Study of Mechanical Properties of Concrete by Replacement of Natural Coarse Aggregate with Recycled Coarse Aggregate with Metakaolin

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Abstract. This research work investigates the compressive strength of concrete specimens cured at the age of 7 & 28 days, the split tensile strength, and the flexural strength of concrete specimens cured at 28 days. Natural coarse aggregate (NCA) has been replaced with 0 percent, 25 percent, 40 percent, 60 percent, and 100 percent by recycled coarse aggregate (RCA) of construction & destruction (C&D) waste of 30-year-old building and Ordinary Portland cement (OPC) has been replaced with 10 percent metakaolin (MK). To understand the fresh properties of concrete of slump test was performed and to find satisfactory results. To analyze the hardening properties of MK with recycled coarse aggregate (RCA) base mix concrete, compressive strength was measured at the age of 7 and 28 days, and split tensile strength, the flexural strength was measured at the age of 28 days. Based on the experiment's study, it can be concise that the 40 percent substitute of NCA with RCA carried good results with 10 percent MK. This research presents the effect of MK as a cement substitute on the properties of fresh and hardened with RCA.

Keywords: NCA, RCA, Metakaolin (MK), Construction & Demolition (C&D), Compressive Strength, Flexural Strength, Split Tensile Strength

1. Introduction
A large quantity of C&D waste has been produced due to the economic growing of infrastructure. The general way to organize of such waste is by landfill. Improper handling of C&D waste as time passes, landfills will cause many environmental issues. The continuous utilization of NCA will reason reserve scarcity. The potential solution for these problems is the recycling of aggregates. Still, due to strength reduction associated with RCA, its usage is restricted for low-strength concrete. Another hand, the incorporation of MK as a cement replacement in RAC could pave a path towards a sustainable future. This research presents the effect of MK as a cement substitute on the property of fresh and hardened RCA as well as NCA.

The RCA is extracted from first-hand cast laboratory cubes with known average compressive strength. The matter of waste disposal has become harsh both in industrialized and developing countries, including India. This one is related to a huge increase in the number of waste products, its...
continuing preservation of dumping grounds, and increasing the cost of transport and removal. The broad extraction of natural aggregate and the huge volumes of C&D waste going to landfill sites are having an effect on the environment & creating serious challenges to the public and environmentalist ambitions of a recyclable future. As a result, this idea of recycling waste and reusing it in some manner has garnered attention. C&D waste is the aforesaid issue in many countries. As a result, recycling technology has made advances in recycling the demolished concrete structure.

The pattern in reduction of aggregate assets can be in India. The scenario in India isn't fearfully severe, there are a few parts of a country wherein stone dust aggregate are inaccessible within a few kilometers. The harshness of an issue in the future requires significant thinking mostly on part of the Indian community, especially as the volume of the concrete building is expected to striking in the coming decades. The use of cement in concrete, along with C&D waste, is indeed a major source of concern for environmentalists. By high carbon emissions the cement manufacturing part is one of the major contributors to climate change. Studies are being conducted to reduce the use of cement by replacing mineral admixtures counting such MK, as a portion of cement. With the huge growth in construction waste more in the previous decade, social and environmental concerns about recycling have grown. The recycling of waste concrete has much increased according to current technological advancements. The characteristics of natural and RA are examined and the behavior of RAC results of MK.

1.1 World Scenario

The use of C&D waste in buildings is not really a new concept. Recycled concrete waste was found to be among the best ways to reduce construction waste. The research of RAC dates all the way back more than three decades. In the developed world C&D waste disposal is a serious problem in so many nations. Due to the lack of disposal sites, a problem had developed. There are major trash dumps in the area, and the rates of waste creation are extremely high. The rate of generation in industrialized countries is quite high. Because traditional recycling methods are ineffective, Sub base filling, land reclamation, and other waste, etc. are insufficient to address the issue of disposal of garbage. According to the extensive review of the literature, one primary obstacle to using RA is the ever-increasing demand for aggregates as infrastructure construction increases. Reduced specific gravity, low packing density, and lower impact crushing, and abrasion resistance are issues with RA. It's been shown that typical structural concrete can be easily achieved by using RA.

1.2 Indian Scenario

In India, there is a severe shortage of infrastructural amenities such as houses, roads, hospitals, and enormous quantities of building materials are supposed to create every one of these facilities. In the 10th and 11th five-year plans, the Indian Planning Commission dedicated approximately half of the financial plan to infrastructure development. Increasing infrastructural development of motorways, airports, other infrastructure, and rising demand for housing, has resulted in a scarcity of building materials and an increase in their cost. Most of the waste produced by destroyed constructions is dumped as landfills. Land-based disposal is producing a scarcity of dumping sites. The Indian standard standards of concrete requirement create no necessities for utilization of RA in concrete. The lack of a codified rule does not involve a limit on the utilization of RA indirectly and directly. As a result, it is start recycling and reusing C&D waste in arrangements to conserve the environment, energy, and money.

2. Literature Review

The resources of natural aggregates of engineering quality can be used. Meta-kaolin has been safely and successfully used as a construction aggregate in applications that as cement concrete, road embankment, road and walkways. The consequence of properties of concrete both fresh and hardened with metakaolin that as partial replacement of the NCA by C&D waste that previously research. Metakaolin is a de-hydroxy method of the clay mineral kaolinite. Metakaolin is an appreciated admixture purpose of utilization of cement. Good stone rocks kaolinite are recognized for example
china clay used in the product acknowledged as porcelain. The size of metakaolin particles is lesser than compared to cement. Metakaolin is a relatively material in the concrete industry that is growing strength decreasing sulphate attack and air-void connection. Pozzolanic reactions disparity the structure of concrete produce through powerful the existing calcium hydroxide of added calcium silicate hydrates subsequent in an enlarged strength and reduced porosity.

The examined the significance of including metakaolin in concrete and mortar was established. Concrete and mortar grieve destruction of workability outstanding to the mixture of metakaolin advanced the critical to improving a superplasticizer. The strengths of compressive and flexural were improved at the age of 7 days. The various parameters of durability were improved after the mixture of 10 to 15 percent metakaolin (1).

In this studies the mechanical properties of RAC with and without metakaolin. The different properties of concrete such comp. strength, splitting tensile and flexural strength is calculated. The variable of test is replacement relations for NA (0%, 20 %, 40 %, 60 %, 80 %, and 100 %) with RA and use of 20 percent metakaolin to replacement of cement. The result of combined RA and metakaolin on the concrete properties of is discovered in this study (2).

In this studied MK partial replacement of cement by 10 percent with RCA had 12 percent and 10 percent increase in mechanical properties for 25 and 30 grades. An increase of content cement improved the mechanical properties of RCA concrete. The totalling of metakaolin as an admixture in concrete completed from RCA reduced the workability of the concrete as the percentage totalling of MK increases. The concrete produced from RCA exceeded the conventional mix; it determined which the usage of MK as an admixture in concrete made from RCA aggregates better-quality both the strength tensile and compressive of concrete (3).

In this studied different result of the RCA ratio of water absorption, RAC mixtures display lesser value of slump of related to NAC mixes. The procedure MK at various substances decreases RAC mixes workability mainly due to the minor of particles that essential content of water. The RCA weaker, the compressive strength of the RAC mixes fallen upto 30 percent associated to the conventional mix with NCA. The processes MK can provision to progress the 28 day’s comp. strength mix of the RAC. The enhancement of strength outstanding for addition of MK that depends on MK. Up to 20 percent strength improvement that attained related to NAC when 20 percent is used of MK. This is subsequently of the reaction of pozzolanic of MK. Addition metakaolin that affect in dropping the absorption of water RAC mixes (4).

The level of replacement of cement by metakaolin is founding 13 percent. The increase in strength due to replacement of cement by metakaolin is 41 percent at the age of 7 days. The workability of concrete is established to reduction as the level of additional of natural aggregate by RA is enlarged. The Compressive strength increases upto 50 percent replacement of natural aggregate by RA and past that it reductions. The results found from non-destructive test are lesser than the obtained, excluding at 100 percent replacement level (5).

The study examines the properties of sandcretes formed the adding of 10 to 20 percent w/c MK in the estimated of binder. The adding of MK has created an enhancement of the properties of the material. The specimens of meta-kaolin in the binder performance improved strength associated to the reference. The progression in strength was extra noticeable in examples with advanced concentration of binder and low ratio of W/B. The strength rise up was experimental in the case of sandcrete samples concluded little binder concentrations (6).

3. Research Significance

It was mentioned in the previous section that brief evaluation writing on the subject was available and that it was not in the proper sequence on the RCA with MK finished. Considering the use of RCA with MK, this research has been considered to evaluate the strength and durability, and mathematical prediction with MK. It is proposed the most suitable mix of components for enhancing concrete durability in terms of RCA and cement additions being suggested. MK has been used the partial
substitute for OPC in various amounts. In addition, all RCA mixes were submitted to comp. strength, flexural strength, and split tensile strength tests.

3.1 Experimental Program

Materials

In the preparation of concrete mixes are divided into two groups. OPC of grade 43 as according to IS 269:2015, natural sand, NCA, and RSA with a maxi. size of 20 mm was utilized. The C&D waste was collected near Gandhinagar Railway Station, Jaipur and manually crushing in at the concrete laboratory of department of Vivekananda Global University, Jaipur. The aggregates were crushed manually and size reduced as per requirement, which was a maximum of 20 mm. As shown in table no.1 show the physical characteristics of the RCA used in this investigation. MK was used as a constituent in cement-based materials in various ratios.

1. Cement

The cement used is Ultratech OPC of 43 grades, which has a specific gravity of 3.15 as per IS: 269:2015.

| Sr. No. | Properties          | Units | Result Obtained | Permissible range specified (IS:269:2015) |
|---------|---------------------|-------|-----------------|-------------------------------------------|
| 1       | Sp. Gravity         | -     | 3.11            | 3.10–3.15                                 |
| 2       | Fineness            | cm²/gm| 2385            | 2250 (mini.)                              |
| 3       | Soundness           | mm    | 4               | 10 (max.)                                  |
| 4       | Consistency         | %     | 33.45           | 30–35                                      |
| 5       | Setting Time of cement | Minutes | 63 | 30 (min.)            | 600 (max.)                                 |
| 6       | Comp. Strength      | MPa   | 24 (3-Days)     | 23.00 (minimum)                           |
|         |                     |       | 36.5 (7-Days)   | 33.00 (minimum)                           |
|         |                     |       | 46.1 (28-Days)  | minimum                                   |

2. Metakaolin (MK)

The development of building products offering scientific and ecological advantages is the primary dispute of the novel millennium single such material is MK that is categorized as current era of additional material of cementitious. Complementary cementitious material is a fine material used to substitute parts of clinker in cement in mix of concrete. MK is distinctive that as is neither a by-product of industrial it is obtained from a naturally occurring mineral and is produced specifically for cement purposes. MK is generated by thermal treatment, i.e. by calculations of kaolin clays in certain limit of temperature. The heating method from the mineral kaolinite (Al2O3·2SiO2·2H2O), the primary component of kaolin clay, and dissolves the structure of material resulting an alumino-silicate (Al2O3·2SiO2). The equation for this di-hydroxylation process is shown below: Al2O3·2SiO2·2H2O → Al2O3·2SiO2 + 2H2O

| Sr. No. | Name of Ingredient | Percent  |
|---------|--------------------|----------|
| 1.      | SiO2               | 52–54%   |
| 2.      | Al₂O₃              | 41–43%   |
| 3.      | Fe₂O₃              | <2.24%   |
| 4.      | TiO₂               | <2.89%   |
| 5.      | SO₄                | <0.45%   |
6. \( P_2O_5 < 0.2\% \)
7. \( CaO < 0.2\% \)
8. \( MgO < 0.1\% \)
9. \( Na_2O < 0.05\% \)
10. \( K_2O < 0.40\% \)
11. L.O.I. < 0.5\%

3. NCA and RCA

The designing a concrete mix, different physical characteristics of NA and RA are determined. During this project, NCA with A size of 20 mm and the grading criteria as per IS: 383-2016 was purchased from locally available quarries. The demolished structure provides the RCA. The waste concrete from the demolished structure is carried to a nearby crusher, where it is converted into aggregates into 20 mm.

| Sr. No. | Description of test          | Test Result of NCA | Test Result of RCA |
|---------|------------------------------|--------------------|--------------------|
| 1       | Fineness Modulus             | 6.94               | 6.82               |
| 2       | Specific Gravity             | 2.66               | 2.48               |
| 3       | Aggregate Impact Value       | 15.41\%            | 28.16\%            |
| 4       | Aggregate Crushing Value     | 15.67\%            | 26.54\%            |
| 5       | Water Absorption             | 0.58\%             | 5.42\%             |

4. Natural Fine Aggregate (Sand)

In this work sand was used FA (sand) confirms to Zone-II of IS 383:2016 purchased from locally available in Jaipur Banas River.

| Sr. No. | Description of test  | Test Result  |
|---------|----------------------|--------------|
| 1       | Silt Content         | 1.65\%       |
| 2       | Moisture Content     | 1.61\%       |
| 3       | Absorption Capacity  | 2.89\%       |
| 4       | Fineness Modulus     | 2.84\%       |
| 5       | Unit Weight          | 1562 kg/m³   |
| 6       | Specific Gravity     | 2.61         |

5. Water

The water used for this research is municipal water of Jaipur, found in the Vivekananda Global University, Campus.

Specimen Preparation

All ten mixes of concrete are produced during the present experimental research each mix has a proper reference mix ID.

Group I: Total five concrete mixes 0\%, 25\%, 40\%, 60\%, and 100\% of RCA replacements were cast as given the targeted compressive strength of 25-grade concrete.

Group II: Total five concrete mixes 0\%, 25\%, 40\%, 60\%, and 100\% of RCA replacement with 10 percent MK were cast as given of 25-grade concrete.

The mixes are prepared in the related guidelines as per IS10262: 2019. In table no. 3 and 4 the proportions for various mixtures that have been taken.
Table 5 Mix Group I mix proportion of concrete (kg per meter cube)

| S. No. | Mix ID | Cement | NCA  | RCA  | FA   | Water | W/C Ratio |
|--------|--------|--------|------|------|------|-------|-----------|
| 1      | M011   | 352.00 | 1055.00 | 0.00 | 880.00 | 201.00 | 0.40      |
| 2      | M012   | 352.00 | 791.25 | 263.75 | 800.00 | 207.00 |           |
| 3      | M013   | 352.00 | 633.00 | 422.00 | 880.00 | 212.00 |           |
| 4      | M014   | 352.00 | 422.00 | 633.00 | 880.00 | 219.00 |           |
| 5      | M015   | 352.00 | 0.00  | 1055.00 | 880.00 | 226.00 |           |

Table 6 Mix Group II mix proportion of concrete (kg per meter cube)

| S. No. | Mix ID | Cement | MK   | NCA  | RCA  | FA   | Water | W/C Ratio |
|--------|--------|--------|------|------|------|------|-------|-----------|
| 1      | M021   | 352.00 | 35.20 | 1055.00 | 0.00 | 880.00 | 201.00 | 0.40      |
| 2      | M022   | 352.00 | 35.20 | 791.25 | 263.75 | 880.00 | 207.00 |           |
| 3      | M023   | 352.00 | 35.20 | 633.00 | 422.00 | 880.00 | 212.00 |           |
| 4      | M024   | 352.00 | 35.20 | 422.00 | 633.00 | 880.00 | 219.00 |           |
| 5      | M025   | 352.00 | 35.20 | 0.00  | 1055.00 | 880.00 | 226.00 |           |

4. Results

The following are the different test results discussed below.

4.1 Fresh Concrete Tests

Slump Test: The horizontal free flow of NCA and RCA concrete mixes was investigated using the slump test. A rigid base plate and a slump cone were used. A slump test is carried out to check the consistency and workability of freshly made concretes. Slump tests conducted for all experiments are presented below.

4.2 Hard Concrete Test

Compressive Strength: In the laboratory, for each mix, three cubes with dimensions of 15cm x 15cm x 15cm were utilized to determine compressive strength at age of 28 days of curing. The compressive strength test is accepted absent in agreement as per IS 516:1959.

Flexural Strength: The property of materials, used to conclude the bend strength. The three beams with dimensions of 10cm x 10cm x 50cm were used to determine flexural strength after 28 days of curing period. The flexural test is performed as per IS 516:1959.

Split Tensile Strength: This test used to determine the tensile strength. Split tensile strength was calculated by cylinder of size 100mm X 300mm. The split tensile testing is showed as per IS 516:1959. The split tensile strength of each mix is calculated using an average of three cylinders.

Table 7 Slump value in mm of Group-I

| Sr. No. | Mix ID | Slump value (mm) |
|---------|--------|------------------|
| 1       | M011   | 77               |
| 2       | M012   | 72               |
| 3       | M013   | 71               |
| 4       | M014   | 68               |
| 5       | M015   | 64               |
Table 8 Slump value in mm of group-II

| Sr. No. | Mix ID | Slump value (mm) |
|---------|--------|------------------|
| 1. | M021 | 77 |
| 2. | M022 | 75 |
| 3. | M023 | 74 |
| 4. | M024 | 71 |
| 5. | M025 | 76 |

Table 9 Compressive Strength Test of Group-I

| Sr. No. | Mix ID | 7-Days | 28-Days |
|---------|--------|--------|---------|
| 1. | M011 | 24.62 | 36.82 |
| 2. | M012 | 20.94 | 32.24 |
| 3. | M013 | 20.46 | 31.81 |
| 4. | M014 | 20.74 | 31.02 |
| 5. | M015 | 18.92 | 28.29 |
Fig. 3. Bar Chart Compressive Strength of Group-I at 7 and 28 days

Table 10 Compressive Strength Test of Group-II

| Sr. No. | Mix ID | 7-Days | 28-Days |
|---------|--------|--------|---------|
| 1       | M 021  | 24.71  | 36.91   |
| 2       | M 022  | 22.07  | 33.12   |
| 3       | M 023  | 21.12  | 32.14   |
| 4       | M 024  | 20.83  | 31.51   |
| 5       | M 025  | 19.76  | 29.42   |

Fig. 4. Bar Chart Compressive Strength of Group-II at 7 and 28 days
Table 11 Split Tensile Strength of Group-I

| Sr. No. | Mix ID | Split Tensile Strength in MPa at 28-Days |
|---------|--------|-----------------------------------------|
| 1.      | M011   | 4.61                                    |
| 2.      | M012   | 3.78                                    |
| 3.      | M013   | 3.76                                    |
| 4.      | M014   | 3.47                                    |
| 5.      | M015   | 3.42                                    |

Fig.5. Bar Chart Split Tensile Strength of Group-I at 28-Days

Table 12: Split Tensile Strength of Group-II

| Sr. No. | Mix ID | Split Tensile Strength in MPa at 28-Days |
|---------|--------|-----------------------------------------|
| 1.      | M021   | 4.75                                    |
| 2.      | M022   | 4.11                                    |
| 3.      | M023   | 3.89                                    |
| 4.      | M024   | 3.72                                    |
| 5.      | M025   | 3.56                                    |

Fig.6. Bar Chart Split Tensile Strength of Group-II at 28-Days
### Table 13 Flexural Strength Test of Group-I

| Sr. No. | Mix ID | 28-Days |
|---------|--------|---------|
| 1       | M 011  | 4.23    |
| 2       | M 012  | 3.72    |
| 3       | M 013  | 3.68    |
| 4       | M 014  | 3.59    |
| 5       | M 015  | 3.28    |

![Fig.7. Bar Chart of Flexural Strength Test of Group-I](image)

### Table 14 Flexural Strength Test of Group-II

| Sr. No. | Mix ID | 28-Days |
|---------|--------|---------|
| 1       | M 021  | 4.59    |
| 2       | M 022  | 3.81    |
| 3       | M 023  | 3.87    |
| 4       | M 024  | 3.71    |
| 5       | M 025  | 3.54    |

![Fig.8. Bar Chart of Flexural Strength Test of Group-II](image)
5. Conclusion

By investigation, some significant conclusions can be made aiming to reuse the RCA instead of NCA as partial substitute of cement. The mechanical properties of RAC with and without MK are explored in this work. In this study, the mixed effect of RCA and MK on concrete is investigated. Based on slump they brief that using RCA in mixed concrete with and without MK a little affects the workability. The Workability of concrete decreases as the substitute of NCA with RCA increases. An acceptable result was experiential with RCA and not effect was seen on workability. The comp. strength at 28 days is 36.91 MPa for mix ID M021. Comp. strength decreases slowly with increasing the RCA replacing of NCA. The effect of MK enhanced the strength of the RCA concrete mix. The compressive strength of mix ID of M 015 was 23.17 percent lesser value than of control concrete mix. Mix ID from M 021 to M 025 had a satisfactory split tensile strength but mix ID M011 to M 015 had a lesser value of strength. The split tensile strength of mix ID of M 015 was 25.81 percent lesser value than of the control concrete mix. The Split tensile strength decreased with growing the content of RCA. Generally RCA base concrete failed to create a adequate pledge between aggregate and cement. To short out this problem use MK in appropriate percentages weight of cement. Mix ID from M 021 to M 025 had acceptable flexural strength apart from mix ID of M 012 to M 015 had a lesser value of flexural strength. The flexural strength of mix ID M015 was 22.46 percent lesser value than of control concrete mix. The split tensile strength reduced with growing the content of RCA. To conquer this complexity use MK in percentile by weight of cement.

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