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

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**ABSTRACT:** In conventional concrete we want to gain more strength with the optimum materials. That's why here we are using Metakaolin and Quartz sand in concrete for the replacement of cement and Fine Aggregate which might absorb CO<sub>2</sub>. Due to rapid change in metrology, deep minimizing emission will be required in coming decades. Global warming is controlled by the process of reducing greenhouse gases like CO<sub>2</sub>, HFC and Sulphur-di-oxide in atmosphere. Metakaolin is a pozzolan, probably the most effective pozzolanic material for use in concrete. It is a product that is manufactured for use rather than a by-product and is formed when china clay, the mineral kaolin, is heated to a temperature between 600 and 800°C. Its quality is controlled during manufacture, resulting in a much less variable material than industrial pozzolans that are by-products. Quartz is the most abundant silica mineral. Pure Quartz is colorless and transparent. It occurs in most igneous and practically all metamorphic and sedimentary rocks. Quartz is mainly made up of silica. In this project, concrete made with cement is partially replaced with Metakaolin and Quartz sand then compared with normal concrete. Here cement in concrete is partially replaced with the metakaolin as constant 10% and Quartz Sand proportions are 25%, 50%, and 75% replacement in fine aggregate the specimens were casted and tested for their mechanical and durability properties.

**KEYWORDS:** Metakaolin, Quartz Sand, compressive strength, split tensile, Flexure Test, Rapid Chloride Permeability test, water permeability test.

## I.INTRODUCTION

Concrete is the most widely used construction material in the world, and its popularity can be attributed to two aspects. First, concrete is used for many different structures, such as dams, pavements, building frames, or bridges, much more than any other construction material. Second, the amount of concrete used is much more than any other material. Its worldwide production exceeds that of steel by a factor of 10 in tonnage and by more than a factor of 30 in volume. In a concrete structure, there are two commonly used structural materials: concrete and steel. A structural material is a material that carries not only its self-weight, but also the load passing from other members.

The concrete of its Flexibility, Durability, Sustainability, and Economy have made it the world's most widely used building material. In the manufacturing of one ton of cement of lime stone, 80 Units of electric power apart from one ton of CO<sub>2</sub> at large into the atmosphere. Out of the total CO<sub>2</sub> emission (from a variety of resource) worldwide, even industries contribute about 7% of CO<sub>2</sub> emissions. Annual cement manufacture rate of the world is increasing very much year by year. The properties of concrete can also be increased by using by-products and natural wastes as supplementary cementing material. Lot of energy and cost can also be saved by using these natural wastes and industrial by-products as partial replacements to OPC.

Metakaolin is a supplementary cementing material which is produced from carefully calcining kaolin clay between 600 and 800°C to make it reactive. Exceeding this temperature can cause the metakaolin to 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<sub>2</sub>O<sub>3</sub>•SiO<sub>2</sub>. 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 silicate hydrate (C-S-H) as well as other hydrates (C<sub>2</sub>ASH<sub>8</sub> [stratlingite], C<sub>4</sub>AH<sub>13</sub>, C<sub>3</sub>AH<sub>6</sub>). Not only improving concrete performance, metakaolin also makes concrete greener because metakaolin production does not produce chemical CO<sub>2</sub>.

as opposed to cement (de-carbonating limestone) and also requires lower temperatures to produce. It has been known for more than a decade that metakaolin improves durability, but as kaolin deposits vary in composition and purity each one needs to be tested for supplementary cementing material (SCM) qualities.

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  $\text{SiO}_2$ . 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 mountain tops and the primary constituent of beach, river and desert sand. 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. In the past, river sand was used as the merely choice for the fine aggregate element in concrete. Though, too much extraction of river sand origins the degradation of rivers. In stream mining lowers the stream bottom, which may lead to bank erosion. Exhaustion of sand in the stream bed and along coastal areas causes the deepening of rivers, and the expansion of river mouths and coastal inlets. It may also lead to saline-water invasion from the nearby sea. The effect of mining is compounded by the effect of sea level rise. Any volume of sand distributed from stream beds and coastal areas is a loss to the system. Excessive in-stream sand mining is a threat to bridges, river banks and nearby structures. Sand mining also affects the neighboring groundwater system and the uses that local people make of the river. Due to these issues, several ecological restrictions were put in place. This increases the scarcity of natural fine aggregates and leads to search for different sources for its replacement.

## II. LITERATURE REVIEW

**Luc Courard et al (2003):** Investigated the effects of Metakaolin on properties of mortar. Comparisons are made to ordinary Portland cement to determine the influence of replacement. Cement is replaced on mass basis of 5% to 20% for metakaolin. The transport properties and chemical behaviors are analyzed by means of chloride diffusion tests and sulfate immersion. Observations made after more than 100 days are used to prescribe mixtures that reduce the rate of chloride diffusion and sulfate degradation. For metakaolin the optimum percentage is between 10% and 15% with regard to inhibition effect on chloride diffusion and sulfate attack.

**E. Badogiannis et al (2005):** Investigation aimed at the use of produced metakaolin as supplementary cementitious material. Samples of poor Greek kaolin and a high purity commercial kaolin were tested. Samples were heated at different temperatures and time intervals. The optimization of calcination conditions was studied by DTA-TG and XRD analysis of the raw and thermal treated kaolin samples, by pozzolanic activity analysis of metakaolin and finally by strength development analysis of cement-metakaolin mixtures. This approach showed that heating at  $650^\circ\text{C}$  for 3 hours is efficient to convert poor kaolins with low alunite content to highly reactive metakaolins. However in the case of kaolin with a high alunite content, thermal treatment at  $850^\circ\text{C}$  for 3 hours is required in order to remove undesirable  $\text{SO}_3$ . Evidence was found that poor kaolins can be efficiently used for the production of highly reactive metakaolin.

**Rafat Siddique et al (2009):** Stated an overview on the use of MK as partial replacement of cement in mortar and concrete. He concluded the Reduction in the slump values and increase in the setting times of concrete. Fluidity of MK-blended cement became poorer. Metakaolin helps in enhancing the early age mechanical properties and long-term strength properties of cement paste mortar and cement concrete. Metakaolin replacement reduces the water penetration into concrete by capillary action. MK modifies the pore structure of the cement mortar and cement concrete and remarkably reduces the permeability, which results in resistance of transportation of water and diffusion of harmful ions which led to the deterioration of the matrix. Metakaolin replacement of cement is effective in improving the resistance of concrete to sulphate attack. Concrete containing 10% and 15% Metakaolin replacements showed excellent durability to sulphate attack.

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**M. Shekarchi et al (2010):** Researched on various transport properties of concrete modified with metakaolin(MK). Usage of metakaolin decreases the initial setting time however the final setting time remains unchanged. Compressive strength increased by 20% when 15% replacement of cement with metakaolin was done. Transport properties measured in terms of water 13 penetration, gas permeability, water absorption, electrical resistivity, and ionic diffusion were improved up to 50%, 37%, 28%, 450%, and 47%, respectively.

**Sadaqat Ullah Khan et al (2014):** Investigated the properties of fresh concrete i.e. workability, heat of hydration, setting time, bleeding, and reactivity by using mineral admixtures that are fly ash (FA), silica fume (SF), ground granulated blast furnace slag (GGBS), metakaolin (MK), and rice husk ash (RHA). Comparison of normal and high-strength concrete in which cement has been partially replaced by mineral admixture has been considered. It has been concluded that mineral admixtures may be categorized into two groups i.e. chemically active mineral admixtures (SF and MK) and micro filler mineral admixtures (FA, GGBS and RHA). A chemically active mineral admixture decreases workability and setting time of concrete but increases the heat of hydration and reactivity. On the other hand, a micro filler mineral admixture increases workability and setting time of concrete but decreases the heat of hydration and reactivity. Small particle size mineral admixtures are favourable to produce highly dense and impermeable concrete but they decreases workability and need more water which may be fulfilled by adding super plasticizer. All mineral admixtures reduce bleeding in concrete. The reactivity of mineral admixtures is of the order: MK > SF > FA > GGBS.

### III. MATERIALS AND METHODOLOGY

The Experimental Program was designed to investigate the effect on the properties of the concrete by using metakaolin and quartz sand as partial replacements for cement with 10% and fine aggregate with different proportions 25%, 50%, 75% respectively. For each test at each curing age, and the average values were used for analysis.

#### 3.1 Materials:

##### 3.1.1 Cement:

The ordinary Portland cement was classified in to three grades, namely 33 grades, 43 grades and 53 grades depending upon the strength of the cement at 28 days when tested as per IS 4031-1988. If 28 days strength is not less than 53 N/mm<sup>2</sup>, it is called 53 grade cement. We are adopting 53 grade Ordinary Portland cement in this project.

S.NO	PARTICULARS	RESULTS
1	Specific Gravity	3.12
2	Initial Setting Time	30min
3	Final Setting Time	450min
4	Normal consistency	29%

##### 3.1.2 Fine aggregate:

Aggregates provide dimensional stability and wear resistance for concrete. Not only do they provide strength and durability to concrete, but they also influence the mechanical and physical properties of concrete. Fine aggregate (sand) is defined as an aggregate with particles of size smaller than 4.75mm and equal to or larger than 75µm. Natural River sand with fraction passing through 4.75mm sieve and retained on 60micron sieve will be used.

##### 3.1.3 Coarse aggregate:

Coarse aggregate consists of rounded river gravel, crushed stone or manufactured aggregate with particles of larger than 4.75mm. Coarse aggregate of size 20mm has been selected for this project. The physical properties will be tested as per IS 2386 (part 1) -1963. It is used to improve the strength of concrete

##### 3.1.4 Water:

Water is needed for the hydration of cement and to provide workability during mixing and for placing. Portable tapwater is used for making concrete and curing the specimens as well.





**3.1.5 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.

Chemical composition	Range
Silicon dioxide, SiO <sub>2</sub>	51.34
Aluminum oxide, Al <sub>2</sub> O <sub>3</sub>	41.95
Ferric oxide, Fe <sub>2</sub> O <sub>3</sub>	0.52
Calcium oxide, CaO	0.34
Loss of ignition	0.72

**3.1.6 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.

**3.2 Preparation and Casting of Specimens:**

Name of the test	Specimen	Curing Period (days)
Compressive strength	150mm cube	7, 28, 56, 90
Rebound hammer (N.D.T)	150mm cube	7, 28, 56, 90
Split tensile strength	150mm Ø* 300mm cylinders	7, 28, 56, 90
Flexure strength	150mm*150mm*700mm beams	7, 28, 56, 90
Permeability	300mm Ø X 150mm cylinders	28, 56, 90
Rapid chloride ion penetration	100mm Ø X 50mm cylinders	28, 56, 90

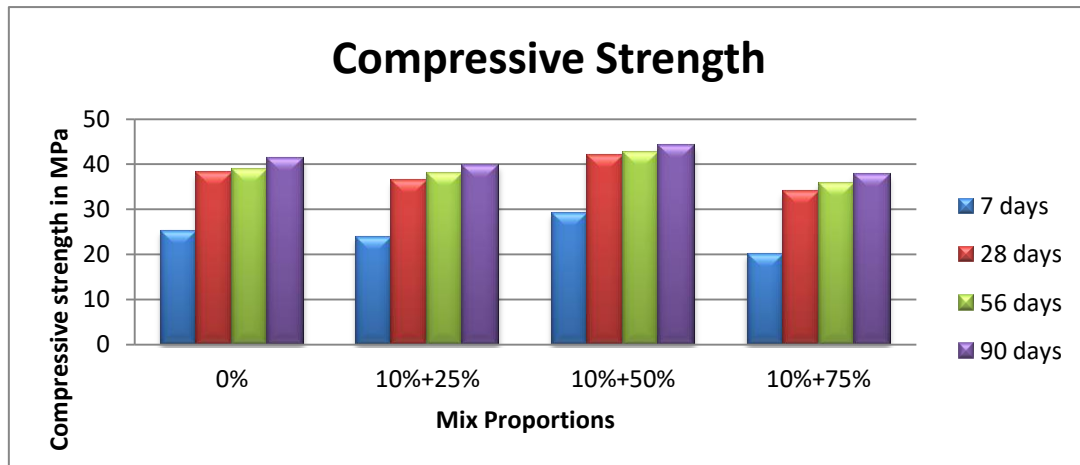
**IV. RESULTS AND DISCUSSIONS**

The results completed in the present investigation are reported in the form of Tables and Graphs for various hardened properties of concrete with a constant percentage of metakaolin as a partial replacement to cement by 10% and quartz sand taken as replacement to fine aggregate by 0%, 25%, 50% and 75% are worked out and tabulated below.

**4.1 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 4.1 shows the effect of metakaolin and quartz sand on the 7, 28, 56 & 90 days compressive strengths of the concrete mixes.

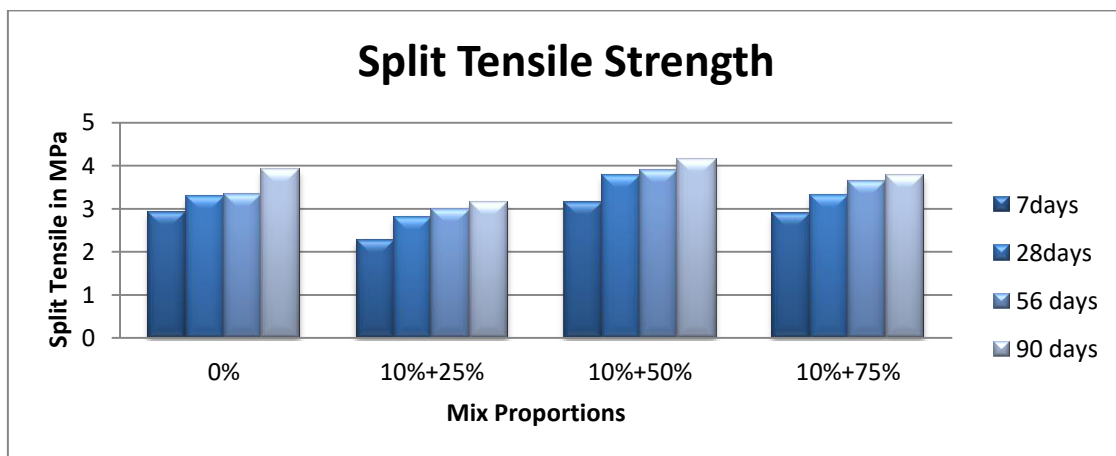
Mix Designation	Proportions of Materials	Compressive strength N/mm <sup>2</sup>			
		7 days	28 days	56 days	90 days
A1	Conventional mix	25.23	38.19	38.75	41.32
A2	10% Metakaolin + 25% Quartz sand	23.81	36.36	37.87	39.81
A3	10% Metakaolin + 50% Quartz sand	29.19	41.97	42.69	44.16
A4	10% Metakaolin + 75% Quartz sand	20.1	34.03	35.81	37.67



**4.2 Split Tensile Strength:**

Concrete does not resist direct tension because of its low tensile strength and brittle nature. Therefore, knowing the tensile strength of concrete is necessary to determine the load at which concrete members may start to crack. Table 4.3 shows the effect of metakaolin and quartz sand on the 7, 28, 56 & 90 days split tensile strengths of the concrete mixes, while the results of the split tensile strength test for all mixtures are shown in Fig. 4.3, whereas fig. 4.4

Mix Designation	Proportions of Materials	Split tensile strength N/mm <sup>2</sup>			
		7 days	28 days	56 days	90 days
A1	Conventional mix	2.91	3.288	3.33	3.91.
A2	10% Metakaolin + 25% Quartz sand	2.256	2.794	2.97	3.15
A3	10% Metakaolin + 50% Quartz sand	3.15	3.768	3.89	4.16
A4	10% Metakaolin + 75% Quartz sand	2.88	3.32	3.64	3.78



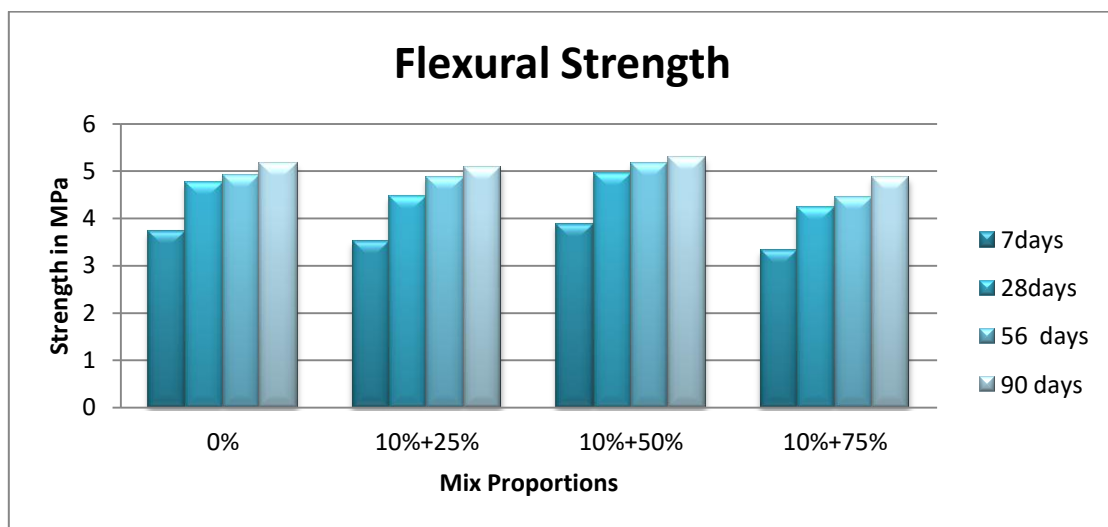
**4.3 Flexural Strength:**

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 4.4.



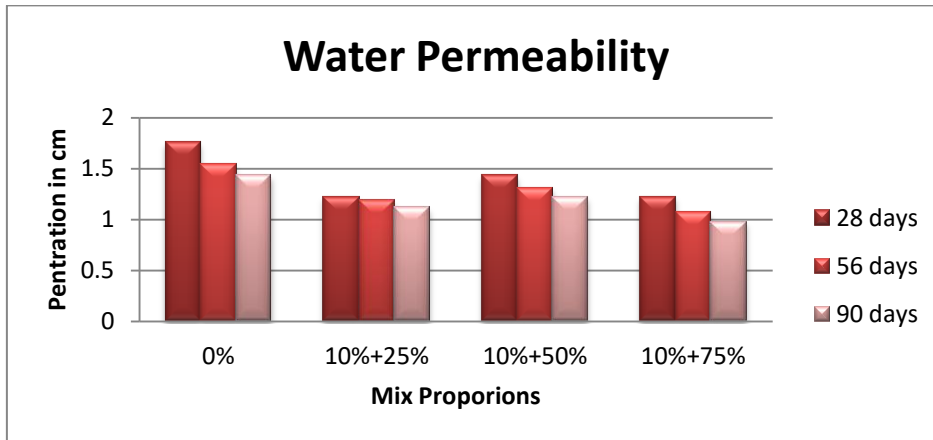
Mix Designation	Proportions of Materials	Flexural strength N/mm <sup>2</sup>			
		7 days	28 days	56days	90 days
A1	Conventional mix	3.73	4.76	4.91	5.16
A2	10% Metakaolin + 25% Quartz sand	3.51	4.47	4.87	5.09
A3	10% Metakaolin + 50% Quartz sand	3.89	4.96	5.16	5.28
A4	10% Metakaolin + 75% Quartz sand	3.31	4.23	4.46	4.86



**4.4 Water Permeability:**

The Water Permeability test of M<sub>30</sub> 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 28days, 56days and 90 days the data are presented in the given below table and graphical presentation of Water Permeability.

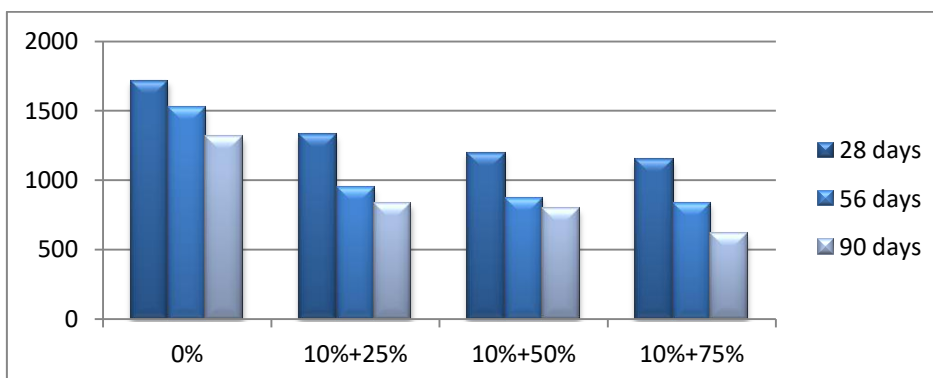
Mix Proportion	Depth of penetration (in cm)		
	28 days	56 days	90 days
A1	1.76	1.54	1.43
A2	1.22	1.18	1.12
A3	1.43	1.31	1.22
A4	1.22	1.07	0.98



**4.5 Rapid Chloride ion Permeability:**

The test results conducted for 28 days, 56 days and 90 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

Mix Designation	Proportions of Materials	Coulombs, mAh		
		28 days	56 days	90 days
A1	Conventional mix	1715	1525	1316
A2	10% Metakaolin + 25% Quartz sand	1325	950	830
A3	10% Metakaolin + 50% Quartz sand	1200	875	796
A4	10% Metakaolin + 75% Quartz sand	1150	840	618



**V. 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<sup>2</sup>) for compressive strength at 90 days. The MK10QS20 specimen enhanced the compressive strength by 10% in comparison with the conventional mix.
2. A combination of 10% metakaolin and 50% quartz sand in concrete is found to be optimum for split tensile strength at 90days. The tensile strength of 3.77 N/mm<sup>2</sup> 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 development of the concrete had similar tendency with compressive strength i.e., the strengths of both properties are proportional to each other.
4. With the obtained results, the compressive strength results with the both destructive and non destructive techniques are approximately alike.
5. A combination of 10% metakaolin and 75% quartz sand in concrete shows the lowest chloride permeability.
6. 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.
7. 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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