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# A comparative study of two-stage mixing concrete against nominal mixing concrete

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**Abstract** The innovative method of two-stage mixing approach developed to incorporate the recycled coarse aggregates from construction demolition waste to achieve the structural characteristics. This study investigates different levels of recycled aggregates substitution like 30%, 50% and 100% in combination of 10% metakaolin replacement with cement and addition of superplasticizers to achieve workability. During the preliminary mixing phase, the recycled aggregates are coated with cement slurry to avoid the internal voids and to decrease the porosity as a two-stage mixing strategical approach to address its weakness. The pre-treatment will help in creating the denser product with enhanced interfacial bond compared to the conventional method. By laboratory experiments, it is observed that the two-stage mixing approach consistently provides superior compressive and split tensile performance against conventional developed control specimens with identical ages of curing.

## 1 Introduction

### 1.1 Overview of Two-Stage Mixing Technology

The two-stage mixing approach shows an exemplary advancement in manufacturing technique of concrete mix to overcome the weak performance by using recycled aggregate concrete. Dividing the concrete mixing process into sequential separate stages improves the quality of resulting concrete when recycled aggregates are used in place of fresh coarse aggregates [1] [2]. The recycled aggregates are deprived from demolished structural elements from old buildings, deteriorated bridges, road pavements, tunnel structures, submerged concrete structures and also naturally occurring waste aggregates due to natural calamities.

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### 1.2 Waste Generation and Sustainability Context

Following factors control the planned demolition and dismantling of deteriorated concrete infrastructure.

- Structural facilities that have exceeded their design service life and experienced progressive deterioration requiring replacement
- Existing construction deemed obsolete relative to contemporary functional requirements and economic opportunities
- Significant infrastructure damage originating from natural disasters including earthquakes, severe flooding, and cyclonic storm systems
- Construction waste streams generated through routine demolition activities and disaster-response debris clearing operations.

As the construction industry continues the construction of infrastructure as well as demolition of significant infrastructure expands globally leading to challenging environmental management systems in order to protect the valuable material resources. To achieve the broader sustainable objectives of resource reserve preservation, effective implementation of technical innovation is much needed [1] [3].

### 1.3 Performance Limitations of Recycled Aggregates

By using recycled aggregates into contemporary concrete will encounter specific technical challenges. Using recycled coarse aggregates (RCA) makes concrete less dense, higher water absorption, increases porosity level which leads to restrict utilization of resulting concrete in important structures as it needs higher mechanical properties, hence this concrete can be used only for lower performance applications like subgrade preparations and surface courses. The waste aggregates drawn from demolished structures undergo service periods, potential damage leading to negative impact on its mechanical properties and durability. Using this demolished waste into a successful new concrete structure eliminates the landfills and increases the sustainable structural construction applications which shows technological development. [3]

## 2 Literature Review

### 1.1 Strength Development in Two-Stage Mixing Concrete Incorporating Fly Ash

The present work emphasizes comparison of two stage mixing and conventional concrete mix. Investigation on enhancement of concrete strength characteristics of two stage mixing method with addition of fly ash. It is specially focused on compressive strength and flexural strength parameters across different proportions of recycled aggregate replacement. This methodology helps in maintaining the sustainability, ecological functionality, biodiversity conservation and human health conservation over expanded temporal horizons. By recycling the concrete waste with proper methods will achieve environmental sustainability which also reduces the usage of fresh aggregates leading to cost reduction also. [4]

### 1.2 Durability Enhancement Through Two-Stage Mixing with Silica Fume

The interfacial transition zone around the aggregates can be enhanced by mixing the cement-silica fume slurry with recycled aggregates at the preliminary mixing stage. This advancement in research showed improved durability property in two-stage mixing with silica fume. Replacement of 5% of silica fume optimized the mechanical strength and durability property such as increased resistance against carbonation and chloride ion penetration [5] [6] Incorporation of silica fume into two stage mixing approach offers technical advantages like exceptional durability metrics performance when compared to traditional mixed concrete.

### 1.3 Diversified Two-Stage Mixing Variations

The study discussed multiple, two stage mixing variations in an organized manner with addition of silica fume during preliminary mixing phases. Two primary approaches are derived as: one involving silica fume addition at the time of initial mixing stage, and another involves incorporation of both silica fume and proportional cement quantities at the time of early mixing operations. This incorporation decreased voids and surface irregularities and helps in effective densification of porous recycled aggregate particles as cementitious material deposits on it, which results in enhanced strength characteristics compared to conventional approach. Therefore this method will have wide application for usage of recycled material concerning higher performance structural uses [5] [6].

### 1.4 Durability Assessment of Recycled Aggregate Concrete

Hong Kong experienced significant construction demolition activities. Over 50% of construction waste materials such as concrete debris were recycled [2] into functional concrete which acted as an efficient strategy in reduction of landfill burden. It observed that 0%, 20% and 100% of RA substitutions have been experimented to compare the durability performance of the Normal Mixing Approach (NMA) and the TSMA. Experiment results highlight that: i) the higher the substitutions of RA, the weaker the performance of RAC [3]; and ii) the deformation and permeability of RAC can be enhanced when adopting TSMA. Therefore, it demonstrates that TSMA can help to improve the durability of RAC, on top of the previously verified strength improvement, and thus opening up wider applications of RAC.

Case study: Hong Kong experienced significant construction demolition activities, where over 50% of construction waste materials such as concrete debris were recycled into functional concrete. Long-term durability monitoring of structures built with recycled aggregates showed acceptable performance when proper treatment methods were employed [5]. These durability improvements validate the two-stage mixing approach as a viable method for producing durable concrete suitable for structural applications in moderate to severe environmental exposure conditions.

### 1.5 Pretreatment Methods for Recycled Aggregates

Various pretreatment techniques have been developed to enhance the quality of recycled concrete aggregates by either removing or strengthening the adhered mortar. Research has shown that pretreatment methods can significantly reduce water absorption by an average of 24.5% and mercury intrusion porosity by 41.3% [7]. Physical removal methods include mechanical grinding, ball milling achieving up to 95% attached mortar removal, and thermal treatment using microwave-assisted processing that leverages differential thermal expansion [8] [9]. Sieve-washing and water immersion methods provide practical solutions with lower energy demands compared to advanced techniques [10].

Chemical treatment approaches involve acid treatment using hydrochloric or sulfuric acid solutions to dissolve cementitious residues, though these introduce secondary pollution risks [11]. Accelerated carbonation curing has emerged as an effective method, with presoak-accelerated carbonation showing superior modification efficiency [12]. Polymer impregnation techniques utilize synthetic resins (vinyl-ester or epoxy-based) with low viscosity to seal surface pores and create barrier layers preventing water penetration into aggregate particles [13]. The effectiveness depends on resin quality and penetration depth.

Pozzolanic slurry immersion methods, similar to the two-stage mixing approach employed in this study, coat aggregates with cementitious slurry containing supplementary materials like silica fume or metakaolin to fill surface voids and improve interfacial bonding. [14] [15]. Among these methods, the two-stage mixing approach with pozzolanic slurry coating represents a practical and industrially feasible solution that balances treatment effectiveness with economic viability.

# 3 Research Objectives and Scope

The present investigation addresses knowledge gaps in two-stage mixing methodology by pursuing the following specific research aims:

1. Characterizing the workability properties of freshly produced concrete through standardized measurement techniques.
2. Assessing compressive strength development in two-stage mixing concrete compared against nominally designed control specimens at multiple curing ages.
3. Evaluating split tensile strength characteristics in two-stage mixing concrete relative to conventional mixing approaches.
4. Analyzing the influence of variable recycled coarse aggregate substitution percentages on overall mechanical performance.

# 4 Experimental Program

## 4.1 Materials Selection and Properties

**Table 1.** The experimental investigation employed the following constituent materials.

| Material Category | Specific Type | Source/Supplier |
|---|---|---|
| Cementitious Binder | Ordinary Portland Cement Grade 53 | Zuari Cement |
| Fine Aggregate | Zone II River Sand | Local river sources |
| Coarse Aggregate | Locally crushed stone | Hassan quarry operations |
| Recycled Coarse Aggregate | Reclaimed aggregate from demolished concrete | Laboratory crushing of concrete specimens |
| Pozzolanic Additive | Metakaolin powder | FNX Solutions |
| Superplasticizer | Polycarboxylate ether-based admixture | Talrak Construction Chemicals |

### *4.1.1 Metakaolin Characteristics and Properties*

Metakaolin is a thermally processed material from natural clay minerals, particularly the kaolinite phase, through controlled heat treatment it has transformed into an amorphous reactive material. It is usually utilized in ceramics manufacturing but it has been observed that partial replacement of metakaolin in cementitious products executed better results. Optimal replacement ranges between 5% - 15% is recommended as without compromise in

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both compressive strength and flexural strength parameters to exhibit measurable improvement. The metakaolin modified concrete exhibits strong pozzolanic reactivity as an amorphous aluminum-silicon oxide compound, during the initial cement hydration, calcium hydroxide liberation takes place due to secondary hydration reactions.

**Table 2.** The Physical and Chemical Properties of Metakaolin.

| Property | Value | Unit |
|---|---|---|
| **Physical** | | |
| Specific gravity | 2.52 | - |
| Color appearance | Off-white | - |
| Physical form | Fine powder | - |
| Average particle diameter | 2.5 | Micrometers |
| **Chemical** | | |
| Silica ($SiO_2$) | 54. | % |
| Alumina ($Al_2O_3$) | 38.3 | % |
| Ferric oxide ($Fe_2O_3$) | 4.28% | % |
| Calcium oxide (CaO) | 0.39% | % |
| Magnesium oxide (MgO) | 0.08% | % |
| Sodium oxide ($Na_2O$) | 0.12% | % |
| Potassium oxide ($K_2O$) | 0.5% | % |
| Silica ($SiO_2$) | 54.3% | % |

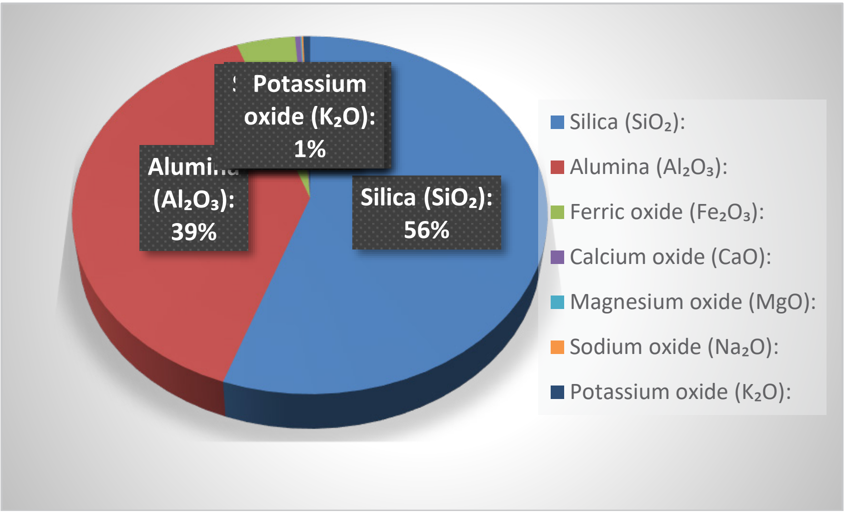


**Fig. 1.** Chemical Composition of Metakaolin

## 4.2 Mix Design Specifications and Material Properties

Following are the M65 grade concrete design specifications of present experimental studies.

**Design Stipulations:**

- Concrete grade classification: M65
- Mix Proportion: 1: 1.25: 2.56
- Water cement ratio: 0.32
- Type of Cement: Ordinary Portland Cement 53 grade (conforming to IS 269)
- Maximum aggregate size: 20 millimeters nominal diameter

- Environmental exposure category: Severe (per IS 456 specifications)
- Target workability: 100-millimeter slump measurement
- Supervision level: Good
- Maximum cementitious content: 450 kilograms per cubic meter
- Chemical admixture: Polycarboxylate ether-based superplasticizer

**Table 3.** Material Properties observed across the preliminary investigation

| Material Property | Specification | Measured Value |
|---|---|---|
| Cement specific gravity | OPC 53 grade (IS 269) | 3.1 |
| Coarse aggregate specific gravity | Natural crushed stone | 2.68 |
| Fine aggregate specific gravity | River sand | 2.625 |
| Recycled coarse aggregate specific Gravity | Laboratory produced | 2.64 |
| Coarse aggregate water absorption | Natural material | 0.36% |
| Fine aggregate water absorption | River sand | 3.0% |
| Recycled coarse aggregate water absorption | Laboratory produced | 0.98% |
| Coarse aggregate moisture content | Natural material | Nil |
| Fine aggregate moisture content | River sand | 2.08% |

### 4.3 Experimental Methodology

The evaluation of both fresh concrete properties and hardened concrete characterization implemented through systematic experimental investigations. Fresh concrete properties were determined by workability assessment with standardized slump measurements. Hardened concrete properties were determined by compressive strength, split tensile strength and flexural strength at multiple curing intervals using UTM conforming to IS specifications.

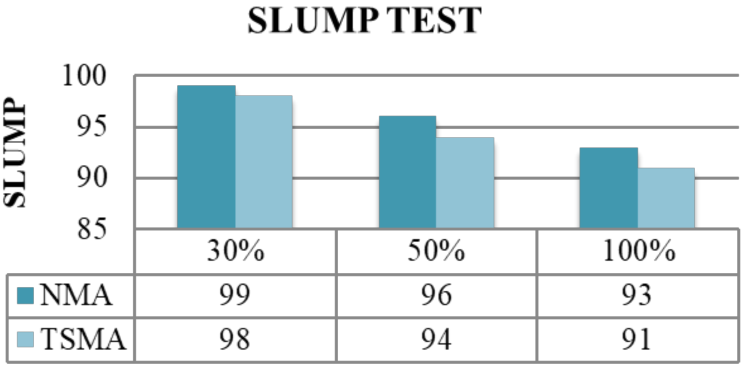
## 5 Experimental Results and Analysis

### 4.4 Fresh Concrete Workability Assessment

Fresh concrete properties were determined by workability assessment with standardized slump measurements.

**Table 4.** Detailed slump measurement results across different recycled aggregate substitution levels.

| RCA Substitution Level | Water-Cement Ratio | Initial Mold Height (mm) | Nominal Mix Slump (mm) | Two-Stage Mixing Slump (mm) |
|---|---|---|---|---|
| 30% | 0.32 | 300 | 99 | 98 |
| 50% | 0.32 | 300 | 96 | 94 |
| 100% | 0.32 | 300 | 93 | 91 |



| | 30% | 50% | 100% |
|---|---|---|---|
| ■ NMA | 99 | 96 | 93 |
| ■ TSMA | 98 | 94 | 91 |

**Fig. 2.** Slump values at various percentages of Replacement

### *4.4.1 Workability Discussion*

Slump measurement values provided direct indication of fresh concrete consistency and flow characteristics. Analysis of the experimental data revealed systematic reduction in slump measurements as recycled aggregate substitution levels increased. At 30% substitution, both nominal and two-stage mixing approaches maintained approximately 99- and 98-millimeters slump respectively, indicating excellent workability characteristics. As substitution increased to 50%, slump values diminished slightly to 96 and 94 millimeters and it declined further to 93 and 91 millimeters respectively at maximum 100% substitution. There was only minimal difference between performance of mixing approaches throughout the test series observed, with two stage mixing approaches showing marginal reduced slump values due to increased surface area during preliminary slurry coating operation. The workability limitations did not have any practical obstacles in implementation of two stage mixing approach even at the maximum RCA substitution levels as it was significant that all measured slump values remained within the acceptable ranges only for any of the typical construction applications.

RCA incorporation led to reduced workability at higher substitution percentages reflecting in higher water absorption. During the consolidation the free water availability will be less for maintaining the concrete flow and ease of placement as the porous recycled particles absorb the mixing water. To overcome this the super plasticizers inclusion into the mix will effectively compensate for these absorption effects and maintain the acceptable workability among all ranges of substitution level tested.

## 4.5 Hardened Concrete Strength Development

### *5.2.1 Compressive Strength Results*

The compressive strength measurements at 3 curing intervals – 7 days, 14 days and 28 days with different recycled aggregate substitution percentages for both normal mixing approach and two-stage mixing approach showed in Table 5.

**Table 5.** Compression Strength Result in N/mm$^2$

| **RCA Substitution %** | **7-Day Strength (N/mm²)** | | **14-Day Strength (N/mm²)** | | **28-Day Strength (N/mm²)** | |
|---|---|---|---|---|---|---|
| | Nominal Mix | Two-Stage Mix | Nominal Mix | Two-Stage Mix | Nominal Mix | Two-Stage Mix |
| 30 | 45.95 | 47.64 | 65.33 | 68.42 | 70.1 | 74.57 |
| 50 | 44.6 | 47.07 | 63.25 | 66.97 | 68.55 | 72.54 |
| 100 | 41.1 | 45.05 | 62.12 | 64.66 | 66.2 | 70.5 |

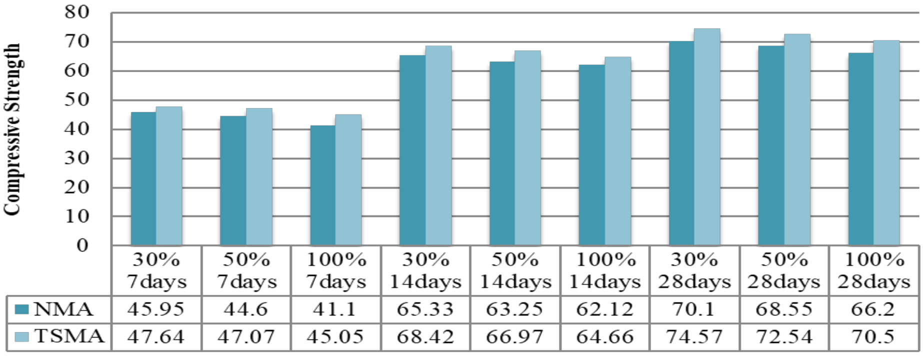


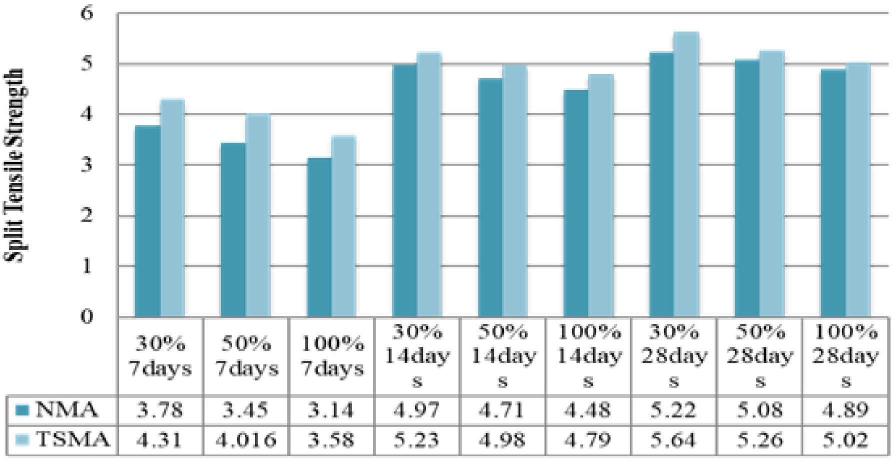
**Fig. 3.** Compressive Strength for 7,14 and 28 days

### *5.2.2 Split Tensile Strength Results*

The Split Tensile strength measurements at 3 curing intervals – 7 days, 14 days and 28 days with different recycled aggregate substitution percentages for both normal mixing approach and two-stage mixing approach showed in Table 6.

**Table 6.** Split Tensile Strength Result in N/mm$^2$

| **RCA Substitution %** | **7-Day Strength (N/mm²)** | | **14-Day Strength (N/mm²)** | | **28-Day Strength (N/mm²)** | |
|---|---|---|---|---|---|---|
| | Nominal Mix | Two-Stage Mix | Nominal Mix | Two-Stage Mix | Nominal Mix | Two-Stage Mix |
| 30 | 3.78 | 4.31 | 4.97 | 5.23 | 5,22 | 5.64 |
| 50 | 3.45 | 4.016 | 4.71 | 4.98 | 5.08 | 5.26 |
| 100 | 3.14 | 3.58 | 4.48 | 4.79 | 4.89 | 5.02 |



| | 30% 7days | 50% 7days | 100% 7days | 30% 14days | 50% 14days | 100% 14days | 30% 28days | 50% 28days | 100% 28days |
|---|---|---|---|---|---|---|---|---|---|
| ■ NMA | 3.78 | 3.45 | 3.14 | 4.97 | 4.71 | 4.48 | 5.22 | 5.08 | 4.89 |
| ■ TSMA | 4.31 | 4.016 | 3.58 | 5.23 | 4.98 | 4.79 | 5.64 | 5.26 | 5.02 |

**Fig. 4.** Split Tensile Strength for 7,14 and 28 days

### *5.2.3 Strength Development Analysis*

The experimental results demonstrate consistent strength advantages when implementing two-stage mixing methodology across all recycled aggregate substitution levels and curing time points. The resulting strength became obvious between two methods and gradually became different as the curing period neared full strength development at 28 days.

The standard reference age of compressive strength is 28 days. At this stage, 30% RCA substitution achieved 74.57 N/mm$^2$ in the two stage mixing approach compared to 70.1 N/mm2 of nominal mix, represents a 6.37% strength improvement. Similarly, 50% RCA achieved 72.54 N/mm$^2$ in TSMA compared to 68.55 N/mm$^2$ of nominal mix, represents a 5.82% strength enhancement, at 100% substitution, it attained 70.5 N/mm$^2$ against 66.2 N/mm$^2$ for the nominal mix (6.49% improvement).

The standard reference age of Split Tensile strength is 28 days. At this stage, 30% RCA substitution achieved 5.64 N/mm$^2$ in the two stage mixing approach compared to 5.22 N/mm$^2$ of nominal mix, represents a 8.05% strength improvement. Similarly, 50% RCA achieved 5.26N/mm$^2$ in TSMA compared to 5.08 N/mm$^2$ of nominal mix, represents a 3.54% strength enhancement, at 100% substitution, it attained 5.02 N/mm$^2$ against 4.89 N/mm$^2$ for the nominal mix (2.65% improvement).

These results suggest that two stage mixing approach prominently helps in improved interfacial bonding development which leads to creating more densified interfacial zones that increases the load transfer efficiency and overall strength development.

The relationship between RCA substitution and overall strength development represents the inverse relationship. The concrete strength is inversely proportional to the percentage of substitution added such that it has been decreased when percentage of substitution increased from 30 -100 throughout the curing period. However, the two stage mixing approach helped to alleviate strength successfully due to well established interfacial zones around the aggregates.

## 6 Conclusions and Findings

Following test parameters evaluated across detailed experimental investigation of two stage mixing approach and nominal mixing approach with recycled aggregates in different proportions.

The compressive strength of the two-stage mixing approach was higher than the nominal mixing approach among all 3 RCA proportional percentages; the strength enhancement varied from 5.82% to 6.49% with curing intervals and the split tensile strength of the two-stage mixing approach was higher than the nominal mixing approach among all 3 RCA proportional percentages; the strength enhancement varied from 2.65% to 8.05% with curing intervals.

1. **Optimal Substitution Performance:** at the age of 28 days, the compressive strength of 30% RCA observed was 74.57N/mm$^2$ for TSMA with excellent workability also, which represents **6.37%** strength improvement.
2. **Workability Maintenance:** the two-stage mixed concrete showed acceptable workability for all the RCA percentages than nominal mix and incorporation of superplasticizers helped RCA for its water absorption demand.
3. **Multi-Strength Parameter Improvements:** due to the observation of intensified compressive strength, research also focused and consistently extended the investigation on split tensile evaluations also leading to comprehensive mechanical performance improvements in which split Tensile strength at 28 days, at this stage it is observed that under 30% RCA substitution, two stage mixing achieved 5.64 N/mm$^2$ and nominal mix achieved 5.22 N/mm$^2$ which represents **8.05%** strength improvement.
4. **Sustainable Material Integration:** the environmentally friendly concrete is produced with better strength characteristics leading to the achievement of sustainable construction methods as recycled aggregates are used instead of fresh which helps in preservation of resources for future.

The two-stage mixing approach using recycled aggregates proves that it is a technically strong and practically viable approach towards structural applications benefiting the environment through reducing the waste accumulation and also reaching the economic advantages through channelized utilization.

## References

1. M. Kumar, S. Kumari, Prachi, M.K. Das, Partial replacement of coarse aggregate by using recycled coarse aggregate and fly ash in concrete by two stage mixing approach, Int. Res. J. Eng. Technol. (IRJET) 7, 57–62 (2020).

2. G.O. Bamigboye, D. Ademola, M. Kareem, B. Orogbade, A. Odetoyan, A. Adeniyi, Durability assessment of recycled aggregate in concrete production, Elsevier 20, 445–467 (2022). https://doi.org/10.1016/B978-0-12-824105-9.00010-X

3. A. Verma, V. S. Babu and Arunachalam S. Influence of modified two-stage mixing approaches on recycled aggregate treated with a hybrid method of treatment, Australian Journal Of Structural Engineering. 23,230-253 (2022). https://doi.org/10.1080/13287982.2022.2048479

4. S.S.Tamgadge, G.D.Dhawale, S.G.Makarande, Mr. M.M. Lohe, Comparative Study of Strength Characteristics of Concrete by Two-Stage Mixing Approach and Normal Mixing Approach. International Journal of Advanced Research in Science, Communication and Technology. 2,297-301. (2022). https://doi.org/10.48175/IJARSCT-3263.

5. A. A. A. Al-Naghi,T. Ali,I.Inam,M. Z. Qureshi,N. B. Kahla,N. Ghazouani, An innovative approach to enhancing the strength and durability of recycled aggregate concrete through fly ash-silica fume coating and rice husk ash supplementation. Scientific Reports. 15,(2025) https://doi.org/10.1038/s41598-025-18138-z.

6. J. Sivamani, N. T. Renganathan, Effect of fine recycled aggregate on the strength and durability properties of concrete modified through two-stage mixing approach. Environ. Sci. Pollut. Res. 29 (57), 85869–85882. (2022) https://doi.org/10.1007/S11356-021-14420-5

7. H.K.A. Al-Bayati, W. Jadaa, S.L. Tighe, Effect of recycled concrete aggregate addition on the asphalt mixtures performance: ITZ area, microstructure and chemical analysis perspectives, Recycling 9 (2024). https://doi.org/10.3390/recycling9030041

8. K. Ouyang, C. Shi, H. Chu, H. Guo, B. Song, Y. Ding, X. Guan, J. Zhu, H. Zhang, Y. Wang and J. Zheng, An overview on the efficiency of different pretreatment techniques for recycled concrete aggregate, J. Clean. Prod. 263, 121264 (2020). https://doi.org/10.1016/j.jclepro.2020.121264

9. L. Li,D. Xuan, S. H. Chu C. S. Poon, Modification of recycled aggregate by spraying colloidal nano silica and silica fume. Mater Struct 54, 223 (2021). https://doi.org/10.1617/s11527-021-01815-6

10. B.Wang, L.Yan , Q.Fu, B. Kasal, A Comprehensive Review on Recycled Aggregate and Recycled Aggregate Concrete, Resources, Conservation and Recycling,171, (2021), https://doi.org/10.1016/j.resconrec.2021.105565

11. M. Kępniak, F. Chyliński, P. Woyciechowski, Enhancing the performance of recycled aggregate concrete through optimized pretreatment methods: A microstructural perspective, Sci. Rep. 15, 29998 (2025). https://doi.org/10.1038/s41598-025-14834-y

12. S. A. Memon, Z. Bekzhanova, A. Murzakarimova A Review of Improvement of Interfacial Transition Zone and Adherent Mortar in Recycled Concrete Aggregate, Buildings, 12, 1600 (2022) https://doi.org/10.3390/buildings12101600

13. H. Panghal, S. Chaudhary, A. Kumar, "Enhancing Sustainable Concrete Performance: Dual Treatment of Recycled Coarse Aggregates for Improved Strength and Durability." European Journal of Environmental and Civil Engineering 29 3225–56 (2025). https://doi:10.1080/19648189.2025.2515490

14. W. Li, H.Zhao, K.Wang, Nano/Micromechanical Properties of Interfacial Transition Zones in Recycled Aggregate Concrete Tested by Nanoindentation. In: Nanocharacterization of Cementitious Composites. Springer, Singapore.165–198 (2025) https://doi.org/10.1007/978-981-96-2917-6_7

15. J.Ying,W. Wang, J. Xiao Chloride diffusion in concrete with carbonated recycled coarse aggregates under biaxial compression. Front. Struct. Civ. Eng. 17, 637–648 (2023). https://doi.org/10.1007/s11709-023-0902-0