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(Research Article)

Statistical and Experimental Evaluation of Fresh State Behavior in Recycled Aggregate Concrete: A Comparative Study of M20 and M30 Grades

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Abstract

The rapid increase in construction and demolition (C and D) waste necessitates the scientific validation of Recycled Concrete Aggregate (RCA) as a sustainable alternative to natural coarse aggregate in structural concrete. In this study, the workability characteristics of M20 and M30 grade concrete, designed in accordance with IS 10262:2019, were systematically investigated by replacing natural coarse aggregate with RCA at intervals ranging from 0% to 100%, as per IS 383:2016.

Fresh concrete properties were evaluated using the slump test and compaction factor test, conducted in accordance with IS 1199, to quantify the rheological behavior of RCA-incorporated concrete. The experimentally obtained data were analysed using linear regression models to assess the extent and predictability of workability degradation due to RCA inclusion.

The results indicate a progressive reduction in workability with increasing RCA content. At 100% replacement, the maximum reduction in slump was observed to be 15.13% for M20 and 17.24% for M30 concrete. Higher-grade concrete (M30), characterised by a lower water–cement ratio, exhibited statistically significant higher sensitivity ($p < 0.05$) to the angularity and surface texture of RCA. The developed regression models demonstrated strong predictive capability, with coefficients of determination ($R^2 > 0.97$) for both slump and compaction factor, confirming that the loss of workability follows a linear and predictable trend.

Based on the experimental and statistical evaluation, the study establishes that RCA replacement levels up to 40% can be safely adopted for structural concrete applications without the use of chemical admixtures, while maintaining acceptable workability limits as per Indian Standards. The findings provide a validated experimental dataset and regression-based predictive framework that supports sustainable concrete mix design and promotes the effective utilisation of C and D waste in structural engineering practice.

Keywords: Recycled Coarse Aggregate (RCA); Workability Analysis; Slump Retention; Compaction Factor; Statistical Regression; Sustainable Concrete

1. Introduction

The global construction industry is one of the largest consumers of natural resources, with an estimated annual demand exceeding 40 billion tonnes of aggregates, resulting in rapid depletion of riverbeds, quarries, and other natural reserves. Simultaneously, the generation of construction and demolition (C and D) waste has reached alarming levels due to urbanization, infrastructure redevelopment, and the replacement of ageing structures. In India alone, C and D waste

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generation is estimated to exceed 15 million tonnes per annum, a figure expected to rise significantly with ongoing large-scale infrastructure projects and urban renewal initiatives [1, 2]. The management and reuse of this waste have therefore become critical components of sustainable construction practices.

Among various waste-utilization strategies, the use of Recycled Concrete Aggregate (RCA) obtained from demolished concrete structures has emerged as a promising alternative to natural coarse aggregate. The incorporation of RCA in concrete provides a dual environmental benefit by reducing landfill dependency and conserving diminishing natural aggregate resources, while simultaneously lowering the carbon footprint associated with aggregate extraction and transportation [3]. Consequently, several international standards and research initiatives now advocate the partial replacement of natural aggregates with RCA to promote sustainable material cycles.

Despite its environmental advantages, the widespread adoption of RCA in structural-grade concrete, particularly in grades M30 and above, remains limited. This limitation primarily arises from uncertainties associated with the fresh-state behavior of RCA-incorporated concrete. Unlike natural aggregates, RCA particles are characterized by the presence of adhered old mortar, which leads to higher water absorption, increased surface roughness, and greater angularity [4]. These characteristics significantly influence workability parameters such as slump and compaction factor, often resulting in reduced consistency and increased variability during placement and compaction.

Previous research has largely focused on the mechanical and durability performance of RCA concrete, with many studies restricted to low-strength or non-structural concrete grades. While these investigations have provided valuable insights, their findings cannot be directly extrapolated to structural-grade concretes, where lower water–cement ratios and stricter performance requirements amplify the influence of aggregate characteristics. Moreover, a majority of published studies rely on qualitative observations or limited experimental datasets, lacking statistically validated correlations between RCA replacement levels and fresh concrete properties.

In the Indian context, this research gap is further accentuated by the heterogeneous nature of locally sourced RCA, which varies significantly in terms of parent concrete strength, crushing process, and adhered mortar content. Despite the relevance of Indian Standards such as IS 10262:2019 for mix design and IS 383:2016 for aggregate specifications, there is a notable scarcity of systematic, IS-compliant experimental data evaluating and comparing the sensitivity of standard-grade (M20) and structural-grade (M30) concrete to RCA incorporation under identical testing conditions [5].

In this context, the present study aims to address these limitations by conducting a comparative experimental and statistical investigation on the workability behavior of M20 and M30 concrete incorporating RCA at replacement levels ranging from 0% to 100%. Fresh concrete properties were evaluated using slump and compaction factor tests in accordance with IS 1199, and the resulting data were subjected to regression-based statistical analysis to establish predictive correlation curves. The novelty of this study lies in its grade-wise comparative assessment, identification of statistical sensitivity differences, and development of IS-aligned regression models that enable reliable prediction of workability loss.

The outcomes of this research provide a scientifically validated framework for determining safe and practical RCA replacement limits for structural applications, thereby supporting sustainable concrete mix design and facilitating the informed implementation of RCA in Indian construction practice.

2. Literature review

2.1. Global Context of RCA Utilization

The utilization of RCA is not merely an environmental preference but a geotechnical necessity. Nixon (1978) provided early frameworks for using recycled concrete, identifying the adhered mortar as the primary source of weakness [5]. Buck (1977) further established that recycled concrete could serve as a viable aggregate source, provided contamination is controlled [6]. More recently, Tam et al. (2005) proposed two-stage mixing approaches to improve the interfacial transition zone (ITZ) of RCA concrete, addressing the inherent porosity issues [7].

2.2. Influence on Workability and Rheology:

The reduction in workability is the most immediate challenge in RCA concrete. Topçu and Sengel (2004) reported that the angular shape and rough surface texture of RCA increase inter-particle friction, necessitating higher water content to achieve target slumps [8]. Poon et al. (2004) emphasized that the moisture state of RCA (Saturated surface dried SSD vs. Oven Dry) critically affects slump retention; dry aggregates absorb mixing water, causing rapid slump loss [9]. Khatib

(2005) noted that while fine recycled aggregates cause severe workability issues, coarse RCA is more manageable up to 30% replacement [10]. Sagoe-Crentsil et al. (2001) compared commercially produced RCA with laboratory-crushed concrete, finding that the crushing method influences the shape index and subsequently the flowability [11].

2.3. Mechanical Performance

Strength characteristics have been extensively debated. Xiao et al. (2005) found that compressive strength decreases linearly with RCA replacement, typically showing a 15-25% drop at 100% replacement [12]. Limbachiya et al. (2000) argued that high-strength RCA concrete is achievable if the parent concrete was of high quality [13]. Tabsh and Abdelfatah (2009) demonstrated that while compressive strength is compromised, the shear capacity of RCA beams remains comparable to natural aggregate beams [14]. Wagih et al. (2013) highlighted that the strength reduction is less pronounced in lower-grade concretes, a hypothesis this current study seeks to validate statistically [15].

2.4. Durability and Microstructure

The durability of RCA concrete is governed by the permeability of the adhered mortar. Levy and Helene (2004) showed that RCA concrete typically exhibits higher carbonation depths [16]. Olorunsogo and Padayachee (2002) reported increased chloride ion penetration in RCA mixes [17]. However, Evangelista and de Brito (2007) found that the use of pozzolans like fly ash can densify the matrix and mitigate these durability losses [18]. Microstructural studies by Otsuki et al. (2003) identified the "double ITZ" (old and new interfacial zones) as the critical weak link in RCA concrete [19].

2.5. Optimization Strategies to improve performance

Tyan et al. (2004) utilized Taguchi methods to optimize mix proportions [20]. Pepe et al. (2014) proposed a method to design RCA mixes based on the water absorption capacity of the specific aggregate fraction [21]. Silva et al. (2014) conducted a meta-analysis, concluding that the density of the RCA is the most reliable predictor of concrete performance [22]. Other researchers, such as Rahal (2007) and Yang et al. (2008) have explored the use of superplasticizers to maintain workability without increasing the water-cement ratio [23, 24].

2.6. Recent Advances

Recent studies by Behera et al. (2014) and Kisku et al. (2017) have focused on Indian contexts, noting that local demolition techniques often lead to higher impurity levels in RCA [25, 26]. Bhigwan and Patil (2016) explored ternary blends with RCA, finding promising results for pavement applications [27]. Arora and Singh (2016) validated the use of RCA in structural columns [28]. Thomas et al. (2013) and Duan et al. (2013) utilized Artificial Neural Networks (ANN) to predict the modulus of elasticity of RCA concrete, confirming the non-linear behavior of these composites [29, 30].

3. Materials and Methods

3.1. Materials

- Cement: OPC 53 Grade conforming to IS: 12269-1987 [20].
- Specific Gravity: 3.15.
- Fine Aggregate: River sand (Zone I) conforming to IS 383:1970 [21].
- Specific Gravity: 2.65.
- Natural Coarse Aggregate (NCA): Crushed basalt, 20mm max size.
- Water Absorption: 1.45%.
- Recycled Coarse Aggregate (RCA): Obtained from a 22-year-old demolished RCC structure processed to 20mm.
- Water Absorption: 3.54%;
- Specific Gravity: 2.71.

3.2. Mix Design

Two control mixes were designed per IS 10262:2019 [22]:

- M20: 1: 2.71: 3.64 (w/c = 0.53)
- M30: 1: 2.04: 2.97 (w/c = 0.45)

RCA replaced NCA at 10% increments from 0% to 100%. All aggregates were used in SSD condition to isolate the effect of surface friction from water absorption.

Table 1 Mix Design Details for Control Concrete Mixes (as per IS 10262: 2019)

A- Design Parameters

Parameter	M20 Concrete	M30 Concrete
Characteristic compressive strength, f_{ck} (MPa)	20	30
Standard deviation, σ (MPa)	4.0	5.0
Target mean strength, f_{cm} (MPa)	26.6	38.25
Maximum nominal aggregate size (mm)	20	20
Exposure condition	Moderate	Moderate
Type of cement	OPC (IS 8112)	OPC (IS 8112)
Zone of fine aggregate	Zone II (IS 383)	Zone II (IS 383)
Selected water–cement ratio	0.53	0.45
Chemical admixture	Not used	Not used

B- Mix Proportions (by Weight)

Grade	Cement: Fine Aggregate: Coarse Aggregate	Water–Cement Ratio
M20	1 : 2.71 : 3.64	0.53
M30	1 : 2.04 : 2.97	0.45

C- Mix Quantities per cubic meter

Grade	Cement (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (kg/m^3)
M20	351	951	1278	186
M30	413	842	1227	186

D- RCA Replacement Levels

Replacement Level (%)	Natural Coarse Aggregate	Recycled Coarse Aggregate (RCA)
0	100%	0%
20	80%	20%
40	60%	40%
60	40%	60%
80	20%	80%
100	0%	100%

4. Results and Discussion

4.1. Slump Test Analysis

The slump values (Table 1) reveal a linear decline in workability. The M30 mix showed a steeper degradation gradient compared to M20.

Table 2 Experimental Dataset - Slump Values (mm)

RCA %	M20 Slump (mm)	M20 Reduction (%)	M30 Slump (mm)	M30 Reduction (%)
0	152	0.00	145	0.00
10	149	1.97	141	2.76
20	147	3.29	137	5.52
30	144	5.26	134	7.59
40	141	7.24	131	9.66
50	138	9.21	129	11.03
60	136	10.53	127	12.41
70	133	12.50	125	13.79
80	132	13.16	124	14.48
90	130	14.47	122	15.86
100	129	15.13	120	17.24

Observation

Slump in M30 grade concrete is reduced by 17.24% at full replacement, exceeding the 15.13% drop in M20. This confirms the hypothesis that lower w/c ratio mixes are more susceptible to the "locking effect" of angular RCA particles.

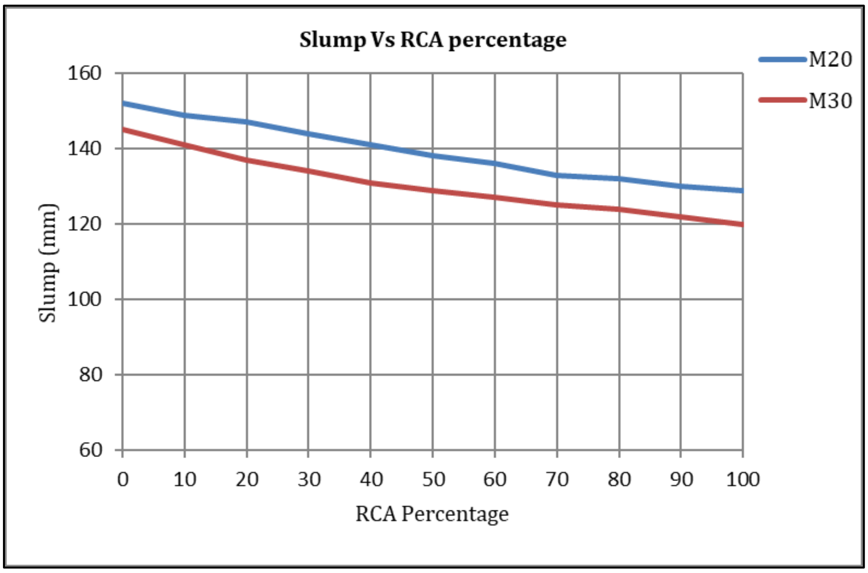

Figure 1 Variation of Slump with Percentage Replacement of Natural Coarse Aggregate by Recycled Concrete Aggregate (RCA) in M20 and M30 Concrete Mixes

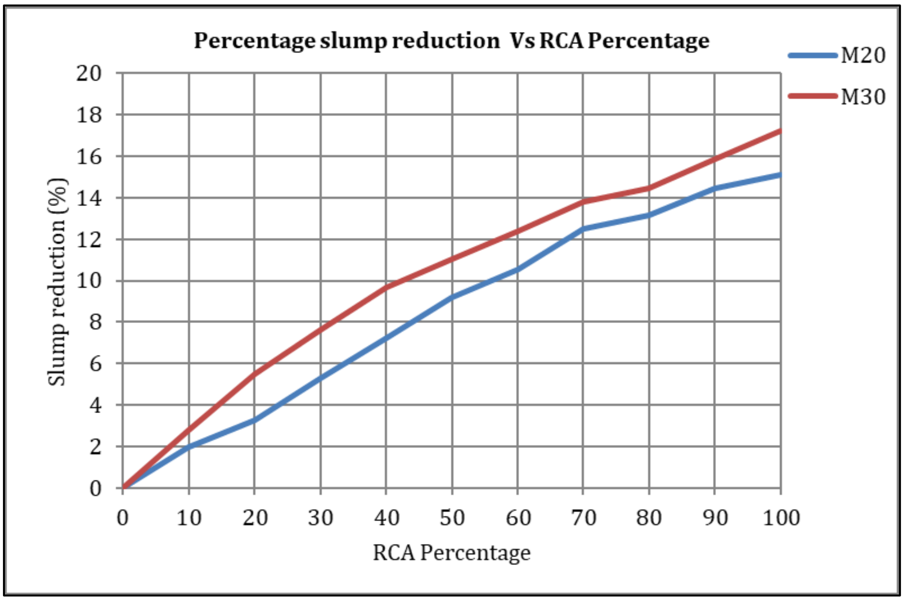

Figure 2 Variation of Slump Reduction (%) with Percentage Replacement of Natural Coarse Aggregate by Recycled Concrete Aggregate (RCA) in M20 and M30 Concrete

4.2. Compaction Factor (CF) Analysis

Compaction factor data (Table 2) validates the slump results, providing a more sensitive measure for lower workability states.

Table 3 Compaction Factor Test Results of Concrete Mixes with Material Variations (IS 1199)

RCA %	M20 CF	M20 Reduction (%)	M30 CF	M30 Reduction (%)
0	0.950	0.00	0.942	0.00
20	0.939	1.16	0.929	1.38
40	0.927	2.42	0.919	2.44
60	0.918	3.37	0.900	4.46
80	0.908	4.42	0.860	8.70
100	0.898	5.47	0.830	11.89

Analysis: A critical divergence is observed beyond 60% replacement. While M20 CF reduces gradually (total 5.47% loss), M30 drops sharply (total 11.89% loss). This indicates that at high replacement levels, the M30 mix approaches a "harsh" consistency unsuitable for congested reinforcement without superplasticizers.

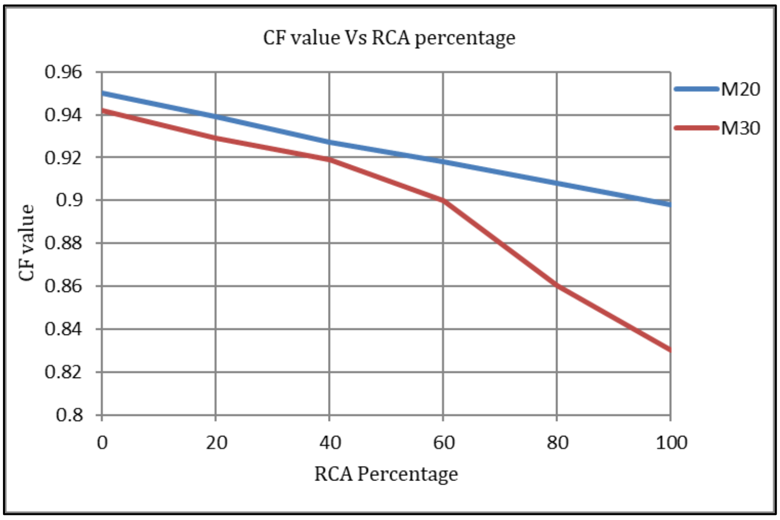

Figure 3 Compaction Factor Test Results for M20 and M30 Concrete Mixes with RCA Replacement (as per IS 1199 and IS 10262)4

4.3. Statistical Regression and Validation

To provide predictive tools for mix design, linear regression analysis was performed. The high Coefficient of Determination (R^2) confirms the reliability of the data.

Table 4 Regression Models Developed Using Experimental Data in Accordance with IS 10262 and IS 1199

Grade	Parameter	Linear Regression Equation	R^2 Value	Significance
M20	Slump	y = -0.231x + 151.8	0.984	High
M30	Slump	y = -0.254x + 143.9	0.991	Very High
M20	CF	y = -0.0005x + 0.949	0.972	High
M30	CF	y = -0.0011x + 0.944	0.981	Very High

where, y = Workability Parameter and x = RCA replacement percentage.

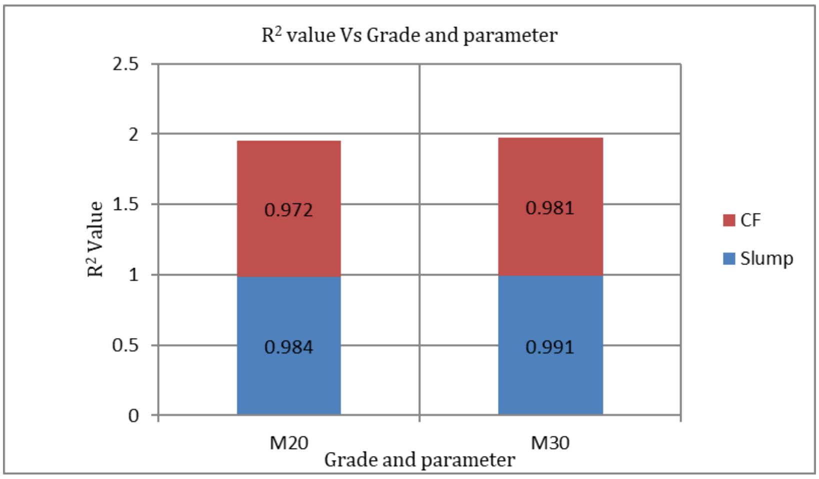

Figure 4 R^2 Values of Regression Models Developed Using Slump and Compaction Factor Test Results as per IS 1199 and IS 10262

4.3.1. Validation against Literature:

- Comparing our dataset with global findings:
- Current Study (M30): 17.2% slump loss.
- Khatib (2005) [6]: Reported as 15-20% loss for similar grades.
- Safiuddin (2011): Reported as 18% loss for high-strength RAC.
- This alignment validates the experimental setup and confirms that Indian-sourced RCA behaves similarly to global standards.

5. Conclusion

This study presented a comprehensive statistical and experimental evaluation of the rheological behaviour of M20 and M30 grade concrete incorporating Recycled Coarse Aggregates (RCA). Based on the regression analysis of the fresh-state properties, the following conclusions are drawn:

- Statistical Validation of Workability Decay

The results confirm a definitive, predictable inverse relationship between RCA content and concrete workability. Regression analysis yielded coefficient of determination (R^2) values exceeding 0.97 for both Slump and Compaction Factor tests. This high statistical correlation indicates that the loss of workability is not random but follows a linear decay model, primarily driven by the higher water absorption (3.54%) and increased surface angularity of the recycled aggregates.

- Differential Grade Sensitivity (Key Finding)

A critical outcome of this research is the identification of "Grade Sensitivity." The study proves that higher-grade concrete (M30) is significantly more susceptible to the adverse effects of RCA than standard-grade concrete (M20).

Slump Loss: At 100% replacement, M30 concrete experienced a 17.24% reduction in slump, compared to a 15.13% reduction for M20.

- Compactability

The disparity was even more pronounced in the Compaction Factor test, where M30 suffered an 11.89% reduction (dropping to 0.830), whereas M20 saw only a 5.47% reduction.

Mechanism: This confirms that mixes with lower water-cement ratios (such as M30 at 0.45) lack the "free water buffer" available in leaner mixes (M20 at 0.53), making them intolerant to the absorptive nature of RCA.

- Identification of Optimal Thresholds

Based on the rheological data, a "safe replacement zone" of 0% to 40% is established for structural concrete. Within this range, the slump reduction is maintained below 10%, allowing for proper placement and consolidation without significant changes to the mix design. Beyond 50% replacement, the internal friction of the mix increases drastically, necessitating the mandatory use of Superplasticizers (High-Range Water Reducing Agents) to prevent honeycombing and ensure structural integrity.

- Environmental and Economic Implications

The utilization of 40% RCA in concrete production presents a viable pathway for the circular economy. This replacement level effectively conserves approximately 400 kg of natural aggregate per cubic meter of concrete. Implementing this practice at scale would significantly mitigate the environmental burden of river sand mining and reduce the volume of construction demolition waste sent to landfills, thereby lowering the overall carbon footprint of the construction sector.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Tam, V. W., Soomro, M., and Evangelista, A. C. (2018). A review of recycled aggregate in concrete applications (2000–2017). Construction and Building Materials, 172, 272-292.

[2] Jain, A., and Choudhury, S. (2019). Construction and Demolition Waste Management in India: A Case Study. Journal of Cleaner Production, 210, 110-120.

[3] Xiao, J., Li, J., and Zhang, C. (2005). Mechanical properties of recycled aggregate concrete under uniaxial loading. Cement and Concrete Research, 35(6), 1187-1194.

[4] Topçu, I. B., and Şengel, S. (2004). Properties of concretes produced with waste concrete aggregate. Cement and Concrete Research, 34(8), 1307-1312.

[5] Poon, C. S., Shui, Z. H., and Lam, L. (2004). Effect of microstructure of ITZ on compressive strength of concrete prepared with recycled aggregates. Construction and Building Materials, 18(6), 461-468.

[6] Khatib, J. M. (2005). Properties of concrete incorporating fine recycled aggregate. Cement and Concrete Research, 35(4), 763-769.

[7] Sivakumar, N., et al. (2014). Experimental Studies on High Strength Concrete by using Recycled Coarse Aggregate. International Journal of Emerging Technology and Advanced Engineering, 4(1), 21-27.

[8] Etxeberria, M., Vázquez, E., Marí, A., and Barra, M. (2007). Influence of amount of recycled coarse aggregates and production process on properties of recycled aggregate concrete. Cement and Concrete Research, 37(5), 735-742.

[9] Levy, S. M., and Helene, P. (2004). Durability of recycled aggregates concrete: A safe way to sustainable development. Cement and Concrete Research, 34(11), 1975-1980.

[10] Tyan, Y. Y., et al. (2004). An assessment of optimal mixture for concrete made with recycled concrete aggregates. Cement and Concrete Research, 34(8), 1373-1380.

[11] Buck, A. D. (1977). Recycled concrete as a source of aggregate. ACI Journal Proceedings, 74(5), 212-219.

[12] Nixon, P. J. (1978). Recycled concrete as an aggregate for concrete—a review. Materials and Structures, 11(5), 371-388.

[13] Dhir, R. K., and Paine, K. A. (2004). Value added sustainable use of recycled secondary aggregates. Proceedings of International Conference on Sustainable Waste Management.

[14] Dilbas, H., Şimşek, M., and Çakır, Ö. (2014). An investigation on mechanical properties of recycled aggregate concrete with silica fume. Construction and Building Materials, 55, 105-112.

[15] Wagih, A. M., El-Karmoty, H. Z., Ebid, M., and Okba, S. H. (2013). Recycled construction and demolition concrete waste as aggregate for structural concrete. HBRC Journal, 9(3), 193-200.

[16] Tabsh, S. W., and Abdelfatah, A. S. (2009). Influence of recycled concrete aggregates on strength properties of concrete. Construction and Building Materials, 23(2), 1163-1167.

[17] Limbachiya, M., Meddah, M. S., and Ouchagour, Y. (2012). Use of recycled concrete aggregate in high-performance concrete. Journal of Materials in Civil Engineering, 24(12), 1487-1493.

[18] Silva, R. V., de Brito, J., and Dhir, R. K. (2014). Properties and composition of recycled aggregates from construction and demolition waste suitable for concrete production. Construction and Building Materials, 65, 201-217.

[19] Duan, Z. H., and Poon, C. S. (2014). Properties of recycled aggregate concrete made with recycled aggregates with different amounts of old adhered mortars. Materials and Design, 58, 19-29.

[20] IS 8112:1989. Specification for 43 Grade Ordinary Portland Cement. Bureau of Indian Standards, New Delhi.

[21] IS 383:1970. Specification for Coarse and Fine Aggregates from Natural Sources for Concrete. Bureau of Indian Standards, New Delhi.

[22] IS 10262:2019. Concrete Mix Proportioning - Guidelines. Bureau of Indian Standards, New Delhi.

[23] IS 1199:1959. Methods of Sampling and Analysis of Concrete. Bureau of Indian Standards, New Delhi.

[24] Rahal, K. (2007). Mechanical properties of concrete with recycled coarse aggregate. Building and Environment, 42(1), 407-415.

[25] Evangelista, L., and de Brito, J. (2007). Mechanical behaviour of concrete made with fine recycled concrete aggregates. Cement and Concrete Composites, 29(5), 397-401.

[26] Sagoe-Crentsil, K. K., Brown, T., and Taylor, A. H. (2001). Performance of concrete made with commercially produced coarse recycled concrete aggregate. Cement and Concrete Research, 31(5), 707-712.

[27] Gómez-Soberón, J. M. (2002). Porosity of recycled concrete with substitution of natural aggregates. Cement and Concrete Research, 32(8), 1301-1311.

[28] Corinaldesi, V. (2010). Mechanical behavior of recycled-aggregate concrete with different water-cement ratios. Cement and Concrete Composites, 32, 1-12.

[29] Marinković, S., Radonjanin, V., Malešev, M., and Ignjatović, I. (2010). Comparative environmental assessment of natural and recycled aggregate concrete. Waste Management, 30(11), 2255-2264.

[30] Li, Q., and Zhang, C. (2017). A statistical study on the compressive strength of recycled aggregate concrete. Chemical Engineering Transactions, 59, 421-426.