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Research Article

Partial Replacement of Cement with Ceramic Waste & Metakaolin Powder And Fine Aggregate With Brick Dust In M20 Concrete

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ABSTRACT

Partial substitution of concrete constituents like cement, sand, and coarse aggregate with unconventional materials like industrial wastes, construction waste, and other materials has proved to be quite promising. Based on prior investigations, cement replacement in concrete with ceramic powder leads to improved performance in the range of 15-40% by weight, and metakaolin leads to enhanced performance in the replacement range of 15-30% by weight. This research work chronicles the experimental findings of the commission of concrete grade M20 with partial replacement of cement and fine aggregate in terms of strength and durability. The fine aggregate replacement with brick dust is kept constant at 25% by weight. Replacement of cement is done separately with ceramic powder at 10%, 20%, and 30% by weight and with metakaolin at 10%, 15% & 20% by weight. Each composition is tested for compression, split tensile and beam flexure strength. Further, each composition is tested for durability performance in terms of coefficient of capillary rise and chlorine bulk diffusion test. Based on the strength and durability test, the optimum replacement of cement is found to be 20% by ceramic powder ceramic and 15% for metakaolin, giving a cost-benefit of 670 & 386 rupees by ceramic replacement and 487& 203 rupees by metakaolin replacement per cubic meter of concrete as compared to conventional mix and mix with 25% fine aggregate replacement with brick dust respectively. This result clearly shows that ceramic and metakaolin powder can be used in concrete mixtures as cement replacement with improved strength & durability than conventional concrete and cost-effectiveness.

Keywords: Ceramic powder, Metakaolin, Brick dust, Strength, Durability, Cost Effectiveness, Sustainable Materials.

Introduction

This investigation deals with the mechanical behaviour and durability aspect of concrete prepared with replacement of fine aggregate with brick kiln dust and cement with ceramic powder in first trial and metakaolin in next trial. It investigates the use of one of the major construction waste and industrial waste apart from raw material metakaolin in concrete making that could minimize its disposal problem and help in improving the concrete mechanical strength and durability. Specific objectives of the current investigation include:

- Investigating the impact on strength of concrete due to partial replacement of cement separately with ceramic powder and metakaolin by weight keeping the fine aggregate replacement with brick dust constant at 25% by weight.
- Investigating the impact on durability of concrete due to partial replacement of cement separately with ceramic powder and metakaolin by weight keeping the fine aggregate replacement with brick dust constant at 25% by weight.

- Determining the optimum replacement proportion of concrete composition to get maximum improvement in concrete mechanical behaviour and durability characteristics and determining the cost effectiveness of optimum composition.

The investigation is done in various stages: Stage I deals with investigation and assessment of material properties used in the research work. The tests include obtaining the physical properties of various materials used in the research like fineness, consistency, initial setting time & compressive strength of cement, metakaolin and ceramic powder and specific gravity & grading of fine aggregate, specific gravity & grading of brick kiln dust and specific gravity, water absorption & sieve analysis of coarse aggregate. Stage II is associated with preparation of mix design of concrete based on the results obtained in the first stage. The design mix is done for M20 grade of concrete with workability of 80mm slump. Stage III is associated with the casting of cylinders & cubes specimens for each proportion replacement that are analysed in the research work based on second stage mix design. Stage IV embraces testing of the strength properties of the specimens like compressive strength of cubes, split tensile strength of cylinders & Flexural Strength of the concrete beams. Stage V deals with testing of the durability properties of the concrete specimens like capillary coefficient of water absorption and Chlorine bulk diffusion test.

1. Related Studies

Sicakova et. al [2017][1]studied the set of mortar samples, as well as set of concrete samples with portions of brick, glass and concrete powders as a partial substitution of natural aggregate. Long-time water absorption coefficient was tested; positive effect of fine-grain additive was demonstrated only in case of concretes, while the concrete powder gave the best results and the glass powder gave the worst one. Effect of time was found to be beneficial in all cases. Siva et al. [2017][2] used bricks as replacement material. Bricks are normally used as the non-bearing wall structure. In this experiment when fine aggregates are partially replaced by crushed bricks in proportion of 10%, 15%, 20% & 25%, then it was found that the workability of concrete is decreases. Compressive strength obtained is maximum when replacement is done with 20% of crushed fire bricks. Because crushed fire brick is made of plastic and non-plastic clay. It was put into kiln at 1300°C for 10 to 15 days. Then its property gets totally changed. The unit weight of fire brick is 20KN/m. Crushed fire brick is sieved on 4.75 mm sieve and which passes from the sieve of 4.75 mm sieve and retained from 75 micron I.S.-sieve. For test the of split tensile strength, cylinder is made of 150mm x 300 mm size for M30 concrete grade after partial replacement. This is kept for 24 hours and curing is done up to 28 days. Fine aggregates of fire brick give higher compressive strength when it replaced 20% of fine aggregates. This compressive strength is 1.2% in higher, but split tensile strength degraded, if percentage of replacement is more than 20%. In contrast to this, Ruchi Chandrakar & Avinash Singh [2017][3] investigated when marble product is mixed in concrete mix M-20 in different percentage (5%, 10%, 15%, 20%, 25%, and 30%) by weight, as a replacement of cement & curing is done for 7 and 28 days, the replacement of cement with 10% of marble powder gives the maximum compressive strength at both 7 days and 28 days curing period. It was found that marble dust is abundant at every processing plant and its cost is very less compared to cement. So, with the replacement of cement by marble dust a cost-effective concrete can be achieved. In the research work of Shruti et al. [2016][4] ceramic Powder has replaced the (OPC & PPC) cement accordingly in the percentages of 0%, 5%, 10%, 15% 20%, & 25% by weight of M-20 grade concrete. Concrete mixtures were developed, tested and compared in terms of compressive strength to the conventional concrete. The purpose of the investigation is to analyse the behaviour of concrete while replacing the cement with ceramic powder in different proportions in concrete. Raval et al. [2013][5] in his study**,** replaced cement by ceramic waste powder accordingly in the range of 0%, 10%, 20%, 30% 40%, & 50% by weight for M-25 grade concrete. The wastes employed came from ceramic industry which had been deemed unfit for sale due to a variety of reasons, including dimensional or mechanical defects, or defects in the firing process. The results demonstrate that the use ceramic masonry rubble as active addition endows cement with positive characteristics as major mechanical strength and the economic advantages. Reuse of this kind of waste has advantages economic and environmental, reduction in the number of natural spaces employed as refuse dumps. Indirectly, all the above contributes to a better quality of life for citizens and to introduce the concept of sustainability in the construction sector. Rashid et al. [2012][6]investigated about the effect of replacing natural coarse aggregate by brick aggregate on the properties of concrete. The properties of concrete obtained replacing stone aggregate as partially or fully by crushed clay bricks. This study was volumetric replacement such as 0%, 25%, 50%, 75% and 100% of stone aggregate as brick aggregate. The use of brick aggregate as a replacement of stone aggregate resulted reductions in unit weight, compressive strength, and modulus of elasticity of concrete by about 14.5%, 33%, and 28% respectively. The reduction in tensile strength of mixed aggregate concrete is found to be less significant up to 50% replacement of stone aggregate by brick aggregate. In their research work Bignozzi et. al. [2011][7] shown that polishing residue (P.R.), coming from porcelain stoneware tiles production, can be successfully used as new constituent for blended cement, however its action for enhancing the durability of cement matrix must be assessed. With this purpose, electrochemical tests (half-cell potential, impressed voltage and linear polarization techniques) have been carried out on steel reinforced mortar samples, prepared using a 25% P.R. based cement and 100% OPC as binder and exposed to a 3.5% NaCl solution. The corrosion resistance results and microstructure analysis highlight better durability performances for P.R.

based cement than those exhibited by OPC, mainly for curing time>28days. A study by Bazaz et al. [2006][8] about the performance of concrete produced with crushed bricks as the coarse & fine aggregate, this experiment has discussed about the physical characteristics of crushed clinker bricks, the compressive and tensile strength test results indicate that the quality of such bricks is low in comparison with natural rocks. The strength and durability of concrete is depending on the porosity, specific gravity, soundness, freezing & thawing resistance, compressive strength. In this study, the properties of concrete made with three types of crushed brick aggregate in terms of size and material.

2. Methodology

The methodology opted to accomplish the objective of the research work is described as below. Following test were performed to determine the effect of replacements in the strength & durability of the modified concrete.

2.1. Materials:

Following materials were adopted and tested for properties:

3.1.1 Cement: Ordinary Portland cement of 53 grade of Emami Double Bull Cement confirming to I.S.: 12269-2013 standards was used. The following tests were performed on cement & results is tabulated as below:

Table 1. Test results of cement

S. No.	Test	Experimental results	Recommended results as per I.S. Specifications
1	Fineness of Cement	6.2 %	Not more than 10%
2	Normal Consistency	30.5 (%)	Not more than 35%
3	Initial Setting Time	96 (min.)	Initial Setting Time ≥ 30 minutes
4	Compressive Strength	38.66 MPa (7 days) 54.21 Pa (28 days)	37 MPa (7 Days) 53 MPa (28 Days)

3.1.2 Fine & Coarse Aggregates: The locally available sand confirming to Zone-II grade of Table 4 of IS 383-1970 has been used as Fine Aggregate. Tests have been carried out as per the procedure given in I.S. Codes. Along with river sand, brick dust is also used and tested for properties as per the standards of fine aggregates. The powdered waste from brick kilns from Sarkanda nearby Koni has been collected in this investigation.

- Grading of aggregates: According to gradation of fine aggregates, it was observed to be confirming to zone-II as per Table 4 of I.S.: 383-1970
- Specific Gravity
- Water absorption

Table 2. Test results of Properties of Aggregates

S. No.	Test	Experimental results	Recommended results as per I.S. Specifications
1	Specific Gravity of river sand	2.65	2.65-2.67
2	Specific Gravity of brick dust	2.88	-
3	Specific Gravity of coarse aggregate	2.747	2.5-3
4	Water Absorption of coarse aggregate	0.576 %	0.1%-2%

***3.1.3* Ceramic powder:** Ceramic powder is a by-product of ceramic industry. It is estimated that 15 to 30% waste are produced of total raw material used, and although a portion of this waste may be utilized on-site, such as for excavation pit refill. Ceramic waste can be used in concrete to improve its strength and other durability factors. Ceramic waste can be used as a partial replacement of cement or as a partial replacement of fine aggregate sand as a supplementary addition to achieve different properties of concrete.

***3.1.4* Metakaolin:** Having twice the reactivity of as that of most other pozzolanas, metakaolin is a valuable admixture for concrete/cement applications. Substituting portland cement with 8–20% (by weight) metakaolin produces a concrete mix that have improved properties, including: the filler effect, the acceleration of OPC hydration, and the pozzolanic reaction.

2.2. Mix nomenclature & Proportions: In the following Table, description of various types of mix has been done along with nomenclature to easily identify various mixes.

Table 3. Different Mix Composition

Mix	Cement replacement	Fine Aggregate replacement
Mix 1	0%	0%
Mix 2	0%	25% by Brick Dust
Mix C1	10% by ceramic powder	25% by Brick Dust
Mix C2	20% by ceramic powder	25% by Brick Dust
Mix C3	30% by ceramic powder	25% by Brick Dust
Mix M1	10% by metakaolin powder	25% by Brick Dust
Mix M2	15% by metakaolin powder	25% by Brick Dust
Mix M3	20% by metakaolin powder	25% by Brick Dust

Thereafter the following table describes various designed proportions of materials by weight, per m^3 of concrete of grade M20, for different specified mixes. The designed ratio was obtained as 0.5:1:1.82:3.01, on the basis of which following proportions have been estimated:

Table 4. Mix Proportions for various mix

Mix	Cement (kg/ m^3)	Ceramic Powder (kg/m^3)	Metakaolin (kg/m^3)	Coarse Aggregate (kg/ m^3)	River sand as fine aggregate (kg/ m^3)	Brick Dust as fine aggregate (kg/ m^3)	Water (L/ m^3)
Mix 1	386	0	0	1162.83	705.93	0	193
Mix 2	386	0	0	1162.83	529.447	176.482	193
Mix C1	347.4	38.6	0	1162.83	529.447	176.482	193
Mix C2	308.8	77.2	0	1162.83	529.447	176.482	193
Mix C3	270.2	115.8	0	1162.83	529.447	176.482	193
Mix M1	347.4	0	38.6	1162.83	529.447	176.482	193
Mix M2	328.1	0	57.9	1162.83	529.447	176.482	193
Mix M3	308.8	0	77.2	1162.83	529.447	176.482	193

2.3. Investigatory tests: To investigate the strength & durability of the concrete mixes produced as per the above-mentioned proportions, following investigatory test were performed:

- Compressive strength test
- Split tensile strength test
- Flexural strength test
- Chlorine bulk diffusion test
- Capillary water absorption test

3.3.1 Compressive strength test: In accordance with I.S.: 516 – 1959, determination of compressive strength of concrete is accomplished by casting cubes of size 150mm X 150mm X 150mm that are cured for 7days and 28days. Compression testing machine installed in the material testing lab of civil engineering department, GGV Bilaspur was used for testing the compressive strength of concrete. At the time of testing the cube is taken out of water and is surface dried and then tested keeping the smooth faces in upper and lower part. In this study, for replacement of cement by ceramic powder, the replacement percent varies as 10%, 20% & 30%, whereas for replacement by metakaolin it varies as 10%.15% & 20%.

3.3.2 Split Tensile Strength Test: Cylindrical specimens of dimensions15 cm diameter & 30cm length has been prepared. The test specimen is made as the concrete is filled into the mould in layers approximately 10 cm deep. Each layer is compacted either by hand or by vibration. The tamping bar is a steel bar of 16 mm diameter, 60 cm long and bullet pointed at the lower end. The test specimen should be stored in a place at a temperature of 27° +/- 2°C for 24 +/- 0.5 hrs from the time addition of water to the dry ingredients. The load is applied continuously without shock at a rate of approximately 14-21kg/cm2/minute. Note down the breaking load (P).

The splitting tensile strength is calculated using the formula given in equation (1):

$$f_{ct} = \frac{2P}{\pi DL} - - - - - - - - (1)$$

Where P = Maximum Applied load, D = Diameter of the specimen, L = Length of the specimen

3.3.3 Flexural strength: In accordance with I.S.: 516 – 1959 the flexural strength of concrete was tested on beams of dimensions 10cm x10cm x50cm. Six beams were casted for various percentage replacements of cement by rice husk ash and tested in UTM by applying two-point loads. These point loads acted equidistant from centre of beams.

3.3.4 Chlorine Bulk Diffusion Test: The chloride diffusion coefficient is an indication of the capacity of any type of concrete to resist chloride penetration and is used to predict the service life of reinforced concrete structures. Nord test is standardized version of bulk diffusion test and is improvement over salt ponding test. It removes sorption effect and considers bulk diffusion and chlorine ion movement-at a constant temperature unaffected by conductors in the concrete. While the Nord test is capable of modelling chloride diffusion into concrete, it is still a long-term test. For low quality concretes, the minimum exposure period is 35 days. For higher quality concrete however, this period must be extended to 90 days or longer, just as for the salt ponding test. Long term –bulk diffusion-considers chlorine ion movement-at a constant temperature – unaffected by conductors in the concrete.

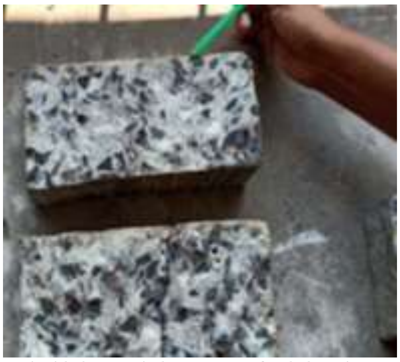

Figure 1. Visible evidence of chlorine diffusion

Figure 2. Measurement of Penetration depth of chlorine in concrete

3.3.5 Capillary water absorption test: Durability can be considered as one of the most significant parameters of building materials, having direct impact on the lifetime of material itself as well as the life-time of whole building. Durability of cement-based mortars/concretes is dependent mainly on the amount of a penetration of the harmful reactive materials inside the core of concrete matrix. Low permeability can improve resistance to the penetration of water, sulphate ions, chloride ions, CO_2, and other harmful substances, which cause chemical attack. Sorptivity expressed by water absorption coefficient is a characteristic of moisture transport into material, and recently it is an important performance characteristic of durability. Capillary water absorption test is performed on cubes of 150×150×150mm after 28 days of water curing according to ASTM 1585.

Figure 3. Water Absorption of cubes by capillary action

Figure 4. Weighing of cubes after water absorption.

3. Results & Discussion

Following results were attained on the basis of experimental investigation done as per the methodology explained:

3.1. Compressive strength test:

Compressive strength test on cubes after curing for 7 days and 28 days are performed as per I.S. 516:1959 part-1. The compressive strength of cube specimen of different composition is shown by graph below:

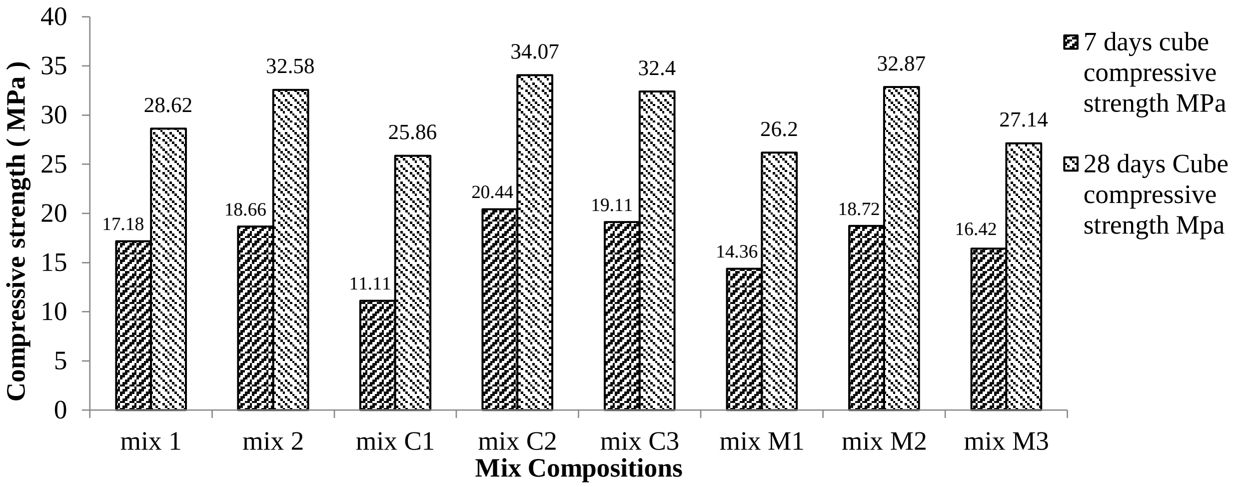

Figure 5. Compressive Strength test result of different mixes after 7 & 28 Days of curing.

Maximum cube compressive strength for 7 days water curing is observed to be 18.97% & 8.9% higher than conventional mix 1 and 9.54% & 0.3% higher than mix 2 at 20% ceramic powder (mix C2) and 15% metakaolin (mix M2) replacement of cement respectively. Maximum cube compressive strength for 28 days water curing is observed to be 19.04% & 14.85% higher than conventional mix 1 and 4.6% & 1.4% higher than mix 2 at 20% ceramic powder (mix C2) and 15% metakaolin (mix M2) replacement of cement respectively.

3.2. Split Tensile strength:

The comparison of the specimens with different replacement proportion of cement separately with metakaolin and ceramic powder and keeping the fine aggregate replacement with brick kiln dust fixed, is done with the conventional mix specimens, kept in water for curing for 28 days and is shown by the following graph.

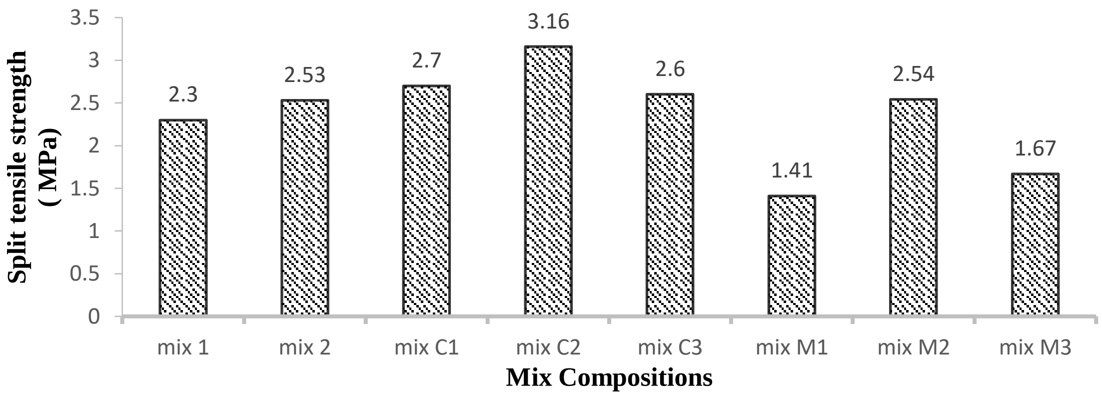

Figure 6. Split Tensile Strength test result of different mixes after 28 Days of curing.

For ceramic powder replacement of cement, the maximum Split Tensile strength is 3.16 MPa obtained at mix C2 i.e., 37.4% higher than conventional mix 1 and 24.9% higher than mix 2. For metakaolin powder replacement of cement, the maximum Split Tensile strength is 2.54 MPa obtained at mix M2 i.e., 10.43% higher than conventional mix 1 and 3.9% higher than mix 2.

3.3. Flexural Strength:

The specimens are cured for 28 days in water at room temperature and tests are performed after letting the specimens being surface dry and then reading are taken accurately. The Beams are kept longitudinally in universal testing machine & two-point load is applied by it. Loading is made by tare which applies the load as per standard distance from edge.

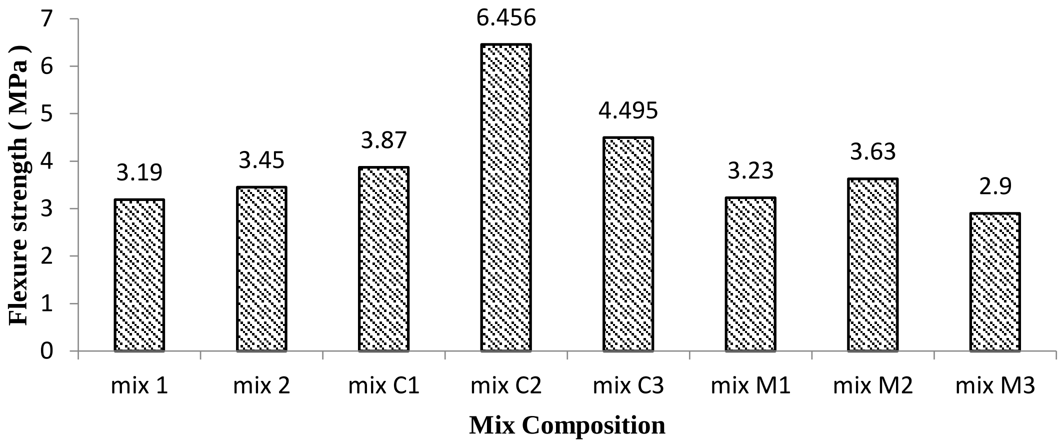

Figure 7. Flexural Strength test result of different mixes after 28 Days of curing.

For ceramic powder replacement of cement, the maximum Flexural strength of 6.456 MPa obtained at mix C2 is 96.4% higher than conventional mix 1 and 87.13% higher than mix 2. For metakaolin powder replacement of cement, the maximum Flexural strength of 3.63 MPa obtained at mix M 2 is 13.8% higher than conventional mix 1 and 5.2% higher than mix 2.

3.4. Chlorine Bulk Diffusion Test:

Capillary water absorption tests is performed on cubes of 150×150×150mm after 28 days of water curing according to ASTM 1585. The results obtained are tabulated as below and are further shown with graph:

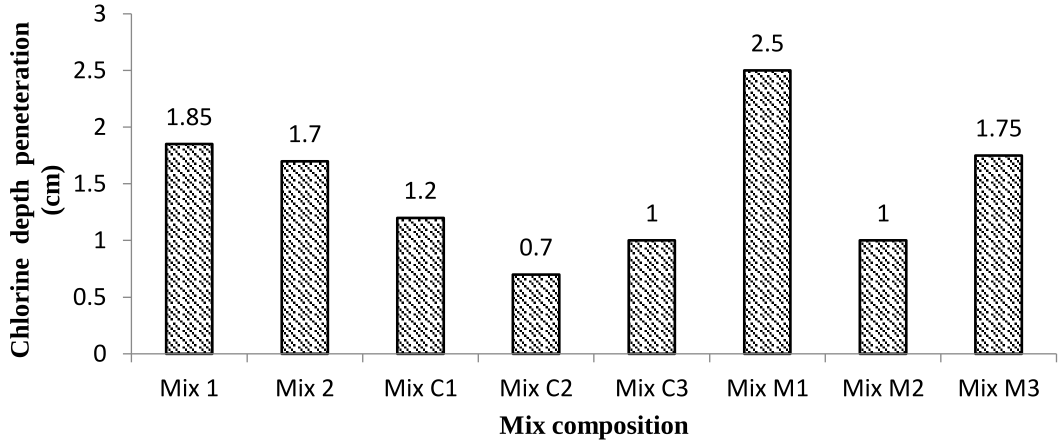

Figure 8. Chlorine depth penetration of different mixes after 28 Days of curing.

For ceramic powder replacement of cement, the minimum Chlorine depth of penetration 0.7 cm is obtained at mix C2 is. 62.16% lower than conventional mix 1 and 58.82% lower than mix 2. For metakaolin powder replacement of cement the minimum Chlorine depth of penetration 1.0 cm obtained at mix M2 is 45.94 % lower than conventional mix 1 and 41.17% lower than mix 2.

3.5. Capillary water absorption test:

Capillary water absorption tests is performed on cubes of 150×150×150mm after 28 days of water curing according to ASTM 1585. The results obtained are tabulated as below and are further shown with graph.

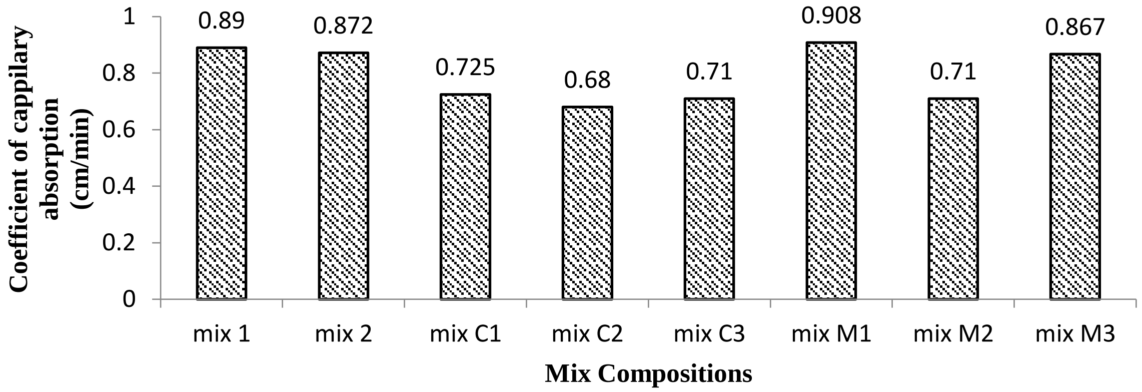

Figure 9. Rate of water absorption by capillary action in different mixes after 28 Days of curing.

For ceramic powder replacement of cement, the minimum Coefficient of Capillary water absorption is 0.68 cm/min obtained at mix C2 is 23.6% lower than conventional mix 1 and 22.01% lower than mix 2. For metakaolin powder replacement of cement the minimum Coefficient of Capillary water absorption is 0.71 cm/min obtained at mix M2 is 20.22% lower than conventional mix 1 and 18.57% lower than mix 2.

3.6. Cost effectiveness:

The optimum replacement proportion is analysed for its cost effectiveness in comparison with conventional mix in a tabulated form given below.

Table 5. Cost comparison of different mixes per cubic meter of concrete

Material	Rate Per Unit Kg (Rs.)	Conventional Mix (Mix1)		Optimum Mix (Mix 2)		Optimum Mix (Mix C2)		Optimum Mix (Mix M2)	
		Wt. PER m^3 (kg)	COST PER m^3 (Rs)	Wt. PER m^3 (kg)	COST PER m^3 (Rs)	Wt. PER m^3 (kg)	COST PER m^3 (Rs)	Wt. PER m^3 (kg)	COST PER m^3 (Rs)
Cement	5	386	1930	386	1930	308.8	1544	328.1	1640.5
Metakaolin	1.5	-	-	-	-	-	-	57.9	86.85
Ceramic powder	-	-	-	-	-	77.2	-	-	-
Sand	1.61	705.93	1136.5	529.45	852.41	529.45	852.41	529.45	852.41
Brick kiln dust	-	-	-	176.48	-	176.48	-	176.48	-
Coarse Aggregate	2.4	1162.83	2791	1162.83	2791	1162.83	2791	1162.83	2791
Total cost	-	-	5857.5	-	5574		5188		5371

The cost of per cubic meter of concrete for conventional mix is 5857.5 rupees, for mix 2 is 5574, for optimal mix C2 is Rs 5188/- and for optimal mix M2 is Rs 5371/-. The optimal mix C2 and M2 comes out to be cost effective as compared to conventional mix and mix 2. The optimal mix C2 gives a cost benefit of Rs 669.5/- & Rs 486.5/- per m^3, over conventional mix and mix 2 respectively. The optimal mix M2 gives a cost benefit of Rs 386/- & Rs 203/- per m^3, over conventional mix and mix 2 respectively.

4. Conclusion

The mechanical & durability properties of different composition of concrete in the experimental program were studied. The durability aspects of concrete were assessed on the basis of coefficient of capillary water absorption and chlorine bulk diffusion test. Based on the results and discussion, the following conclusions are summarized:

1. The 7 & 28 days cured Compressive Strength of cement replaced concrete was found to be enhanced as compared to conventional concrete mix & fine aggregated replaced concrete mix, at 20% replacement with ceramic powder (mix C2) & at 15 % replacement with metakaolin (mix M2). The enhancement in strength is obtained by the pozzolanic action of major chemical compound i.e. silica in both the replacement materials.
2. For 20% ceramic powder replacement of cement (mix C2) & 15% metakaolin replacement of cement (mix M2), the Split Tensile strength & Flexural strength obtained after 28 days of curing is higher than conventional concrete mix & fine aggregated replaced concrete mix as discussed in the result above.
3. The minimum Coefficient of Capillary water absorption is obtained at 20% replacement with ceramic powder (mix C2) & at 15 % replacement with metakaolin (mix M2). Hence, with the increase in content of

such pozzolanic materials, the durability aspect of the concrete can be enhanced as it restricts the capillary flow of water inside the concrete.

4. The minimum Chlorine depth of penetration is obtained at 20% replacement with ceramic powder (mix C2) & at 15 % replacement with metakaolin (mix M2). Hence, with the increase in content of such pozzolanic materials, the durability aspect of the concrete can be enhanced as it restricts the danger of carbonation i.e. corrosion of reinforcements by the chloride attack in the concrete.

5. Based on strength and durability test results, the optimum replacement percentage of cement is found to be 20% with ceramic powder (mix C2) and 15% with metakaolin (mix M2). The replacement in optimum percentages by ceramic powder & metakaolin improves strength & durability due to their pozzolanic actions & finer particle sizes.

6. The optimal mix C2 and M2 is found to be cost effective as compared to conventional mix concrete and mix 2.

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