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# Comparative Analysis of Two Different Combinations of Pretreatment Methods for Treating Recycled Concrete Aggregates

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## Abstract

**Objectives**: This research is aimed at comparing the performance of two sets of treatments. The first set of treatments tests the performance of heated, abrasioned, and fly ash-treated recycled concrete aggregates (RCA), while the other set of treatments examines the performance of heated, abrasioned, and silica fume-treated aggregates. Though previous research has examined the performance of the standalone treatment methods for enhancing RCA properties, there is a research gap that attempts to study the performance of the combinations of various treatments and their merits. To bridge the gap in the literature, this study compares the combination of two sets of treatment methods to investigate the relative effectiveness of the combination of the treatment methods that can improve RCA properties. **Methods**: The study was conducted using the concrete mix design procedure outlined in IS 10262-2019 in the laboratory. As part of the experimentation program, a total of 24 sample cubes were casted and tested. **Findings**: A 14.5% reduction in water absorption was observed for 10mm heated, abrasioned, and fly ash-treated aggregates, whereas a 15.2% reduction in water absorption was observed for 20mm heat-treated, abrasioned, and fly ash-treated aggregates compared to untreated aggregates. Similarly, for heat-treated, abrasioned, and silica fume-treated aggregates, a 41.7% reduction in water absorption was observed for 10mm aggregates, and a 45% reduction was observed for 20mm aggregates over untreated aggregates. A 133% increase in slump value was observed for heated, abrasioned, and fly ash-treated aggregates, whereas a 150% increase in slump value was observed in the case of heated, abrasioned, and silica fume-treated aggregates. Further, a 150 % increase in compressive strength was observed for heated, abrasioned, and fly ash-treated aggregates, and a 165% increase in compressive strength was observed for heated, abrasioned, and silica fume-treated aggregates over untreated aggregates. **Novelty:** This research addresses the ninth United Nations Sustainability

Development Goal, i.e., Industry, Innovation, and Infrastructure, as it promotes the use of eco-friendly construction practices. Moreover, the present research offers a manifold contribution to the state-of-the-art literature on construction management and offers numerous implications for the construction industry.

**Keywords:** Recycled concrete aggregates; Silica fume treatment; Fly ash treatment; Water absorption; Workability; Compressive strength

# 1 Introduction

Many research studies have advocated the application of recycled concrete aggregate as a potential substitute for natural aggregates in construction projects. However, due to the cement mortar attached to the RCA surface, it has high water absorption and inferior engineering properties compared to natural aggregates. Therefore, several pretreatment methods have been recommended by researchers to remove the attached cement mortar and improve the microstructure of RCA[(1)]. These methods are mainly classified as thermal, mechanical, and chemical treatments, having their benefits and limitations[(1)]. In chemical treatment, the application of pozzolanic material, such as fly ash and silica fume, for pretreatment of RCA surface has been documented by various research studies[(2–5)]. The pozzolanic properties of silica fume and fly ash can improve the microstructure of RCA by filling up surface pores in the adhered mortar and reducing the Ca/Si ratio[(2)]. Alqarni, Abbas, Al-Shwikh, and Al-Salloum compared the performance of silica fume slurry treatment with fly ash slurry treatment and observed that silica fume results in higher water reduction compared to fly ash[(2)]. The addition of 10-15% silica fume in RCA concrete mix can help to achieve compressive strength comparable to natural concrete.[(6,7)]. However, the addition of silica fume can also lead to a reduction in the workability of recycled aggregate concrete[(3)]. Fernando, Selvarajan, Srikanth, and Gamage observed that treatment of RCA surfaces with a slurry of fly ash and rice husk ash can help to reduce the porosity of RCA and increase its microhardness[(8)]. Fawzy, Elshami, and Ahmed observed that the addition of 1% nano-silica can enhance the slump value of recycled aggregate concrete by 11.1% and also improve the compressive strength[(9)]. The application of fly ash and superplasticizer in developing high-strength self-compacting concrete was studied by Katar, Ibrahim, Malik, and Khahro[(10)]. Although many research studies have been conducted on the application of fly ash and silica fume in recycled aggregate concrete, a comparative analysis of the effectiveness of both these pozzolanic treatments in combination with other treatments needs to be investigated. Therefore, this study has attempted to compare the performance of two sets of RCAs treated with a combination of treatment methods. The first combination of selected treatment methods includes heat treatment, abrasion treatment, and silica fume slurry treatment, whereas the second combination of treatment methods includes heat treatment, abrasion treatment, and fly ash slurry treatment. Both microwave and abrasion treatments have been recommended as energy-efficient and effective methods for the removal of attached mortar[(11,12)] For comparing the treatment effectiveness, water absorption was selected as a performance parameter. The study outcome would assist the concrete industry in making reasonable judgments regarding the suitability of treatment combinations to be applied to improve RCA surface.

# 2 Methodology

## 2.1 Cement

The cement conforming to Bureau of Indian Standard Specification (BIS) 12269 with specifications as shown in Table 1 was used for the experimentation work.

**Table 1. Cement specifications**

| Type | Ordinary Portland Cement (O.P.C) |
|---|---|
| Grade | 53 |
| Consistency | 31% |
| Specific gravity | 3.15 |
| Initial setting time | 165 min |
| Final setting time | 600 min |
| Compressive strength | 53.8 Mpa |

## 2.2 Sand

The sand conforming to IS 383-1970 with the characteristics shown in Table 2 was used for the experimentation program.

**Table 2. Sand specifications**

| Specifications | |
|---|---|
| Specific gravity | 2.6 |
| Moisture content | 2.1% |
| Water absorption | 1% |
| Silt content | 9% |
| Fineness modulus | 3.885 |

## 2.3 Recycled concrete aggregates

The RCA was collected from the concrete waste of a demolished two-story building. The concrete blocks were crushed at the crusher plant into various sizes and later on separated into 20mm, 10mm, and 6mm size aggregates. The sieve analysis of 10mm and 20mm size aggregates was carried out under the guidelines of IS 2386:1963, and the grading percentage for both 10mm and 20mm was finalized according to IS 383:1970. The physical properties of natural aggregates and RCA, including specific gravity and water absorption, were obtained under IS 2386-1 1963 guidelines as shown in Table 3. The untreated RCA is shown in Figure 1.

**Table 3. Physical properties of Natural aggregates and Recycled concrete aggregates (RCA)**

| | Specific Gravity | Water Absorption (%) | Bulk density | Abrasion value (%) | Crushing value (%) | Impact value (%) |
|---|---|---|---|---|---|---|
| **NA** | | | | | | |
| 10mm | 2.90 | 1.42 | 1.50 | 10 | 14 | 15 |
| 20mm | 2.94 | 1.2 | 1.55 | 15 | 12 | 12 |
| **RCA** | | | | | | |
| 10mm | 2.54 | 4.5 | 1.31 | 14 | 29.32 | 32 |
| 20mm | 2.53 | 4.72 | 1.38 | 9.48 | 16.62 | 24.3 |

## 2.4 Silica Fume

For the study, silica fume was procured from M/S sales fiber region company, Chennai, with the physical and chemical composition given in Tables 4 and 5.

## 2.5 Superplasticizer

The superplasticizer used in this experimental study was Sika Master Rheobuild 822NJ, the specifications of which are given in Table 6.

**Table 4. Physical properties of silica fume**

| Physical state | Micronized powder |
|---|---|
| Odor | Odourless |
| Appearance | White color powder |
| Color | White |
| Pack density | 0.76gm/cc |
| pH of 5% solution | 6.90 |
| Specific gravity | 2.63 |
| Moisture | 0.058% |
| Oil absorption | 55ml/100gm |

**Table 5. Chemical properties of silica fume**

| Chemical properties | |
|---|---|
| Silica ($SIO_2$) | 99.886% |
| Alumina ($Al_2O_3$) | 0.043% |
| Ferric Oxide | 0.040% |
| Titanium Oxide | 0.001% |
| Calcium Oxide | 0.001% |
| Magnesium Oxide | 0.00% |
| Potassium Oxide | 0.001% |
| Sodium oxide | 0.003% |
| Loss of ignition | 0.015% |
| Lead | 0.00% |

**Table 6. Specifications of superplasticizer**

| Parameters | Specifications |
|---|---|
| Physical state | Dark brown free-flowing liquid |
| Chemical ingredient | Naphthalene formaldehyde polymers |
| Relative density at 25 °C | 1.135 |
| pH | 8.42 |
| Chloride ion content | 0.0030 |
| Dry material content | 26.34 |

## 2.6 Fly ash

The fly ash used for the experimentation program was unprocessed raw fly ash supplied by M/s Tusi Buildcon RMC plant in Aurangabad, Maharashtra.

## 2.7 Treatment Methods of RCA

The treatment method employed to improve the surface properties of RCA consisted of heated, abrasion, and GGBS slurry treatment.

### *2.7.1 Heat treatment*

In the heat treatment method, the RCA was heated in a Microwave oven at 350 °C for 2 hours. After 2 hours, the aggregates were removed from the oven and immediately immersed in water. These aggregates were later dried at lab temperature. The objective of heat treatment was to produce thermal stresses in the microstructure surface of RCA so that the attached mortar could be loosened and gradually removed. The heat treatment of RCA has been shown in Figure 1 below.

**Fig 1. Heat treatment for recycled concrete aggregate**

### *2.7.2 Abrasion treatment*

The heat-treated aggregates were placed in a Los Angeles abrasion machine, and treatment was conducted according to IS 2386 part 4 guidelines. The aggregates were placed in an LA abrasion machine containing 12 steel balls having a 60 mm diameter, and they were offered 300 revolutions for 10 minutes. The objective of abrasion treatment was to remove attached mortar through peeling and friction action of steel balls. The abrasion treatment of aggregates is shown in Figure 2.


**Fig 2. Abrasion treatment for recycled concrete aggregate**

#### *2.7.3 Fly ash slurry treatment*

The volume of slurry containing cement, fly ash, and water was taken as 15% of the total volume of dry loose-weight aggregates. The percentage of fly ash and cement was taken as 70%: 30% of slurry volume so that the effect of fly ash becomes more visible compared to cement. The slurry treatment was applied to heated and abrasioned RCA in batches, with each batch consisting of 27 kg of aggregates. For $1m^3$ of concrete, the water content was taken as 629 kg, the fine aggregate was taken as 629 kg, and the cement volume was taken as 270 kg. In this way, the first batch of heated, abrasioned, and fly ash slurry-treated aggregates were prepared as shown in Figure 3.

**Fig 3. Heated, abrasioned and FA treated aggregate**

#### *2.7.4 Silica fume slurry treatment*

The silica fume slurry treatment was applied to the second batch of heated and abrasioned aggregates with the same volumetric proportions as fly ash. The heated, abrasioned, and silica fume slurry-treated aggregates are shown in Figure 4.

**Fig 4. Heated, abrasioned & SF treated aggregates**

### 2.8 Concrete mixture proportions

A total of 24 mixes were prepared as part of the experimentation program using the below mix proportions outlined in Table 7. The base water content, for which cohesive mix and desired medium workability were obtained for 0.4 w/c ratio, was 170 liters.

**Table 7. Mix proportion for 0.4 w/c ratio**

| % of FA: RCA | 45:55 | 50:50 |
|---|---|---|
| W/C | 0.4 | 0.4 |
| Target workability | Medium | Medium |
| Water (Kg) | 170 | 170 |

*Continued on next page*

*Table 7 continued*

| | | |
|---|---|---|
| Calculated Cement (Kg) | 340 | 340 |
| Flyash (10%) | 34 | 34 |
| Actual cement | 306 | 306 |
| Air ( %) | 1 | 1 |
| Superplasticizer (ml) | 3.4 | 3.4 |
| 10mm RCA (kg/m$^3$) | 947 | 861 |
| 20mm RCA | 105 | 96 |
| Fine aggregates (kg/m$^3$) | 897 | 997 |

# 3 Results

## 3.1 Water absorption

The water absorption values were obtained in accordance with IS 2386 -3 1963 guidelines. These values are shown in Figure 5.

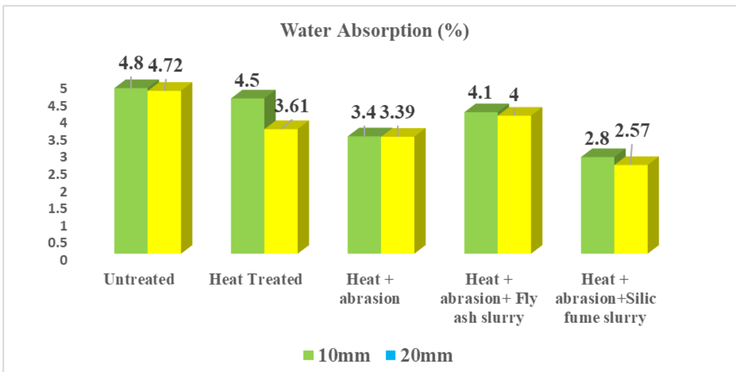


**Fig 5. Water absorption results for various pretreatments**

### *3.1.1 Effect of heat treatment*

The application of heat treatment led to a reduction in water absorption from 4.8% to 4.5 % for 10mm aggregates and from 4.72% to 3.61% for 20mm aggregates. This reduction was observed mainly due to the generation of thermal stresses, which led to the weakening of adhered mortar and gradual removal of the same.

### *3.1.2 Effect of heat cum abrasion treatment*

A further reduction in water absorption was observed after the application of both heat and abrasion treatment to RCA. For 10mm aggregates, this reduction was observed from 4.8% to 3.4%, and for 20mm aggregates, it was observed from 4.72% to 3.39%. This was mainly due to the removal of adhered mortar due to friction and the peeling action of steel balls in the abrasion machine.

### *3.1.3 Effect of heat, abrasion, and FA slurry treatment*

An increase in water absorption was observed from 3.4% to 4.1% for 10mm aggregates and 3.39% to 4% for 20mm aggregates after the application of all 3 treatments, which include heat, abrasion, and fly ash slurry treatment. The increase in water absorption could be attributed to the extra water added to the aggregate during the ash slurry treatment. Although this water absorption value was still lower than untreated aggregates.

### *3.1.4 Effect of heat, abrasion, and SF slurry treatment*

The reduction in water absorption trend was observed for heat, abrasioned, and SF slurry-treated aggregates from 3.4% to 2.8% for 10mm aggregates and 3.39% to 2.57% for 20mm aggregates. This was the lowest reduction in water absorption for treated RCAs, mainly due to the filling of pores and densification of RCA microstructure.

### 3.2 Slump Values

The slump value was obtained by the guidelines of IS 1199-2 2018 and shown in Figure 6. It was observed to be 30mm for the FA: RCA proportion of 45:55 and 20mm for the FA: RCA proportion of 50:50. The slump value for heated, abrasioned, and fly ash slurry-coated aggregates was observed to be 70mm for FA: RCA proportion of 45:55 and 50mm for FA: RCA proportion of 50:50. The slump value for heated, abrasioned, and Silica Fume slurry treated aggregates was observed to be 75mm for FA: RCA proportion of 45:55 and 70mm for FA: RCA proportion of 50:50.

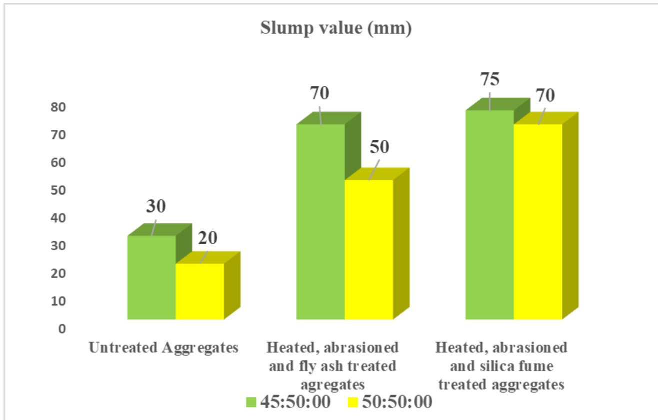


**Fig 6. Slump values for pretreated aggregate concrete**

### 3.3 Compressive Strength

The compressive strength was obtained by IS 516-1959 guidelines and shown in Figure 7. It was observed to be 20mpa for the FA: RCA proportion of 45:55 and 18 Mpa for the FA: RCA proportion of 50:50. For heated, abrasioned, and fly ash slurry treated aggregates, the compressive strength was 50mpa for FA: RCA proportion of 45:55 and 45Mpa for FA: RCA proportion of 50:50. Further, improvement in compressive strength was observed for heated, abrasioned, and Silica fume slurry coated aggregates, which is 53 Mpa for 45:55 and 50Mpa for 50:50 proportion.

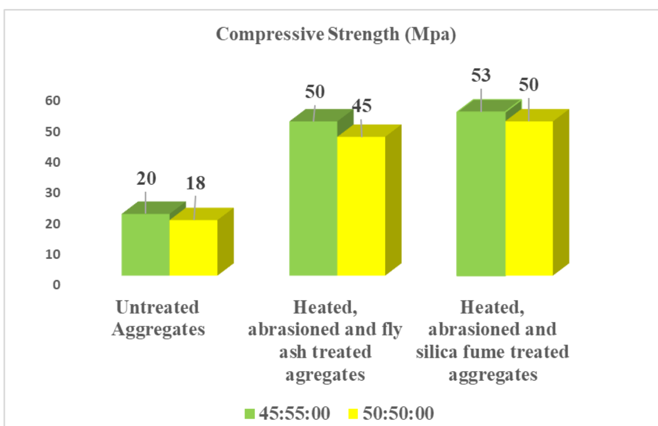


**Fig 7. Compressive strength values for pretreated aggregate concrete**

## 4 Discussion

In this study, the effectiveness of two different combinations of treatment was evaluated. The first combination included pre-treating RCA with heat, abrasion, and fly ash slurry treatment. The second combination included pre-treating RCA with heat, abrasion, and silica fume slurry treatment. Based on the study results, the following conclusions can be obtained:

1. The water absorption value for heated, abrasioned, and fly ash-treated aggregate was 14.5% lower compared to untreated aggregates for 10mm aggregates and 15.2% lower for 20mm aggregates. For heated, abrasioned, and silica fume-treated aggregates, the reduction in water absorption was 41.6% for 10mm aggregates and 45% for 20mm aggregates. The reduction in water absorption was achieved mainly due to the effective removal of adhered mortar from the RCA surface by applying heat and abrasion treatment. Heating the RCA in a microwave oven followed by immediately immersing them in water helped to loosen the adhered mortar, and the peeling action during the abrasion process led to the disintegration of mortar. Further, the pozzolanic properties of fly ash and silica fume helped to fill the micropores of the RCA surface, thereby providing a healing effect.
2. The water absorption value for heated, abrasioned, and silica fume-treated aggregates declined by 31% for 10mm heated, abrasioned, and fly ash-treated aggregates and 35% for 20mm aggregates. The higher reduction in water absorption for silica fume was observed due to its finer particle size and higher pozzolanic reactivity.
3. The slump value for heated, abrasioned, and fly ash-treated aggregates increased from 30mm to 70mm when the percentage of fine aggregates to recycled coarse aggregate was maintained at a ratio of 45:55 in the concrete mix. The slump value increased from 20mm to 50mm when the percentage of fine aggregate to recycled coarse aggregate was maintained at 50:50.
4. The slump value for heated, abrasioned, and silica fume-treated aggregates increased from 30mm to 75mm when the % of fine aggregates to recycled coarse aggregates was 45:55 in the concrete mix. This value increased from 20mm to 70mm when the % of fine aggregate to recycled coarse aggregate was 50:50. These results are in direct contrast to the reduction in slump value observed by Ahmed et al [6] when silica fume was added to the concrete mix.
5. The 28-day compressive strength achieved for heated, abrasioned, and fly ash-treated aggregates was 50Mpa for a fine aggregate to recycled coarse aggregate ratio of 45:55 and 45Mpa when the fine aggregate to coarse aggregate ratio was 50:50.
6. The 28d compressive strength achieved for heated, abrasioned, and silica fume-treated aggregates was 53Mpa for the fine aggregate to recycled coarse aggregate ratio of 45:55, and 50Mpa, when the fine aggregate to recycled coarse aggregate ratio was 50:50. In the study conducted by Ahmed et al., the maximum compressive strength achieved using only silica fume slurry treatment was 35.5Mpa [6]. However, in that study, the author replaced both natural fine aggregates and coarse aggregates with recycled fine aggregates and recycled coarse aggregates.
7. For both combinations of treatment, a reduction in slump and compressive strength was observed with an increase in the volume of fine aggregate and a decrease in the volume of coarse aggregates.

### 4.1 Theoretical contribution

This study contributes to the existing literature in three ways. First, the study results can facilitate a better understanding of an effective combination of treatments that can enhance RCA's properties. Second, instead of implementing a single-stage treatment method, a multi-stage treatment could be more effective in reducing water absorption and enhancing the workability and compressive strength of recycled aggregate concrete. Third, the use of secondary products such as fly ash and recycled aggregates in concrete production can also help to promote their applications instead of simply discarding these products as waste materials.

### 4.2 Practical implications

In the proposed study, the compressive strength of concrete manufactured using 3-stage treated RCA was achieved between 45-53 Mpa, which satisfies the strength criteria for small-scale commercial and civil construction projects. Further, the workability of the concrete achieved was between 50-75 mm, making it suitable to use in light reinforcement sections. Thus, by pretreating RCA, it is feasible to manufacture environmentally sustainable concrete that not only satisfies field requirements but also meets the 9$^{th}$ United Nations sustainability development goals.

## 5 Conclusion

Both silica fume and fly ash are effective treatment methods in reducing water absorption of RCA and improving fresh and hardened properties of concrete, with silica fume exhibiting higher effectiveness compared to fly ash. However, the procurement cost of silica fume is higher compared to fly ash. Fly ash is waste material that can be directly procured from thermal plants with minimum cost. Therefore, the selection of treatment between silica fume and fly ash would require careful consideration of cost and treatment efficiency.

## 6 Future Scope

The current study focuses on comparing the treatment efficiency of heated, abrasioned, and fly ash slurry-treated aggregate with heated, abrasioned, and silica fume-treated aggregates. The future scope of study may include comparing the performance of heated, abrasioned, and silica fume aggregates with heated, abrasioned, and ground-granulated blast slag (GGBS) treated aggregates.

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