Performance Assessment of M30 Grade Concrete by Mixing Recycled Concrete Aggregates from Prithvi Rajmarga

Shubham Pokhrel[1], Rabindra Poudel[1], Parkash Chandra Joshi[1], Avishek Adhikari[2], Pradip Sigdel[3], Sahanshil Paudel[3], Samrat Poudel[1]*
[1]Department of Civil Engineering, Pashchimanchal Campus, IOE, TU, Nepal
[2]School of Engineering, Pokhara University, Nepal
[3]Ministry of Energy, Water resources and Water Supply, Gandaki Province, Nepal
*samrat@ioepas.edu.np

(Manuscript Received 6th April, 2025; Revised 25th April, 2025; Accepted 2nd May, 2025)

Abstract

This study assesses the performance of M30 grade concrete incorporating Recycled Coarse Aggregate (RCA) sourced from Prithvi Rajmarga as a partial replacement for Natural Coarse Aggregate (NCA). RCA was manually processed and used to replace NCA at 0%, 10%, 20%, 30%, and 40% by weight. A control mix was designed with a constant water-cement ratio of 0.38 and a mix proportion of 1:1.94:3.22 (C:S:A). Comparative analysis revealed that RCA exhibited lower specific gravity and higher water absorption than NCA. Incorporation of RCA led to reductions in slump and fresh density. The 28-day compressive strength values were 38.69 MPa, 35.33 MPa, 34.70 MPa, 34.26 MPa, and 32.07 MPa for 0% to 40% RCA replacement levels, respectively. Compressive strength remained above the target threshold (fck + 4 = 34 MPa) up to 30% replacement. A similar declining trend was observed in flexural strength, with recorded values of 6.4 MPa, 5.98 MPa, 4.98 MPa, 4.52 MPa, and 4.04 MPa. The results indicate that RCA can replace NCA up to 30% without significantly compromising structural performance. This supports the potential of RCA in sustainable construction and contributes to effective construction and demolition waste management strategies

Keywords: *Compressive strength, Construction and Demolition Waste, Flexural Strength, Recycle coarse aggregate,*

1. Introduction

1.1 Background

Concrete, owing to its durability, strength, and cost-effectiveness, remains the most consumed construction material globally, with production exceeding 30 billion tons annually (Sverdrup and Olafsdottir 2023). However, this enormous scale of usage is accompanied by environmental and resource-based concerns, particularly due to the continuous extraction of natural coarse aggregates (NCA) and the generation of large volumes of construction and demolition waste (C&DW). The depletion of riverbeds and hillsides due to quarrying activities not only degrades ecosystems but also threatens long-term aggregate supply (Langer and Arbogast 2003; Wiejaczka et al. 2018). At the same time, increasing demolition from urban renewal and infrastructure rehabilitation adds millions of tons of waste into the environment each year (Lee, Chang, and Lee 2024; Tam et al. 2018). In Nepal, these dual challenges are especially pressing. Major highway infrastructure projects such as Prithvi Rajmarga, a vital east-west corridor linking Kathmandu to Pokhara and beyond, produce substantial concrete waste during maintenance and expansion. Currently, this debris is typically disposed of in landfills or informally dumped, causing both environmental degradation and missed opportunities for material recovery (Ehler and Shrestha 2015; Labra Cataldo et al. 2024). This highlights a significant gap in Nepal's construction sector: the lack of a formal mechanism or guideline for C&DW recycling and reuse.

Recycling of concrete debris, particularly through the use of coarse recycled aggregates (CRA) derived from crushed concrete, offers a sustainable alternative to conventional practices. Compared to fine recycled aggregates, which are more susceptible to high water absorption and poor mechanical interlock, CRA (particles >4.75 mm) demonstrates better mechanical properties and can partially or even fully replace NCA in structural applications (Nedeljković et al. 2021). Past studies have shown that with appropriate processing—such as crushing, grading, and contaminant removal CRA can replace 30–50% of NCA without significant loss in compressive strength or durability (González-Fonteboa and Martínez-Abella 2008; Kou and Poon 2012). Nevertheless, concerns remain when CRA is used at higher replacement ratios, especially in structural-grade concretes like M30, due to its relatively higher porosity, adhered mortar content, and variability in strength (Malešev, Radonjanin, and Marinković 2010; Silva, Brito, and Dhir 2014). A major contributor to performance variation in recycled aggregate concrete (RAC) is the interfacial transition zone (ITZ), the microstructural region surrounding aggregate particles where mechanical bonding occurs. In concrete containing CRA, this zone becomes more complex due to the presence of multiple ITZs the first between old natural aggregates and residual mortar in the CRA, and the second between the CRA surface and the new cement paste. These zones are often porous and rich in microcracks, resulting in a weakened matrix, especially at higher CRA content. As such, optimizing CRA content becomes essential not only to ensure mechanical performance but also to control long-term durability and shrinkage behavior (Li, Zhao, and Wang 2025).

While global leaders such as the Netherlands recycle over 85% of their C&DW for use in road base and structural concrete (Zhang et al. 2020), Nepal lacks such policy-driven recycling infrastructure. This creates a compelling need to generate local evidence for sustainable aggregate substitution in structural applications. Accordingly, this study focuses on assessing the feasibility of using CRA sourced from Prithvi Rajmarga in M30 grade concrete, with the aim of determining the optimal replacement percentage of NCA by CRA that maintains structural performance while maximizing environmental benefits. To achieve this, a series of concrete mixes were designed with varying proportions of CRA, ranging from partial to full replacement of NCA. The resulting mixes were evaluated in terms of fresh and hardened properties, including workability, compressive strength, density, and water absorption. Particular attention was given to the effects of increasing CRA content on the performance of the concrete, especially the behavior of the ITZ, which governs the composite action between paste and aggregate.

1.2. Literature Review

Natural aggregates, such as crushed stone, sand, and gravel, account for 70% to 80% of the total volume in conventional concrete (Wilburn, and Goonan 1998). These aggregates are non-renewable and extracted through environmentally intensive quarrying processes. Despite their abundance, concerns have arisen due to increased production costs, limited accessibility to quarries, and the environmental degradation associated with their extraction. As a result, the construction industry has explored alternative materials such as recycled concrete aggregates (RCA), which are derived from crushed demolition waste (Verian 2012). Concrete produced with RCA, referred to as recycled aggregate concrete (RAC), presents an environmentally friendly and economically viable solution. According to the Canadian Council of Ministers of the Environment, construction, renovation, and demolition (CRD) waste is a significant source of recycled aggregates. Modern processing techniques and quality control measures are crucial to ensure the effective use of RCA (Dosho et al., 2005). Numerous international case studies have demonstrated successful implementation of RCA. In the United Kingdom, 10% of total aggregates used in construction have been replaced with RCA (Collins, 1996). The Netherlands used approximately 78,000 tons of RCA in 1994 (de Vries, 1996), while Germany set a recycling target of 40% for construction and demolition waste as early as 1991 (van Acker, 1998). Denmark and Sweden have reported similar initiatives during the 1990s (Schimmoller et al. 2000). In the United States, nearly 100 highway pavement projects had incorporated RCA by the mid-1990s (Burke et al., 1992). The practice of recycling concrete began in Europe after World War II for post-war reconstruction and expanded in the United States during the 1970s for use in foundations and road base layers (Buck 1977). Recycled concrete aggregate (RCA) has lower density and higher water absorption than natural aggregates due to residual cement paste, though its properties still meet standards. Up to 30% RCA replacement does not affect compressive strength across various curing periods, but higher amounts lead to strength reduction. Adjusting the water/cement ratio can help offset these effects (Limbachiya, Leelawat, and Dhir 2000). Additionally, RCA exhibits 7% to 9% lower relative density and nearly double the water absorption compared to natural aggregates, affecting mix design and durability (Shoeb Iliyas et al. 2019). Concrete and brick waste can be effectively reused by converting them into coarse aggregates, fine aggregates, and powder for recycled concrete applications.

When these recycled coarse aggregates are thoroughly cleaned and free from impurities, they can match the performance of conventional aggregates. Although the fresh and 28-day densities dropped by 7.1% and 7.7% respectively, the compressive strength after 28 days increased by 4.5%, indicating promising results for structural use (Gyawali 2022). Using recycled concrete aggregate (RCA) below 20% replacement has negligible impact on strength. Partial replacement of only coarse aggregates yields better strength than replacing both coarse and fine aggregates. RCA use supports sustainability with comparable strength, but further durability studies are needed (Hassan 2018). Using a novel triple mixing (TM) method and SEM analysis revealed that coating recycled aggregates (RA) with pozzolanic particles, especially fine-ground slag, significantly improves the compressive strength and chloride resistance of recycled aggregate concrete (RAC) compared to the double mixing (DM) method or fly ash use. The pozzolanic particles react with calcium hydroxide to form additional hydration products, enhancing the interfacial transition zone (ITZ) and strengthening the RA, thereby improving the overall strength and durability of RAC (Kong et al. 2010). Recycled concrete aggregates (RCA) generally exhibit inferior properties compared to natural aggregates (NA) due to their porous microstructure and weak interfacial transition zone (ITZ). RCA typically has lower density, specific gravity, and bulk density, along with higher water absorption. Mechanically, RCA performs less effectively, with higher crushing and impact values and lower crushing strength caused by adhered mortar and weak ITZ. Nonetheless, various enhancement techniques can be employed to improve these properties (Memon, Bekzhanova, and Murzakarimova 2022). When the old concrete used to produce RCA has higher strength than the new concrete, the interfacial transition zone between the old aggregate and new mortar (ITZOA-NM) exhibits the lowest micro-hardness, minimizing the negative impact of adhered old mortar on RAC properties thus, removing the old mortar is unnecessary. Conversely, if the old concrete is weaker than the new concrete, the interfacial zone between the old aggregate and old mortar (ITZOA-OM) becomes the weakest link, significantly degrading RAC performance. In such cases, it is advisable to remove as much adhered old mortar from the RCA as possible (Yue et al. 2020). ITZ between new and old mortar and old mortar and old aggregate is shown in Fig. 1.

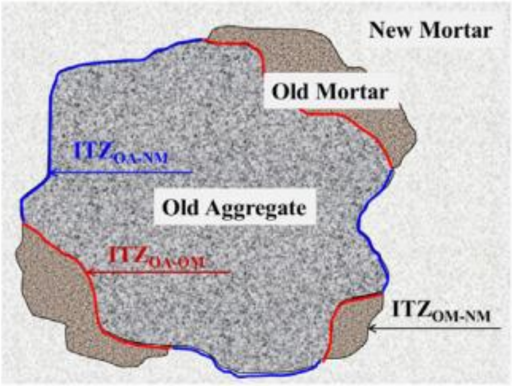


Fig. 12: Image of RCA and Prepared Concrete

1.3 Research Gap

Despite extensive research on RCA, limited studies have focused on recycled coarse aggregates sourced from infrastructure demolitions like highways, culverts, and footpaths. These elements, unlike typical buildings, experience heavier and more variable loads, potentially affecting the quality and performance of RCA. This creates a need to assess their suitability in structural concrete, particularly in contexts like Nepal’s Rajmarga projects.

1.4 Objectives of the Study

This study aims to evaluate the mechanical performance of M30-grade concrete by replacing natural coarse aggregates with RCA obtained from demolished Rajmarga structures. The specific objectives of this research are to:

1. Investigate the effect of varying proportions of RCA on the compressive and flexural strength of the concrete.
2. Assess the impact of RCA substitution on the workability and water absorption characteristics of the concrete.
3. Examine the feasibility of incorporating RCA into high-strength structural concrete production.

2. Materials and Methods

This research follows a quantitative design, focusing on objective and replicable measurements. It uses experimental methods to assess the effects of RCA on concrete performance. Rooted in sustainable construction theory, it supports resource conservation and reuse. All testing adheres to IS codes, ensuring reliability, with numerical data used to establish cause-effect relationships in concrete behaviour.

2.1 Materials

2.1.1. Cement

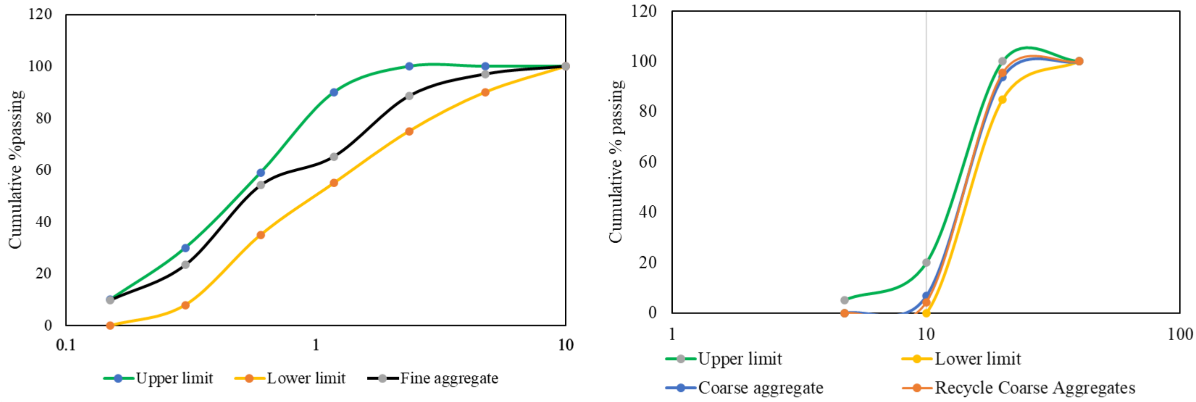
This study utilized a variety of materials to investigate the mechanical properties of M30-grade concrete incorporating recycled coarse aggregates (RCA) sourced from demolished infrastructure. The primary binding material used was Ordinary Portland Cement (OPC) of 43-grade, a commonly used type of cement in structural concrete, which meets the requirements specified by Indian Standards. The cement was thoroughly examined for its physical and mechanical properties to ensure that it met the necessary quality standards for use in concrete. The specific gravity, fineness, and setting times of the cement were determined following the guidelines of IS 4031-Part-1 (2005), IS 4031-Part-4 (2005) and IS 4031 Part-5 (2005), respectively. In addition, the compressive strength of the cement was measured after 28 days of curing, in accordance with the relevant IS standards, to assess its suitability for concrete applications. Detail properties of cement are presented in Table 1.

Table 1: Properties of cement

Properties	Value	Test Standard
Specific gravity	3.15	(IS 4031-Part-11,2005)
Colour	Grey	Virtual Observation
Fineness	2.01	(IS 4031-Part-1,2005)
Normal consistency	29%	(IS 4031-Part-4,2005)
Initial setting time	58 min	(IS 4031-Part-5,2005)
Final setting time	455 min	(IS 4031-Part-5,2005)
Compressive strength at 28 days	45.22	(IS 4031-Part-6,2005)

2.1.2. Aggregates

The normal coarse aggregates and fine aggregates used in this study were sourced from local suppliers, ensuring that the materials were representative of typical regional availability. The physical properties of these aggregates were carefully tested, including sieve analysis to determine their gradation and fineness modulus. The recycled coarse aggregates (RCA), which form the focus of this study, were sourced from demolished concrete elements along the Prithvi Rajmarga. Prithvi Rajmarga was selected as a source for RCA due to the large volume of concrete waste generated during road widening projects and maintenance activities. This provided a practical and abundant supply of RCA, which is especially relevant in the context of Nepal's growing infrastructure demands and the need for sustainable construction practices. The demolished concrete was initially crushed into smaller particles, from which the coarse aggregates were separated and cleaned to remove any impurities such as dirt and dust. After cleaning, the RCA was sieved through a 20mm sieve to exclude any particles larger than the specified limit, ensuring a uniform size distribution appropriate for incorporation into concrete mixtures. Sieve analysis of NCA and RCA was done as per IS 383 (1970). Particle size distribution of FA and of CA and RCA are shown in Fig. 2.



A) Fine aggregate

B) Coarse and Recycle Coarse Aggregates

Fig. 13: Aggregates particle distribution curve

According, to the data from above graph and according to IS: 383 (1970), the sand fulfills all the criteria of zone II. In every mix design we used the sand of zone II.

2.1.3. Water

For the preparation of concrete mixes and curing purposes, fresh potable water was used throughout the study. The use of potable water ensures that the quality of the mix is maintained, as non-potable or contaminated water can adversely affect the setting, hardening, and strength development of concrete.

2.1.4. Superplasticizers

A high-performance polycarboxylate ether (PCE) superplasticizer, conforming to ASTM C 494 Type D, was used in this study. This superplasticizer, in liquid form, has a specific gravity of 1.11, pH of 7-8, and viscosity of 15-18 seconds. It was employed to improve the workability of the concrete mix without increasing the water content, enabling a lower water-to-cement ratio. This enhances the concrete's strength and durability while maintaining flowability, especially in high-strength mixes like M30-grade concrete.

2.1.5. Fly Ash

For this study, commercially available fly ash was used as a supplementary material in the concrete mix. The fineness of the fly ash was determined using the wet sieving method, in accordance with the guidelines provided in IS 3812 (Part 1). The fly ash used was grey in color, as confirmed through visual inspection. The specific gravity of the fly ash was found to be 2.25, as per IS 4031 (Part 11). Additionally, the calcium content of the fly ash was measured to be 3.1 %. These properties are important in understanding the fly ash’s reactivity and its potential role in enhancing the performance of the concrete mix.

2.2. Mix Proportions

In this study, M30-grade concrete was prepared by replacing natural coarse aggregate (NCA) with recycled coarse aggregate (RCA) at five different levels: 0%, 10%, 20%, 30%, and 40%. The total coarse aggregate content was kept constant across all mixes, and the replacements were made by weight. The cement, fly ash, and sand contents were held constant at all replacement levels to maintain uniformity in the mix matrix. Specifically, RCA was introduced as a percentage of the total coarse aggregate content, with 0% RCA (100% NCA) in the control mix, and 10%, 20%, 30%, and 40% RCA replacing an equivalent percentage of NCA in subsequent mixes. To account for the higher water absorption capacity of RCA, the water content was increased by approximately 28.6% in mixes with RCA from 149 kg in the control mix to 191.58 kg in the RCA mixes ensuring consistent workability across all mixes. This adjustment was crucial due to the porous nature of RCA and the presence of old adhered mortar, which tends to absorb more water compared to natural aggregates. Additionally, 1% superplasticizer was incorporated into all mixes to maintain consistent workability despite variations in the aggregate composition. The uniform binder and fine aggregate content, combined with proportional replacement and water adjustment, allowed for a systematic evaluation of RCA's influence on concrete properties while aligning with sustainable construction practices. Detail of mix proportions was shown in Table 2.

Table 2: Mix proportion with various % of RCA

Mix %	Cement (kg)	Fly Ash (kg)	Sand (kg)	NCA (kg)	RCA (kg)	Water (kg)
0%	290.65	72.63	706.4	1172.3	-	149
10%	290.65	72.63	706.4	1055.07	117.23	191.58
20%	290.65	72.63	706.4	937.7	234.46	191.58
30%	290.65	72.63	706.4	820.61	351.69	191.58
40%	290.65	72.63	706.4	703.31	468.92	191.58

2.3. Mixing and Test Specimen Preparation

In this study, a 70-liter drum-type mixer was employed to prepare the concrete mix, following the provisions of IS 516 (2004). The mixing process began with the dry blending of fine and coarse aggregates for approximately 30 seconds, ensuring even distribution and homogeneity. Following this initial mixing, a superplasticizer, conforming to ASTM C494 Type D, was used to improve the workability of the concrete. The required dosage of superplasticizer was first dissolved in about 75% of the total mixing water and gradually added to the drum while mixing continued. This allowed for efficient dispersion of the admixture and minimized the possibility of clumping or segregation. The mixing was then continued for an additional 2 minutes, until a consistent, workable, and cohesive concrete mix was obtained. Finally, the remaining 25% of the water was added, and the mix was stirred for another 1 minute to ensure complete hydration and uniformity. All activities related to mixing, casting, and curing were conducted under controlled laboratory conditions. The ambient temperature was maintained at 20 ± 2°C, and the relative humidity was regulated at approximately 65%. These environmental settings were crucial to prevent fluctuations in curing behaviour and ensure consistent and reproducible results. By standardizing these conditions, the integrity of the experimental program was preserved, enabling accurate assessment of the fresh and hardened properties of the concrete.

For mould preparation, 150 mm × 150 mm × 150 mm cube moulds were used for the compressive strength (CS) tests, while 500 mm × 100 mm × 100 mm beam moulds were employed for flexural strength (FS) tests. Prior to casting, the moulds were thoroughly cleaned to remove any debris or remnants of old concrete and then lubricated with a release agent to facilitate easy removal of the hardened specimens. Concrete was poured into each mould in three layers, and each layer was tamped 25 times to ensure adequate compaction and to remove air voids, as specified by IS 516 (2004). The surface was levelled to ensure uniformity, and after casting, the specimens were stored in a cool area and wrapped with clean, humid cloths for 24 hours to prevent rapid moisture loss. The specimens were then transferred to a curing tank, where they were kept submerged in water for the remainder of the curing period, as shown in Fig. 3. All tests were carried out according to the procedures outlined in IS 516 (2004).

a) Mixing of Concrete b) Cube Specimen c) Beam Specimen d) Wet Curing

Fig. 14 : Concrete Mixing and Specimen Preparation

2.4 Test Methods

To assess the quality and durability of the aggregates used in the concrete mix, a series of standard laboratory tests were conducted. The specific gravity and water absorption of both fine and coarse aggregates were determined in accordance with IS 2386: Part 3 (1963). For this, oven-dried aggregate samples were brought to room temperature before testing, using a pycnometer for fine aggregates and a wire basket for coarse aggregates. These parameters are essential in determining the aggregate's density and its influence on the water demand of the mix. Furthermore, the abrasion resistance of coarse aggregates was evaluated using the Los Angeles Abrasion Test, following the guidelines of IS 2386: Part 4 (1963). In this test, a specified quantity of aggregate was placed in a rotating drum along with standard steel balls, and the machine was operated for a set number of revolutions. The percentage weight loss of the aggregates after the test provided a measure of their resistance to wear and mechanical degradation. These tests were crucial to ensure that the aggregates met the strength and durability requirements necessary for high-performance concrete production.

The workability of the freshly prepared concrete mix was determined using the slump cone test as per IS 1199 (1959). This test was carried out immediately after mixing to assess the flowability and consistency of the concrete. The slump cone was filled in three successive layers, with each layer compacted 25 times using a tamping rod to eliminate entrapped air and achieve proper compaction. Upon removal of the cone, the vertical settlement of the concrete (slump value) was measured and recorded as an indication of its workability. For strength assessment, cube and beam specimens were demolded after 24 hours and subsequently cured in water until the specified testing days. Compressive, flexural, and flexural strength tests were conducted at 7 and 28 days of curing. Before testing, specimens were cleaned using a dry cloth and left to air-dry on a level surface to eliminate surface moisture. The dimensions and mass of each specimen were recorded to compute their respective densities. Test setup for both compressive and flexural strength was depicted in Figure 4.

Compressive strength was determined on 150 mm × 150 mm × 150 mm cube specimens using a compression testing machine, following IS 516 (2004). The compressive strength fc was calculated using the equation:

$$f_c = \frac{P}{a^2} \qquad (1)$$

where fc is the compressive strength (MPa), P is the maximum applied load (N), and a is the side length of the cube (mm).

Flexural strength tests were conducted on 100 mm × 100 mm × 500 mm beam specimens using a universal testing machine (UTM) of 1000 kN capacity. A three-point bending load was applied at the center of the beam, as per IS 516 (2004). The flexural strength fb was computed using the formula:

$$f_b = \frac{3PL}{2bd^2} \qquad (2)$$

where fb is the flexural strength (MPa), P is the applied load (N), L is the effective span (mm), b is the breadth (mm), and d is the depth (mm) of the beam.

a) Compressive Strength Test   b) Flexural Strength Test

Fig. 15 : Test on hardened concrete

3. Results and discussion

3.1 Specific Gravity and Water Absorption of Aggregates

The specific gravity and water absorption of natural coarse aggregate (NA) and recycled coarse aggregate (RCA) were tested as per IS 2386 – Part 3 (1963). The specific gravity of NA was 2.62, while RCA had a lower value of 2.54, mainly due to the residual mortar attached to RCA particles, which also contributes to its increased porosity. The water absorption of RCA (6.83%) was significantly higher than that of NA (1.31%), owing to the porous nature of the adhered mortar and the presence of microcracks within the recycled particles. These microcracks, formed during the recycling process, not only reduce the density of RCA but also increase its water absorption capacity, impacting the water demand in concrete mixes. This trend is consistent with previous studies, which report similar results for RCA's physical properties.

3.2. LA Abrasion Test of Aggregates

The Los Angeles (LA) abrasion test was conducted to assess the resistance of both natural coarse aggregate (NCA) and recycled coarse aggregate (RCA) to wear and tear caused by impact forces between steel balls and the aggregates. The results showed that the abrasion value for NCA was 4.6%, while RCA exhibited a higher abrasion value of 8.44%. This increased mass loss in RCA can be attributed to the presence of soft, adhered old mortar and the formation of cracks within the aggregates during the crushing process. The old mortar, which is more porous and weaker than the base aggregate, makes RCA more susceptible to abrasion. Additionally, the crushing process of RCA often causes the formation of microcracks, which further reduces the aggregate's strength and increases its susceptibility to abrasion. These findings are consistent with previous studies, which have observed that RCA generally shows higher abrasion values due to the inherent characteristics of recycled material, such as the residual mortar and weakened particle structure (Alqarni et al. 2022).

3.3 Workability of Concrete

The workability of the concrete was assessed using the slump test, and the results showed a clear trend: the maximum workability was observed at 0% replacement of natural coarse aggregates (NCA) with recycled coarse aggregates (RCA), and the minimum workability was recorded at 40% replacement with RCA, as shown in Fig. 5. This decrease in workability with increasing RCA content can be attributed to the higher water absorption rate of RCA compared to NCA. As the amount of RCA in the mix increases, more water is absorbed by the aggregates, reducing the available water for hydration and consequently lowering the workability of the concrete. The irregular and rough shape of RCA particles, along with the presence of adhered old cement paste, further contributes to this reduction in workability. Kurda et al., (2017) indicated that the water absorption rate in concrete with RCA is higher due to these factors, which leads to a decrease in workability. Therefore, as the RCA content increases, the concrete becomes more difficult to mix, place, and compact.

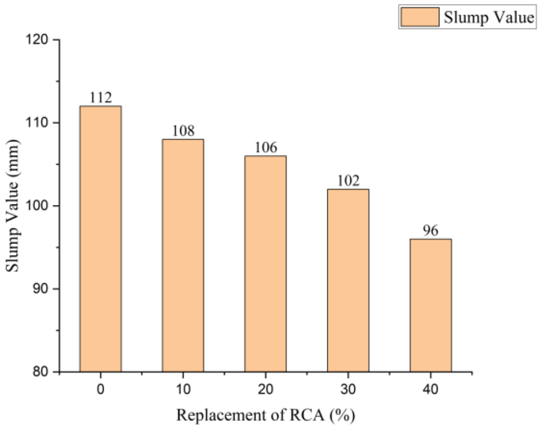


Fig. 16 : Slump value of concrete

3.4 Fresh density

The fresh density of concrete was observed to decrease with an increase in the RCA content, from 0% to 40%, as shown in Figure 6. This reduction in density can be attributed to the lower specific gravity of RCA compared to natural coarse aggregates (NCA). Since RCA has a specific gravity of 2.54, which is lower than that of NCA (2.62), the overall density of the concrete mix decreases as more RCA is incorporated into the mix. The lower specific gravity of RCA means that it contributes less to the overall mass of the concrete, leading to a decrease in its fresh density. This effect is particularly noticeable as the replacement percentage increases, with the concrete becoming progressively lighter with higher RCA content.

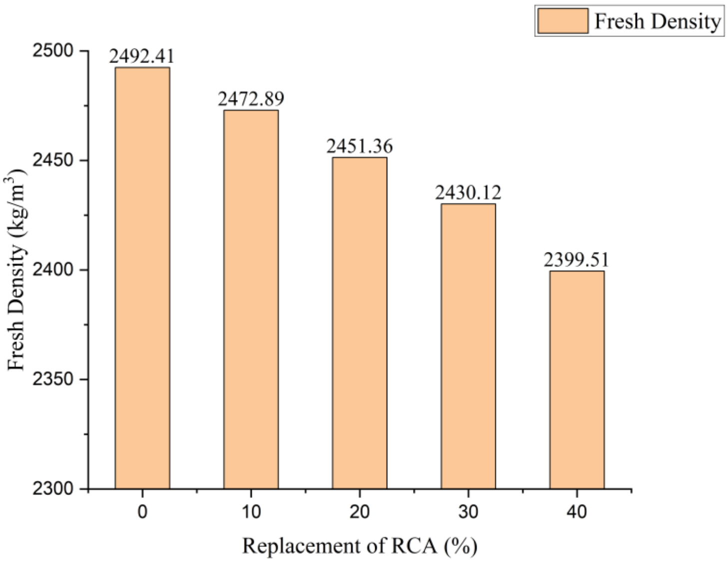


Fig. 17 : Fresh density of concrete

3.5 Compressive strength

The compressive strength of concrete was observed to decrease with an increase in the content of recycled coarse aggregates (RCA). The compressive strength values after 7 days and 28 days of curing were recorded for different replacement levels of RCA, as shown in Fig. 7. For 7 days, the compressive strength values were 26.65 MPa, 25.98 MPa, 25.44 MPa, 25.14 MPa, and 23.70 MPa for 0%, 10%, 20%, 30%, and 40% RCA replacement, respectively. For 28 days, the compressive strength values were 38.69 MPa, 35.33 MPa, 34.70 MPa, 34.26 MPa, and 32.07 MPa, for 0%, 10%, 20%, 30%, and 40% RCA replacement, respectively. Relation of compressive strength of concrete with various replacement of recycled aggregate is illustrated in Figure 6.

The reduction in compressive strength with increasing RCA content is attributed to the formation of two distinct interfacial transition zones (ITZ) in concrete with RCA. In conventional concrete using natural aggregates (NA), the ITZ is formed between the aggregates and the surrounding mortar. However, in concrete with RCA, the ITZ is formed not only between the new aggregates and the new mortar but also between the old mortar and the new aggregates (Memon, Bekzhanova, and Murzakarimova 2022). This alteration in the ITZ results in a weaker bond and, consequently, a decrease in compressive strength as the RCA content increases (Sáez del Bosque et al. 2017).

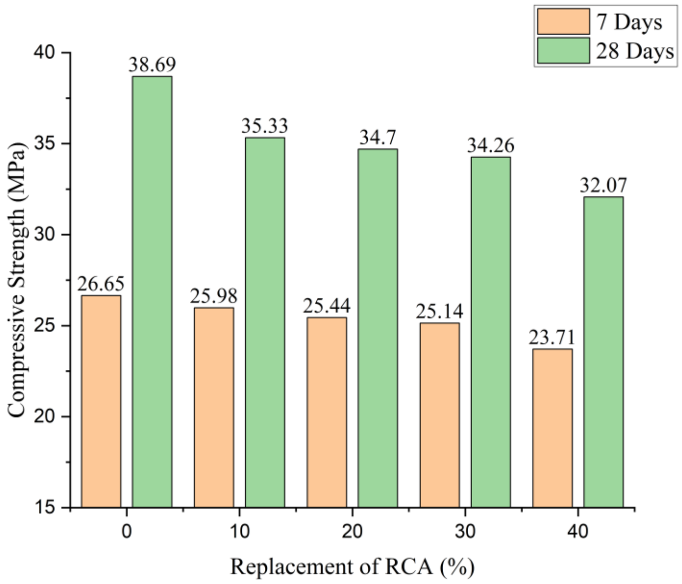


Fig. 18 : Compressive strength with varying % of RCA

It is noteworthy that the compressive strength remained above the target threshold according to IS 456 (2000) (fck + 4 = 34 MPa) up to 30% RCA replacement. The equation y = 39.473e(-0.041x) fits the data for 28-day strength, with an R^2 value of 0.8985, indicating a strong correlation between RCA content and compressive strength reduction. However, at 40% RCA replacement, the compressive strength fell below the target threshold, indicating that higher RCA content significantly impacts the strength of the concrete. Thus, while RCA can be effectively used in concrete up to 30% replacement without compromising strength performance, higher replacement levels may result in strength reductions that may not meet the required standards for certain applications. Trend of 28 days compressive strength was illustrated in Fig. 8.

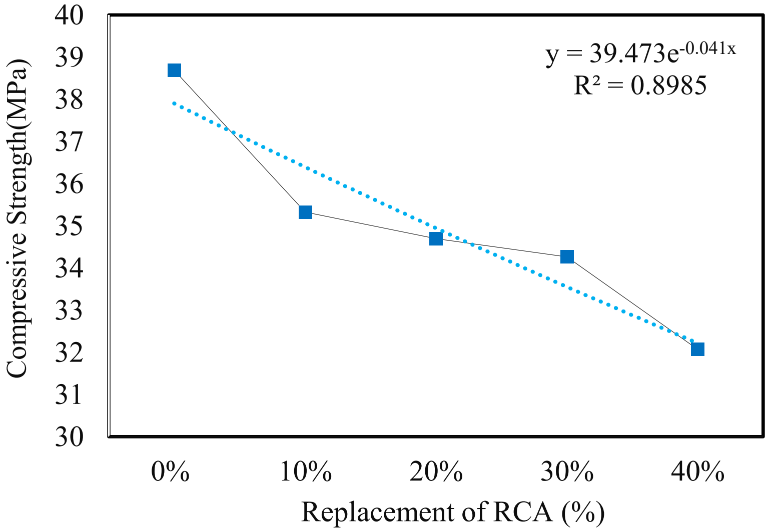


Fig. 19: Trend of 28 days Compressive Strength

3.6 Flexural strength

The flexural strength of concrete was found to decrease progressively with an increase in the percentage of recycled coarse aggregates (RCA), as presented in Fig. 9. At 7 days of curing, the flexural strength values were 4.58 MPa, 4.24 MPa, 3.88 MPa, 3.62 MPa, and 3.36 MPa for 0%, 10%, 20%, 30%, and 40% RCA replacement, respectively. Similarly, at 28 days, the flexural strength was recorded as 6.4 MPa, 5.98 MPa, 4.98 MPa, 4.52 MPa, and 4.04 MPa for the respective replacement levels.

This reduction in strength can be attributed to the weaker mechanical properties of RCA compared to natural coarse aggregates (NCA), which is due to the adhered old mortar and increased porosity that results in a less dense and weaker interfacial transition zone (ITZ). These characteristics contribute to a reduction in the concrete's resistance to bending stress as RCA content increases. Despite the decreasing trend, it is important to note that the 28-day flexural strength values remained above the minimum required threshold for M30 concrete as per IS 456, which is 0.7√fck = 3.83 MPa. Hence, even with 40% replacement, the concrete meets the flexural strength requirement for structural applications.

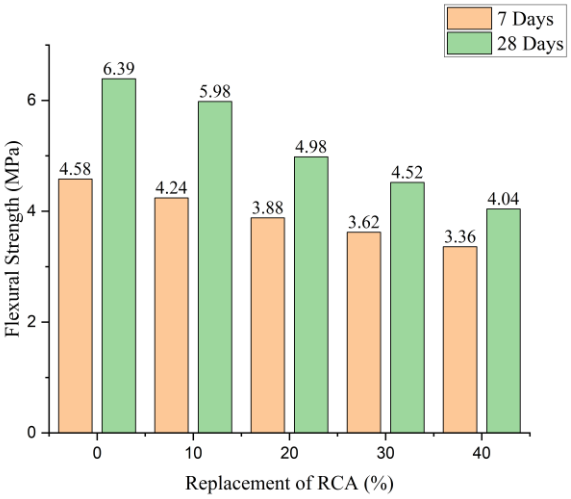


Fig. 20 : Flexural strength with varying % of RCA

The trend of 28-day flexural strength, shown in Fig. 10, follows the exponential decay equation $y = 7.3227e{-}0.12x$, with a high coefficient of determination ($R^2 = 0.9809$), indicating a strong correlation between RCA content and the reduction in flexural strength. This suggests that while RCA can be used in concrete mixes, careful control of its proportion is necessary to maintain desired mechanical performance.

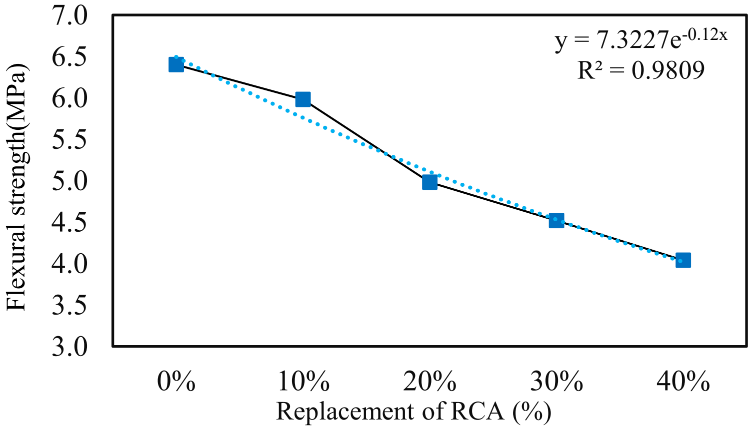


Fig. 21: Trend of 28 days Flexural Strength

3.7 Correlation of Mechanical properties

To establish a predictive relationship between the compressive strength (CS) and flexural strength (FS) of concrete incorporating recycled coarse aggregates (RCA), a nonlinear regression model was developed. The best-fit equation derived from this study is of the form:

$y = kxl$

Where,

y is the flexural strength (MPa),

x is the compressive strength (MPa),

k=0.0005 and l=2.5918 are the empirical constants.

and the coefficient of determination R^2=0.84 indicating a strong correlation.

This relationship is illustrated in Fig. 11, which also compares the findings of this study with models from previous research. The figure shows that while earlier studies such as Juki et al., (2013) and Gyawali, (2023) reported a more linear or moderate relationship between CS and FS, the current study and that of (Diogo Serpa and Jorge Pontes 2015) identified a more pronounced nonlinear trend. Notably, the exponent value l=2.5918 from this study is the steepest among all, suggesting that flexural strength increases more sharply with compressive strength in this mix. However, the low constant k=0.0005 tempers this rate, highlighting the significance of aggregate type, mix design, and the presence of adhered mortar in RCA. Table 3 summarizes the values of k and l used in various models from different studies, reinforcing the variability in FS-CS relationships due to differences in materials and methodologies. This correlation model can aid in estimating the flexural strength of RCA-incorporated concrete using compressive strength data, which is often more readily available.

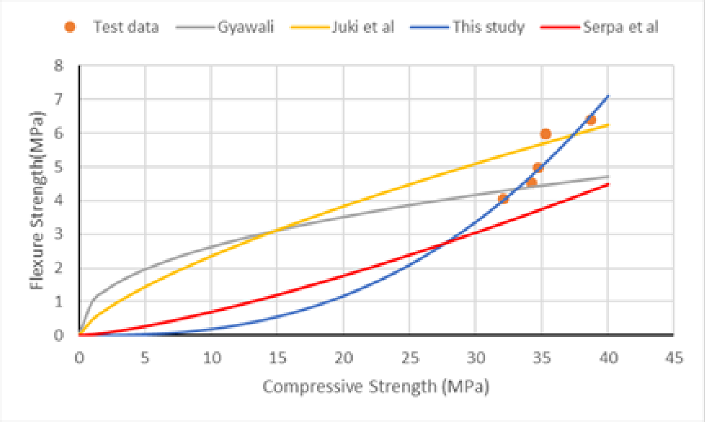


Figure 22: Relation between Flexural Strength and Compressive Strength

Table 3: Value adopted in Modelling

Modelling	k	l	Authors
FS and CS	0.466	0.703	(Juki et al., 2013)
	0.0323	1.3376	(Serpa et al., 2015)
	1.400	0.400	(Gyawali et al., 2024)
	0.0005	2.5918	This study

4. Conclusion

Based on the experimental investigation, it can be concluded that recycled coarse aggregates (RCA) sourced from demolished structures of the historic Prithvi Rajmarga—a major national highway with significant infrastructural legacy exhibit lower specific gravity and higher water absorption than natural coarse aggregates (NCA), owing to adhered mortar and internal porosity. These characteristics lead to a reduction in workability with increasing RCA content, as observed by a decline in slump values due to increased water absorption. However, the mechanical properties of RCA concrete remained within acceptable limits at certain replacement levels. Compressive strength results demonstrated that up to 30% replacement of NCA by RCA is feasible, with 28-day strength exceeding the target threshold (fck + 4 MPa), while flexural strength remained above the IS 456 minimum requirement up to 40% replacement. Importantly, this study not only validates the mechanical viability of RCA in M30-grade concrete but also highlights the potential of transforming demolition waste from national heritage infrastructure like Prithvi Rajmarga into valuable resources for new construction. Rather than being discarded as waste, such RCA can be sustainably repurposed in infrastructure development, reducing environmental burden and supporting circular economy principles in the construction sector.

References

Alqarni, Ali S et al. 2022. “Concrete Performance Produced Using Recycled Construction and By-Product Industrial Waste Coarse Aggregates.” *Materials (Basel, Switzerland)* 15(24).

ASTM C 494. 2022 Standard Specification for Chemical Admixtures for Concrete. *Am Soc Test Mater*.

https://doi.org/10.1520/C0494_C0494M-19

Burke, T. T., Cohen, M. D., & Scholer, C. F. (1992). Synthesis Study on Use of Concrete Recycled from Pavement and Building Rubble in the Indiana Highway System.

Buck, Alan D. 1977. “Recycled Concrete as a Source of Aggregate.” *ACI Journal Proceedings* 74(5).

De Vries, P. (1996, June). Concrete recycled: crushed concrete aggregate. In Proc. of the International Conference: Concrete in the Service of Mankind. I. Concrete for Environment Enhancement and Protection, Dundee, Scotland (pp. 121-30).

Dosho, Y. (2005, October). Application of recycled aggregate concrete for structural concrete: a recycling system for concrete waste. In International Symposium on Sustainable Development of Cement, concrete and concrete structures (Toronto, Canada 2005) (pp. 459-478).

Diogo Serpa and Jorge Pontes, Jorge de Brito. 2015. “Concrete Made with Recycled Glass Aggregates: Mechanical Performance.” *ACI Materials Journal* 112(1).

Ehler, Pavel, and Santosh Shrestha. 2015. “A Study to Promote Recycling of Construction and Demolition Waste in the Kathmandu Valley, Nepal.” In *IWWG-ARB2015*,.

González-Fonteboa, B, and F Martínez-Abella. 2008. “Concretes with Aggregates from Demolition Waste and Silica Fume . Materials and Mechanical Properties.” *Building and Environment* 43(4): 429–37.

Gyawali, Tek Raj. 2022. “Re-Use of Concrete/Brick Debris Emerged from Big Earthquake in Recycled Concrete with Zero Residues.” *Cleaner Waste Systems* 2: 100007. https://www.sciencedirect.com/science/article/pii/S2772912522000070.

Gyawali Tek Raj. 2023. “Effect of the Mixing Procedure on the Properties of Lightweight EPS Mortar.” *Journal of Building Engineering* 68: 106012. https://www.sciencedirect.com/science/article/pii/S2352710223001912.

Hassan, S S. 2018. “Effects of Recycled Concrete Aggregate on Some Mechanical Properties of High Strength Concrete.” *IOP Conference Series: Materials Science and Engineering* 433(1): 12033. https://dx.doi.org/10.1088/1757-899X/433/1/012033.

IS 1199. 1959 Methods of sampling and analysis of concrete. *Bureau of Indian Standards*, New Delhi

IS 2386-Part 3. 1963. Methods of test for aggregates for concrete: specific gravity, density, voids, absorption and buckling. *Bureau of Indian Standards*, New Delhi

IS 2386-Part 4. 1963. Methods of test for aggregates for concrete: mechanical properties. *Bureau of Indian Standards*, New Delhi

IS 383.1970. Specification for Coarse and Fine Aggregates from Natural Sources for Concrete. *Bureau of Indian Standards*, New Delhi

IS 3812 - Part 1. 2003. Pulverized fuel ash specification:for use as pozzolana in cement, cement mortar and concrete. *Bureau of Indian Standards*, New Delhi

IS 4031-Part 1.1996. Methods of physical tests for hydraulic cement: determination of fineness by dry sieving. *Bureau of Indian Standards*, New Delhi

IS 4031-Part 4. 1988. Methods of physical tests for hydraulic cement: determination of consistency of standard cement paste. *Bureau of Indian Standards*, New Delhi

IS 4031-Part 5. 1988. Methods of physical tests for hydraulic cement: determination of initial and final setting times. *Bureau of Indian Standards*, New Delhi

IS 4031-Part 6. 1988. Methods of physical tests for hydraulic cement: Determination of compressive strength of hydraulic cement (other than masonry cement). *Bureau of Indian Standards*, New Delhi

IS 4031-Part 11. 1988. Methods of physical tests for hydraulic cement: determination of density. *Bureau of Indian Standards*, New Delhi

IS 516. 1959. Methods of tests for strength of concrete. *Bureau of Indian Standards*, New Delhi

Juki, Mohd Irwan et al. 2013. “Relationship between Compressive, Splitting Tensile and Flexural Strength of Concrete Containing Granulated Waste Polyethylene Terephthalate (PET) Bottles as Fine Aggregate.” *Advanced Materials Research* 795: 356–59. https://www.scientific.net/AMR.795.356.

Kong, Deyu et al. 2010. “Effect and Mechanism of Surface-Coating Pozzalanics Materials around Aggregate on Properties and ITZ Microstructure of Recycled Aggregate Concrete.” *Construction and Building Materials* 24(5): 701–8. https://www.sciencedirect.com/science/article/pii/S0950061809003754.

Kou, S C, and C S Poon. 2012. “Enhancing the Durability Properties of Concrete Prepared with Coarse Recycled Aggregate.” *Construction and Building Materials* 35: 69–76. https://www.sciencedirect.com/science/article/pii/S0950061812001092.

Kurda, Rawaz, Jorge de Brito, and José D Silvestre. 2017. “Combined Influence of Recycled Concrete Aggregates and High Contents of Fly Ash on Concrete Properties.” *Construction and Building Materials* 157: 554–72. https://www.sciencedirect.com/science/article/pii/S0950061817319529.

Labra Cataldo, Nicolás et al. 2024. “Waste Management in Nepal: Characterization and Challenges to Promote a Circular Economy.” *Circular Economy and Sustainability* 4(1): 439–57. https://doi.org/10.1007/s43615-023-00283-0.

Langer, William, and Belinda Arbogast. 2003. “Environmental Impacts Of Mining Natural Aggregate.” *Deposit and Geoenvironmental Models for Resource Exploitation and Environmental Security*: 151–69.

Lee, Seonho, Heeeun Chang, and Jechan Lee. 2024. “Construction and Demolition Waste Management and Its Impacts on the Environment and Human Health: Moving Forward Sustainability Enhancement.” *Sustainable Cities and Society* 115: 105855. https://www.sciencedirect.com/science/article/pii/S2210670724006796.

Li, Wengui, Hanbing Zhao, and Kejin Wang. 2025. “Nano/Micromechanical Properties of Interfacial Transition Zones in Recycled Aggregate Concrete Tested by Nanoindentation BT - Nanocharacterization of Cementitious Composites: Unveiling Properties at Multiscale” eds. Wengui Li, Hanbing Zhao, and Kejin Wang. *Nanocharacterization of Cementitious Composites*: 165–98. https://doi.org/10.1007/978-981-96-2917-6_7.

Limbachiya, M C, T Leelawat, and R K Dhir. 2000. “Use of Recycled Concrete Aggregate in High-Strength Concrete.” *Materials and Structures* 33(9): 574–80. https://doi.org/10.1007/BF02480538.

Malešev, Mirjana, Vlastimir Radonjanin, and Snežana Marinković. 2010. “Recycled Concrete as Aggregate for Structural Concrete Production.” *Sustainability* 2(5): 1204–25. https://www.mdpi.com/2071-1050/2/5/1204.

Memon, Shazim Ali, Zere Bekzhanova, and Aray Murzakarimova. 2022. “A Review of Improvement of Interfacial Transition Zone and Adherent Mortar in Recycled Concrete Aggregate.” *Buildings* 12(10). https://www.mdpi.com/2075-5309/12/10/1600.

Nedeljković, Marija et al. 2021. “Use of Fine Recycled Concrete Aggregates in Concrete: A Critical Review.” *Journal of Building Engineering* 38: 102196. https://www.sciencedirect.com/science/article/pii/S2352710221000528.

Sáez del Bosque, I F et al. 2017. “Properties of Interfacial Transition Zones (ITZs) in Concrete Containing Recycled Mixed Aggregate.” *Cement and Concrete Composites* 81: 25–34. https://www.sciencedirect.com/science/article/pii/S0958946517304006.

Schimmoller, Vincent E. et al. 2000. “Recycled Materials in European Highway Environments Uses, Technologies, and Policies.” *U.S. Department of Transportation* (October): 134. https://international.fhwa.dot.gov/pdfs/recycolor.pdf.

Shoeb Iliyas, Sayed et al. 2019. “Experimental and Analytical Study on High Strength Concrete (M70) Using Recycled Concrete Aggregate.” *International Research Journal of Engineering and Technology* (June): 2096–2100. www.irjet.net.

Silva, R V, J De Brito, and R K Dhir. 2014. “Properties and Composition of Recycled Aggregates from Construction and Demolition Waste Suitable for Concrete Production.” *Construction and Building Materials* 65: 201–17. http://dx.doi.org/10.1016/j.conbuildmat.2014.04.117.

Sverdrup, Harald Ulrik, and Anna Hulda Olafsdottir. 2023. “Dynamical Modelling of the Global Cement Production and Supply System, Assessing Climate Impacts of Different Future Scenarios.” *Water, Air, & Soil Pollution* 234(3): 191. https://doi.org/10.1007/s11270-023-061831.

Tam, Vivian W Y, Mahfooz Soomro, Ana Catarina, and Jorge Evangelista. 2018. “A Review of Recycled Aggregate in Concrete Applications (2000 – 2017).” *Construction and Building Materials* 172: 272–92. https://doi.org/10.1016/j.conbuildmat.2018.03.240.

van Acker, A. (1998). Recycling of concrete at a precast concrete plant. In Sustainable Construction: Use of Recycled Concrete Aggregate: Proceedings of the International Symposium organised by the Concrete Technology Unit, University of Dundee and held at the Department of Trade and Industry Conference Centre, London, UK on 11–12 November 1998 (pp. 321-332). Thomas Telford Publishing.

Verian, Kho. 2012. “Using Recycled Concrete as Coarse Aggregate in Pavement Concrete.” Purdue University.

Wiejaczka, Łukasz, Lakpa Tamang, Danuta Piróg, and Paweł Prokop. 2018. “Socioenvironmental Issues of River Bed Material Extraction in the Himalayan Piedmont (India).” *Environmental Earth Sciences* 77(20): 718. https://doi.org/10.1007/s12665-018-7897-1.

Wilburn, D. R., & Goonan, T. G. (1998). Aggregates from natural and recycled sources. US Geological survey circular, 1176, 36.

Yue, Gongbing et al. 2020. “Damage Behavior of the Multiple ITZs in Recycled Aggregate Concrete Subjected to Aggressive Ion Environment.” *Construction and Building Materials* 245: 118419. https://www.sciencedirect.com/science/article/pii/S0950061820304244.

Zhang, Chunbo et al. 2020. “Upgrading Construction and Demolition Waste Management from Downcycling to Recycling in the Netherlands.” *Journal of Cleaner Production* 266: 121718. https://www.sciencedirect.com/science/article/pii/S0959652620317650.