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COMPARATIVE ANALYSIS OF COMPRESSIVE STRENGTH OF NATURAL AND BRICK AGGREGATE CONCRETE

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ABSTRACT

An experimental study had been conducted to study of substituting natural coarse aggregate with different proportions of crushed brick aggregate impacts the compressive strength of concrete. The study aims to compare the compressive strength of nominal mixed M15, M20 and M25 grade concrete by replacing stone aggregate with crushed bricks aggregate with volumetric replacement (0%,25%,50%,75% and 100%) also find the relation between the results of NDT and destructive test. A total of 45 number of concrete mixes specimens are casted with and without crushed bricks. These specimens were tested at 28 days for compressive strength. In this paper experimental research has been carried out involving both destructive with universal testing machine and non-destructive test with rebound hammer test. The result indicated that using crushed bricks reduces the strength of concrete. The research emphasizes reusing bricks which reduces waste and enhance recourse recycling and conservation.

Key words: *Compressive strength, Brick Aggregate, Natural Aggregate, NDT*

1. Introduction

Concrete is a composite construction material made by mixing cement, fine aggregates (sand), coarse aggregates (gravel or crushed stone), and water, which hardens over time through the process of hydration. Concrete is the backbone of modern construction, valued for its strength, durability, and adaptability However, ensuring its quality and reliability is no simple task. One of the key measures of concrete's performance is its compressive strength, which determines how well it can withstand heavy loads without failing. Traditionally, compressive strength is tested using methods that require breaking concrete samples in a lab. While effective, these methods are not always practical. They can be costly, time-consuming, and, most importantly, cannot be used to test concrete that's already part of a building or structure. This is where Non-Destructive Testing (NDT) comes in. Techniques like the rebound hammer and ultrasonic pulse velocity allow us to assess concrete's strength without damaging it, making them highly useful for real-world applications.

The use of locally available brick aggregate as a partial and full replacement for coarse aggregate in concrete. Their study found that 50% replacement-maintained strength, while 100% with silica fume slightly reduced it (Bangwar et al., 2017). The use of recycled brick aggregate (RBA) as coarse aggregate in concrete, comparing it with virgin brick aggregate. Their study shows that RBA exhibits similar or better performance in terms of absorption and abrasion. Concrete made with RBA at a lower W/C ratio (0.45) achieves comparable or superior compressive strength to virgin aggregate concrete. The research also finds that partial replacement (up to 50%) of virgin aggregate with RBA does not significantly reduce strength, suggesting its viability in concrete production (Mohammed et al., 2015).

Testing five MAS levels, they found compressive and tensile strengths decreased with larger MAS at high cement content, while moderate MAS improved strength at lower content. Young's modulus and ITZ quality were MAS-dependent. Empirical models for stress-strain and strength relationships were proposed, emphasizing MAS's critical role in brick aggregate concrete design(Uddin et al., 2017).The relationship between rebound surface hardness and concrete compressive strength, emphasizing the limitations of simple two-parameter regression models. The model shows that rebound hardness correlates with compressive strength for low-strength concretes and with young's modulus for high-strength concretes, though its application is limited to specific concrete types (Szilágyi et al., 2015).The effect of replacing natural coarse aggregate with crushed brick on concrete properties. They found that increasing brick aggregate content reduced unit weight, compressive strength, tensile strength, and modulus of elasticity. A 100% replacement led to a 33% reduction in compressive strength, while mixed aggregates showed improved performance compared to pure brick aggregate concrete. The study highlights the potential of brick aggregates for low-strength applications but emphasizes the limitations for higher-strength concretes (Rashid et al., 2012)25%, 50%, 75%, and 100%.In investigated how parent concrete properties affect recycled aggregate concrete (RAC). Using three aggregate sizes and strengths, they found RAC has lower compressive, tensile, and flexural strength than parent concrete. RAC required lower water–cement ratios for similar strength. Higher parent concrete strength increased water absorption in recycled aggregates, reducing performance. Their findings highlight the need for size- and strength-specific RAC mix designs (Padmini et al., 2009)each of them made with three maximum sizes of aggregates. The relative physical and mechanical properties of fresh granite aggregate are discussed. Using these nine recycled aggregates, three strengths of recycled aggregate concrete (RAC . When tested using destructive methods, the compressive strength was found to decrease by anywhere from 6% to 41%, depending on the level of compaction. This highlights just how important proper compaction is in ensuring the structural integrity and performance of concrete (Kumavat et al., 2021) . Vyas Municipality, Nepal, researchers aimed to assess the compliance of residential building concrete with the National Building Code (NBC) norms. They employed both non-destructive testing (NDT) using rebound hammers and destructive testing (DT) on concrete samples cured for 7 and 28 days to evaluate their compressive strength. The results revealed a strong correlation between rebound numbers and compressive strength, with correlation coefficients of 89.3% at 7 days and 93.3% at 28 days. These findings suggest that rebound hammer testing can serve as an effective on-site method for estimating concrete strength, facilitating quality control and ensuring compliance with NBC standards in residential construction (Bibek Shrestha and Giri, 2023) The influence of partial substitution of natural fine aggregate with 30% brick dust (BD), stone dust (SD), and recycled fine aggregate (RFA) in both natural aggregate concrete (NAC) and recycled aggregate concrete (RAC) (Structural Concrete). Using M25 grade mixes with 50% recycled coarse aggregate in RAC, the study evaluated strength, density, UPV, water absorption, and acid resistance. Results showed SD yielded maximum strength gains, BD and SD reduced water absorption, while RFA marginally improved strength. However, RAC remained less dense and more vulnerable to durability loss (Chakradhara Rao, 2021).The use of refractory brick aggregate (RBA) as a partial replacement for ordinary crushed stone (OCS) in concrete. With replacement levels of 0–50% and water–binder ratios of 0.52 and 0.49, they assessed workability, compressive strength, stress–time response, and toughness index. Results showed improved workability and cost savings with RBA, while 15% replacement achieved comparable strength and optimal toughness. Higher RBA contents reduced strength, and brittleness remained unchanged under stress–time behavior.(Jureje et al., 2024) The stone and brick aggregate concrete using non-destructive testing (UPV and Schmidt's Rebound Hammer). Using M20–M30 concretes, they observed that strength prediction accuracy declined with higher brick content, while stone aggregate concrete showed stronger correlations. Modulus values converged with age, though brick-rich mixes displayed weaker relations. Workability and prediction accuracy were limited by high water absorption of bricks(Thapa et al., 2021)both methods were applied and correlated with destructive testing of concrete. The focus of the study was on developing the non-destructive testing relationships for concrete made with coarse aggregates consisting of different mixtures of stone and brick aggregates. The correlation between Young's modulus (static, dynamic and shear

2. Materials and Method

The experimental investigation was carried out in the civil laboratory of Itahari Sub Metropolitan City. Forty five concrete specimens are casted with and without using of crushed bricks. Cement, sand and aggregate or (crushed bricks) are mixed in dry state then the required quantity of water (0.5%) is added and mixed throughly. Before casting, machine oil smeared on the inner surfaces of the cast iron mould. Concrete is poured into the mould in three layers and compacted thoroughly using a standard compact metal road diameter 16 mm and 600 mm long. The number of compact beats is 25 times for all cubes for each concrete layers. The top surface is finished by means of a trowel. The specimens are removed from the mould after 24 hours and then cured under water for a period of 28 days. The nominal mix for nominal grade M15 (1:2:4), M20 (1:1.5:3) and M25(1:2:4) concrete at a water to cement ratio of 0.5 was prepared in accordance with Indian standards (IS) for the nominal grades. The samples were made by replacing the coarse aggregates with Crushed bricks aggregates at various replacement ratios, including 0 percent, 25 percent, 50 percent,75 percent and 100 percent in all three classes of concrete. The specimens are taken out from the curing tank just prior to the test.

After curing the 28 days then the destructive and non-destructive test was carried out. The destructed test was conducted by Universal testing machine and non-destructive test was done by rebound hammer test.

Figure 1: Crushed Bricks

Figure 2: Concrete Cube

Figure 3: Universal Testing Machine

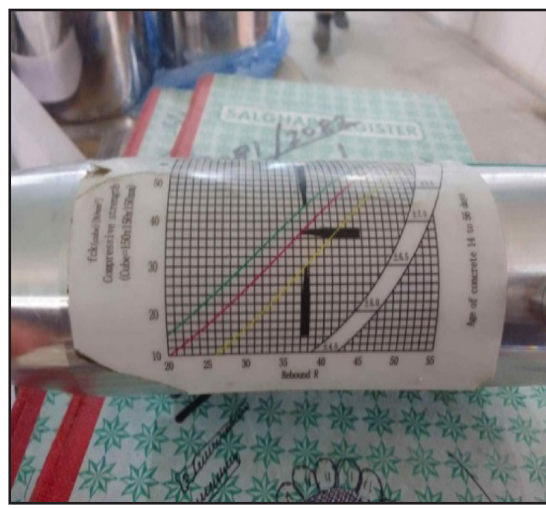

Figure 4: Rebound Hammer

3. Results and Discussions

The experimental results obtained are shown in table. The average value of result obtained of three samples in each sample type was considered. A set of three cubes were prepared for every replacement proportion and design strength. After 28 days of curing in a water curing tank, the samples were taken out and dried to remove moisture. Then, firstly the cubes were weighted and tested with rebound hammer to obtain rebound number, followed by destructive testing to get maximum compressive load. The data collection along with some computations is shown in tables 1, 2, 3 for M15, M20 and M25 grade respectively. The steps involved in computations are described below.

Table1 : Rebound number and compressive load values for M15 concrete with various replacement proportion

S.N	% repl.	Wt. (kg)	Rebound number	Avg. rebound No.	Mean of avg. rebound number	Max comp. load KN	Estimated Comp. strength by NDT N/mm²	Comp strength by DT N/mm²	Avg. estimate comp strength by NDT N/mm²	Avg. comp. strength by DT N/mm²
S1	0%	8.73	30, 34, 26, 20, 26, 26, 28, 27, 27, 26	27	27.7	520	20	23.11	21.67	22.37
S2		8.62	28, 30, 32, 34, 34, 32, 32, 30, 31, 32	31.5		600	28	26.67		
S3		8.62	26, 30, 20, 22, 24, 26, 25, 24, 24, 25	24.6		390	17	17.33		
S1	25%	8.36	24, 26, 22, 24, 22, 25, 24, 22, 26, 24	23.9	20.77	400	15	17.78	11.67	17.78
S2		8.34	15, 16, 20, 15, 26, 16, 18, 26, 20, 22	19.4		350	10	15.56		
S3		8.4	18, 16, 17, 20, 16, 16, 17, 20, 22, 28	19		450	10	20		
S1	50%	8.13	16, 22, 22, 28, 27, 20, 28, 18, 22, 22	22.5	22.33	350	13	15.56	12.67	16.15
S2		8.56	21, 18, 27, 22, 29, 22, 20, 19, 20, 21	21.9		380	12	16.89		
S3		8.13	28, 22, 26, 18, 21, 22, 19, 22, 22, 26	22.6		360	13	16		
S1	75%	7.86	26, 16, 26, 21, 16, 20, 23, 16, 20, 19	20.3	20.1	300	10	13.33	10.33	13.63
S2		7.9	19, 23, 23, 23, 20, 20, 22, 14, 22, 23	20.9		360	11	16		
S3		8.01	20, 20, 18, 18, 22, 16, 20, 21, 18, 18	19.1		260	10	11.56		
S1	100%	7.76	19, 17, 24, 20, 18, 22, 25, 18, 25, 19	20.7	20.9	300	10	13.33	10.67	13.18
S2		7.62	20, 24, 18, 22, 22, 24, 24, 20, 20, 20	21.4		290	11	12.89		
S3		7.75	16, 22, 24, 18, 26, 19, 20, 22, 24, 15	20.6		300	11	13.33		

Table 2 Rebound number and compressive load values for M20 concrete with various replacement proportion

S.N	% repl.	Wt. (kg)	Rebound number	Avg. rebound No.	Mean of avg. rebound number	Max comp load KN	Estimated Comp. strength by NDT N/mm²	Comp strength by DT N/mm²	Avg. estimate comp. strength by NDT N/mm²	Avg. comp. strength by DT N/mm²
S1	0%	8.49	22, 24, 24, 26, 28, 26, 30, 28, 26, 27	26.1	25.2	490	19	21.78	17.67	20.89
S2		8.42	22, 20, 26, 28, 24, 28, 26, 26, 24, 26	25		470	17	20.89		
C3		8.1	28, 24, 26, 22, 24, 24, 26, 22, 24, 25	24.5		450	17	20		
S1	25%	8.59	25, 25, 27, 25, 28, 24, 24, 26, 24, 26	25.4	25.13	410	18	18.22	17	19.56
S2		8.77	22, 21, 20, 26, 32, 27, 26, 24, 27, 22	24.7		470	16	20.89		
S3		8.86	30, 24, 22, 24, 24, 22, 30, 30, 22, 25	25.3		440	17	19.56		
S1	50%	7.92	26, 27, 26, 24, 20, 19, 25, 16, 20, 20	22.3	22.33	400	13	17.78	13	17.48
S2		8	25, 26, 22, 26, 20, 25, 19, 17, 21, 22	22.3		380	13	16.89		
S3		8.02	24, 27, 28, 24, 19, 18, 21, 27, 20, 16	22.4		400	13	17.78		
S1	75%	7.83	24, 25, 24, 26, 18, 22, 24, 16, 20, 24	22.3	22.47	300	13	13.33	13.33	15.26
S2		7.75	20, 24, 24, 26, 24, 26, 20, 21, 25, 21	23.1		380	14	16.89		
S3		7.96	24, 25, 22, 18, 16, 24, 29, 24, 16, 22	22		350	13	15.56		
S1	100%	7.59	24, 22, 18, 25, 24, 17, 23, 18, 23, 19	21.3	21.27	340	11	15.11	11.33	13.78
S2		7.48	23, 22, 25, 26, 18, 18, 22, 20, 19, 22	21.5		280	12	12.44		
S3		7.58	26, 15, 22, 16, 20, 22, 26, 22, 20, 21	21		310	11	13.78		

Table 3: Rebound number and compressive load values for M25 concrete with various replacement proportion

S.N	% repl.	Wt. (kg)	Rebound number	Avg. rebound No.	Mean of avg. rebound number	max comp load KN	estimated Comp. strength by NDT N/mm²	Comp strength by DT N/mm²	Avg. estimate comp strength by NDT N/mm²	Avg. comp. strength by DT N/mm²
S1	0%	8.79	24, 28, 28, 28, 30, 32, 30, 32, 28, 31	29.1	29.2	580	23	25.78	23.33	25.19
S2		9.12	30, 28, 32, 32, 30, 28, 30, 30, 32, 28	30		570	25	25.33		
S3		8.82	30, 26, 24, 28, 30, 32, 30, 28, 28, 29	28.5		550	22	24.44		
S1	25%	8.32	22, 24, 30, 28, 30, 28, 28, 28, 25, 29	27.2	26.17	500	20	22.22	18.67	22.96
S2		8.43	20, 26, 22, 24, 26, 24, 25, 26, 22, 26	24.1		550	16	24.44		
S3		8.58	24, 30, 29, 26, 30, 24, 26, 26, 30, 27	27.2		500	20	22.22		
S1	50%	7.93	24, 28, 26, 28, 22, 27, 24, 30, 24, 28	26.1	25.63	450	19	20	18	22.37
S2		7.67	20, 20, 31, 26, 28, 22, 26, 28, 24, 27	25.2		560	17	24.89		
S3		8.03	22, 29, 26, 20, 32, 24, 27, 26, 28, 22	25.6		500	18	22.22		
S1	75%	7.96	22, 26, 24, 24, 27, 25, 21, 20, 23, 25	23.7	24.2	400	15	17.78	15.67	18.07
S2		8.02	21, 26, 28, 20, 22, 26, 28, 26, 22, 26	24.5		430	16	19.11		
S3		7.86	24, 26, 24, 22, 26, 22, 24, 26, 24, 26	24.40		390	16	17.33		
S1	100%	8.00	20, 22, 24, 20, 18, 22, 24, 23, 20, 23	21.60	21.20	340	12	15.11	11.33	15.41
S2		7.67	18, 19, 22, 22, 24, 21, 24, 23, 19, 24	21.60		360	12	16.00		
S3		7.88	17, 18, 22, 21, 24, 20, 20, 21, 19, 22	20.40		340	10	15.11		

Effect of substitution of natural aggregates on compressive strength

In this study, various levels of substitutions of natural aggregates by brick aggregates was made for M15, M20 and M25 grade of concrete. All tables and charts expresses the compressive strength in terms of N/mm².

The Figure 5 (graph) shows that for M15 grade of concrete, the compressive strength of concrete decreases by 20.52%, 27.81%, 39.07% and 41.06% for 25%, 50%, 75% and 100% respectively. SimilarlyM20 grade of concrete, the compressive strength decreases by 6.38%, 16.31%, 26.95% and 34.04% for 25%, 50%, 75% and 100% replacement of natural stone aggregates by brick aggregates respectively. Finally, for M25 grade of concrete, the compressive strength of concrete decreases by 8.82%, 11.17%, 28.23%, and 38.82% for 25%, 50%, 75% and 100% replacement respectively. To sum up, the results show lesser reduction in compressive strength with lower replacement proportions but exhibit higher decrease in compressive strength with higher replacement proportions.

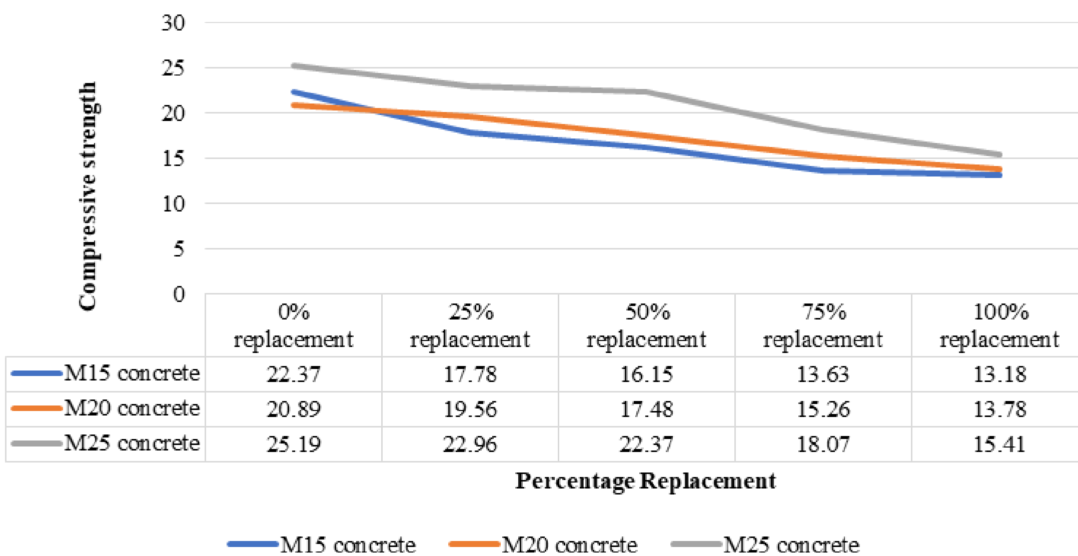

Figure 5: Graph showing percentage replacement vs compressive strength

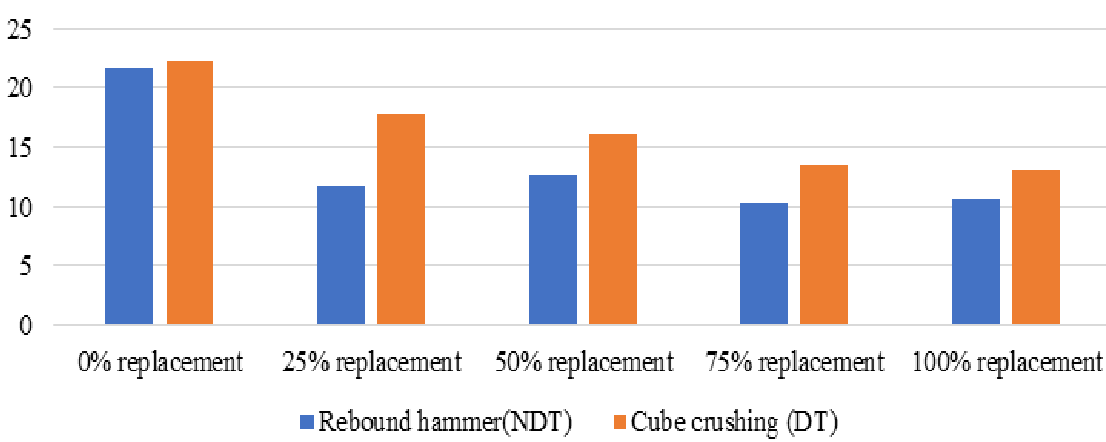

Figure 6 : Compressive strength results for M15 concrete with various replacement percentages

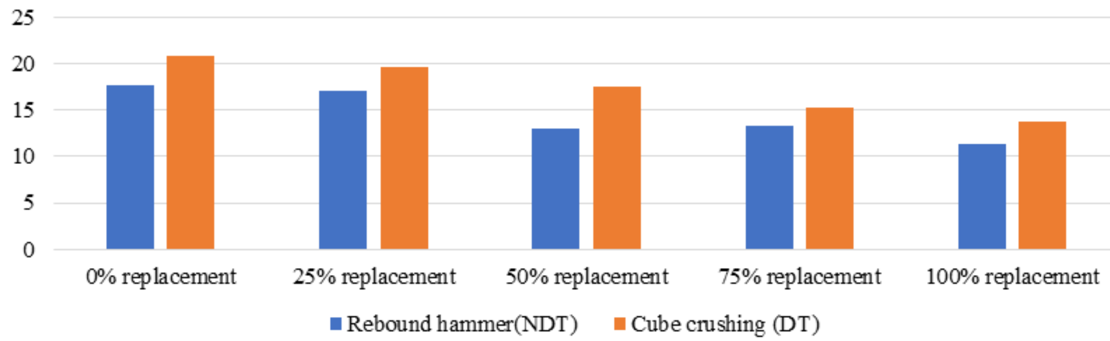

Figure 7 :Compressive strength results for M20 concrete with various replacement percentages

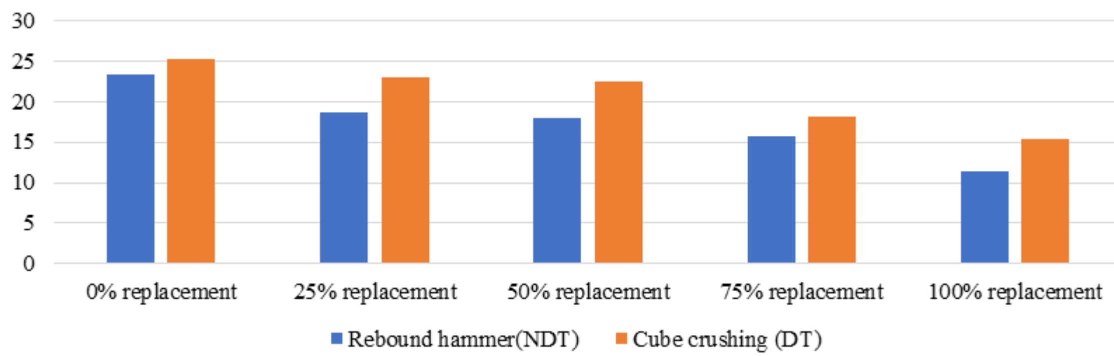

Figure 8 :Compressive strength results for M25 concrete with various replacement percentages

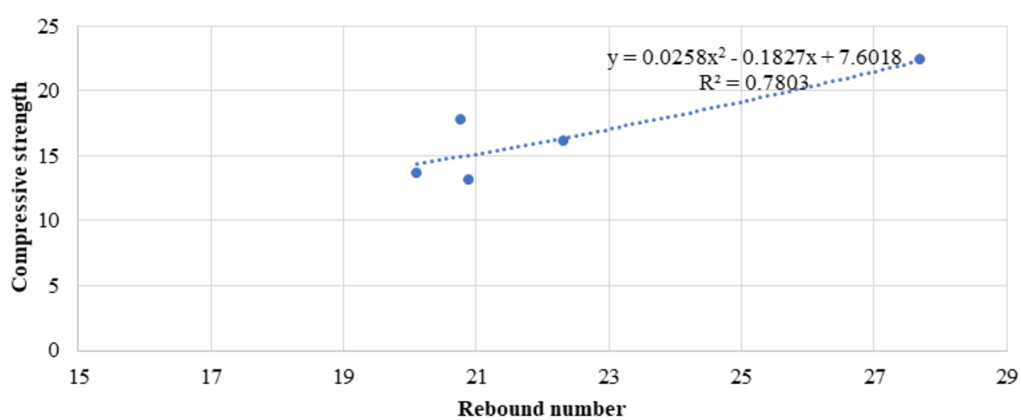

Figure 9: Rebound number vs compressive strength for M15 concrete

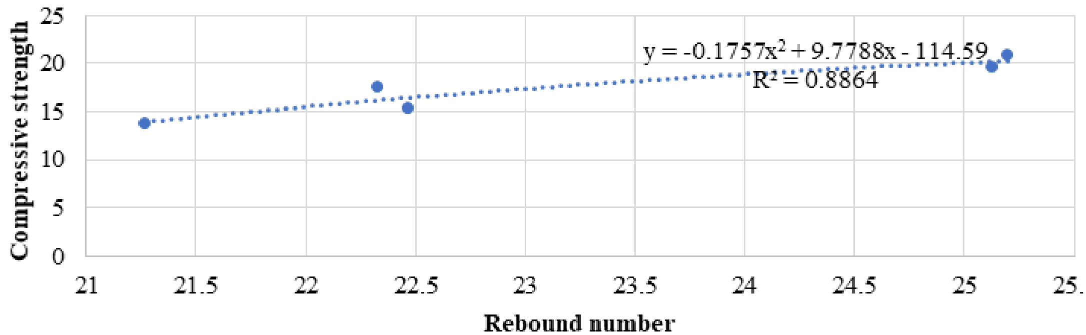

Figure 10 :Rebound number vs compressive strength for M20 concrete

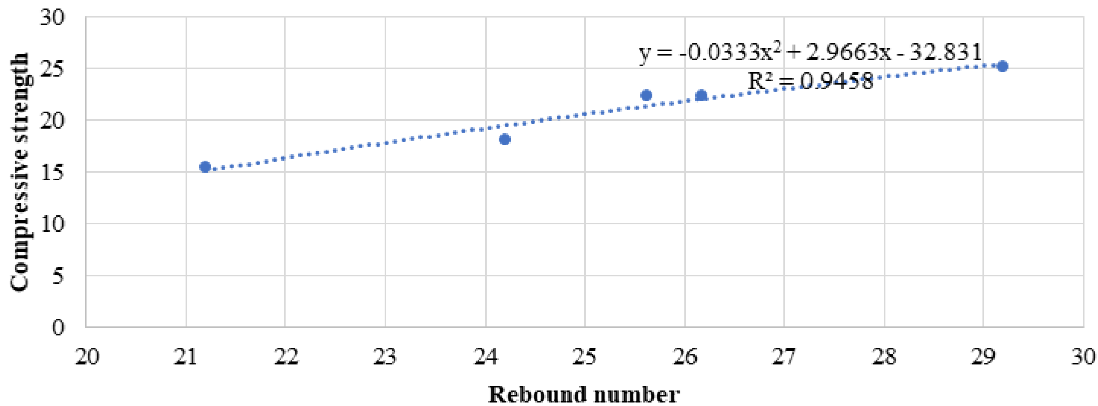

Figure 11: Rebound number vs compressive strength for M25 concrete

A scatter plot is a graphical representation where points are plotted in a two dimension. The points obtained from data collection are plotted on x-axis and y-axis respectively. Here, rebound number is plotted on x-axis (as independent variable) and compressive strength for cube crushing (DT) is plotted on y-axis (as dependent variable).

A trend line also called as best fit line is drawn to establish the relationship between the two variables. If the tread line moves upward (from left to right), it indicates positive correlation meaning as the value of rebound number increases, compressive strength compressive strength also increases and vice-versa.

Similarly, a correlation coefficient can also be calculated to the strength of relationship between rebound number and compressive strength. Values closer to one indicates strong positive correlation between the variables and closer to zero indicates the data aren't closely associated with one another.

Table 4 : Summary

Grade of concrete	Best fit model	R^2
M15	Compressive strength = 0.0258(Rebound number)^2 -0.1827(Rebound number) + 7.6018	0.78
M20	Compressive strength = -0.1757(Rebound number)^2 +9.7788(Rebound number) - 114.59	0.88
M25	Compressive strength = -0.0333(Rebound number)^2 +2.9663(Rebound number) - 32.831	0.94

4. Conclusions

With lower replacement proportions, the compressive strength of brick aggregate concrete reduced slightly. As the percentage of brick aggregate increased, the compressive strength decreased, with 100% replacement, the compressive strength decreased by 34-39%, which suggests that brick aggregates don't have the same mechanical properties as traditional aggregates. That said, there are still opportunities for using brick aggregates in non-structural applications where strength isn't the primary concern. When it comes to rebound hammer tests for non-destructive testing for brick aggregate concrete, the results for estimated compressive strength obtained from rebound number and that of obtained from crushing of concrete varied significantly. However, they showed a reasonable link with compressive strength, which means they can be a helpful tool for inspecting concrete but new relationships have to be derived to enhance the accuracy of these tests for brick aggregate concrete. The model showed a polynomial relationships between rebound number and compressive strength for M15, M20 and power relationship for M25 concrete and the calculated coefficient of determination (R2) for developing a new predictive model for estimation of compressive strength of M15 brick aggregate concrete was 0.71, for M20 was 0.76 and for M25 brick aggregate concrete was 0.74 which are high, thus establishing precisions in predicting compressive strength.

5. Conflict of Interest

The authors have declared that there are no conflicts of interest regarding the publication of this research work. The study was conducted independently, and no financial or personal relationships influenced the collection, analysis, or interpretation of the data.

6. Acknowledgements

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