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# Experimental Study on Partial Replacement of Cement with Metakaolin and Coarse Aggregate with RCA in M30 Grade

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**ABSTRACT:** The present experimental study focuses on the strength performance of the blended concrete with varying percentages of Metakaolin (MK). In this study cement is partially replaced accordingly with the variation of 0%, 5%, 10%, 15%, and 20% Metakaolin and replacement of NCA with 25% constant RCA. Concrete specimens of cubes and cylinders are tested at the age of 7 and 28 days under 3 different types of curing methods such as Acceleration curing, Immersion curing & Gunny bag curing. Finally, we have attained the enhancement of the strength of blended concrete with inclusion of Metakaolin. We have noticed that 10% MK replacement to cement appears to be the optimum replacement where blended concrete exhibits enhanced strength at all the stages. Each set comprises of 9 cubes, 9 cylinders and 9 beams. 7, 14 and 28-days compressive test, tensile strength and flexural strength tests are to be performed in the hardened state. The test results are showed on overall strength properties in various trials. Therefore, the strength properties of M30 grade of concrete was studied.

**KEYWORDS:** Metakaolin, Recycled Coarse aggregate, Cement M30 Grade.

## I. INTRODUCTION

MK is a dehydroxylated form of the Kaolin clay mineral. Stones having the high percentage of kaolinite are called china clay (or) kaolin was traditionally used in the manufacturing of the porcelain ceramic material. MK reacts with  $\text{Ca}(\text{OH})_2$  which is one of the by-products of hydration reaction of cement results in the formation of C-S-H gel. The formation of C-S-H gel indicates enhancement of strength and durability of the concrete. The replacement of cement with Metakaolin enhances the strength properties, durability & reduces the voids & permeability.

Day by day the quantity of RCA available from the demolished buildings and roads is increasing. The disposal of this waste into dumping yards causes a serious environmental problem. If it is possible to recycle and reutilize the RCA in making the concrete by partial replacement of NCA, thus it will not only save the construction cost but also control the environmental pollution by restraining disposal of the demolished waste. In Europe and some other countries in Asia, instead of NCA utilization of the recycled waste material in the form of recycled coarse aggregate (RCA) has gained its importance. RCA is the most emerging replacement of NCA in the concrete production. It is the effective solution to the shortage of aggregate in construction industry. At the same time, Concrete made with this partial replacement can attain the comparable compressive and tensile strength. For satisfactory utilization of this alternative waste material, several phases of examination need to be technical feasibility, durability of hardened concrete and economic feasibility.

## II. RELATED WORK

### REVIEW ON RCA AND MK:

Ahmad et al. (2015) aimed to study the "Influence of Metakaolin and Steel Fibre on Recycled Aggregate Concrete". In their research work RCA at 15%, 30% and 45% replacement of NCA in concrete and later focused on the improvement of strength properties of RCA concrete by utilizing 10% MK as cement replacement and addition of 1% steel fibre at the curing age of 28 days. The concrete used in this study was M30. RCA were partially replaced in the ratio of 0%, 15%, 30% and 45% by weight of NCA in concrete. MK was used to partially replace cement by 10%. The steel fibre was 1% of the concrete volume. Finally, they concluded that the use of RCA helps in conserving the dwindling natural resources. The strength properties of RCA concrete can be improved by utilizing the supplementary materials in

appropriate quantity. The presence of MK act as filler to make the interfacial transition zone more compact and Steel fibres act as crack resistor and restrict slipping when stress is applied.

### III. METHODOLOGY

Experimental investigation consists of casting and testing of the test specimen's 150mm x 150mm x 150mm cubes for compressive strength, 150mm x 300mm cylinders for split tensile strength and 500mm x 100mm x 100mm beams for Flexural strength were casted according to IS: 516-1959. In this research work totally 108 specimens were casted (36 cubes, 36 cylinders and 36 beams). The specimens were tested by using the CTM at the age of 7 and 28 days. The test procedure was followed as per relevant Indian standard specifications. From the test results it has been observed that the compressive strength of M<sub>30</sub> grade concrete attaining 62.2% of target strength for control mix concrete at 7 days and strength going to be increased gradually at 0%, 5%, 10%, 15% and 20% replacement of MK and RCA with 20% RCA are 63.64%, 75.89%, 79.65%, 78.77% and 66.93% as compared to control mix. Initially the compressive strength at 28 days 1.26% is decreased for M<sub>1</sub> and later strength increased gradually up to 10% replacement of MK and it was observed to be 7.96% more than that of conventional concrete and later it decreases gradually. Here we have tested the gunny bag cured cylindrical specimens of M<sub>30</sub> grade of different mixes from M<sub>0</sub> to M<sub>5</sub> for Split Tensile strength using Compression Testing Machine (CTM).

These Split Tensile Strength values are drawn on the graph by taking the various mixes on X-axis and Split Tensile Strength on Y-axis. From the above graph we have got the best results for the Mix 4 – (M<sub>3</sub>, 10% of Meta Kaolin added and 20% of RA) is 1.18 times the tensile strength of Mix 1 – M<sub>0</sub> (For the Normal M25 Grade concrete without added RA & MK). It can be noticed that the Split Tensile Strength of Mix 3 (10% of Meta Kaolin added and 20% of RA) is 1.14 times the Mix 2 – M<sub>1</sub> (For the Normal M25 Grade concrete with 20% added RA & 0% MK). The 7 days of split tensile strength of all mixes is more than 70% of the 28 days tensile strength of concrete. The above graph indicates the increase of the split tensile strength upto the Mix 4 and then it is reducing. In other words the Mix 4 gives the best results by the addition of 10% of MK and 20% of RCA. The moulds are applied with a lubricant before placing the concrete. After a day of casting, the moulds are removed. The cubes, cylinders and prisms are moved to the curing tank carefully.

**MATERIALS:** The constituent materials used in these studies are given below

1. Cement
- 2) Fine aggregate
- 3) Recycled Coarse Aggregates
- 4) Meatakaolin

**CEMENT:** The cement used was Ordinary Portland cement (OPC) of 53-grade conforming to IS 12269 is used in experimental work.

#### Cement Test Results

S.No	Property	Experimental Value	Requirements As Is Codes
1	Specific gravity of cement	3.15	3.15
2	Normal consistency of cement	30%	
3	Initial setting time Final setting time	35 min 6hrs 30min	30. in 600 min (max) As per 12269

**AGGREGATE:** It should be passed through IS Sieve. As fine aggregate (F. A) natural sand from river is used conforming to IS383-1970. Which comes under zone II. As a coarse aggregate hard granite chips passing 20mm down where used conforming to IS383-1970. Various tests such as specific gravity water absorption and sieve analysis have been conducted on (F.A) and (C.A) to know the good quality and grading.

**Recycled Coarse Aggregate (RCA):** The RCA was produced by crushing the tested concrete specimens from the concrete laboratory. All the aggregate sizes were separated to give the combined coarse aggregate size higher than 4.75mm but lower than 20mm. Coarse aggregate of sizes 20-10mm and 10-4.75mm were separated. The different size aggregate fill each other and thus increase the strength. The particle shape of the RCA was round and surface texture is porous and rough. This was due to the presence of attached mortar of the old natural aggregate. The specific gravity of the RCA was lower than the corresponding NCA and water absorption is higher due to the presence of low-density porous mortar. The resistance against crushing is slight lower than the natural aggregate.

**Physical properties of Recycled Coarse Aggregate**

S. No	Property	Requirement as per IS:NA	Observed Value
1	Water absorption (%)	-	2.9
2	Fineness Modulus	-	7.1
3	Specific gravity	-	2.47
4	Moisture content (%)	-	2.02
5	Impact Value (%)	-	15

**Metakaolin:** Metakaolin, generally known as the “calcined clay” is a reactive alumina-silicate pozzolana obtained by the heating kaolinite at a particular temperature condition. Kaolinite is a hydrous aluminium silicate of the composition  $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$ . Kaolinite is the clay mineral that provides the plasticity to the raw material and change during the heating to produce permanent material. Metakaolin is a Pozzolanic material used in concrete industry as a partial replacement for the Ordinary Portland cement usually (8-20) % by weight. These materials were not limited to special structures as they had been already widely used before in water tanks, aqueducts and bridges. Calcination conditions of kaolinite and the further classification of MK have been studied since the 19th century. Pera and Ambroise (1985) showed that cement containing 30% calcined laterites produced strengths (between 7 and 28 days) higher than that of the plain cement paste. At 180 days the strength of the concrete containing 50% calcined laterites was 87% of that developed by the plain Portland cement. As the temperature increases, the interlayer and hydrate water is removed from the Kaolin mineral. The effect of the heating treatment is normally evaluated by Differential Thermal Analysis (DTA). DTA nature curve for the common clay is investigated by Swami in 1986. In the process of endothermic reaction absorption of heat caused by the process of dihydroxylation or expulsion of combined water. Amboise, in 1985 determined the effect of calcining temperature of kaolinite in between the 450–750°C on the strength development of the concrete. The optimum calcination temperature, to give maximum strength at 3, 7 and 28 days was at 700°C.

**Metakaolin Chemical Composition**

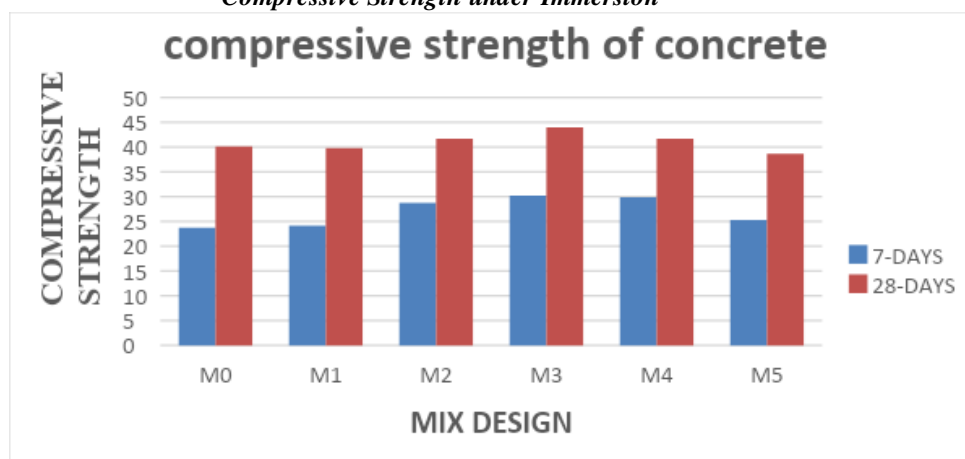
Chemical Composition	Mass (%)
$\text{SiO}_2$	52-54
$\text{Al}_2\text{O}_3$	44-46
$\text{Fe}_2\text{O}_3$	0.6-1.2
$\text{TiO}_2$	0.65
$\text{CaO}$	0.09
$\text{MgO}$	0.03
$\text{Na}_2\text{O}$	0.1
$\text{K}_2\text{O}$	0.03

**IV. EXPERIMENTAL RESULTS**

**Compressive Strength:** The effect of RCA and MK used in the present research study on compressive strength of concrete for M<sub>25</sub> grade of concrete with varying dosages 0%, 5%, 10%, 15% and 20% of MK replacing cement by weight and NCA with 20% RCA at 7 and 28 days has been shown in below table.

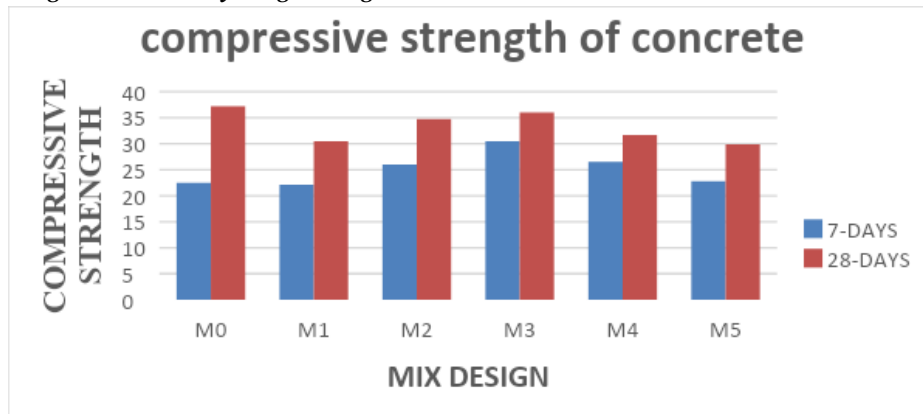
**Compressive Strength of Cube Specimens under Immersion curing**

S.NO	Mix Designation	Target Strength (N/mm <sup>2</sup> )	Comp. Strength At 7 Days (N/mm <sup>2</sup> )	Comp. Strength At 28 Days (N/mm <sup>2</sup> )
1	Mix 1 (M <sub>0</sub> )	38.25	23.72	40.16
2	Mix 2 (M <sub>1</sub> )	38.25	24.10	39.78
3	Mix 3 (M <sub>2</sub> )	38.25	28.69	41.69
4	Mix 4 (M <sub>3</sub> )	38.25	30.22	43.99
5	Mix 5 (M <sub>4</sub> )	38.25	29.84	41.69
6	Mix 6 (M <sub>5</sub> )	38.25	25.25	38.63

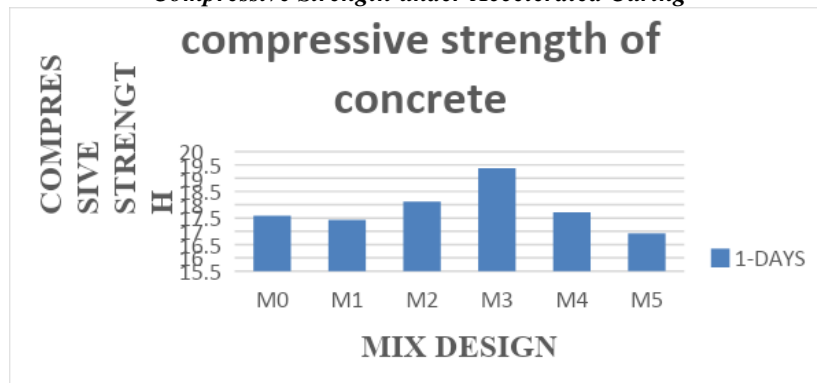
**Compressive Strength under Immersion***Curing***Compressive Strength of Cube Specimens under Gunny bag Curing**

S.NO	Mix Designation	Target Strength (N/mm <sup>2</sup> )	Comp. Strength At 7 Days (N/mm <sup>2</sup> )	Comp. Strength At 28 Days (N/mm <sup>2</sup> )
1	Mix 1 (M <sub>0</sub> )	38.25	22.51	37.22
2	Mix 2 (M <sub>1</sub> )	38.25	22.14	30.48
3	Mix 3 (M <sub>2</sub> )	38.25	25.96	34.72
4	Mix 4 (M <sub>3</sub> )	38.25	30.45	35.98
5	Mix 5 (M <sub>4</sub> )	38.25	26.50	31.65
6	Mix 6 (M <sub>5</sub> )	38.25	22.78	29.85



**Compressive Strength under Gunny Bag Curing****Compressive Strength of Cube Specimens by Accelerated Curing**

S.NO	Mix Designation	By Accelerated Curing (N/mm <sup>2</sup> )
1	Mix 1 (M <sub>0</sub> )	17.59
2	Mix 2 (M <sub>1</sub> )	17.43
4	Mix 4 (M <sub>3</sub> )	19.38
5	Mix 5 (M <sub>4</sub> )	17.72
6	Mix 6 (M <sub>5</sub> )	16.92

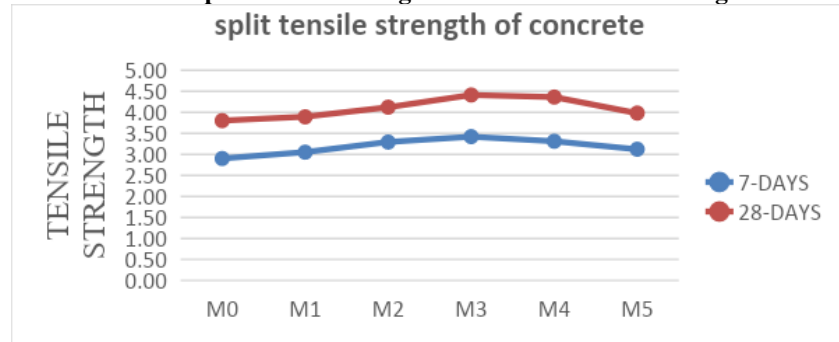
**Compressive Strength under Accelerated Curing**

**Split Tensile Strength:** Split Tensile strength is used to find the tensile strength of the concrete in compression testing machine (CTM). Here we need to place the cylinder vertically under the support of the plates and apply the load gradually and jot down the load at which the concrete fails give the split tensile strength of the concrete. The effect of RCA and MK used in the research present study on Split Tensile strength of concrete for M<sub>25</sub> grade of concrete with varying dosages 0%, 5%, 10%, 15% and 20% of MK replacing cement by weight and NCA with 20% RCA at 7 and 28 days has been shown in below.

**Split Tensile Strength on Cylindrical Specimens under Immersion Curing**

S.NO	Mix Designation	Split Tensile Strength At 7-Days (N/mm <sup>2</sup> )	Split Tensile Strength At 28-Days (N/mm <sup>2</sup> )
1	Mix 1 (M <sub>0</sub> )	2.90	3.80
2	Mix 2 (M <sub>1</sub> )	3.05	3.89
3	Mix 3 (M <sub>2</sub> )	3.29	4.12
4	Mix 4 (M <sub>3</sub> )	3.42	4.41
5	Mix 5 (M <sub>4</sub> )	3.31	4.36
6	Mix 6 (M <sub>5</sub> )	3.12	3.98

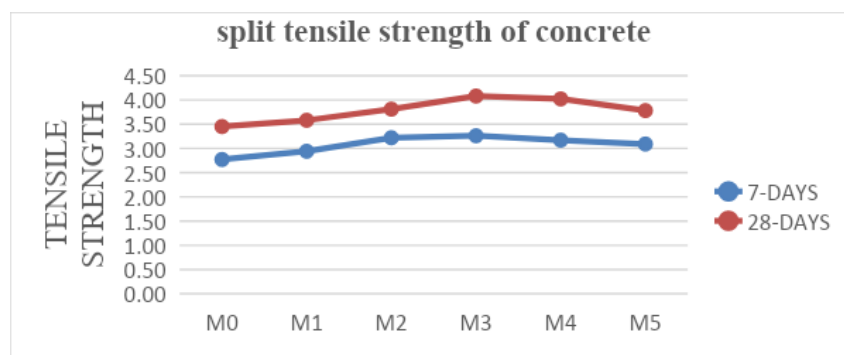
### Split Tensile Strength under Immersion Curing



### Split Tensile Strength on Cylindrical Specimens under Gunny Bag Curing

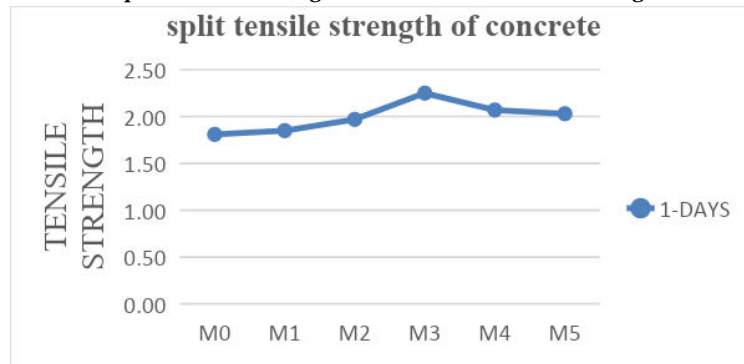
S.NO	Mix Designation	Split Tensile Strength At 7-Days (N/mm <sup>2</sup> )	Split Tensile Strength At 28-Days (N/mm <sup>2</sup> )
1	Mix 1 (M <sub>0</sub> )	2.77	3.45
2	Mix 2 (M <sub>1</sub> )	2.94	3.58
3	Mix 3 (M <sub>2</sub> )	3.22	3.81
4	Mix 4 (M <sub>3</sub> )	3.26	4.08
5	Mix 5 (M <sub>4</sub> )	3.17	4.02
6	Mix 6 (M <sub>5</sub> )	3.09	3.78

### Split Tensile strength Under Gunny Bag Curing

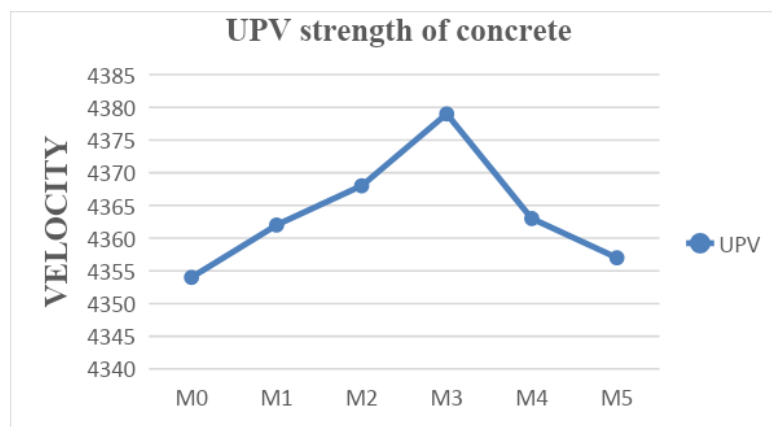


### Split Tensile Strength of Cylindrical Specimens by Accelerated Curing

S.NO	Mix Designation	Accelerated Curing Strength(N/mm <sup>2</sup> )
1	Mix 1 (M <sub>0</sub> )	1.81
2	Mix 2 (M <sub>1</sub> )	1.85
3	Mix 3 (M <sub>2</sub> )	1.97
4	Mix 4 (M <sub>3</sub> )	2.25
5	Mix 5 (M <sub>4</sub> )	2.07
6	Mix 6 (M <sub>5</sub> )	2.03

**Split Tensile strength Under Accelerated Curing****Ultrasonic Pulse Velocity Strength**

S.NO	Mix Designation	Velocity Measured (m/s)
1	Mix 1 ( $M_0$ )	4354
2	Mix 2 ( $M_1$ )	4362
3	Mix 3 ( $M_2$ )	4368
4	Mix 4 ( $M_3$ )	4379
5	Mix 5 ( $M_4$ )	4363
6	Mix 6 ( $M_5$ )	4357

**Graph Representing UPV strength****IV. CONCLUSION**

Based on the analysis of experimental results and discussion there upon the following conclusions can be drawn:

**Workability:** It was observed in this research work that at constant W/C ratio with increasing Recycled Coarse Aggregate content in the concrete mix the workability is gradually decreasing, this is due to the presence of the mortar on the surface of the Recycled Coarse Aggregate. Whenever the Recycled Coarse Aggregate can be used in construction, but lesser water quantity would cause the lower workability. Whenever Recycled Coarse Aggregate is used, water content in the mix should be monitored carefully as the water absorption capacity of the Recycled Coarse Aggregate is varying. RCA poses relatively lower bulk density, specific gravity and more water absorption capacity as compared to the NCA. This is mainly due to the sticky mortar adhering to the RCA. It is advisable to carry out the trial



mixes with the RCA proposed to be used in order to arrive at the water content and its proportion to suitable for workability levels and strength requirements, respectively.

**Compressive Strength:** From the test results it has been observed that the compressive strength of  $M_{25}$  grade concrete attaining 62.2% of target strength for control mix concrete at 7 days and strength going to be increased gradually at 0%, 5%, 10%, 15% and 20% replacement of MK and NCA with 20% RCA are 63.64%, 75.89%, 79.65%, 78.77% and 66.93% as compared to control mix. At 10% replacement of MK strength observed to be optimum and after that strength is gradually decreasing. Initially the compressive strength at 28 days 1.26% is decreased for  $M_1$  and later strength increased gradually up to 10% replacement of MK and it was observed to be 7.96% more than that of conventional concrete and later it decreases gradually.

**Split Tensile Strength:** From the test results it has been observed that the Split tensile strength of  $M_{25}$  grade concrete increases gradually as 3.38%, 13.53%, 17.67%, 13.91% and 6.77% at 0%, 5%, 10%, 15% and 20% partial replacement of cement with MK and NCA with 20% RCA at 7 days as compared to control mix of the concrete. The Split tensile strength is increased as 1.45%, 8.41%, 16.23%, 14.5% and 4.93% at partial replacement of cement with MK and NCA with RCA at 28 days as compared to control mix of the concrete. The Split tensile strength of concrete is increasing up to 10% addition of MK with cement and after that strength is gradually decreasing.

**Flexural Strength:** From the test results it has been observed that the Flexural strength of  $M_{25}$  grade concrete increases gradually as 1.94%, 8.74%, 13.6% up to  $M_3$  mix and later gradually decreases with the partial replacement of cement with MK and NCA with 20% RCA at 7 days as compared to control mix of the concrete. The Flexural strength initially 12.33% decreases for  $M_0$  mix and later increased as 6.16%, 13.01% up to  $M_3$  mix and later gradually decreasing at partial replacement of cement with MK and NCA with 20% RCA at 28 days as compared to control mix of the concrete.

- Economical and environmental pressures justify the accountability of this alternative material source for in places where there is non-availability of virgin aggregate or available source of new rocks are inaccessible either because of high land values and zoning constraints.
- The Scarcity of Recycled Coarse Aggregate, which is significant ingredient in the concrete mix, has become an issue. Its excessive usage causes a negative impact on environment. RCA is an alternative building material to NCA which satisfied all technical specification specified in the Indian Standard codes. It was understood that RCA can be undoubtedly as an alternative for NCA.
- Cement is a building material which is used as bonding ingredient in the concrete mix. But it has become as expensive commercial engineering material, apart from this manufacturing of cement has great negative impact on environment. Hence, it is necessary to replace the cement fully or partially, with alternative or supplementary material without violating any properties of concrete in fresh and hardened state.
- Metakaolin is one of the supplementary cementitious materials, which can partially replace the ordinary Portland cement. Usage of Metakaolin as a partial replacement of cement proved that Metakaolin is able to produce the desired properties of concrete in fresh and hardened state. From the above results we can conclude that 10% of cement can be replaced by Metakaolin

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