistance, freezing and thawing resistance, fire resistance etc. This necessitates a detailed study on High strength concrete (HSC). This paper formulates a simplified mix design procedure for HSC by combining BIS and ACI code methods of mix design along with available literatures on HSC. Based on the above procedure M60 mix of ternary blended high strength concrete with different percentage replacement of cement by metakaolin (MK) and redmud (RM) is arrived at. These HSC mixes are tested experimentally for compression, split tension, flexure and workability. The performance of the designed mixes is very good and the results are reported in this paper.

Selection and peer-review under responsibility of Institute of Technology, Nirma University, Ahmedabad.

Keywords: high strength concrete, mix design, cement replacement, metakaolin, redmud.

1. Introduction

HSC is a construction material which is being used increasingly in recent years due to its long-term performance and better rheological, mechanical and durability properties than CC. HSC possesses invariably high strength, reasonable workability and negligible permeability. Compared to CC, preparation of HSC requires lower water-binder (w/b) ratio and higher cement content. The durability properties of concrete are given importance, which make High Strength Concrete (HSC) into high performance concrete (HPC). High strength and better durability properties become reality for CC by the reduction of porosity, inhomogeneity, micro-cracks in concrete and the transition zone. High strength concrete provides a solution, and achieves a specified service life by enhancing the concrete characteristics such as volume stability, long term mechanical properties etc. [1]. Incorporation of mineral admixtures act as pozzolanic materials as well as microfillers, thereby the microstructure of hardened concrete becomes denser and improves the strength and durability properties. Addition of chemical admixtures, such as superplasticizer, improves the properties of plastic concrete with regard to workability, segregation etc. Low permeability characteristic of HSC reduces the risk of corrosion of steel and attack of aggressive chemicals. This permits the use of HSC in marine/offshore structures, nuclear power plants, bridges and places of extreme and adverse climatic conditions. Eventually, HSC reduces maintenance and repair costs.

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* Corresponding author. Tel.: +919443431154
E-mail address: r.rathanraj@gmail.com

Selection and peer-review under responsibility of Institute of Technology, Nirma University, Ahmedabad.
doi:10.1016/j.proeng.2013.01.012

This study aims at determining the beneficial effect when cement is blended with metakaolin and redmud to strengthen and to develop a simplified mix design procedure, especially for HSC by varying the percentage replacement of cement by MK and RM (0-14%) with different MK:RM proportions at a constant dosage of superplasticizer. Metakaolin is basically made up of silica and alumina in an amorphous state, that react with calcium hydroxide (CH) produced by Portland cement hydration to form calcium hydro silicate (C-S-H) and calcium hydroaluminosilicate (essentially gehlenite-C_2ASH_8) [2]. Attempts were based mainly on the use of redmud as a partial substitute for clay in the production of bricks and other ceramics products [3, 4]. Redmud is reddish-brown in colour and a superfine, fine particle-size distribution as its physical characteristics, as well as alkalies, iron oxides and hydroxides, aluminium hydroxides, calcium carbonate, titania and silica in its chemical composition. This superfine particle characteristic of redmud makes this a promising admixture for mortar and concrete [5]. The redmud is fairly caustic, with pH of pastes being typically in the range 11-13. Except for the residual NaOH left after the final washing in the plant, the components of redmud are usually considered to be relatively inert and nonreactive [6]. Despite its apparent inertness and obvious lack of reactive silica, the idea of utilizing the pozzolanic reaction to bind redmud mixtures seemed to be a feasible and potentially cost effective alternative for the very simple reason that the redmud has a high pH environment. The chemicals in red mud hydrate to produce cementitious components, which are fairly well known from the fact that they are responsible for the strengths of high alumina cement mortars [7]. Hence in this investigation more emphasis is given to study HSC using MK, RM and superplasticizer so as to achieve better concrete composite and also to encourage the increased use of MK and RM to maintain ecology.

2. Experimental procedure

2.1. Materials and mix proportion

The following are the materials that were used in this investigation. The chemical composition of ordinary Portland Cement (OPC), Metakaolin (MK) and Redmud (RM) are presented in Table 1.

- Ordinary Portland Cement (OPC), 53 Grade conforming to BIS: 12269 – 1987 (specific gravity: 3.15, Blaine fineness: 320 m^2/Kg).
- Metakaolin as mineral admixture in dry densified form was obtained from ELKEM INDIA (P) LTD., Mumbai conforming to ASTM C – 1240 (specific gravity: 2.54, Blaine fineness: 15 m^2 / gm).
- Redmud as wastes and by products in dry densified form was procured from Madras Aluminium Co. Ltd (MALCO), Mettur (specific gravity: 2.74, Blaine fineness: 10.5 m^2 / gm).
- Superplasticizer (chemical admixture) based on Sulphonated Naphthalene Formaldehyde condensate – CONPLAST SP 430 conforming to BIS: 9103 – 1999 and ASTM C-494.
- Locally available quarried and crushed granite stones confirming to graded aggregate of nominal size 12.5 mm as per table 2 of BIS: 383 – 1970 (specific gravity: 2.82, fineness modulus: 6.73) as Coarse aggregates (CA).
- Locally available Karur river sand conforming to Grading zone II of table 4 of BIS: 383-1970 (specific gravity: 2.60, fineness modulus: 2.964) as fine aggregates (FA).
- Water: Drinking water used for concreting and curing.

Table 1. Chemical Composition of OPC, MK and RM

Type	SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3	MgO	Na_2O	K_2O	Ig. loss
OPC	21.8	4.8	3.8	63.3	2.2	0.9	0.21	0.46	2.0
MK	52.3	44.9	0.4	0.5	< 0.1	0.2	0.12	0.02	0.8
RM	9.91	20.8	49.0	1.92	0.21	< 0.01	4.11	< 0.01	11.50

2.2. Mix design for HSC

Since there is no existing method of mix design found suitable for HSC, a simplified mix design procedure is formulated by combining the BIS method, ACI methods for concrete mix design and the available literatures on HSC. The formulation of mix and detailed design procedure is given in Appendix A

A concrete mix proportion of characteristic target mean compressive strength of 60Mpa was designed without any mineral admixtures. To get the optimum proportions, trial mixes were obtained by replacing 0, 2, 4, 6, 8, 10, 12 and 14 percent of the mass of cement by metakaolin and redmud alone and also in the proportions of 50:50, 60:40, 70:30 and 80:20 respectively. In all the above combinations, a superplasticizer (SP) was used at 1% by weight of the binder for obtaining workable concrete. The details of composition of the ternary blended concrete mixture are given in Table 2.

Table 2. Details of HSC trial mixes for characteristic target mean compressive strength of 60MPa (w/b ratio = 0.33)

Mix	Replace-ment %	% Ratio	Cement Kg	MK Kg	RM Kg	FA Kg	CA Kg	SP Litres	Water Litres
CC	0%	--	439.39	--	--	846.98	1044.91	8.99	143.26
MK$_2$	2%	--	430.60	8.79	--	845.09	1044.91	8.99	143.26
RM$_2$			430.60	--	8.79	845.31	1044.91	8.99	143.26
MK$_4$	4%	--	421.81	17.58	--	843.21	1044.91	8.99	143.26
RM$_4$			421.81	--	17.58	843.63	1044.91	8.99	143.26
MK$_6$	6%	--	413.03	26.36	--	841.32	1044.91	8.99	143.26
RM$_6$		--	413.03	--	26.36	841.96	1044.91	8.99	143.26
MR$_{6A}$		50:50	413.03	13.18	13.18	841.64	1044.91	8.99	143.26
MR$_{6B}$		60:40	413.03	15.82	10.55	841.57	1044.91	8.99	143.26
MR$_{6C}$		70:30	413.03	18.45	7.91	841.51	1044.91	8.99	143.26
MR$_{6D}$		80:20	413.03	21.09	5.27	841.45	1044.91	8.99	143.26
MK$_8$	8%	--	404.24	35.15	--	839.43	1044.91	8.99	143.26
RM$_8$		--	404.24	--	35.15	840.29	1044.91	8.99	143.26
MR$_{8A}$		50:50	404.24	17.58	17.58	839.85	1044.91	8.99	143.26
MR$_{8B}$		60:40	404.24	21.09	14.06	839.78	1044.91	8.99	143.26
MR$_{8C}$		70:30	404.24	24.61	10.55	839.68	1044.91	8.99	143.26
MR$_{8D}$		80:20	404.24	28.12	7.03	839.61	1044.91	8.99	143.26
MK$_{10}$	10%	--	395.45	43.94	--	837.55	1044.91	8.99	143.26
RM$_{10}$		--	395.45	--	43.94	838.62	1044.91	8.99	143.26
MR$_{10A}$		50:50	395.45	21.97	21.97	838.08	1044.91	8.99	143.26
MR$_{10B}$		60:40	395.45	26.36	17.58	837.98	1044.91	8.99	143.26
MR$_{10C}$		70:30	395.45	30.76	13.18	837.87	1044.91	8.99	143.26
MR$_{10D}$		80:20	395.45	35.15	8.79	837.76	1044.91	8.99	143.26
MK$_{12}$	12%	--	386.66	52.73	--	835.66	1044.91	8.99	143.26
RM$_{12}$		--	386.66	--	52.73	836.95	1044.91	8.99	143.26
MR$_{12A}$		50:50	386.66	26.36	26.36	836.31	1044.91	8.99	143.26
MR$_{12B}$		60:40	386.66	31.63	21.09	836.19	1044.91	8.99	143.26
MR$_{12C}$		70:30	386.66	36.90	15.82	836.06	1044.91	8.99	143.26
MR$_{12D}$		80:20	386.66	42.18	10.54	835.93	1044.91	8.99	143.26
MK$_{14}$	14%	--	377.88	61.52	--	833.77	1044.91	8.99	143.26
RM$_{14}$		--	377.88	--	61.52	835.27	1044.91	8.99	143.26

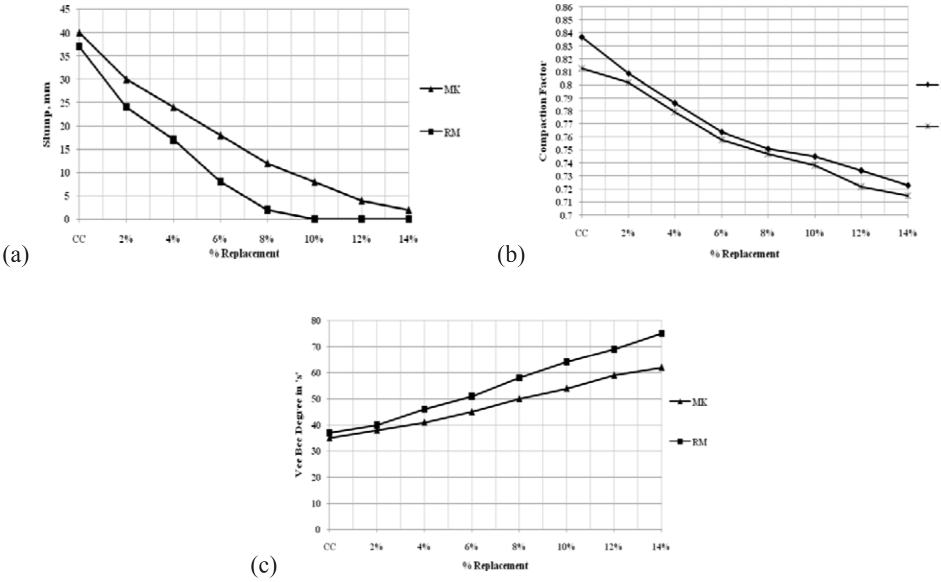
2.3. Tests on fresh and hardened concrete

Workability tests such as slump test, compaction Factor test, vee-bee consistometer test and flow table test were carried out for fresh concrete as per BIS specifications, keeping the dosage of superplasticizer as constant at 3 % by weight of binder. For hardened concrete, cube compression strength test on 150 mm size cubes at the age of 1 day, 3 days, 7 days, 14 days, 28 days & 56 days of curing were carried out using 400 tonne capacity compression testing machine as per BIS : 516-1959. Also compression strength and split tensile strength tests on 150 mm x 300 mm cylinders and flexure test on 100 mm x 100 mm x 500 mm beams were carried out on 28 days cured specimens as per BIS specifications.

3. Results and discussions

3.1. Tests on fresh concrete

The variation in slump, Vee-Bee degree and compaction factor of different % replacement of metakaolin and redmud high strength concrete is given in Fig. 1 (a), (b) & (c). While observing the characteristic of fresh concrete of different mixes, it was noted that, the concrete matrix when replaced by different proportion of MK and RM, the workability decreased with increasing quantity of MK and RM. This is due to the increase of the quantum of fine material in the concrete mix. As a result, it became difficult to have the same level of good workability even by using superplasticizer. The increase in the percentage of replacement of MK and RM results in more paste volume, which also contributes to a reduction in bleeding. The concrete behaved in a cohesive and mobile manner during the compacting factor and Vee-Bee degree tests. It is to be noted that all the mixtures used in this work exhibited slumps less than 50 mm which is considered as very low. There is no slump in concrete at increased percentage of replacement of RM by 10%. There is a considerable reduction in the compaction factor value by 0.1 also an increased value of the Vee-Bee degree by 38 seconds. The decrease in slump, compacting factor and increase in Vee-Bee degree may be attributed to the fineness and water absorbing characteristics of redmud. There is also a function of high chemical reactivity, which results in an increase in water demand.



(a) (b)

(c)

Fig. 1. Influence of MK and RM on workability of concrete (a) slump value, (b) compaction factor and (c) Vee-Bee degree.

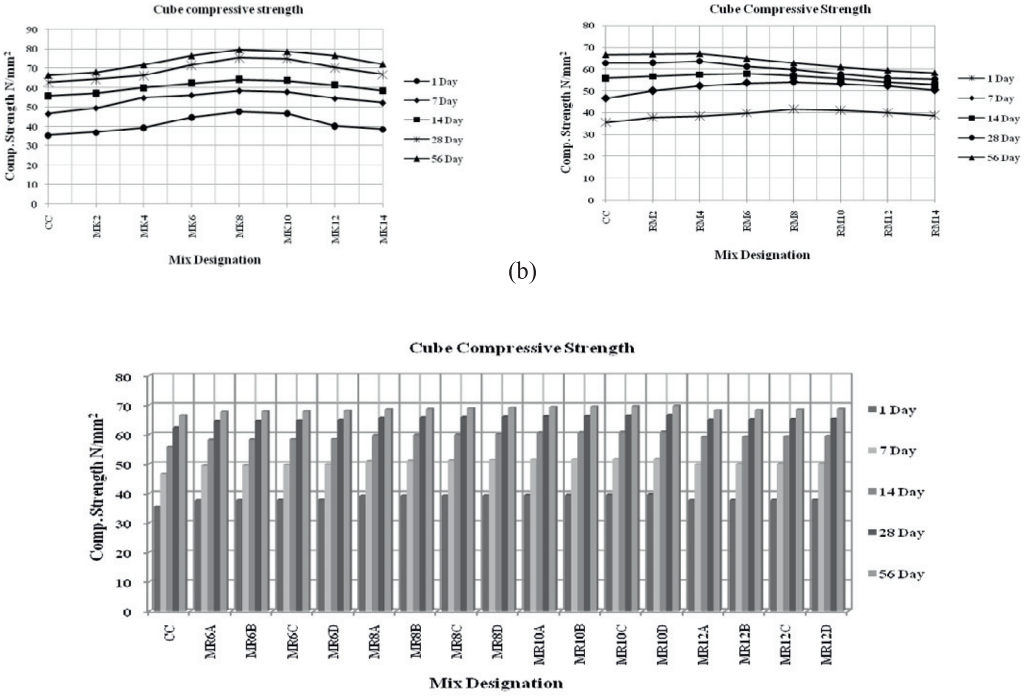
3.2. Cube compression test

For the cube compression testing of concrete, 150mm cubes were employed. All the cubes were tested in saturated condition, after wiping out the surface moisture. For each trial mix combination, three cubes were tested at the age of 1, 7, 14, 28 and 56 days of curing. The tests were carried out at a uniform stress after the specimen has been centered in the testing machine. The variations in the strength of concrete with increasing replacement level of OPC by MK, RM and MK-RM blend are shown in Fig. 2 (a), (b) & (c). The strength of metakaolin concrete increases systematically with an increase in metakaolin level at all curing times. The maximum compressive strength for mixes obtained by replacement of 8% of OPC with MK at 28th day testing is 75.52 MPa and 56th day testing is 79.58 MPa which clearly shows this concrete is High Strength Concrete (> 60 MPa). That is, as the metakaolin content increases from 0%, the compressive strength gradually increases until metakaolin content reaches 8% and thereafter, it gradually falls. This is due to the fact that the compressive strength increases in concrete due to the pozzolanic reaction and filler effect of the metakaolin. In the pozzolanic reaction, the metakaolin reacts with calcium hydroxide (which is a hydration product of cement) and produces more C-S-H gel. C-S-H gel is the source of strength of hardened concrete, as it is the binder which binds the aggregate together. The 7 days to 28 days compressive strength ratio of 8 % replacement is 0.773; whereas for the control concrete is 0.743.

From the Fig. 2 (b) it is seen that the strength increases up to 4% replacement of redmud. The maximum strengths for 28 -day and 56-day testing are 63.48MPa and 64.98 MPa respectively. However beyond 4% the strength starts decreasing for all mixes. The increase in strength may be due to the fact that the cement replacement of around 4% increases the finer particles in the mix, which increase its density by filling the voids. Another reason for increase in strength may be due to extra availability of Al_2O_3, SiO_2 and TiO_2 whose presence up to certain percentage increases the strength of concrete by combining with other constituents of cement during the progress of hydration. The 7 days to 28 days compressive strength ratio of 4% replacement is 0.823; whereas for the control concrete is 0.743.

Fig. 2 (c) shows, 1, 7, 14, 28 and 56 day strengths of concrete containing various metakaolin and redmud blends as partial OPC replacement. The graph represents different total percentage of replacement levels (6%, 8%, 10% and 12%) with the different metakaolin:redmud (MK:RM) proportions (50:50, 60:40, 70:30 and 80:20). In general, the strength increases with the increase in MK content of the blend and the strength decreases as RM content of the blend increases. In all the w/b ratios at 10% of total replacement, where a maximum strength occurs at 80% MK and 20% RM (28-day and

56-day strengths are 66.60 MPa and 69.72 MPa respectively). Beyond the 10% replacement levels there are remarkable reduction in the strength; it shows that 10% replacement is acting as the optimum replacement level to give higher strengths. In 10% replacement level the compressive strength of MK:RM proportion 50:50 and 80:20 are 6.2% and 6.7% which is higher than the control concrete.



(a) (b)

(c)

Fig. 2. Influence of binder content on cube strength of concrete (a) metakaolin, (b) redmud and (c) metakaolin-redmud blend.

3.3. Cylinder compression test

Fig. 3 shows the influence of MK, RM and MK-RM blend composition on cylinder compressive strength at 28 days. It was observed that the compressive strength is increased for mixes in all w/b ratios, with replacement of OPC by MK. That is, as the metakaolin content in the concrete increases from zero, the compressive strength gradually increases and metakaolin content replacement of 8% can be the optimum percentage of replacement. The increased percentage of cylinder compressive strength of 8% replacement of metakaolin compared to the control concrete is 29.6%. The cylinder to cube compressive strength ratio is 0.671. With the replacement of redmud in concrete, there are no remarkable changes in increasing the strength. The compressive strengths gradually increase up to 4% of replacement of RM by OPC can be the optimum percentage and thereafter there is decrease in the strength. The increased percentage of cylinder compressive strength of 4% replacement of redmud compared to the control concrete is 2.6%. The cylinder to cube compressive strength ratio is 0.632.

For the 28 day strengths of concrete containing various MK-RM blends, it was observed that, 10% of MK-RM blend replacement level show the higher compressive strength compared with the compressive strength of control concrete, also the MK:RM proportion 80:20 shows the increased compressive strength compared with the proportion 50:50. The increased percentage of cylinder compressive strength of 10% replacement of MK-RM blend compared to the control concrete with MK:RM proportion 80:20 and 50:50 are 8.6% and 7.6% respectively. The cylinder to cube compressive strength of 10 % replacement of MK-RM blend with MK:RM proportion 80:20 is 0.609.

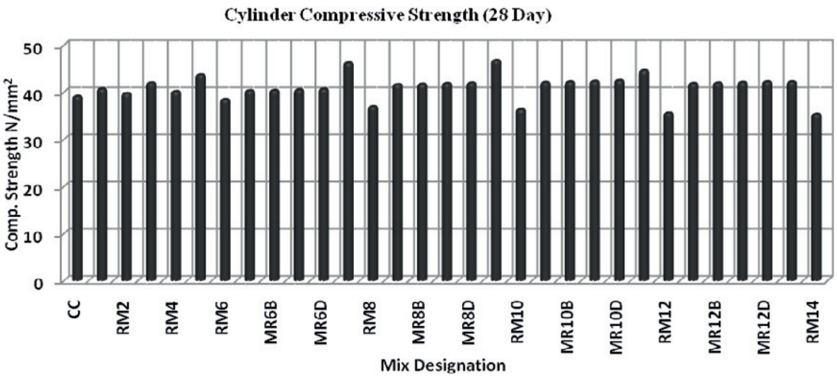


Fig. 3. Influence of binder content on cylinder compressive strength of concrete.

3.4. Split tensile strength test

This an indirect tests to determine the tensile strength of the specimen. Splitting tensile strength test was carried out on 150mmx300mm cylinder specimen after 28 days of curing. The load was applied gradually till the specimen split and readings were noted. In the test setup, for the split tensile strength test on the cylindrical specimen, the wooden strips are used to avoid the direct load on the specimen. The variation of splitting tensile strength of concrete at the age of 28 days with increasing replacement level of OPC by MK, RM and MK-RM blend is plotted in the form of graph as shown in Fig. 4. From the test results, it was observed that the maximum splitting tensile strength is obtained for mixes with 8% and 4% replacement of cement by MK and RM respectively. It is also observed that the splitting tensile strength increases with the increase in MK content. Moreover, the strength of concrete in compression and the strength of concrete in splitting tension are closely related and the ratio of the two strengths depends on the general level of strength of concrete. In other words, higher compressive strength shows higher tensile strength, but the rate of increase of tensile strength is less for HSC. The maximum tensile strength is observed for MK-RM blend replacement in concrete is 10%, also the MK:RM proportion 80:20 shows the increased tensile strength compared with the proportion 50:50.

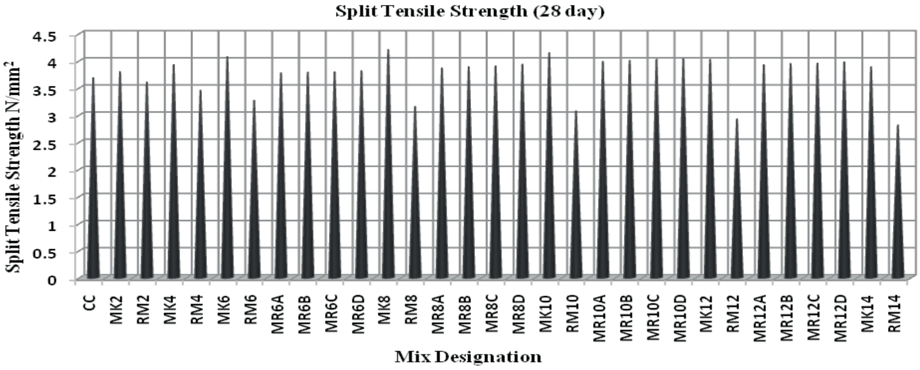


Fig. 4. Influence of binder content on split tensile strength of concrete.

3.5. Flexural strength test

Flexural strength tests were carried out on 100mmx100mmx500mm beams at the age of 28 days curing, using 100 KN capacity flexural strength machine by subjecting the specimen to two points loading to determine the flexural strength as per BIS: 516-1959. The variation flexural strength of concrete at the age of 28 days with increasing replacement level of OPC by MK, RM and MK-RM blend is plotted in the form of graph as shown in Fig. 5. The results show that maximum flexural strength is obtained for mixes with 8% and 4% replacement of cement by MK and RM respectively. The maximum flexural strength is observed for MK-RM blend replacement in concrete is 10%, also the MK:RM proportion 80:20 shows the increased tensile strength compared to the proportion 50:50. The flexure strengths obtained experimentally are higher than the value calculated by the expression 0.7 $\sqrt{f_{ck}}$ as per BIS: 456-2000.

4. Conclusions

Based on the investigation carried out on the ternary blended HSC mixes, the following conclusions are drawn.

- A simplified mix design procedure for HSC using MK, RM, MK-RM blend and superplasticizer is formulated by combining BIS & ACI code methods of mix design and available literatures on HSC & HPC.
- The optimum percentage of cement replacement by MK, RM & MK-RM blend are 8%, 4% & 10% respectively for achieving maximum compressive, split tensile and flexural strengths.
- The 7 days to 28 days compressive strength ratio of HSC with MK & RM replacement are 0.773 & 0.823.
- The BIS: 456-2000 code underestimates the flexural strength for HSC.
- Use of MK & RM in concrete reduces the workability in terms of slump, compaction factor and Vee-Bee value.

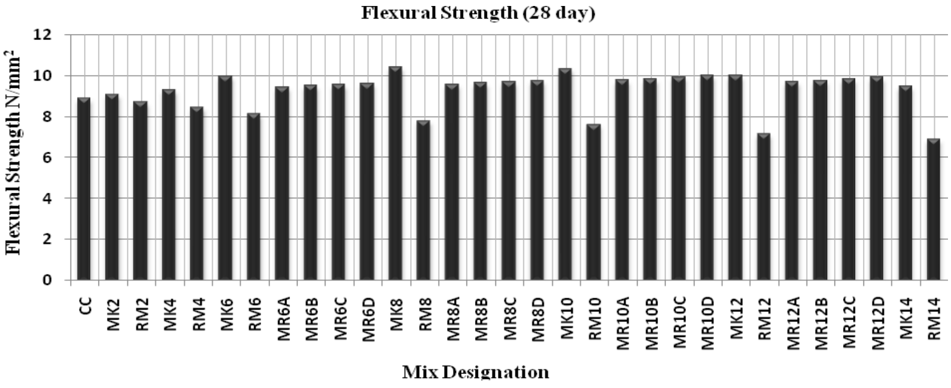


Fig. 5. Influence of binder content on flexural strength of concrete.

Acknowledgements

The authours gratefully acknowledge and wish to thank the English Indian Clay Limited, Trivandrum and the Madras Aluminium Co. Ltd (MALCO), Mettur for providing Metakaolin and Redmud required for this investigation.

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Appendix A. Detailed mix design procedure for HSC

A.1. Target mean strength

The target mean strength ($\overline{f_{ck}}$) is calculated as follows:
($\overline{f_{ck}}$) = fck + (t x S) with usual BIS notations. When adequate data is not available to establish 'S', the ($\overline{f_{ck}}$) value can be determined from the following table 1 as given by ACI Report 318.

Table 1 Target mean strength when data are not available to establish a standard deviation

Specified characteristic compressive strength, f_{ck} (MPa)	Target mean compressive strength, $\overline{f_{ck}}$ (MPa)
Less than 20.5	f_{ck} + 6.9
20.5 - 34.5	f_{ck} + 8.3
More than 34.5	f_{ck} + 9.7

A.2. Selection of maximum size of coarse aggregate (CA)

The maximum size of the coarse aggregate is selected from the following table 2 as given by ACI Report 211.4R.93.

Table 2 Maximum size of coarse aggregate

Required Concrete Strength (MPa)	Maximum aggregate size (mm)
Less than 62	20 - 25
Greater than or equal to 62	10 – 12.5

A.3. Estimation of free water content

The water content to obtain the desired workability depends upon the amount of water and amount of superplasticizer and its characteristics. However, the saturation point of the superplasticizer is known, and then the water dosage is obtained based on table 3. If the saturation point is not known, it is suggested that a water content of 145 litres/m^3 shall be taken to start with.

Table 3 Determination of the minimum water dosage

Saturation point (%)	0.6	0.8	1.0	1.2	1.4
Water dosage (l/m^3)	120 to125	125 to135	135 to145	145 to155	155 to165

A.4. Superplasticizer dosage

The superplasticizer dosage is obtained from the dosage at the saturation point. If the saturation point is not known, it is suggested that a trial dosage of 1.0% shall be taken to start with.

A.5. Estimation of air content

The air content (approximate amount of entrapped air) to be expected in HPC is obtained from table 4 as given by ACI Report 211.4R.93 for the maximum size of CA having been used. However, it is suggested that an initial estimate of entrapped air content shall be taken as 1.5% or less since it is HPC, and then be adjusted on the basis of the result obtained with the trial mix.

Table 4 Approximate entrapped air content

Nominal maximum size of coarse aggregate (mm)	Entrapped air, as percent of volume of concrete
10	2.5
12.5	2.0
20	1.5
25	1.0

A.6. Selection of coarse aggregate (CA) content

The coarse aggregate content is obtained based on the method described in table 5 as a function of the typical particle shape. If there is any doubt about the shape of the CA or if the shape of it is not known, it is suggested that a CA content of 1000 kg/m^3 of concrete shall be taken to start with. The CA so selected should satisfy the requirements of grading and other requirements of BIS: 383 – 1970.

Table 5 Coarse aggregate content

Coarse aggregate particle shape	Elongated or Flat	Average	Cubic	Rounded
Coarse aggregate dosage (kg/m^3)	950-1000	1000-1050	1050-1100	1100-1150

A.7. Selection of water-binder (w/b) ratio

The water-binder ratio for the target mean compressive strength is chosen from figure 1, the proposed w/b ratio Vs compressive strength relationship. The w/b ratio so chosen is checked against the limiting w/c ratio for the requirements of durability as per table 5 of BIS: 456–2000, and the lower of the two values is adopted.

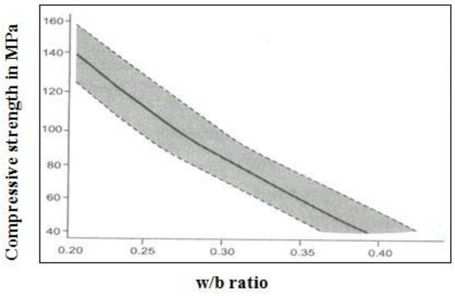

Fig. 1 Proposed w/b ratio Vs compressive strength relationship

A.8. Calculation of binder contents

The binder or cementitious contents per m^3 of concrete is calculated from the w/b ratio and the quantity of water content per m^3 of concrete. Assuming the percentage replacement of cement by MK & RM (0-14%), the MK & RM content is obtained from the total binder contents. The remaining binder content is composed of cement. The cement content so calculated is checked against the minimum cement content for the requirements of durability as per table 5 and 6 of BIS: 456–2000 and the greater of the two values is adopted.

A.9. Superplasticizer content

The mass of solids in the superplasticizer (M_{sol}) in kg, the volume of liquid superplasticizer (V_{liq}), the volume of water in the liquid superplasticizer (V_w) and the volume of solids in the liquid superplasticizer (V_{sol}) are calculated from the following equations (1 - 4)

$$M_{sol} = C \times \frac{d}{100} \tag{1}$$

$$V_{liq} = \frac{M_{sol} \times 100}{s \times S_s} \tag{2}$$

$$V_w = V_{liq} \times S_s \left[\frac{100 - s}{100} \right] \tag{3}$$

$$V_{sol} = V_{liq} - V_w \tag{4}$$

Where

C = mass of the cementitious materials (kg)
d = superplasticizer dosage expressed as the % of its solid content
S = total solid content of the superplasticizer in percentage, and
S_s = specific gravity of the liquid superplasticizer

A.10. Estimation of fine aggregate (FA) content

The absolute volume of FA is obtained from the following equation (5)

$$V_{fa} = 1000 - \left[V_w + \frac{M_c}{S_c} + \frac{M_{mk}}{S_{mk}} + \frac{M_{rm}}{S_{rm}} + \frac{M_{ca}}{S_{ca}} + V_{sol} + V_{ea} \right] \tag{5}$$

Where

V_{fa} = absolute volume of FA in litres per m^3 of concrete
V_w = volume of water (litres) per m^3 of concrete
M_c = mass of cement (kg) per m^3 of concrete
S_c = specific gravity of cement
M_{mk}, M_{rm}, M_{ca} = total masses of the metakaolin, redmud and coarse aggregate (kg) per m^3 of concrete
S_{mk}, S_{rm}, S_{ca} = specific gravities of saturated surface dry metakaolin, redmud and coarse aggregate
V_{sol}, V_{ea} = volume of solids in the superplasticizer and entrapped air (litres) per m^3 of concrete

The fine aggregate content per unit volume of concrete is obtained by multiplying the absolute volume of fine aggregate and the specific gravity of the fine aggregate.

A.11. Moisture adjustments

The actual quantities of CA, FA and water content are calculated after allowing necessary corrections for water absorption and free (surface) moisture content of aggregates. The volume of water included in the liquid superplasticizer is calculated and subtracted from the initial mixing water.

A.12. Unit mass of concrete

The mass of concrete per unit volume is calculated by adding the masses of the concrete ingredients.