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Recycled Aggregate Concrete as a Structural Element

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Abstract

The growing engrossment in production, resulting accumulation of demolition waste has led to an exigency for effective debris management and resource conservation. This research mainly aimed to compare the properties of recycled aggregate concrete (RAC) with natural aggregate concrete (NAC). A series of experiments like water absorption test, impact test and los- angeles abrasion test were done with 25%, 50%, 75%and 100% replacement of NA by RA. After, different concrete mixtures were made using different ratios of RA and NA and the compressive strength of each mixture was determined. The result shows that recycled coarse aggregate behaves similarly to natural aggregate. Although RA exhibited higher water absorption, the impact and abrasion values are considerable meeting the required standards for concrete pouring. Consequently, when RA replaces 25% NA in the concrete mix the compressive strength is interchangeable with that of 100% NA, propounding substitution is an approach for reducing debris and preserving natural aggregate. Furthermore, the results recommends that recycled aggregate can be used in other less important structures like pavement, retaining walls, river training works etc.as other ratios (50%, 75% and 100%) also gave the compressive strength near to M15.The main aim of this research is to promote sustainable construction practices, minimize waste materials, and mitigate the environmental impact of the construction industry. The broader implications of this study highlight the possibility of widespread adoption of recycled materials in the construction sector, encouraging innovation and resilience in building practices while addressing the global challenge of resource depletion and environmental degradation.

Keywords: *compressive strength, construction waste management, debris management, natural aggregate concrete, recycled aggregate concrete*

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Introduction

We can notice the way old structures being demolished leave behind piles of concrete debris on construction sites. What if there was a way to transform that debris into something beneficial? Recycled aggregate concrete can help with that.

Concrete is a widely used building material made by mixing cement, water, and aggregate. Among the above mentioned materials, aggregate is most important for concrete which occupies around 60-70% of the overall volume Behera et al. (2014). Aggregate which includes sand, gravel and crush stone plays a pivotal role for the structural strength, durability, and workability of concrete. They provide volume and stability, making it more capable of its load bearing. For the developing countries like Nepal, urbanization growth rate is very high due to industrialization. There are a lot of construction and demolition (C&D) waste as a result of these demolitions and the development of new structures. 40% of the debris generated during demolition is made up of concrete, 30% is ceramix 5% is plastic, 10% is wood, 5% is metal and 10% is miscellaneous combinations (Sonawane & Pimplikar, 2013).

The idea of recycling of waste concrete as recycled concrete aggregate is not a novel concept. The term "recycled aggregate" describes the reusable materials that are left over after building and other structures are demolished, rebuilt, or renovated. The concept of recycled aggregate concrete has emerged as a sustainable alternative to traditional concrete. In place of natural aggregate, RAC uses crushed concrete from demolition sites, which lowers the need for new materials and keeps the construction waste out of landfills (The CivilEngineer.org, 2020) .This method fits with the idea of using resources wisely and reusing materials whenever possible in construction. It's about recycling materials instead of throwing them away, which helps us make the most of what we have and reduces waste. Although RAC has much potential to reduce environmental effects and conserve natural resources, more research and validation are needed to ensure its structural performance and suitability for construction. Different factors including quality of recycled aggregate, the methods used during processing, and the composition of the concrete mix can influence the mechanical strength, durability and long-term behaviors of RAC (MDPI, 2021).

Literature Review

RAC can be extracted from debris which can replace natural concrete aggregate (NAC) to some extent and there has been much research regarding this topic. Nanya et al. (2016), Thomas et al. (2018), Etxeberria et al. (2007), Marthong et al. (2017), and McNeil, Katrina, and Thomas H.-K. Kang (2013**)**, investigated the RA properties in terms of aggregate (water absorption, specific gravity, impact test, and los angeles' abrasion test) and concrete properties (compressive strength test, flexural test, and splitting test) and compared it with NA which showed that when RA replaces up to 30% of NA then there is no significant changes in their properties.

Meanwhile, Xiao et al. (2012) investigated the effects of the adoption of recycled aggregate concrete as a structural material on the carbon footprint of high-rise buildings high-rise buildings. Limbachiya et al. (2000), Thomas, C., et al. (2013) experimented by differentiating w/c ratios, and Singh & Singh (2023) experimented by adding admixture like ureolytic bacteria. Sultana, Afroja, et al. (2023) studied the effect of the strength of multiple recycling on aggregate differentiating into 1st generation, 2nd generation, and 3rd generation aggregates.

Overall, recycled aggregate helps reduce carbon footprint when 1st generation recycled aggregate is used instead of natural aggregate by replacing certain amounts (up to 30%), differentiating w/c ratios, and using different admixtures.

Research Methodology

Study Area

The Chitwan district was the study's primary focus, specifically, attention paid to the locations where a significant amount of demolition waste is generated. The selected sites included Chaubiskoti, Hakimchowk, the bypass area, and Geetanagar. These sites were chosen because they have different levels of urban development, which made a wide variety of demolition for the experiment.

Methodology

After RA was collected from the site location, it was transported to the civil engineering lab of oxford college of Engineering and Management. Then sieve analysis was carried out using a sieve. After the analysis, it was known that the required size of aggregate was not enough for further testing. Then manual hammering was done to get the required size and quantity of aggregate. Finally, the aggregate sample was prepared after washing and sun-drying it properly. Afterwards, different tests like impact test, water absorption test and Los-Angele's test on recycled aggregate were conducted in order to find out different physical properties.

Following that, the process of making concrete cube samples with natural aggregate and then substituting recycled aggregate in varying amounts for the natural aggregate began. Initially, it was planned to create a cube with M20 strength in accordance with the specified code, using a nominal design ratio of 1:1.5:3. Afterwards, different batches with 100% NA and 100% RA, while replacing 25%, 50%, and 75% of RA over NA was created.

Then the different components were mixed with the appropriate proportion of aggregate and sand along with a significant amount of water to create a wet mixture for the sample. After slump test was carried out in order to find out whether it is workable or not which was found.(see Table 3.1)

Table 1: *Slump Test*

Proportion	Slump Value (mm)
100% NAC	75
25% RAC	65
50% RAC	80
75% RAC	85
100% RAC	85

The result presents the slump values (in millimeters) for different proportions of recycled aggregate concrete (RAC) compared to natural aggregate concrete (NAC). It demonstrates that as the proportion of RAC increases, the slump generally increases, indicating that higher amounts of recycled material led to a more fluid concrete mix, influencing its workability. However, the values of our proportion were workable (see Table 1).

After knowing that the mixture was workable, placing of samples in cube molds along with compaction was done to eliminate voids. Then it was kept in cube mold for 24 hours and placed in curing for 28 days.

Then finally the compressive strength test on 7, 14 and 28 days on both natural aggregate concrete and recycled aggregate concrete were carried out. Afterwards relative comparison of them were made to find out whether the RAC could be an alternative for NAC or not.

Results and Discussion

With the concrete aggregate collected from our site, we carried out impact test, water absorption test, Los Angeles test, and compressive strength test in order to find out the characteristics of the concrete aggregate. From the test we conducted, we got the following results.

Impact Test

Impact test evaluates material response to sudden loads. It is used to assess toughness, strength and durability in different industries. According to table 4.1 below, 100% RAC has the highest average impact value (16.61%), whereas 100% NAC has the lowest average impact value (11.90%). It can be observed that with the increase of the proportion of RAC the average impact value is also increasing through which it can be found out that proportion of RAC is directly proportional to average impact value. Since all values are less than 20, and since it is aware that impact values under 20 are very tough, all the proportions can be favorable. However, there is a difference between 100% RAC and 100% NAC of roughly 5%, which is significant. As a result, 25% RAC would be a better option as a replacement for 100% NAC because the difference is minimal (see Table 2).

Table 2: *Average Impact Values for Different Proportions of RAC and NAC*

Percentage (%)	Average Impact value (%)
100% NAC	11.90
25% RAC	12.48
50% RAC	12.98
75% RAC	15.09
100% RAC	16.61

Water Absorption Test

The water absorption test is a procedure used to determine the amount of water that a material can absorb under specified conditions. It is commonly performed on porous materials such as concrete, bricks, tiles and wood. Water absorption of aggregate measures the weather resistance. It is the percentage of water the aggregate absorbs when immersed in water. Table 4.2 demonstrates that the water absorption capacity goes on increasing with the increase in proportion of RAC with NAC in comparison to the sole NAC. With this it is known that the water absorption capacity is directly proportional to the proportion of RAC mixed. From the table the water absorption of NAC, 25%RAC, 50%RAC, 75%RAC and 100%RAC are 2.54, 2.84, 3.34, 4.26, 4.42 respectively. In addition to this data, 25% RAC can be the better option to use in place of NAC as there is a minimal difference in comparison to other proportions (see Figure 1).

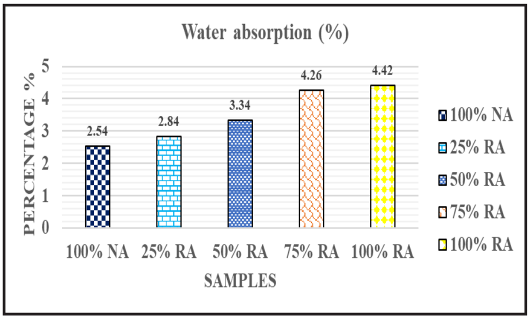

Figure 2: *Bar Chart of Water Absorption Value*

Angele's test

Table 3: *Los Angele's Abrasion Value*

Aggregate replacement in percentage (%)	Los Angele's Abrasion Value (%)
100% NAC	24.42
25% RAC	26.15
50% RAC	26.56
75% RAC	26.82
100% RAC	29.96

Table 3: *Different Water Absorption Values at Different Proportion of RAC*

Sample	100%NAC	25%RAC	50%RAC	75%RAC	100%RAC
W_1	3.765	3.765	3.766	3.821	3.767
W_2	1.706	1.706	1.697	1.742	1.742
W_3	2.049	2.059	2.069	2.079	2.099
W_4	1.998	2.002	2.002	1.994	2.010
Water absorption (%)	2.54	2.84	3.34	4.26	4.42

The Los Angele's abrasion test is a procedure used to determine the resistance of aggregates (such as crushed stone, gravel, etc.) to abrasion and wear. It measures the degradation of the aggregates caused by repeated impacts and abrasion from steel balls within a drum. To the reference of the table 4.3 above, 100% RA had the highest wear value in Los Angeles (29.96%), while 100% NA had the lowest mean impact value (24.42%). It can be observed that as the rate of RA increases, so does the wear value of Los Angele's, which allows us to discover that the ratio of RAC is proportional to the wear value of Los Angele's. Since all values are quite similar and less than 30%, and it is known that Los Angele's abrasion values less than 30 are allowable values for concrete pouring, all the ratios are favorable. However, there is a difference between 100% RAC and 100% NAC which is about 5%, which is very significant. Therefore, RAC 25% would be a better choice to replace 100% NAC because the difference is very small (see Table 3)

Compressive Strength Test

The compressive strength test evaluates a material's ability to withstand compression forces. While commonly used on construction materials like concrete and rock, it can also be applied to other substances. To calculate the compressive strength, there are the following notations (see Table 4).

Table 4: *Composition with their Notation*

Notation	Composition
N	100% Natural Aggregate Concrete (NAC)
R	100% Recycled Aggregate Concrete(RAC)
A	25% Recycled Aggregate Concrete (RAC) + 75% Natural Aggregate Concrete (NAC)
B	50% Recycled Aggregate Concrete (RAC) + 50% Natural Aggregate Concrete (NAC)
C	75% Recycled Aggregate Concrete (RAC) + 25% Natural Aggregate Concrete (NAC)

The average compressive strength (N/mm²) of five samples (N, A, B, C, R) at 7, 14, and 28 days. By seeing Figure 4.4 it can be seen that there is a similar pattern in 7,14 and 28 days. Sample N exhibits the highest strength over time, with values increasing from 15.60 N/mm² at 7 days to 25.63 N/mm² at 28 days, while Sample R has the lowest but still increases steadily. 25% NA replaced RAC has 11.12N/mm² at 7 days to 21.90 N/mm^2 which is quite like natural aggregate concrete and can be considered as a better alternative for NAC (see Table 5).

Table 5: *Average Compressive Strength in Different Days*

Sample	Average Compressive Strength (N/mm²)		
	7 days	*14 days*	*28 days*
N	15.60	17.28	25.63
A	11.12	13.25	21.90
B	10.79	12.87	19.50
C	9.98	12.68	18.37
R	9.43	12.61	18.16

Previous research Nanya, Muddasir, Shah and Prasad (2021); Thomas, Thaickavil, & Wilson (2018); Etxeberria et al. (2007), Marthong et al. (2017), and McNeil, and Kang (2013)) suggests that 30% replacement could be a viable option, which is consistent with the results of our impact test, water absorption test, Los-Angele's abrasion test, and compressive strength test, which show that 25% replacement could be another option.

Conclusion

With the study, It is visible that the behavior of recycled coarse aggregate and natural coarse aggregate is quite similar to each other. In case of water absorption, recycled aggregate exhibits a higher water absorption (4.42%) than natural aggregate (2.54%). It goes same with the impact value of recycled aggregate (16.61%) which is more than that of natural aggregate (11.90%) but impact value of every proportion is less than 20% which is supposed to be very tough. However, the replacement of natural aggregate by 25% recycled aggregate shows the impact value quite near to natural aggregate. Abrasion value is quite similar to impact value, abrasion value of recycled aggregate (24.42) is less than that of natural aggregate (29.96) but every proportion is less than 30% which is supposed to be allowable values for concrete pouring and it also suggests that 25 % proportion is preferable. Finally, the compressive strength also shows the similar pattern and shows that 25% RAC is only near to the desired compressive strength of i.e. M20 which was our goal. Other than that remaining proportions also gave the compressive strength near to M15 which can be used in less important structures like pavement, retaining walls, river training works etc.

From above, it can be concluded that replacement of NAC by 25% RAC seems to be a viable option for the reduction of debris and also the reduction of high use of natural aggregate. The research studied by Thomas et al. (2018) and Etxeberria et al. (2007) aligns with the overall results of our research. Both conclusions suggest that replacing natural aggregate concrete with recycled aggregate concrete at a rate of 25% is a viable option.

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