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Comparative Analysis of the Strength of Concrete made from various Coarse Aggregates

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Abstract

Concrete is a fundamental construction material whose performance is significantly influenced by the properties of its coarse aggregates. This study aimed to evaluate and compare the effect of different coarse aggregates granite, dolomite, marble, limestone, and Recycled Concrete Aggregate (RCA) on the mechanical and fresh properties of concrete. A comprehensive experimental investigation was conducted, including tests for aggregate properties (sieve analysis, specific gravity, water absorption, bulk density, crushing value, moisture content, and impact value) and concrete performance (slump, compacting factor, compressive strength, density, modulus of elasticity and abrasion resistance). Specific gravity ranged from2.39 to 2.77, while water absorption varied from 0.43% to 1.86%, aggregate crushing value ranged from 16.09% to 34.01%, and aggregate impact value ranged from 7.43% to 39.48%. The 28 day compressive strength ranged from 26.8 Mpa to 42.5 Mpa. An internal correlation was done to examine the relationship between aggregate properties and 28 day compressive strength. The study concludes that granite is the most suitable aggregate for high-strength structural concrete, while RCA offers a viable eco-friendly option for medium-strength applications. Proper aggregate selection is crucial for optimizing concrete performance, cost, and sustainability in construction.

Keywords: Coarse aggregates; concrete strength; compressive strength; aggregate properties; concrete performance; correlation

Introduction

Coarse aggregates are one of the primary elements of concrete and construction materials. They are materials that are retained on a 4.75 mm sieve and generally range in size from 5 mm to 150 mm (Neville, 2011). Their main role is to give strength, stability, and volume to concrete and asphalt mixes. Together with fine aggregates (like sand), cement, and water, coarse aggregates play a very crucial role in the structural integrity of construction materials (Neville, 2011).The characteristics of coarse aggregates directly affect the durability, workability, and load-bearing capacity of concrete (Mehta and Monteiro, 2014). The mechanical properties of concrete are strongly affected by aggregate shape and surface texture, which influence bond strength (Butler *et al*., 2014).

Hamid and Abas (2015) examined the handling of four types of aggregate for concrete work. Some laboratory tests were conducted in this study for the objective of understanding the difference between the uses of several sizes aggregate in the concrete mix design.

Various works have been done on the effect of coarse aggregate on concrete. They mainly focus on individual aggregates or little comparison of two or three coarse aggregates at a time. There is minimal comparative study on Granite, Limestone, Dolomite, Marble and Recycled concrete aggregate focusing on the same mix designs, curing methods and test procedure. Therefore, there is an unclear direct performance ranking based on strength concerning these aggregates.

This study therefore intends to determine the physical properties of coarse aggregates (granite, dolomite, marble, limestone, recycled concrete aggregates), develop an appropriate mix design for each of these coarse aggregates, estimating the consistency (slump and compacting factor test) for the fresh concrete mix and determine the hardened concrete performance test (compressive strength test, density, modulus of elasticity and abrasion test) for each concrete. In addition, the study proceeds with carrying out a trend line analysis evaluating the properties of the coarse aggregates influence on strength of the concrete.

Materials and Methods

This study employed an experimental research design to investigate the influence of five coarse aggregate types granite, marble, dolomite, limestone, and recycled concrete aggregate (RCA) on the strength and properties of concrete. The methodology followed a systematic approach, beginning with the characterization of aggregates, followed by concrete mixing, curing, and testing of both fresh and hardened properties. All tests were conducted in accordance with recognized international standards to ensure reliability and reproducibility. The materials used in this study included Ordinary Portland cement (ASTM Type 1), natural fine aggregate (River sand), and five coarse aggregates sourced locally (granite, marble, dolomite, limestone, and recycled concrete aggregate). Water and a superplasticizer were used in all concrete mixes to maintain consistency and workability. The use of superplasticizers in concrete mixes containing recycled aggregates is essential for maintaining adequate slump retention without compromising the water-cement ratio (Revilla-Cuesta *et a*l., 2022).

Prior to concrete production, each coarse aggregate underwent a series of physical and mechanical tests. Sieve analysis (ASTM C136) was conducted to determine particle size distribution. Specific gravity and water absorption were measured using AASHTO T 85, while bulk density was assessed following ASTMC29. The mechanical integrity of aggregates was evaluated through the Aggregate Crushing Value (ACV) test (BS 812-110), moisture content analysis (ASTM C566), and the Aggregate Impact Value (AIV) test (BS 812-112). These tests provided essential data on aggregate quality and suitability for concrete production. The selection of suitable aggregates is fundamental to producing concrete that meets requirements for workability, strength, and durability, as aggregates occupy 60% to 80% of the concrete volume and significantly influence nearly all concrete properties (Kosmatka & Kerkhoff, 2021).

Concrete mix designs were developed targeting a characteristic strength of 40 MPa (M40 grade), in accordance with IS 10262:2019. A total of five mixes were prepared one for each aggregate type with consistent water-cement and aggregate-cement ratios. For each mix, twelve 150 mm cubes were cast and cured in water for 3, 7, and 28 days. Workability of fresh concrete was assessed using the slump test (ASTMC143) and the compacting factor test (BS EN 12350-4). Hardened concrete tests included compressive strength evaluation at 3, 7, and 28 days (BS EN 12390-3), density measurement (BS EN 12390-7), abrasion resistance testing (BS 812- 113), and determination of the modulus of elasticity (BS EN 12390-13). All specimens were tested in a controlled laboratory environment, and mean values from triplicate samples were used for analysis. An internal correlation using observed trends and relevant literature was done to identify correlations between individual aggregate properties and concrete 28 day strength. Ethical considerations were upheld throughout the study, including adherence to safety protocols, environmental responsibility in waste disposal, and transparent reporting of all results without manipulation.

Results and Discussion

This section shows the data collected and analyze the results gotten from tests performed to answer research questions. The results were organized to show adequate understanding of the research outcomes.

Results of individual tests on aggregates

Specific gravity

Figure 1 shows that Dolomite (2.75) is the densest while Recycled concrete aggregate is the lowest in specific gravity and most porous/lightweight. Typical values for specific gravity for natural aggregates is 2.6 – 2.9 (ASTM C127). Lower values often mean light weight while higher value means dense and heavy aggregates. For concrete this means Granite (2.62) falls within normal range which means it will produce a normal weight concrete (2400 to 2500 kg/m^3). Concrete will have adequate compressive strength and durability making granite ideal for structural concrete. Marble (2.72) is higher than average which means concrete may achieve higher compressive strength but structural members will be heavier which increases dead load in design. Dolomite (2.77) means heavier than normal concrete being the highest. Limestone (2.54) will produce lighter than normal concrete, will be more porous which increases water absorption and may reduce strength which means weak concrete. Recycled concrete aggregate (2.39) will produce light weight concrete, it indicates porosity and higher water absorption which affects workability and reduces density, Concrete will be lighter (good for reducing dead load) but it will require strict water control (ASTMC127-24).

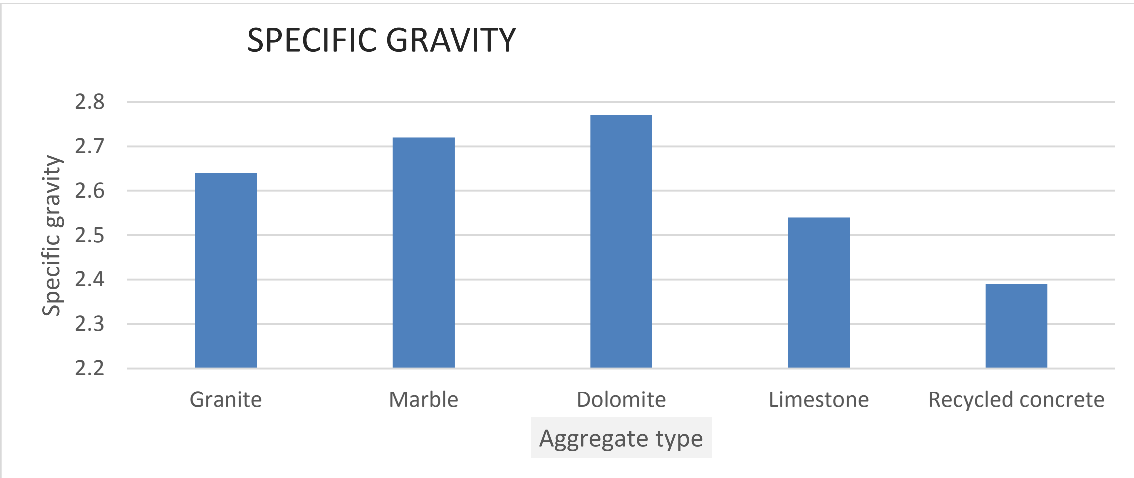

Figure 1: Specific gravity
Source: Author's research

Sieve Analysis
Figure 2 shows that granite and marble aggregates are well-graded with low fines content (≤0.44% passing 4.75 mm), contributing to good interlocking, reduced voids, and higher compressive strength (Neville, 2011). Limestone and dolomite have slightly more fine particles and less uniform gradation, which can increase water demand and reduce strength due to higher porosity (Mindess *et al*., 2013). Recycled concrete aggregate (RCA**)** has an irregular grading, with 0% retained on the 25 mm sieve and more material in finer sieves, affecting workability (Kou and Poon, 2012). Overall, well-graded aggregates like granite enhance concrete performance, while more variable or finer gradations may compromise quality unless adjustments are made in the mix design (Mehta and Monteiro, 2014).

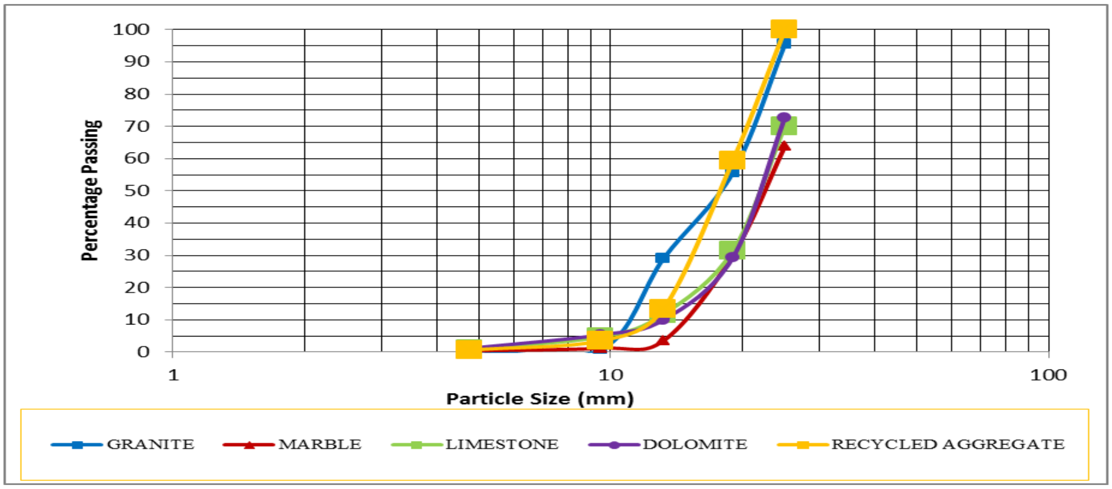

Figure 2: Sieve analysis
Source: Author's research

Water Absorption Test

Marble (0.43%) is very dense and non-porous. Minimal water is absorbed and means less cement paste is wasted filling pores (Figure 3). Limestone (1.86%) is the highest in water absorption test which means it will absorb a lot of mixing water and reduce the effective water available for cement hydration. The aggregates with low absorption mean they need extra water or pre-soak aggregates and demand careful adjustment to avoid poor workability, aggregates with high absorption (limestone, recycled concrete aggregate) means they need extra water or pre-soak aggregates and demand careful adjustment to avoid poor workability (ASTMC127-24).

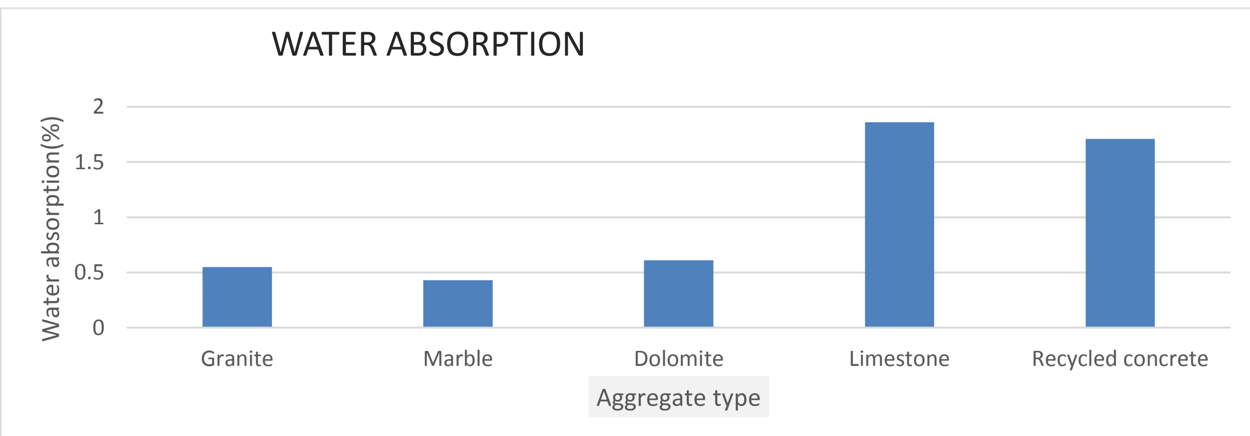

Figure 3: Water absorption
Source: Author's research

Bulk Density Test

Figure 4 shows that marble is the highest in bulk density test meaning that it has the best packing ability, fewer air gaps between particles which means less cement paste needed to fill the gaps while the lowest in bulk density test is limestone has the weakest packing meaning more air gaps between particles and it needs more cement paste to achieve workability (ASTMC29/C29M-17a: 2017).

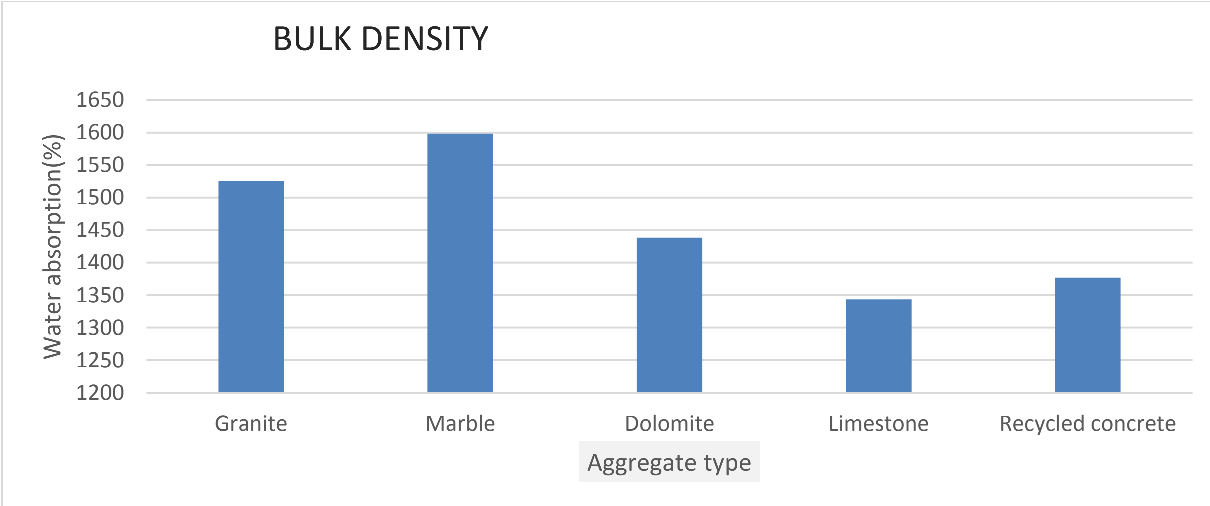

Figure 4: Bulk density
Source: Author's research

Aggregate Crushing Value
Recycled concrete aggregates has the lowest ACV (16.09%), it is the strongest against crushing while Dolomite has the highest ACV (34.01%) which makes it the weakest as shown in Figure 5. Aggregates with lower ACV are expected to produce concrete with better load bearing and compressive performance (BS EN 1097-2:2020). Recent studies confirm a strong inverse correlation between aggregate crushing value (ACV) and concrete compressive strength, emphasizing that aggregates with ACV below 25% are preferable for structural concrete applications (Kumar &Sharma, 2021).

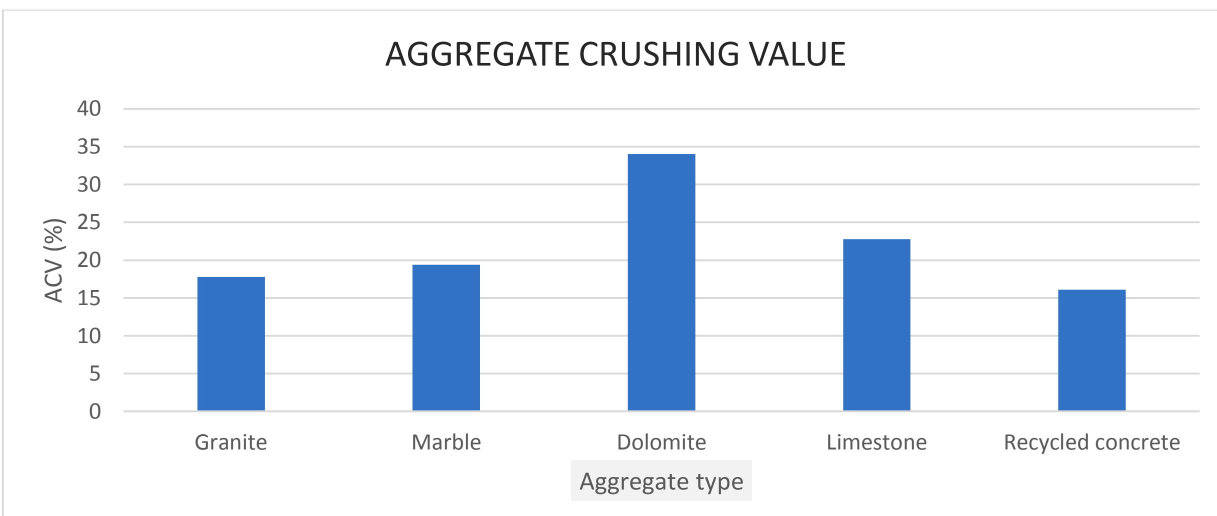

Figure 5: Aggregate crushing value%
Source: Author's research

Moisture Content test
Recycled concrete aggregate has the highest moisture content at 3.58% which retained more water while marble has no moisture as presented in Figure 6. Low moisture content like in marble, granite and dolomite

makes it aggregate predictable and easy to use in concrete. High moisture content like recycled concrete aggregate requires careful calculation and adjustment of the mix water to prevent serious detrimental effects on the concrete`s strength, durability and integrity (ASTMC566-19).

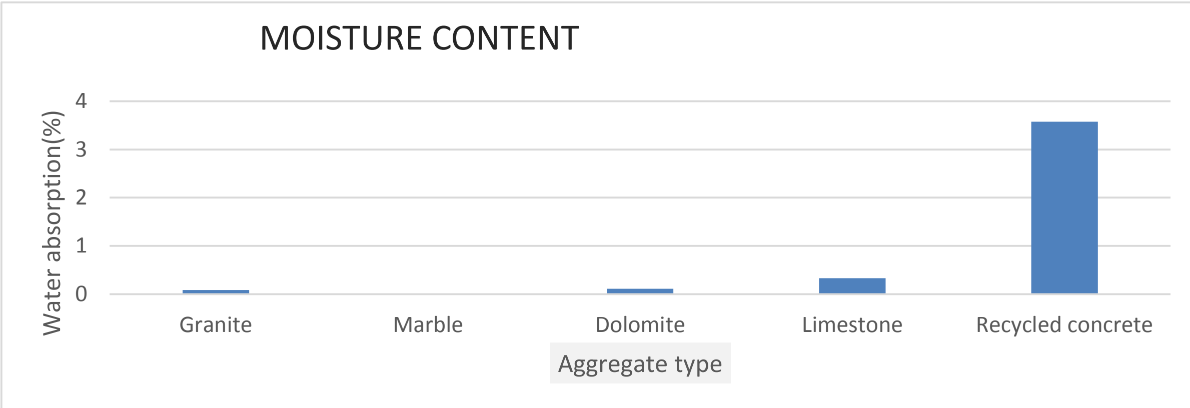

Figure 6: Moisture content
Source: Author’s research

Aggregate Impact Value
Figure 7 show that Granite (AIV 7.43%) is the strongest against impact amongst the five which is excellent for high strength and heavy load concrete, followed by Recycled concrete aggregate (AIV 9.95%) which suggest the parent concrete was of good quality and will be good for structural applications while Dolomite (AIV 39.48%) is the weakest and fails under shock loads, it is unsuitable for structural applications. Lower AIV (%) means tougher aggregate (less likely to shatter under impact) while higher AIV (%) means weaker aggregate (more likely to break under sudden loading) (BS EN 1097-2:2020).

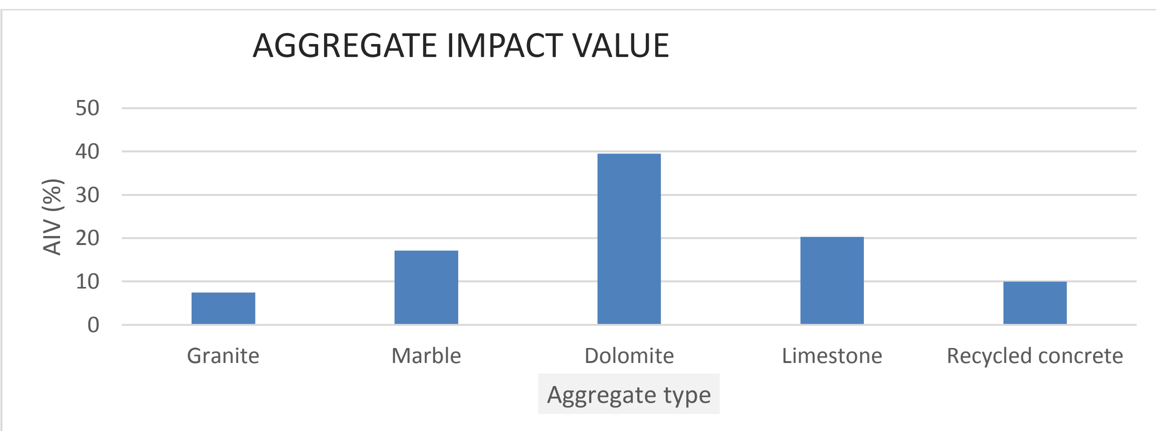

Figure 7: Aggregate impact value
Source: Author’s research

Results of tests on fresh concrete
Slump Test
Figure 8 show that all mixes fall within (50-100 mm) which is suitable for a grade 40 Mpa (BS EN 206:2013). The slump variation reflects the shape, texture, and absorption of each concrete. All the mixes exhibit sufficient workability for proper compaction ensuring uniform placement without significant risk of segregation or bleeding.

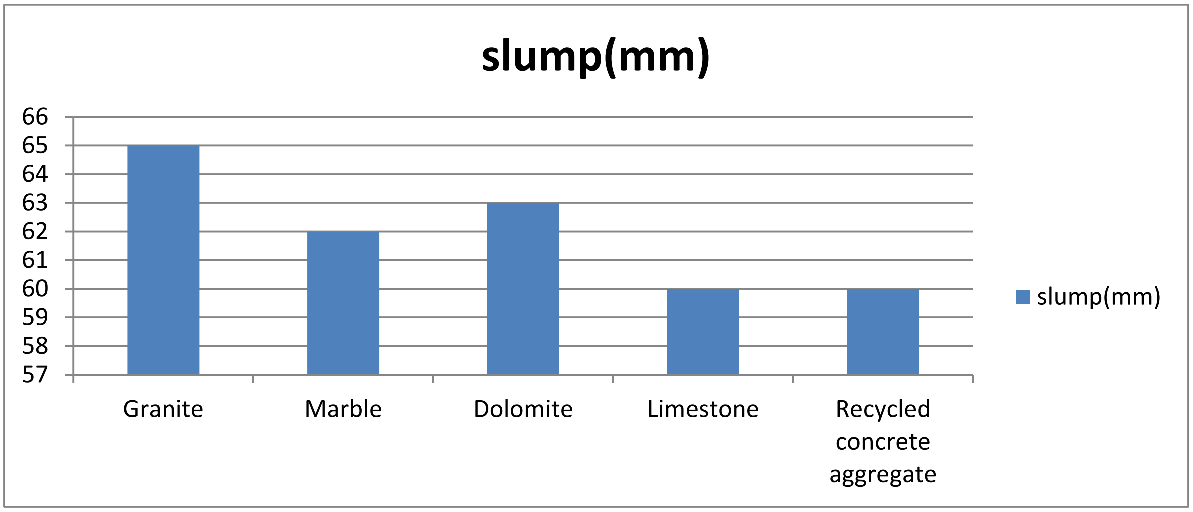

Figure 8: Slump
Source: Author's research

Compacting factor test

The workability of the concrete mixes was assessed using the compacting factor test in accordance with BS EN 12350-4:2019. Figure 9 shows the compacting factors ranging from 0.8416 to 0.9630. Granite exhibited the highest compacting factor (0.9630), indicating very high workability, while recycled concrete aggregate (RCA) had the lowest (0.8416), reflecting slightly lower workability. Marble, limestone, and dolomite produced compacting factors within the medium workability range (0.85–0.92), suitable for normal reinforced concrete placement (BS EN 12350-4:2019). The results validate the theoretical relationship between two tests. Higher slump corresponds to a higher compacting factor. Both tests consistently identified Granite as the most workable mix and recycled concrete aggregate as the least workable.

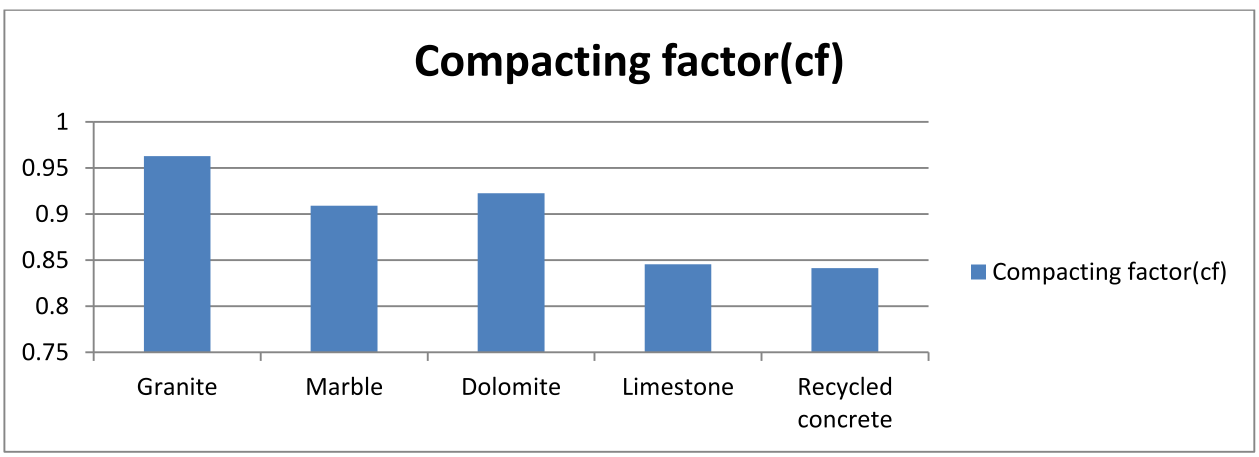

Figure 9: Compacting factor
Source: Author's research

Mix Design

Table 1: Test Result for Mix Design

Variation	Water Content	Cement Content	Fine Aggregate	Coarse Aggregate 10mm	Coarse Aggregate 20mm	Total Coarse Aggregate	Super plasticizer

	(kg/m³)	(kg/m³)	(kg/m³)	(kg/m³)	(kg/m³)	(kg/m³)	(kg/m³)
Mix1 Granite	225	625	588	294	588	882	3.125
Mix2 Marble	225	625	612	306	612	918	3.125
Mix3 Dolomite	225	625	612	306	612	918	3.125
Mix4 Limestone	225	625	588	294	588	882	3.125
Mix5 Recycled Concrete aggregate	225	625	560	280	560	840	3.125

Source: Author's research

Results of tests on hardened concrete

Compressive strength test

Figure 10 illustrate that among the coarse aggregates used, concrete made with granite recorded the highest strength at all ages (24.6 MPa at 3 days, 32.3 MPa at 7 days, and 42.5 MPa at 28 days). This superior performance is attributed to the hard, dense, and angular nature of granite, which enhances the bond between the aggregate and cement paste (Shetty, 2019). Marble aggregate produced the next highest 28-day strength of 35.7 MPa, followed by recycled concrete aggregate (RCA) with 32.4 MPa (Figure 10). In addition, the recycled concrete aggregate performed better than dolomite (28.0 MPa) and limestone (26.8 MPa), which suggests that the parent concrete from which the RCA was obtained had a relatively high original strength and a rough surface texture that improved mechanical interlock and bond with new paste (Padmini *et al*., 2009). The performance of recycled aggregate concrete depends largely on the quality and composition of the adhered mortar present on the recycled particles (Silva *et al*., 2014). This finding supports the growing body of research indicating that properly processed RCA can yield comparable or even superior strength to some natural aggregates, especially when used in well-designed mixes (Kou & Poon, 2012).

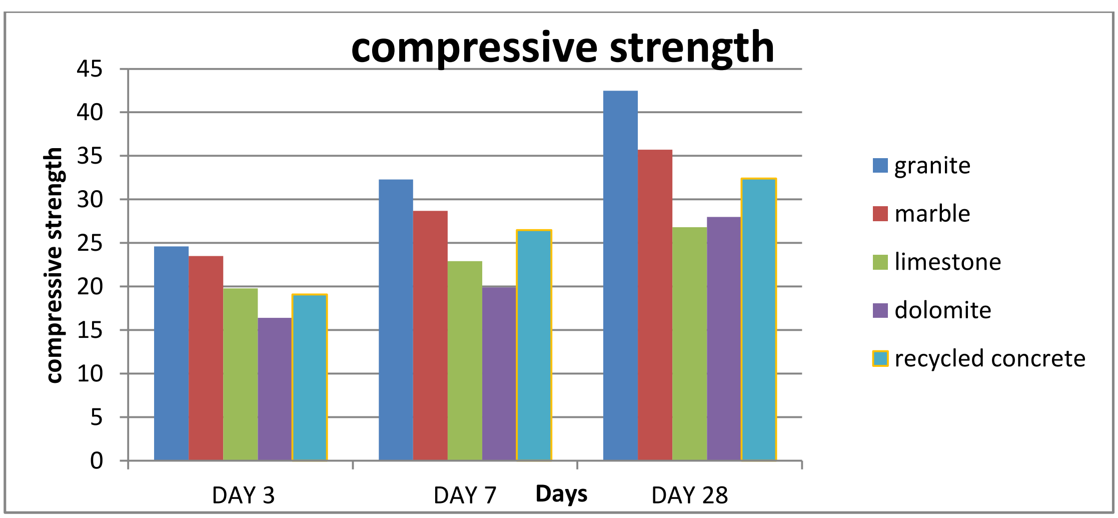

Figure 10: Compressive strength

Source: Author’s research

Density

The density of concrete is the mass per unit volume and serves as an important indicator of its quality and compactness. Marble has the highest density value while recycled concrete aggregates has the lowest which means marble is tightly packed while recycled concrete aggregates is porous in nature because it has used and broken materials (Figure 11). High-density concrete generally has fewer voids, resulting in higher strength, lower permeability, and better durability against water and chemical attack. (ASTM C642: 2021).

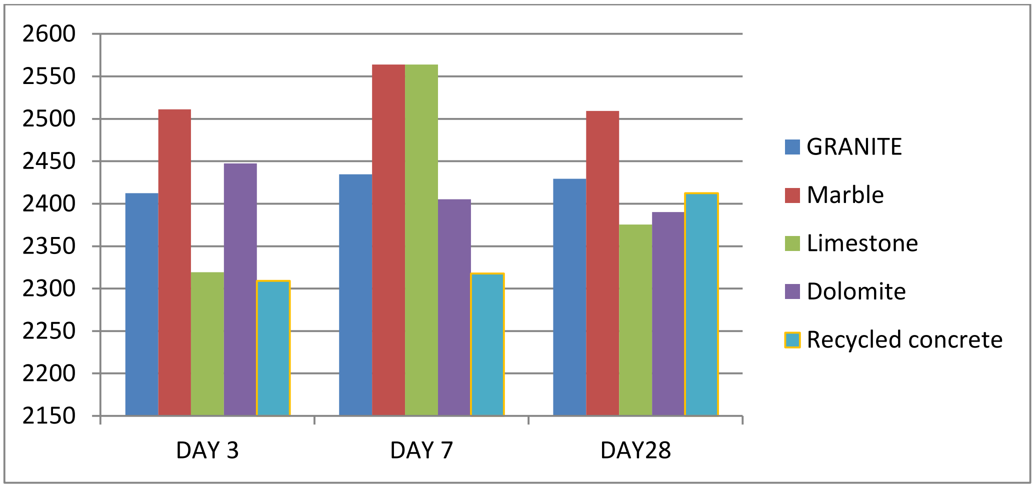

Figure 11: Density

Abrasion test

Figure 12 illustrate the abrasion loss (%) of 28-day cured 150×150 mm concrete cubes made with five different aggregates. Granite concrete exhibited the lowest abrasion loss (2.35%), indicating it has the hardest surface and highest resistance to wear, suitable for heavy-duty applications such as industrial floors and pavements (BS 812-112, 1990). Dolomite concrete had a slightly higher abrasion loss (2.64%) but still performed better than limestone, reflecting its slightly harder nature compared to limestone (BS 812-112, 1990). Limestone concrete showed higher abrasion loss (3.34%) due to the softer aggregate, making it more prone to surface wear under mechanical action (Gambhir, 2025). The use of limestone as coarse aggregate in high-strength concrete is limited by its relatively low resistance to mechanical abrasion and higher porosity compared to igneous rock aggregates (Sahoo *et al.*, 2022). Marble concrete had an abrasion loss of 2.36%, slightly higher than granite, while recycled concrete aggregates exhibited the highest abrasion loss (3.86%), likely due to the lower quality or heterogeneous nature of the old concrete aggregates (Li *et al.*, 2023).

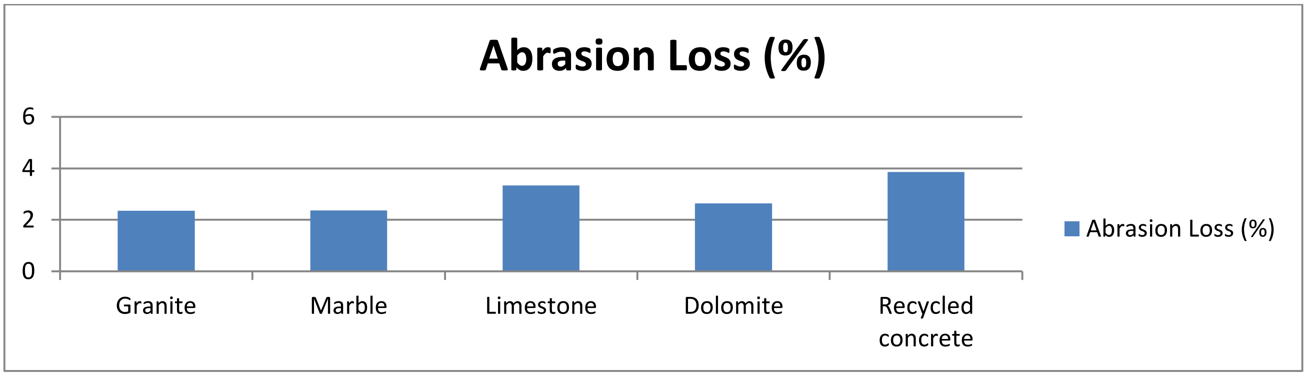

Figure 12: Abrasion loss (%)

Internal Correlation between Aggregate Properties and Concrete Performance

Internal correlations were examined by relating 28 day compressive strength to measured individual aggregate properties using observed trends supported by relevant findings from previous studies.

Granite

Granite concrete achieved the highest 28-day compressive strength (42.5 MPa). This corresponds with its low water absorption (0.55%), low AIV (7.43%), low ACV (~17.76%), high specific gravity (2.62), and low abrasion loss (2.35%). Aggregates with low porosity and high resistance to crushing and impact generally produce stronger concrete due to improved interfacial transition zone (ITZ) bonding and reduced micro cracking (Zhang *et al*., 2021; Li *et al*., 2023). The high compacting factor (0.9630) and high hardened density (~2429 kg/m³) indicate effective compaction and minimal voids, which are directly associated with improved compressive strength development (Wu & Sun, 2022). The internal relationship therefore confirms that low porosity and strong aggregate skeleton significantly enhanced strength performance.

Marble

Marble concrete reached 35.7 MPa at 28 days. It is very low water absorption (0.43%) and high bulk density (1598 kg/m³) resulted in high hardened density (~2509 kg/m³). Dense aggregates are known to improve concrete compactness and reduce permeability (Rahman *et al*., 2020). However, mechanical resistance properties such as crushing and abrasion behavior also influence strength development (Singh & Sharma, 2022). Although marble exhibited good density characteristics, its moderate abrasion resistance slightly limited its overall strength performance. This confirms that density alone does not fully control compressive strength; aggregate hardness remains a critical factor.

Dolomite

Dolomite concrete recorded 28.0 MPa at 28 days. Despite its high specific gravity (2.77), it exhibited high ACV (34.01%) and AIV (39.48%), indicating weak resistance to crushing and impact. Recent studies emphasize that aggregates with high fragmentation values reduce concrete load-bearing capacity because failure often initiates within the aggregate particles themselves (Kim et al., 2021). The internal correlation shows that mechanical weakness significantly influenced strength reduction, demonstrating that aggregate resistance to mechanical degradation is more critical than density alone in controlling compressive performance.

Limestone

Limestone concrete produced 26.8 MPa, the lowest compressive strength. This aligns with its high water absorption (1.86%) and low bulk density (1343 kg/m³), indicating higher porosity and weaker packing. High absorption aggregates tend to weaken the ITZ due to increased internal voids and water movement (Chen *et al*., 2022). Its relatively higher abrasion loss (3.34%) further reflects reduced surface hardness. The internal relationship confirms that high porosity and lower mechanical integrity contributed to reduced strength development.

Recycled Concrete Aggregate (RCA)

RCA concrete achieved 32.4 MPa at 28 days. Although it had low specific gravity (2.39) and high moisture content (3.58%), its relatively low ACV (16.09%) and moderate AIV (9.95%) supported strength development. Studies confirm that the quality of parent concrete significantly influences RCA mechanical performance (Li *et al*., 2023; Silva *et al*., 2021). However, higher abrasion loss (3.86%) and lower compacting factor (0.8416) indicate higher porosity and potential micro cracks inherited from previous service life. The internal correlation therefore shows that while mechanical resistance of RCA supported compressive strength, residual porosity limited its performance.

Conclusions

This study has demonstrated that the type of coarse aggregate used in concrete significantly influences its strength and workability. Among the six aggregate types tested granite, dolomite, marble, limestone, and recycled concrete aggregates, granite and marble consistently produced the highest compressive strengths, lowest water absorption, and greatest resistance to crushing. The superior than expected performance of recycled concrete aggregate which surpasses two natural aggregates in compressive strength strongly suggests that the parent concrete from which it was derived from was of high quality and substantial original strength. This inherent strength and good interfacial bonding inherited from the parent concrete enabled the RCA to achieve comparable performance to natural aggregates in medium strength applications. Conversely, dolomite and limestone produced the weakest concrete with 28 days strength of 28.0 and 26.8 MPa respectively, primarily due to their poorer mechanical properties and higher porosity. Ultimately, the findings confirm that careful selection of coarse aggregate is essential in achieving high-performance concrete suitable for specific construction needs. Internal correlations which were accessed qualitatively using observed trends and relevant literature shows that aggregate properties influence concrete strength.

Recommendations

The following recommendations were made from the present study

i. Granite should be prioritized for structural concrete where high strength and durability are essential. Marble is also suitable for strong, aesthetic, or architectural concrete. Recycled concrete aggregate (RCA) can be effectively used for medium-strength concrete, pavements, and non-critical structures after proper cleaning and grading. Limestone and dolomite should be reserved for light structures, masonry blocks, and non-structural components.
ii. Recycling of demolished concrete should be encouraged, as RCA demonstrated acceptable mechanical properties and provides an eco-friendly alternative that reduces demand on natural aggregates.
iii. Future research should explore the long-term durability of concrete made with these aggregates, including resistance to environmental factors.
iv. Consider blending recycled concrete aggregates with stronger types (e.g., granite) to improve performance while promoting sustainability.

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