Scientific Journal of Impact Factor (SJIF): 4.72
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 4, Issue 12, December -2017

Experimental Analysis on Concrete with Partial Replacement of Cement with Metakaolin and Fine Aggregate with Quartz Sand

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Abstract: *The use of quartz sand as partial replacement of fine aggregate and metakaolin as partial replacement of cement is an economical solution for making the concrete resistant to weathering e.t.c., Experimental work was carried out to investigate the effect of Metakaolin and quartz sand by partial replacement of cement and sand respectively and keeping same water cement ratio. Making 10% partial replacement of cement with metakaolin as constant and 25%, 50% and 75% quartz sand is made partial replacement of fine aggregate. Results revealed that the combination of metakaolin and quartz sand provided a positive influence on the mechanical and durability properties of concrete. The samples integrated the replacement with a combination of 10% metakaolin and 50% quartz sand showed maximum compressive strength of 41.97 MPa. In terms of chloride ion penetration, the mix having 10% MK and 75% QS reduces the penetration of chloride ion when compared with the rest of the mixtures.*

Key words: *Quartz Sand, Metakaolin, Concrete, Compressive Strength, Split Tensile Strength, Flexural Strength, Water Penetration, Rapid Chloride Ion-Permeability.*

1. INTRODUCTION

Production of every one tonne of OPC emits about one tonne of carbon dioxide (CO_2) into the atmosphere, causing global warming. Statistics expose that the Cement industry constitutes about 5 % of the total emission of green house gases (GHG) in India. Every one tonne of OPC requires 1.2 to 1.5 tonnes of lime stone as raw material and around 0.2 tonnes of coal as fuel for burning, causing depletion of natural resources. Metakaolin is a supplementary cementing material which is produced from carefully calcining kaolin clay between 600 and 800^oC to make it reactive. Exceeding this temperature can cause the metakaolin be less reactive or even inert. Metakaolin is composed mainly of alumina and silica phases, which can vary by approximately 10% and 8% respectively depending on the kaolin source. Metakaolin has the general form Al_2O_3•SiO_2. When blended with Portland cement in appropriate amounts, typically below 20%, it will enhance the strength and durability of the concrete. Metakaolin improves concrete performance by reacting with available calcium hydroxide to produce secondary calcium silica hydrate (C-S-H) as well as other hydrates (C_2ASH_8 [stratlingite], C_4AH_{13}, C_3AH_6). Not only improving concrete performance, metakaolin also makes concrete greener because metakaolin production does not produce chemical CO_2 as opposed to cement and also requires lower temperatures to produce. Sand becomes a scarce material, alternative for sand is needed all over, and also providing good strength than conventional concrete and some additional advantages. This study gives a new alternative for fine aggregate. Resistant nature to weathering is very useful for buildings in future. Quartz is the most abundant silica mineral. Pure Quartz is colourless and transparent. It occurs in most igneous and practically all metamorphic and sedimentary rocks. Quartz is mainly made up of silica. The formula for it is SiO2. It has a hardness of 7 on the Mohs scale. It is highly resistant to both mechanical and chemical weathering. This durability makes it the dominant mineral of mountaintops and the primary constituent of beach, river and desert sand.

Objectives of the project:

- Finding the optimum percentage of quartz sand that can be replaced for sand.
- Comparing the strength properties of conventional concrete mix of M30 with the properties of concrete with quartz sand and metakaolin partially replacing sand and cement respectively.
- Investigating the effects of metakaolin and quartz sand over the hardened properties of concrete.

2. EXPERIMENTAL PROGRAM

2.1 Materials:

i. Cement:

Cement is the most important material in concrete and it acts as a binding material. The cement is of 53 grade OPC manufactured by Zuari Cement Company confirming to IS 12269-1987 is used in this investigation. The physical properties of cement are shown in the table below.

S. No	Property	Test results
1	Normal consistency	29%
2	Specific gravity	3.12
3	Initial setting time	30 minutes
4	Final setting time	**2** minutes

Table 2.1: Properties of cement

ii. Fine aggregate:

In this investigation, natural sand was used as fine aggregate. Sand was obtained from Cheyyeru River near Nandalur in Kadapa district. The table 2.2 shows the physical properties of fine aggregate.

S.no	Paticulars	Results
1	Type	Normal sand
2	Specific gravity	2.9
3	Grading size	4.75mm
4	Water absorption	1%
5	Fineness modulus	2.88

Table 2.2: Properties of fine aggregate

iii. Coarse Aggregate:

In the present investigation, crushed granite aggregate of 20mm size was used. The coarse aggregate which is used in this project is obtained from nearby quarry (Aakepadu quarry). The following table shows the physical properties of coarse aggregate.

S.no	Paticulars	Results
1	Type	Crushed stone
2	Specific gravity	2.72
3	Maximum size	20 mm
4	Water absorption	0.8%
5	Fineness modulus	4.66
6	Bulk density	1688 Kg/m3

Table 2.3: Physical properties of coarse aggregate

iv. Water:

Water is used for mixing and curing of concrete. In the present investigation, tap water available in the campus was used for both mixing and curing of concrete.

v. Metakaolin:

Metakaolin manufactured from pure raw material to strict quality standards. Metakaolin is a high quality pozzalonic material, which when blended with Portland cement improves the strength and of concrete. Metakaolin removes chemically reactive calcium hydroxide from the hardened concrete. Metakaolin densities and reduces the thickness of the interfacial zone, thus improving the adhesion between the hardened cement paste and particles of sand or coarse aggregate. The mineral admixture metakaolin was obtained from the ASTRRA chemicals, Chennai. The metakaolin was in conformity with the general requirements of pozzolana. The chemical composition of metakaolin is listed below in table 2.4.

Chemical composition	Range
Silicon dioxide, SiO_2	51.34
Aluminum oxide, Al_2O_3	41.95
Ferric oxide, Fe_2O_3	0.52
Calcium oxide, CaO	0.34
Loss of ignition	0.72

Table 2.4: Chemical composition of Metakaoli

vi. Quartz Sand:

Quartz is the most important sand-forming mineral. Because it is resistant to both physical and chemical weathering and it is also physically hard. Quartz is the most important hydrothermal mineral, filling cracks in the crust with many other and often economically important minerals.

2.2. Mix design and mixture composition:

Control concrete mixture was designed for M30 as per Indian Standard Specifications IS: 10262–2009 to have 28-day compressive strength of 38.25 MPa. The other concrete mixtures viz. A2, A3 and A4 were made by replacing cement with 10% of metakaolin by mass and fine aggregate with 25%, 50% and 75% of quartz sand by mass. In doing so, water-to-cementitious materials ratio was kept same to investigate the effects of replacing cement with metakaolin and fine aggregate with quartz sand when other parameters were almost kept same. Mixture proportions are given in table 2.5.

S.no.	Material	As per mix design, Kg/m^3	Per unit
1	Cement	390	1
2	Fine aggregate	785	2.1
3	Coarse aggregate	1169	2.9
4	water	176	0.45

Table 2.5: Designed values of materials

The proportions of mixture are binder, sand and coarse aggregate ratio is 1:2.1:2.9 respectively for the whole casting in this project. The binder which is cement was replaced with MK at replacement level of 10% and fine aggregate was replaced with quartz sand at 25%, 50% and 75% by total weight. Design quantities are given in below table.

mix. no. →	A1	A2	A3	A4
Cement, Kg/m^3	390	351	351	351
Metakaolin %	0	10	10	10
Metakaolin, Kg/m^3	0	39	39	39
Fine aggregate, Kg/m^3	785	588.75	392.5	196.25
Quartz sand %	0	25	50	75
Quartz sand, Kg/m^3	0	196.25	392.5	588.75
Water, Kg/m^3	175	175	175	175
Coarse aggregate	1169	1169	1169	1169
W/binder	0.45	0.45	0.45	0.45

Table 2.6: Mixture proportions

2.3. Testing procedures:

2.3.1. Compressive Strength Test:

The compressive strength of concrete (150 mm × 150 mm × 150 mm) are tested by means of compressive testing machine according to ASTM C39. All proportions were tested after 7 days, 14 days and 28 days curing period at standard 20 ± 2°C. Along with this test a Non-Destructive Test (NDT) is also conducted called Rebound hammer test to the all mix proportions.

2.3.2. Split Tensile Strength Test:

Split tensile strength test on concrete cylinder is a method to determine the tensile strength of concrete. Spilt tensile strength of concrete is as prescribed by ASTM C496 is conducted. Specimens of 150mm diameter × 300mm height were used for this test. The specimens were tested for 7, 14, 28 and 60days.

2.3.3. Flexure strength test:

For each mix, totally twelve number of prism of size 150 x 150 x 700 mm were cast and tested using Flexural Testing Machine (FTM). The specimen was placed perpendicular to normal axis on the platform of the flexural testing machine. The load was applied gradually until the failure stage. The ultimate load was noted and calculated the flexural strength of corresponding specimen. The flexural strength test will be carried out on the specimens at the end of 7 days and 28 days of curing.

2.3.4. Rapid Chloride ion penetration test:

According to ASTM C1202 test, a water-saturated, 50 mm thick, 100 mm diameter concrete specimen is subjected to a 60v applied DC voltage for 6 hours using the RCPT apparatus. In one reservoir is a 3.0% NaCl solution and in the other reservoir is a 0.3 M NaOH solution. The total charge passed is determined and this is used to rate the concrete according to the criteria included.

2.3.5. Water permeability test:

Three specimen of concrete each of 200mm dia and 120mm height are cast.After 24 hours, the middle portion of 100mm dia is roughened and the remaining portion is sealed with cement paste. The specimens are cured for 28 days and then water pressure is applied on the middle roughened portion so that water can penetrate inside the concrete. The water pressure is maintained at 10 bars. After this, the specimens are split to know the penetration of water. The specimen are split in compression machine by applying concentrated load at two diagonally opposite points slightly away from central axis. The average of three maximum values of penetration is calculated. The depth of penetration of water should not be more than 25mm otherwise the specimen are considered to be failed in permeability test.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Compressive strength:

Compressive strength of concrete is considered to be the most valuable and important property of concrete since it gives the overall picture of the concrete quality. Table 3.1 shows the effect of metakaolin and quartz sand on the 7 and 28 day compressive strengths of the concrete mixes.

Mix Designation	Proportions of Materials	Compressive strength N/mm^2	
		7 days	28 days
A1	Conventional mix	25.23	38.19
A2	10% Metakaolin + 25% Quartz sand	23.81	36.36
A3	10% Metakaolin + 50% Quartz sand	29.19	41.97
A4	10% Metakaolin + 75% Quartz sand	20.1	34.03

Table 3.1: Compressive strength test results

As seen from the table 4.1, there is an evident increase in the compressive strength owing to the increase in the quartz sand content. The compressive strength values varied between 34–42 MPa. It was observed that the 7 and 28 days compressive strength of the concretes incorporated with metakaolin and quartz sand was followed a zigzag trend, which is clear that quartz sand influences the strength greatly.

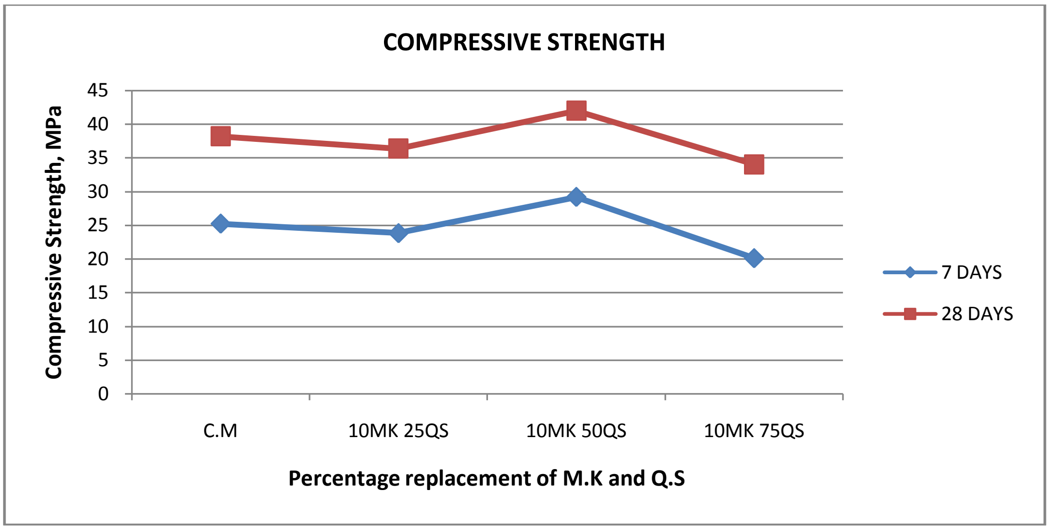

Fig. 3.1: Effect of percentage variation on compressive strength

From fig. 4.1, the control mix had more strength than A2 (10MK 25QS) and less strength than A3 (10MK 50QS) for 28 days compressive strength. From mix design, our target mean strength is 38.25 MPa and the strength of control mix (38.19 MPa) approximately reaches the target but replacement of 50% quartz sand in fine aggregate exceeds the target and achieves highest strength (41.97 MPa) comparing to other mixes. The compressive strength of mixes A2 and A4 are decreased at 4.79% and 10.89% with respect to control mix respectively. The compressive strength of M3 (MK10 QS50) had an increment of 9.89% which shows the positive effect of quartz sand in concrete.

Rebound hammer test (N.D.T):

The specimens were tested at the age of 7 days and 28 days for water cured concrete. The compressive strength results of concrete with respect to rebound hammer test are tabulated below with age.

Table 3.1 shows the compressive strength of concrete cubes with various percentages of M.K and Q.S by using Schmidth rebound hammer (N.D.T). From the obtained results it is clear that strength of a conventional mix is 24.56 MPa and 38 MPa at 7 days and 28 days respectively. By the replacement of 50% quartz sand in fine aggregate the compressive strength increased from 38 to 41.25 MPa at 28 days curing period.

Mix Designation	Proportions of Materials	Compressive strength N/mm^2	
		7 days	28 days
A1	Conventional mix	24.56	38.0
A2	10% Metakaolin + 25% Quartz sand	20.18	35.89
A3	10% Metakaolin + 50% Quartz sand	28.86	41.25
A4	10% Metakaolin + 75% Quartz sand	21.46	33.63

Table 3.2: Compressive strength (N.D.T) test results

From the above results of table 3.1 and 3.2, we can say that the strength gained by two methods i.e., destructive and non destructive tests were almost same. There by the results which we obtained were in similar manner.

3.2. Split Tensile Strength:

Mix Designation	Proportions of Materials	Split tensile strength N/mm^2	
		7 days	28 days
A1	Conventional mix	2.91	3.288
A2	10% Metakaolin + 25% Quartz sand	2.256	2.794
A3	10% Metakaolin + 50% Quartz sand	3.15	3.768
A4	10% Metakaolin + 75% Quartz sand	2.88	3.32

Table 3.3: Split tensile strength test results

Table 3.3 shows the effect of metakaolin and quartz sand on the 7 and 28 day split tensile strengths of the concrete mixes, while the results of the split tensile strength test for all mixtures are shown in Fig. 3.2.

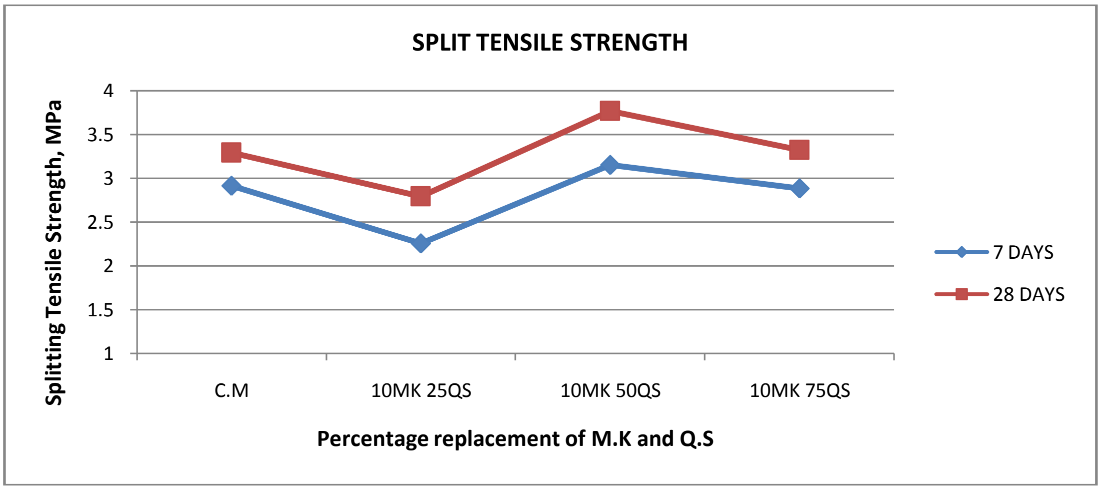

Fig. 3.2: Effect of percentage variation on split tensile strength

Test results showed that the split tensile strength of mix A3 exceeded the corresponding value of control mixture. A 14.58% increase has been observed in mixture with 10% cement replacement with MK and 50% fine aggregate with QS. The maximum split tensile strength obtained at 50% of QS was 3.768 MP as shown in Table 3.3.

3.3. Flexural strength:

Flexural strength also known as modulus of rupture, bend strength or fracture strength, a mechanical parameter for brittle material, is defined as a material's ability to resist deformation under load.
The results of the Flexural Strength tests on concrete beams are shown in Table 3.4.

Mix Designation	Proportions of Materials	Flexural strength N/mm^2	
		7 days	28 days
A1	Conventional mix	3.73	4.76
A2	10% Metakaolin + 25% Quartz sand	3.51	4.47
A3	10% Metakaolin + 50% Quartz sand	3.89	4.96
A4	10% Metakaolin + 75% Quartz sand	3.31	4.23

Table 3.4: Flexural strength test results

The results of the Flexural strength of concrete beams show that the Flexural strength reduced as the percentage of quartz sand increased to 25% and again strength gained at 50% quartz sand. Finally, flexural strength decreases more when compare to mix A2. It is seen from Table 3.4 that for the conventional beam, the flexural strength increased from 3.73 N/mm2 at 7 days to 4.76 N/mm^2 at 28 days. At the 50% replacement of quartz sand, the flexural strength increased from 3.89 N/mm^2 to 4.96 N/mm^2. At that percentage (10MK 50QS) the optimum flexural strength is obtained.

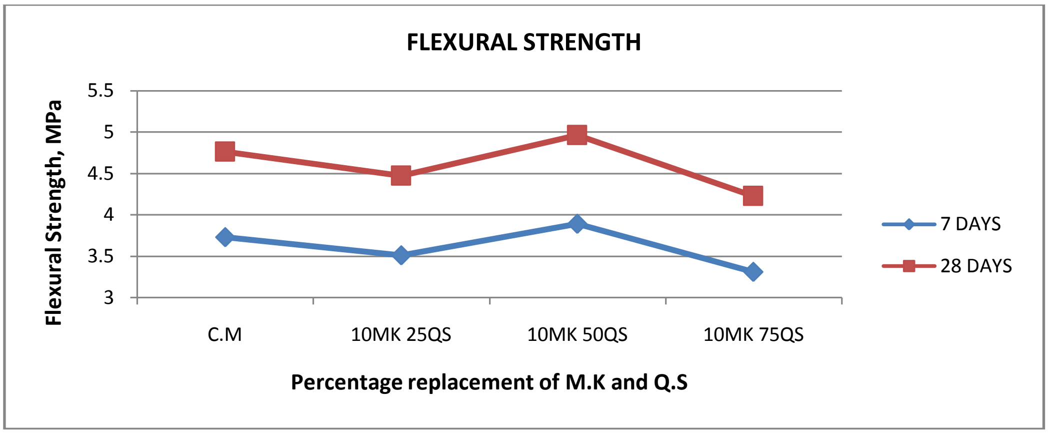

Fig. 3.3: Effect of percentage variation on flexural strength

From the above fig. it has been shown that the flexural strength increases with an increment of quartz sand by 25% and by keeping metakaolin at 10% as constant. After mix A3 which consists of 10% metakaolin and 50% quartz sand, the flexural strength decreases which shows its optimum range. Therefore mix A3 (10MK 50QS) is obtained as optimum.

3.4. Water permeability:

The Water Permeability test of M_{30} grade of concrete by replaces in ordinary Portland cement with metakaolin by 10% and fine aggregate with quartz sand by 25%, 50% and 75% by total weight. The results of Water Permeability of A1, A2, A3 & A4 concrete mixtures tested at 56days, the data are presented in the given below table and graphical presentation of Water Permeability.

Mix Proportions	Water permeability, cm	Co-efficient of permeability, m/sec
A1	2.1	$9.39\mathbf{X}10^{-13}$
A2	1.75	$7.82\mathbf{X}10^{-13}$
A3	1.43	$6.44\mathbf{X}10^{-13}$
A4	1.62	$7.30\mathbf{X}10^{-13}$

Table 3.5: Water permeability test results

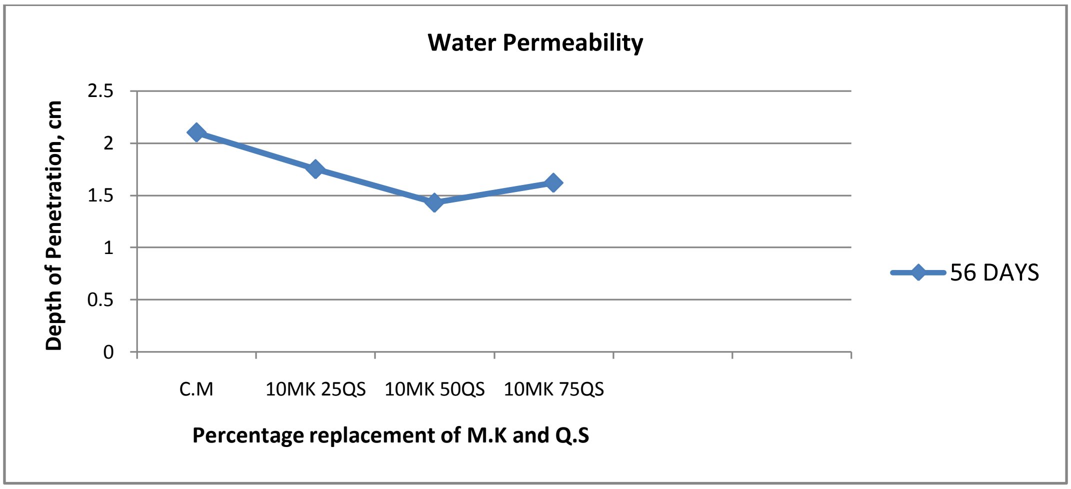

Fig. 3.4: Effect of percentage variation on depth of penetration of water

From the above fig. it has been seen that the depth of water penetration is decreased by the replacement of fine aggregate with quartz sand up to 50% and keeping metakaolin constant as 10% in place of cement. After mix A3 which consists of 10% metakaolin and 50% quartz sand, the water permeability increases which shows its optimum range. The minimum permeability that mix 3 attained is 1.43 cm. Therefore mix A3 (10MK 50QS) is obtained as optimum.

3.5. Rapid Chloride Permeability Test:

The test results conducted for 28 days and 56 days of rapid chloride permeability test with constant percentage replacement of cement with metakaolin and various percentage replacement of fine aggregate with quartz sand are presented in the table below and then discussed. From the results it may be observed that decreasing the values by replacing various percentages of fine aggregate with quartz sand.

The chloride permeability of M30 grade concrete mixes replacing quartz sand by fine aggregate at 25%, 50% and 75% is investigated. The results of chloride permeability of concrete mixtures tested at 28 days and 56 days are presented in table 3.6. Graphical representation between chloride permeability in coulombs and quartz sand & metakaolin replacement percentages is represented in Fig. 3.5.

Mix Designation	Proportions of Materials	Coulombs, mAh	
		28 days	56 days
A1	Conventional mix	1715	1525
A2	10% Metakaolin + 25% Quartz sand	1325	950
A3	10% Metakaolin + 50% Quartz sand	1200	875
A4	10% Metakaolin + 75% Quartz sand	1150	840

Table 3.6: Rapid chloride permeability test results

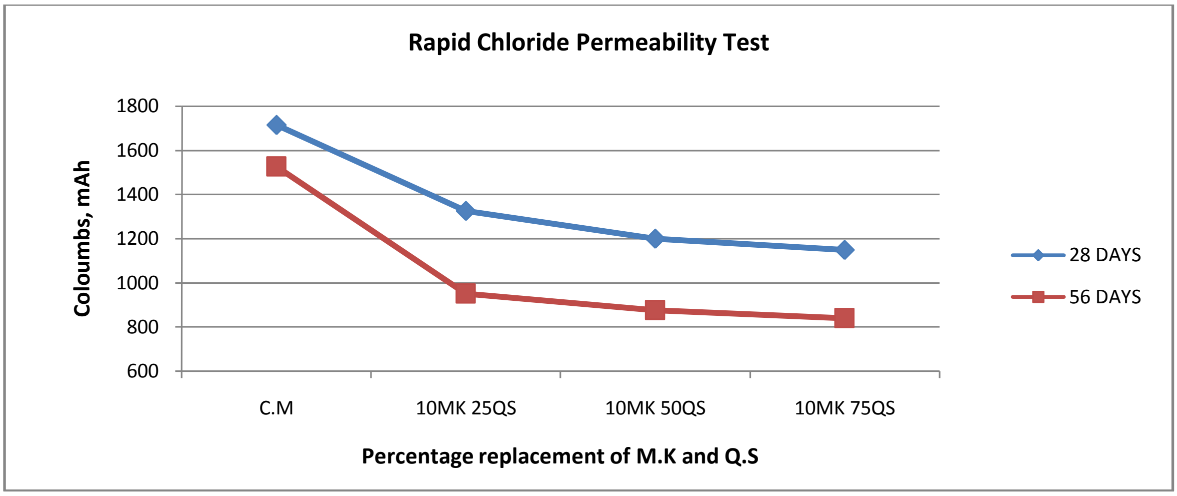

Fig. 3.5: Effect of percentage variation on chloride permeability

It is observed that the 28 days of chloride permeability of concrete decreases with increasing the percentage of quartz sand in concrete. All the percentages of concrete show a very low chloride penetrability of concrete. It is observed that the 56 days of chloride permeability of concrete reduces its chloride attack while increasing its curing age and also decreases the ion attack while increasing the percentage of quartz sand in concrete.

4. CONCLUSION

Based on the findings of the experimental program presented above, the following conclusions can be drawn:

1. A combination of 10% metakaolin and 50% quartz sand in concrete is found to be optimum (41.97 N/mm^2) for compressive strength at 28 days. The MK10QS20 specimen enhanced the compressive strength by 10% in comparison with the conventional mix. With the obtained results, the compressive strength results with the both destructive and non destructive techniques are approximately alike.
2. A combination of 10% metakaolin and 50% quartz sand in concrete is found to be optimum for split tensile strength at 28 days. The tensile strength of 3.77 N/mm^2 is recorded as maximum for MK10QS20 mix. The MK10QS20 mix improved the tensile strength by 14.6% in contrast with the conventional mix.
3. According to the test results obtained in this project, it was observed that the split tensile strength and flexure strength development of the concrete had similar tendency with compressive strength i.e., the strengths of these properties are directly proportional to each other.

4. A combination of 10% metakaolin and 75% quartz sand in concrete shows the lowest chloride permeability.
5. The results from the water permeability test, the mix having 10% metakaolin and 50% quartz sand which had highest compressive strength had shown lowest permeability which is a good indication for better concrete.
6. Amongst the all mixes the conventional mix and the mix having 10% metakaolin and 50% quartz sand shown the minimum permeability (0.75 c.m) when compare to the rest of mixes.

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