Original Article *Journal of Sustainability and Environmental Management (JOSEM), Vol. 3, No. 4 (2024), 195 – 202*
p-ISSN 2822-1729, e-ISSN 2822-1737 Available online at https://www.nepjol.info/index.php/josem

Performance Evaluation of Recycled Coarse Aggregate on Compressive Strength of Concrete

Tek Bahadur Malla[1], Arjun Baniya[1], Suresh Malla[2], Rabindra Paudel[3*]

[1]United Technical College, Pokhara University, Nepal
[2]Nepal Engineering College, Pokhara University, Nepal
[3]Pashchimanchal Campus, IOE, Tribhuban University, Nepal

**Corresponding author: rbndrpdl@gmail.com*

Abstract: The recycling of construction and demolition waste (CDW) is of paramount importance due to its sustainability and economic benefits, encompassing the reduction of landfill waste, conservation of natural resources, and mitigation of pollution. This practice has become integral to the construction industry, particularly in addressing the substantial construction waste generated from the demolition of reinforced concrete (RC) structures. The experimental examination of the performance of recycled coarse aggregate (RCA) on concrete behavior is fundamental in this context. Recycled Coarse Aggregate (RCA) is produced by crushing, screening, and salvaging concrete waste from demolished structures. A study was conducted to examine the properties of recycled coarse aggregate intended for use as coarse aggregate. The percentage of recycled coarse aggregate replacing natural coarse aggregate varied at 0%, 25%, 50%, 75%, and 100%. Concrete cubes were cast and tested in laboratory. To assess performance across various curing periods, 90 standard concrete cubes are formed as NCA alternatives, and their compressive strength is evaluated at 7, 14, and 28 days. After analyzing the physical and mechanical properties of these proportions, it was observed that, except for 75% and 100% replacements, all met the specified limits. The results of the compressive strength tests indicated that both M20 and M25 design mix concretes, without admixture and with 100% NCA, showed higher values at 27.05 MPa and 32.09 MPa, respectively. Conversely, 100% RCA recorded the lowest values at 18.93 MPa and 22.07 MPa for M20 and M25, respectively. The tests were conducted in accordance with the procedures outlined in the Standard IS Codes. The results show that up to 50% replacements of natural crushed aggregate have nominal strength of concrete. The analysis of coarse aggregate and concrete mix test results for the mentioned proportions suggests that up to 50% of natural crushed aggregate can be replaced by recycled coarse aggregate without compromising the characteristics strength of concrete.

Keywords: *Construction and demolition waste, Reinforced concrete, Recycled coarse aggregate, Natural crushed aggregate*

Conflicts of interest: None
Supporting agencies: None

Received 14.10.2024; Revised 14.12.2024; Accepted 23.12.2024

Cite This Article: Malla, T.B., Baniya, A., Malla, S. & Paudel, R. (2024). Performance Evaluation of Recycled Coarse Aggregate on Compressive Strength of Concrete. *Journal of Sustainability and Environmental Management*, 3(4), 195-202.

1. Introduction

The construction sector is experiencing rapid growth due to rising living standards, increased infrastructure demand, changing shopping habits, and natural population growth. This growth has led to a significant increase in concrete output during construction and demolition phases (Luangcharoenra et al., 2019). Consequently, concrete waste has emerged as a global environmental concern requiring urgent attention. Improper disposal poses environmental risks and can result in serious pollution issues if not managed effectively (Bakchan et al., 2019). Concrete remains the primary construction material worldwide, generating millions of tons of debris annually. The composition and volume of demolition waste vary based on the structure type, materials used, and age. Common waste types include wood, rubble, aggregates, ceramics, metals, and paper products. While no standard percentage exists for each waste stream, demolition waste from residential buildings is estimated at 1.3 to 1.6 tons per square meter of ground floor area (Dhakal et al., 2022), and for industrial structures, it ranges from 1.5 to 2.0 tons per square meter. Overall, demolition waste typically falls between 1.0 to 2.0 tons per square meter. According to Transparency Market Research, global construction waste generation is projected to nearly double to 2.2 billion tons by 2025. In the European Union, around 900 million tons of construction waste are produced annually, accounting for 25%–30% of total waste, with 90 million tons classified as hazardous (Saez et al., 2019).

Despite global advancements in waste management, Nepal continues to face challenges in handling Construction and Demolition Waste (CDW). The country lacks a formalized framework for CDW recycling, and awareness among stakeholders remains low. While some traditional materials, such as bricks and wood, are repurposed, much of the debris—including concrete waste—ends up in open dumpsites or landfills, contributing to environmental degradation (Shah et al., 2019). The increase in modern concrete structures has led to higher resource consumption and material accumulation in urban areas, highlighting challenges due to insufficient recycling infrastructure. A 2004 study by Solid Waste Management Resource Mobilization Center (SWMRMC) reported that approximately 28.5 tons of C&D waste were generated daily in the Kathmandu Valley, with this amount significantly increasing since 2012 due to ongoing road widening and improvement projects. Much of this material ends up in landfills, where it serves no further purpose, adversely affecting the environment and land fertility.

The 2015 Gorkha earthquake generated a massive 18.85 million tons of concrete and brick debris (Gyawali, 2022), highlighting the need for efficient recycling strategies to manage such waste effectively. Despite the alarming rate of construction and demolition waste production, the disposal and treatment methods are evolving much more slowly. Traditionally, waste has been managed through landfilling; however, the growing volume necessitates more landfill space, making this approach unsustainable (Arul et al., 2016). The construction industry generates substantial debris that should be recycled and reused as Recycled Aggregates (RAs) to partially or fully replace natural aggregates. Recycling not only reduces waste but also decreases energy consumption, contributing to a more sustainable construction sector (Djelloul et al., 2018). Recycling involves processing used materials to create new products. As infrastructure development intensifies, the demand for natural aggregates increases. To mitigate this, recycled aggregates—comprised of crushed, graded inorganic particles from previously used construction materials can be employed as replacement materials.

However, the strength and durability of concrete made with RCA depend on several factors, including the quality of the recycled material and the mix design. While extensive research has been conducted on the mechanical properties of RCA-based concrete in developed nations, studies specific to Nepal's construction waste composition and environmental conditions remain limited. This study aims to address this research gap by evaluating the performance of RCA in concrete applications under Nepalese conditions.

Figure 1: Demolished Building Waste

2. Materials and methods

2.1. Materials

Cement used was Ordinary Portland Cement that complies with IS: 8112-1989 was utilized. The physical and mechanical properties of the cement were determined following the IS code which are presented in Table 1.

Table 1: Properties of cement

Physical Property	Result
Finess (Retained on 90µm sieve)	<10%
Normal Consistency	28%
Vicat Initial setting time(minutes)	165
Vicat final setting time(minutes)	358

Specific Gravity	3.12
Compressive Strength At 7- days	34.00Mpa
Compressive Strength at 28- days	48.5Mpa

Table 2: Physical properties of coarse and fine aggregate

Physical Property	Fine Aggregate	Coarse Aggregate
Specific Gravity	2.62	2.667
Fineness Modulus	3.14	7.72
Surface Texture	Smooth	
Particle Shape	Rounded	Angular
Impact Value	-	15.25

Natural sand, locally available and with a maximum size of 4.75 mm, was used as the fine aggregate, with specific gravity, fineness modulus, and unit weight specified in Table 2. The gradation curve of sieve analysis is shown in Figure 2. From the analysis it was conformed that the sand was Zone 2 Sand. Natural crushed stone, having a maximum size of 20 mm, served as the natural coarse aggregate, and its specific gravity, fineness modulus, and unit weight are also presented in Table 2.

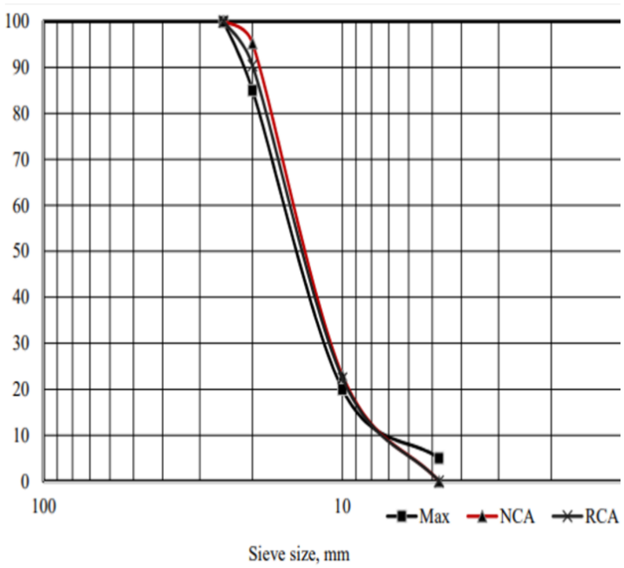

Figure 2: Sive analysis of sand (Zone2)

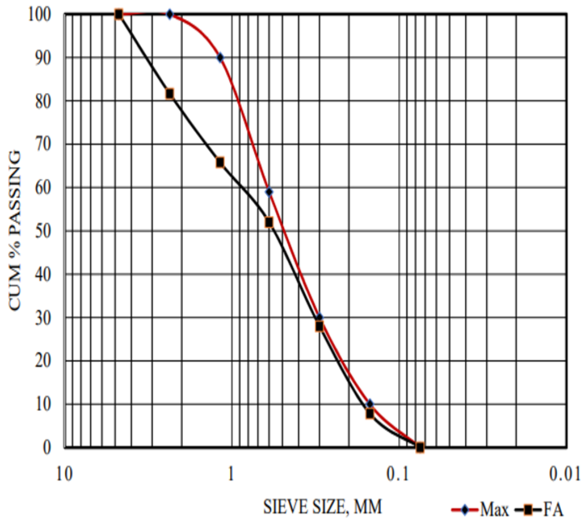

Figure 3: Sive analysis of coarse aggregate

Coarse recycled aggregate (RA) was obtained from the demolition site at Malpot chowk, Bishalchowk Chitwan. Figure1 shows the demolished structure from where the recycled aggregate were obtained. RA that passed through a 20 mm sieve and was retained on a 4.75 mm sieve was used in five distinct concrete mixture compositions for evaluation. Which are 0%, 25%, 50%, 75%,100%. Here by termed by NCA, RCA1, RCA2, RCA3,RCA respectively. Test were conducted in accordance with the IS code. Tests were conducted on the aggregates to assess water absorption, aggregate impact value, and aggregate abrasion value. The physical properties of the coarse aggregate at different proportions are presented in Table 4.

The Chitwan Business Complex construction site in Bharatpur was chosen for acquiring natural crushed aggregate and fine aggregate, both sourced from the Manahari River. The sampling duration extended from June 2023 to July 2023. The test for Natural aggregate are presented in Table 2.

2.2. Method

The study involved the preparation and testing of 90 concrete cube specimens (150 mm × 150 mm × 150 mm) to evaluate the performance of Recycled Coarse Aggregate (RCA) in concrete mixes. The test sample were six for each proportion as suggested by IS code. Two concrete grades, M20 and M25, were used, with varying replacement levels of 0%, 25%, 50%, 75%, and 100% RCA.

The base mix were prepared for both M20, and M25. Were the replacement percentage were 0%. The mix proportions were determined based on concrete mix design in accordance with IS: 10262:2019. The quantities of cement, sand, and coarse aggregate were measured according to the ratios of 1:1.96:3.13 for M20 and 1:1.63:2.71 for M25 which are presented in table 3. The targeted mean strength were 26.6 N/mm2, 31.6 N/mm for M20 and M25 respectively.

Batching were conducted by weight. Batching was performed to calculate the volume of materials needed to produce concrete cube specimens measuring 150mm×150mm×150mm. Following this, the subsequent stage in sample preparation involved concrete mixing. Initially, the coarse aggregates and fine aggregate were thoroughly blended, and then cement was introduced to the aggregate mixture. The concrete underwent further mixing until achieving uniformity. The drum type concrete mixture were used for mixing. The concrete was mixed until reaching a consistent state.

Table 3: Characteristics of concrete

Physical Property	Proportion for M20	Proportion for M25
Cement (Kg/m3)	358.18	410.41
Water (Kg/m3)	196.99	196.99
Fine Aggregate(Kg/m3)	703.20	669.04
Coarse Aggregate(Kg/m3)	1125.80	1115.34
W/C ratio(Kg/m3)	0.55	0.48

Table 4: Physical properties of recycled aggregate

S. N	Physical Property	NCA	RCA 1	RCA 2	RCA 3	RCA
1	Water Absorption	1.57	-	-	-	2.89
2	Agg. Impact Value	15.25	15.89	16.39	18.13	19.46
3	Agg. Abrasion Value	24.42	26.15	26.56	26.82	29.96

2.3. Fresh tests, production of specimens and tests

After mixing workability test of the mixture were carried out in accordance with IS: 1199-1959, Figure 4 a illustrates the slump test conducted on fresh concrete. The specimen was cast in three layers. After casting each layer, compaction was applied uniformly using a tamping rod with 20 strokes. For the 7-day, 14-day, and 28-day compressive strength tests, a total of 90 cubes (150 mm × 150 mm × 150 mm).

3.1. Water Absorption and Specific Gravity

Water absorption refers to the amount of moisture that aggregates can absorb. This capacity is evaluated under both saturated surface dry and oven-dried conditions, as the water content in a concrete mix directly influences the setting time and compressive strength of the concrete. The water absorption capacity of recycled aggregate is greater than that of natural crushed aggregate, as shown in the Figure 4 recycled aggregate exhibiting twice the water absorption of natural aggregate in the saturated dry condition.

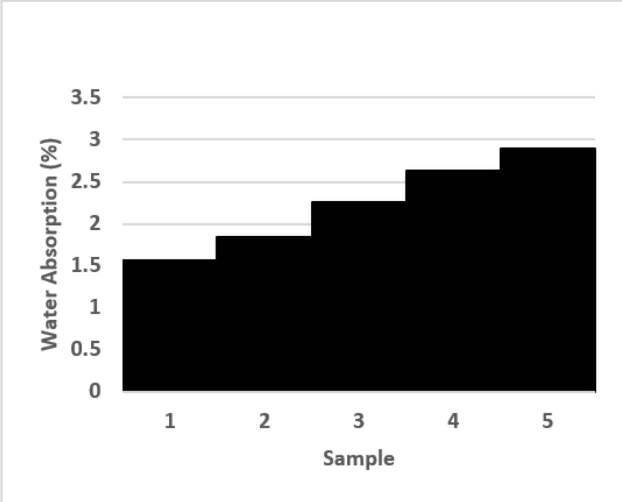

Figure 4: Water absorption of coarse aggregate

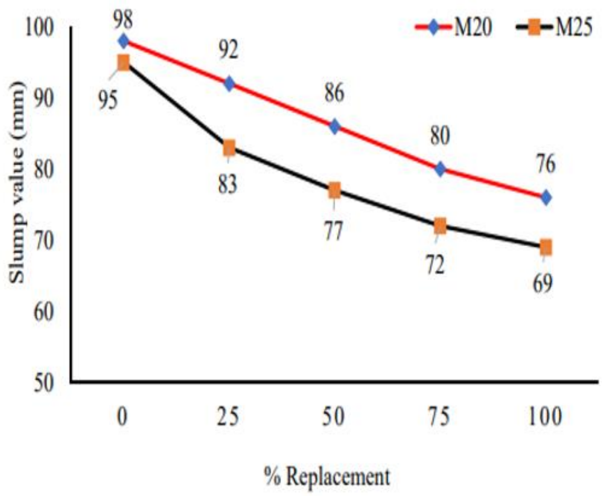

Figure 4 a : Slump value of fresh concrete

3.2. Aggregate Impact Value

The impact test serves as a reliable indicator of strength and durability. Figure 5 present the impact value result, showing that impact value of 100% natural coarse aggregate (NCA) was found to be lower than that of recycled aggregate (RCA) and other combinations, indicating that the recycled aggregate is relatively weaker than the natural aggregate due to presence of adhered mortar.

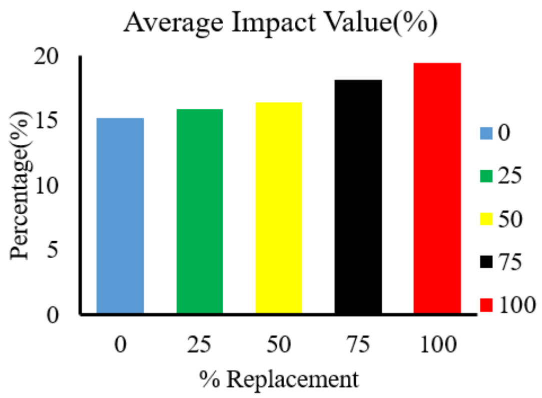

Figure 5: Aggregate impact value

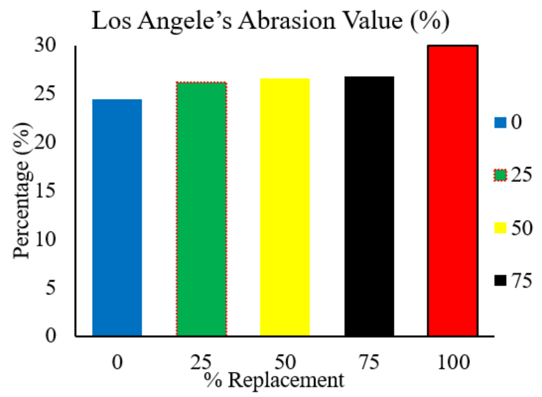

Figure 6: Aggregate abrasion value

3.3 Aggregate Abrasion Value

As illustrated in Figure 6, the abrasion value of 100% recycled coarse aggregate (RCA) was higher than that of natural coarse aggregate (NCA) and other mixture proportions. It is due to RCA composed of residual mortar and cement paste form original concrete. Upon thorough analysis of the data, it was observed that utilizing 100% NCA demonstrates superior performance in resisting wear and tear, registering a value of 24.42%. The alternative combinations (25% RCA & 75% NCA, 50% RCA & 50% NCA, and 75% RCA & 25% NCA) exhibit average resistance to wear, with an abrasion value of 26%. Notably, 100% RCA recorded the highest value at 29.96%, indicating its inferior ability to withstand wear and tear. In the study conducted by Zoriyeh et al. (2023), it was observed that the average abrasion values for recycled coarse aggregate (RCA) were notably higher at 32.3% compared to natural crushed aggregate (NCA).

This study faced some limitations, including environmental factors like temperature and humidity variations affecting concrete curing. Material variability in recycled aggregates from different sources introduced inconsistencies, and human errors in batching and compaction may have slightly influenced results. Future research should focus on standardized RCA sourcing and controlled testing conditions for improved accuracy.

Table 5: Slump Value of Fresh Concrete

S.N.	Mix Grade	Mix Proportions	W/C Ratio	Slump Value	Increase or decrease in slump value with respect to 100% NCA	Workability
1.	100% NCA	M20	0.55	98	0	Medium
2.	25% RCA		0.55	92	-7.36%	Medium
3.	50%RCA		0.55	86	-12.63%	Medium
4.	75%RCA		0.55	80	-15.78%	Medium
5.	100% RCA		0.55	76	-18.94%	Medium
6.	100% NCA	M25	0.48	95	0	Medium
7.	25% RCA		0.48	83	-7.8%	Medium
8.	50%RCA		0.48	80	-14.60%	Medium
9.	75%RCA		0.48	72	-19.1%	Low

10.	100% RCA	0.48	69	-22.49%	Low

4. Results and discussion

4.1. Workability

After examining the laboratory data outlined in table 5, it was evident that employing 100% natural crushed aggregate (NCA) led to higher slump values for both M20 and M25 concrete, measuring 98mm and 95mm, respectively. This indicated improved workability compared to concrete mixes with varying recycled aggregate proportions. Conversely, concrete mixes with 100% recycled coarse aggregate (RCA) exhibited the least workability, with slump values of 77mm for M20 which is 18.94% less than base concrete and 69mm for M25 concrete which is 22.49 % less than base concrete suggesting more challenges in handling and finishing.

As the proportion of recycled coarse aggregate increases in the concrete mix, there is a consistent decline in slump values for both M20 and M25 grades of concrete. This indicates that mixes incorporating recycled coarse aggregate demand more water compared to those utilizing natural crushed aggregate. This may be due to recycled aggregates have higher porosity due to adhered mortar and micro cracks, leading to increased water absorption and weak zones in the concrete. This also weakens the interfacial transition zone (ITZ) with the new cement paste, as absorbed water creates voids and reduces bond strength, ultimately lowering compressive strength. At a 25% replacement, the slump values measure 92mm for M20 and 83mm for M25 concrete. With a 50% replacement, the slump values decrease to 43 86mm for M20 and 77mm for M25, showcasing reductions of 6.52% and 7.22%, respectively. At 75% replacement, the slump values further decrease to 80mm for M20 and 72mm for M25, signifying reductions of 13.04% and 13.25%. At 100% replacement, the slump values are 76mm for M20 and 69mm for M25, representing reductions of 17.39% and 16.86%, respectively. Despite these variations, all mix proportions meet the specified limits of 75-100 mm slump for M20 concrete, while the scenarios for M25 concrete with 75% and 100% replacement do not meet these criteria. The following figure 2 a provides further insight into the slump values of both M20 and M25 concrete in this context. The finding align with Zhang et al., (2018), recycled coarse aggregate exhibits higher porosity, leading to increased water absorption and a consequent reduction in concrete workability. Similar study conducted by Ngekpe et al. (2025), concluded that significant water absorption of recycled aggregate (RCA), the workability of the concrete was found to be approximately 25% lower than that of base concrete, validating the present result.

4.2. Strength

After analyzing the test data presented in Table 5, a consistent pattern emerged: as the percentage of recycled coarse aggregate replacing natural crushed aggregate increased, there was a corresponding decrease in compressive strength. At a 25% replacement, the compressive strength measured 25.02 MPa for M20 and 29.40 MPa for M25 concrete. With a 50% replacement, the compressive strength decreased to 23.06 MPa for M20 and 25.42 MPa for M25, resulting in reductions of 7.83% and 13.53%, respectively. Progressing to a 75% replacement, the compressive strength further decreased to 20.46 MPa for M20 and 23.15 MPa for M25, representing reductions of 18.22% and 21.25%. At 100% replacement, the compressive strength was 18.93 MPa for M20 and 22.07 MPa for M25, indicating substantial decreases of 24.34% and 24.93%, respectively. In this study, the targeted 28-days compressive strength for structural concrete was set at 26.6 MPa for M20 and 31.6 MPa for M25.The concrete mix comprising 100%NCA successfully achieved this strength requirement for both M20 and M25 grades. Meanwhile, the mixes incorporating 25% RCA and 75% NCA, 50% RCA and 50% NCA, and 75% RCA and 25% NCA all met the characteristic strength for M20 concrete. However, the mix with 75% RCA and 25% NCA did not meet the specified characteristic strength of 25 MPa for M25 concrete. Despite allowing a maximum replacement proportion of 100% RCA, the results for this proportion at 28 days of curing were 18.93 MPa and 22.07 MPa. Figures 4.5 and 4.6, presented a graphical representation of the observed data

The reduction in compressive strength at higher RCA percentages can be attributed to the weaker interfacial transition zone (ITZ) between the recycled aggregates and the cement paste, leading to lower bond strength. Additionally, the presence of adhered mortar and micro cracks in RCA increases porosity, reducing the overall strength of the concrete mix (Tam et al., 2008; Kou et al., 2011). This decline in strength highlights the need for optimizing RCA treatment methods or using supplementary cementitious materials (SCMs) such as fly ash or silica fume to enhance the performance of high-RCA concrete (Kou & Poon, 2012).

Table 6: Variation of compressive strength (MPa) for M20, M25

Ratio	Sample	NCA	RCA 1	RCA 2	RCA 3	RCA
M20	7 days	18.6	17.76	16.19	12.87	11
	28 days	27.05	25.02	23.06	20.46	18.93
M25	7 days	20.68	19.33	18.16	17.4	14.75
	28 days	32.09	29.4	25.42	23.15	22.07

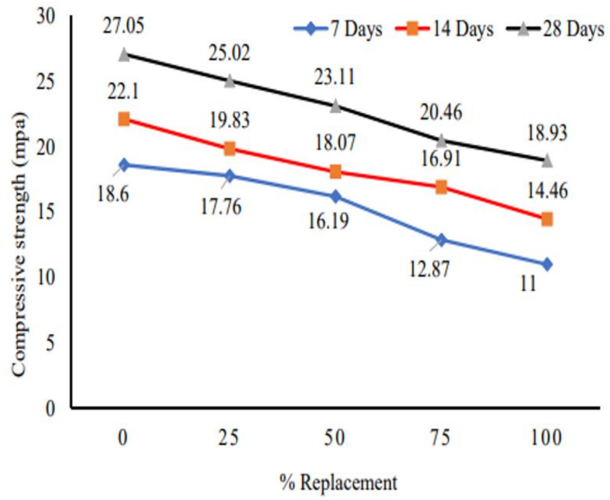

Figure 7: Compressive strength for *M20*

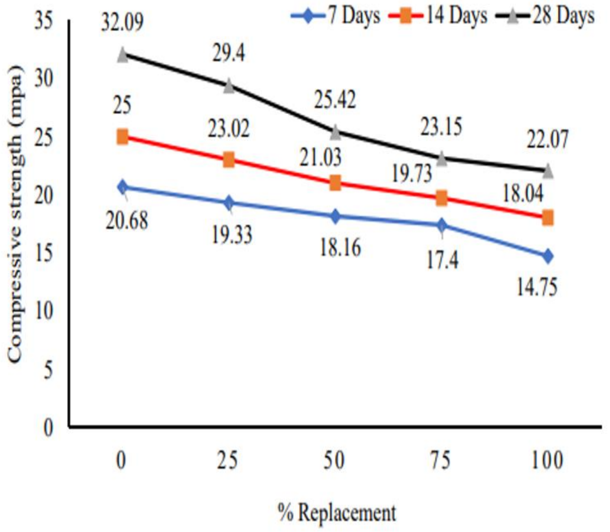

Figure 8: Compressive strength for *M25*

5. Conclusion

The experimental investigation showed that recycled coarse aggregate (RCA) has higher water absorption (2.89%) than natural crushed aggregate (1.57%), affecting concrete performance. RCA also had a higher impact value (19.46%) than NCA (15.25%) but remained below the 30% toughness threshold, indicating sufficient resistance. Although RCA exhibited greater abrasion loss (29.96%) than NCA (24.42%), both were within acceptable limits for concrete use.

Increasing RCA content consistently reduced workability, making handling and placement more difficult due to its porous structure and higher water demand. Compressive strength results showed that up to 50% RCA replacement produced strength comparable to conventional concrete, but higher replacements caused significant reductions, limiting structural applications.

For practical use, RCA replacement should be limited to 50% to maintain performance and sustainability. Pre-treatment methods like washing, pre-soaking, and supplementary cementitious materials (SCMs) such as fly ash can help improve RCA properties. Future research should explore advanced RCA processing, optimized mix designs, and long-term durability to enhance its viability in sustainable construction.

References

Abdelfatah, A., Tabsh, S., & Yehia, S. (2011). Utilization of recycled coarse aggregate in concrete mixes. *Journal of Civil Engineering and Architecture, 5*(6), 562-566.

Arul, G. R., Vidhya Lakshmi, A., Karthikeyan, K., & Uthayakuar, P. (2016). Study on Strength of Concrete by Using Recycled Aggregate from Demolition Waste in Concrete. *International Journal of Research in Engineering and Technology, 5*(6), 176-181.

Bakchan, A., & Faust, K.M. (2019). Construction waste generation estimates of institutional building projects: Leveraging waste hauling tickets. *Waste Management, 87*, 301–312.

Dhakal, B., & Chopra, A. (2022). *Use of building demolition waste as lime treated base course in bituminous road.* Materials Today: Proceedings, 48(Part 5).

Djelloul, O. K., Menadi, B., Wardeh, G., & Kenai, S. (2018). Performance of self-compacting concrete made with coarse and fine recycled concrete aggregates and ground granulated blast-furnace slag. *Advances in concrete construction, 6*(2), 103.

Gyawali, T. R. (2022). Re-use of concrete/brick debris emerged from big earthquake in recycled concrete with zero residues. *Cleaner Waste Systems*, 2, 100007.

Kou, S. C., & Poon, C. S. (2012). Enhancing the durability properties of concrete prepared with coarse recycled aggregate. *Construction and Building Materials, 35*, 69-76.

Kou, S. C., Poon, C. S., & Etxeberria, M. (2011). Influence of recycled aggregates on long-term mechanical properties and pore size distribution of concrete. *Cement and Concrete Composites, 33*(3), 286-291.

Luangcharoenrat, C., Intrachooto, S., (2019). Factors influencing construction waste generation in building construction: Thailand's perspective. *Sustainability, 11*(13), article 3638.

Ngekpe, B. E., Rivers State University, & Ebi, J. (2025). Assessing the mechanical properties of normal strength recycled aggregate concrete. *Journal of Advanced Concrete Technology, 3*, 31–41. Doi:10.5281/zenodo.13859369

Saez, P.V. and Osmani, M., (2019). A diagnosis of construction and demolition waste generation and recovery practice in the European Union. *Journal of Cleaner Production, 241*, 118400.

Shah, S., Shrestha, S., Maharjan, S., & Karki, N. (2019). *Behaviour of Waste Concrete Debris in Concrete.* In 2nd International Conference on Earthquake

Engineering and Post Disaster Reconstruction Planning, April, 90-95.

Tam, V. W., Gao, X. F., & Tam, C. M. (2008). Microstructural analysis of recycled aggregate concrete produced from two-stage mixing approach. *Cement and Concrete Research, 38*(10), 1215-1223.

Zoriyeh, H., & Yıldırım, A. (2023). Properties of Recycled Aggregates and Their Effects on Concrete.