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Concrete Strength and Aggregate Properties: In-Depth Analysis of Four Sources

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Abstract

In the field of Reinforced Concrete Construction, concrete emerges as the predominant and extensively employed construction material. Concrete comprises a solid, chemically inert granular substance called coarse aggregate (CA) bonded with cement and water. Compared to fine aggregate or cement, CA has a larger volume of concrete. By examining the characteristics of the coarse aggregate using various laboratory testing processes, the coarse aggregate may be properly used in concrete. Bangladesh is experiencing significant growth in its infrastructure industry due to the construction of mega projects nationwide. For the building of RCC in Bangladesh, coarse aggregate is mainly procured from two sources in Bangladesh, and another is imported from China. This study aims to develop a clear understanding of aggregate and concrete strength quality for different coarse aggregates and track changes in the appearance of CA from multiple sources in China and Bangladesh. Coarse aggregates were collected from four prominent sources: Jaflong and Bholaganj (Bangladesh), Shandong, and Jiangsu (China). ACV (aggregate crushing value), gradation, voids, and unit weight; AIV (aggregate impact value), absorption, specific gravity, and resistance to abrasion-induced deterioration; and Los Angeles (LA) machines' impact tests have been conducted for all sources of CA. The concrete cylinder was made and tested for all sources of CA with the same ratio of cement, sand, and water to know the concrete strength for different CAs.

Keywords: Unit-Weight; Concrete Strength; Coarse Aggregate; Fineness Modulus; Abrasion; Specific Gravity.

1. Introduction

Concrete, characterized by its economic viability, constitutes the second most employed construction material globally, surpassed solely by water, with an annual consumption approaching nearly 30 billion tons [1]. The main elements of concrete are coarse aggregate, water, cement, and fine aggregate [2]. Even though concrete is used extensively, it might not be easy to anticipate its strength at different stages [3]. Naderi & Kaboudan [4] conducted an experimental study of the effect of aggregate type on concrete strength and permeability and observed that coarse aggregates comprise the majority of the concrete mix; they can significantly affect the permeability and strength of concrete. Barham et al. researched the effect of maximum coarse aggregate size on shear strengthening. Their experimental results showed that using full rough aggregate size positively impacts the ultimate shear strength,

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maximum deflections, toughness, and stiffness of strengthened RC members [5]. According to researchers, coarse aggregate changes may affect concrete strength failure characteristics [6]. According to Ezeldin & Aitcin [7], high-strength coarse aggregate typically results in higher compressive strength in high-strength concrete, whereas in standard-strength concrete, the strength of coarse aggregate has no bearing on compressive strength. Giaccio et al. directed research regarding different coarse aggregates and stated that most coarse aggregate particles in concrete containing limestone were shattered, but in concrete containing basalt, stress, mainly cracking, happened at the matrix-aggregate contact [8].

Lee et al. [9] and a team of ASCE researched on mechanical properties of concrete and concluded that the weakest point in low-strength concrete nearly always lies at the interface of matrix aggregate, and the mechanism of progressive micro cracking is that mortar cracks span adjacent joint cracks. High-strength concrete displayed fewer and smaller microcracks at all weights than normal-strength concrete. The observed behavior can be explained by treating high-strength concrete as a more homogeneous material. The compatibility of coarse aggregate with mortar strength and elastic characteristics is improved by matrix density and void content. The reduced stress at the matrix-aggregate interface also lowers the risk of interfacial failure, another benefit of the increased compatibility. As a result, microcracks are likely to spread through the aggregate, and their size gets smaller as the concrete's strength rises. Giaccio et al. conducted research on the fracture energy of high-strength concretes and observed that weak aggregates like limestone significantly lower the compressive strength of concrete since the strength of the concrete's aggregates determines how strong it may be [10]. Basalt mixes had a higher flexural strength in all eras than limestone combinations with the same mixing ratio. Up until a specific aggregate volume, the compressive strength of concrete improves with increasing coarse aggregate content and subsequently falls. Concrete compression is a complicated phenomenon. Several factors influence the behavior of concrete under such pressures. Sample size, shape, and friction are the main variables influencing concrete compaction [11]. Cordon et al. [12] observed that the variation in aggregate size significantly impacts concrete's compressive strength and split tensile strength. Concrete strength depends on the proportion of various aggregate sizes. Li & Song [13] developed a model to predict the compressive strength of rice husk ash concrete and observed that the two most significant factors affecting concrete's compressive strength are age and cement. A study on the effect of coarse aggregate quality on the mechanical properties of concrete has been done by Beshr et al. [14], who observed that it is essential to select suitable coarse aggregate to increase the compressive strength of concrete.

Although much research has been done on the impact of aggregate in concrete, there is little research based on the quality of different locations' coarse aggregates and their influence on concrete. In this study, several laboratory tests have been conducted to examine the properties of coarse aggregate and whether to use CA in the concrete mixture properly. From these tests, a holistic view of aggregate properties, such as size of aggregate, aggregate shape, and texture, has been gained. Four types of coarse aggregate were tested in the laboratory for different aggregate properties. Aggregate variation properties concerning sources have been recorded and compared. The main aim is to investigate changes in other material properties of gravel using various sources and their effects on the compressive strength of concrete.

2. Research Methodology

From four distinct sources in Bangladesh and China, four varieties of crushed stone coarse aggregate of 20mm grade were gathered. The CA sample gathered from four sources is shown in Figure 1.

All types of collected CA were tested for ACV-aggregate crushing value [15], gradation [16], absorption and specific gravity [17], voids and unit weight [18], AIV-aggregate impact value, resistance to abrasion-induced deterioration, and the Los Angles (LA) machine's impact [19].

Jaflong (Bangladesh)

Bholaganj (Bangladesh)

Shandong (China) Jiangsu (China)

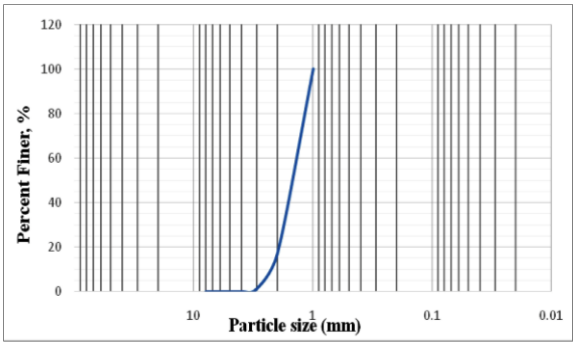
Figure 1. Location of coarse aggregate

2.1. Gradation

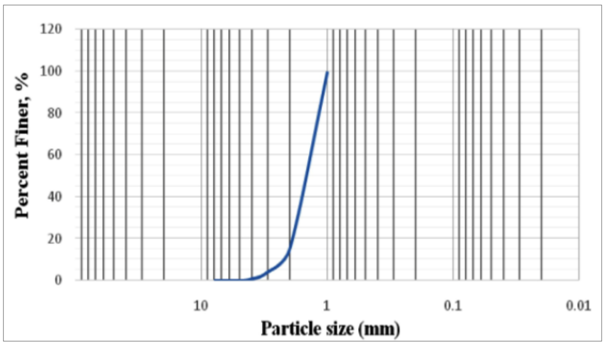
The determination of aggregate grade is a crucial stage in the development of concrete mixtures [20]. Local aggregate sources often produce concrete economically [21, 22]. Aggregation sources can have different aggregation properties, so blends are designed differently [23-25]. When defining the link between workability and the quantity of paste needed in concrete mixtures, the term "aggregate grading" has been applied [26-28]. In this work, sieve analysis was used to evaluate CA samples. The 20mm, 11mm, 4.80mm, 2.40mm, 1.20mm, 0.7mm, 0.4mm, and 0.20mm sieves were chosen for testing. The mechanical screen on which the CA sample was placed was used for grading. By multiplying the cumulative percentage of material retained on ASTM standard sieves by 100 and adding the result, the fineness modulus (FM) was determined. Table 1 displays the computed FM values for various CA sources. Figure 2 also shows the particle size distribution curves for each of the four types of CA.

Table 1. FM values of coarse aggregate

Location of CA	Jaflong	Bholaganj	Shandong	Jiangsu
FM	7.86	7.92	7.4	7.91



Jaflong



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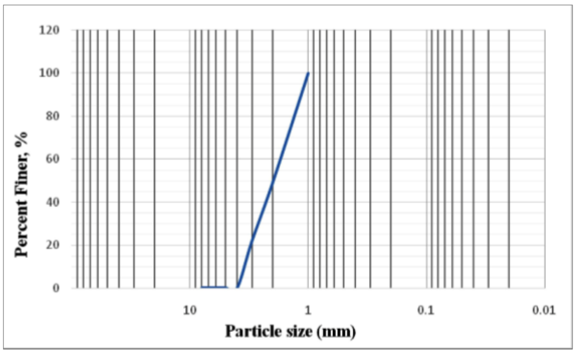
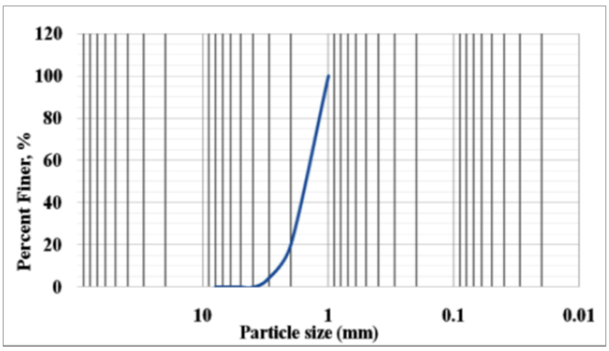


Shandong



Jiangsu

Figure 2. Curve of gradation for coarse aggregate

2.2. Resistance to Abrasion-Induced Deterioration and Los Angles (LA) Machine's Impact

The most commonly used technique for assessing aggregates' abrasion resistance is the Los Angeles Abrasion Value Test (LAAV) [29]. This test evaluates an aggregate's resistance to wear brought on by abrasion between rock grains and impact and crushing by steel balls [30]. The Los Angeles Tester was used in this test to examine the resistance to deterioration of four coarse aggregate sources. For aggregates used in high-traffic roadways and floors, this test is crucial. Table 2 displays the abrasion values that the LA machine generated for various CA locations. Figure 3 shows some photographs captured during the laboratory testing phase.

Table 2. Coarse aggregate abrasion values

Location of CA	Jaflong	Bholaganj	Shandong	Jiangsu
Abrasion value	16.6%	17.1%	17.3%	18.6%

Figure 3. Photograph captured during the laboratory testing phase

2.3. Absorption and Specific Gravity

In the transportation sector, coarse aggregate specific gravity (Gs) and absorption capacity (Wa%) are crucial design factors [31]. In volumetric hot-mix asphalt construction, including super pave, the bulk-specific gravity of fine aggregate is used to calculate the quantity of asphalt binder absorbed by the aggregate and the porosity of the mineral aggregate [32]. Experiments for specific gravity and absorption were conducted on four distinct CA sources. Table 3 provides the derived values for the specific gravity, apparent specific gravity, and absorbance of oven dry basis (OD) and saturated surface dry basis (SSD).

Table 3. Absorption and specific gravity of coarse aggregate

Location of coarse aggregate	Jaflong	Bholaganj	Shandong	Jiangsu
Bulk-specific gravity (OD)	3.45	3.41	3.67	3.6
Bulk-specific gravity (SSD)	3.67	3.6	3.75	3.68
Apparent specific gravity	4.11	3.95	3.88	3.81
Absorption	9.07%	7.83%	3.01%	3.02%

2.4. Unit Weight and Voids

Vacuums within the aggregate are an essential parameter to ensure the durability of the concrete mixture [33]. The ideal grade must have the most miniature voids per unit weight and surface area [34]. Average unit weight (kg/m^3) and void percentages were calculated for four types of CA. Table 4 shows the results.

Table 4. Voids and unit weight of different coarse aggregates

Location of coarse aggregate	Jaflong	Bholaganj	Shandong	Jiangsu
Unit weight (kg/m^3)	1653	1684	1770	1711
Voids	11.63%	8.57%	5.23%	7.21%

2.5. Aggregate Impact Value (AIV)

The well-known AIV test is a British standard that provides a relative assessment of an aggregate's resistance to abrupt shock or impact, which can vary from the aggregate's resistance to a gradual compression load in some cases [35, 36]. Previous studies on lightweight aggregates have confirmed that lightweight aggregates produce higher values of AIV, and aggregates with greater coarseness may have lower values of AIV [37]. The total impact value, which compares resistance to abrupt shock or impact with resistance to progressively applied pressure, might differ. Table 5 displays the four CA kinds of AIV that were discovered.

Table 5. Aggregate impact value of coarse aggregate

Location of coarse aggregate	Jaflong	Bholaganj	Shandong	Jiangsu
AIV	25.5%	19.72%	12.26%	15.6%

2.6. Aggregate Crushing Value (ACV)

For asphalt mixes to remain stable, the crushing properties of the aggregates are crucial. Utilizing an aggregate crushing value test, crushing resistance is often measured statistically [38]. ACV is the famous British standard test for measuring resistance to AD when crushed by compressive loads [36, 39]. The aggregate crushing value test for coarse aggregates measures an aggregate's resistance to crushing under graded compressive loads. Table 6 displays the attained ACVs for four CA sources.

Table 6. ACV of different coarse aggregate

Location of coarse aggregate	Jaflong	Bholaganj	Shandong	Jiangsu
ACV	29.85%	21.35%	14.1%	29.6%

2.7. Compressive Strength of Concrete Cylinder

Concrete's compressive strength is one of its most crucial characteristics. In addition, it is frequently used as a benchmark for numerous other characteristics of concrete, including its elastic modulus and tensile strength. Additionally, compressive strength provides a decent general indication of concrete quality [25, 40]. The concrete cylinder was made and tested for all sources of CA with the same cement, sand, and water ratio to determine the concrete strength for different CAs. The concrete cylinders were made using a 1:1.5: 3 mixing ratio of cement, sand, and CA, respectively, and tested for 7 days, 14 days, and 28 days as per ASTM C39 [41]. Table 7 displays the concrete strength test data for different days, and Figure 4 shows the flowchart of the study.

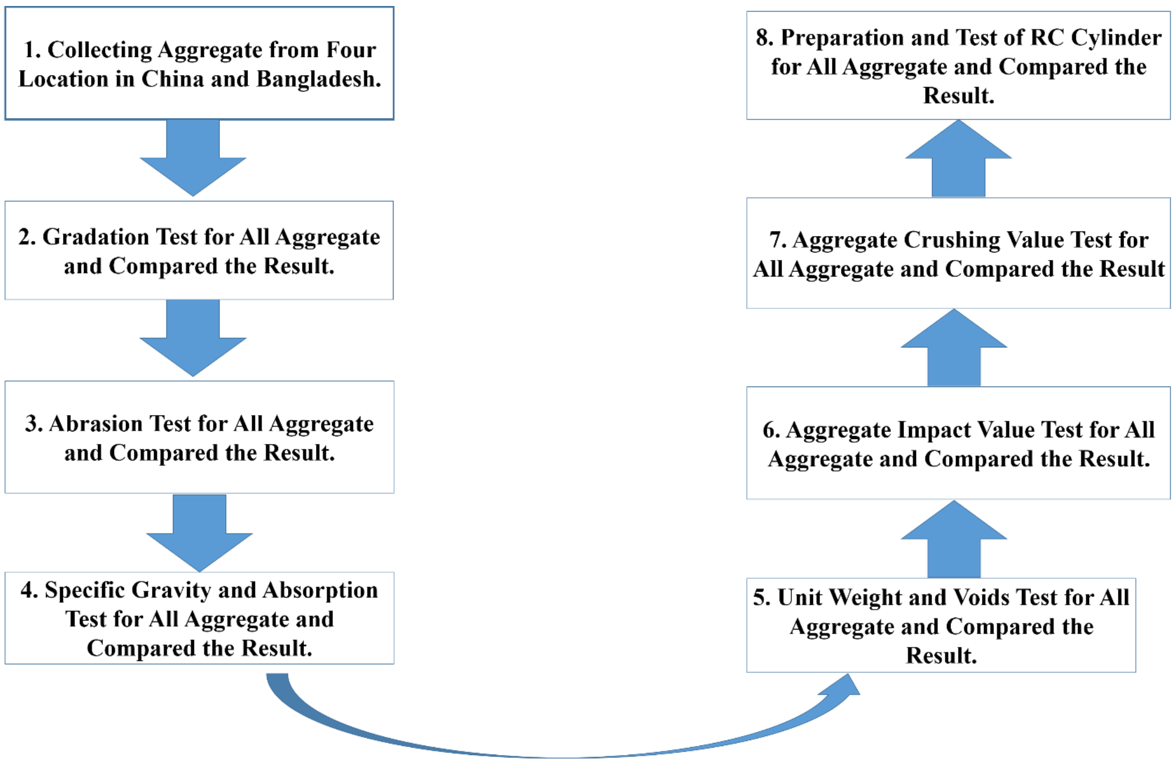


Figure 4. Flow chart of the study

Table 7. Concrete Compressive strength of different coarse aggregate

Location of CA	7 days Strength (psi)	14 days Strength (psi)	28 days Strength (psi)
Jaflong	2275	3150	3500
Bholaganj	2242	3105	3450
Shandong	2080	2880	3200
Jiangsu	2197	3042	3380

3. Result and Discussion

All results obtained from the various laboratory tests described above are displayed in bar graphs and compared concerning changes in the CA source. Figure 5 shows the FM values for different CA sources, from which it can be seen that CA Bholaganj has the highest FM value at 7.92, while CA Jiangsu and CA Shandong have similar values. The FM score was the lowest at 7.4.

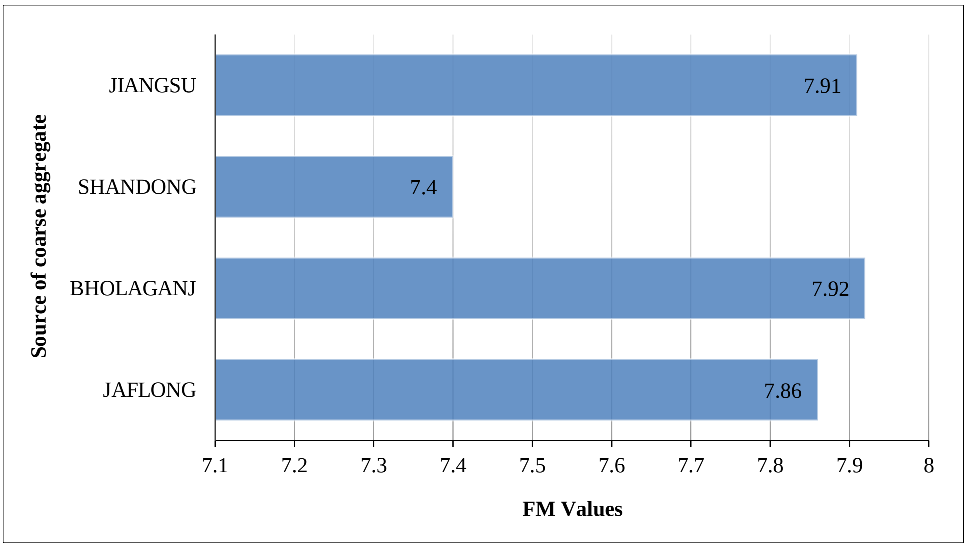


Figure 5. FM values of coarse aggregate

Figure 6 displays the abrasion values for four CA sources. With an 18.6% turnover rate, CA Jiangsu had the most significant turnover rate, followed by CA Jaflong and Bholaganj, with somewhat lower turnover rates, and CA Shandong, with the lowest.

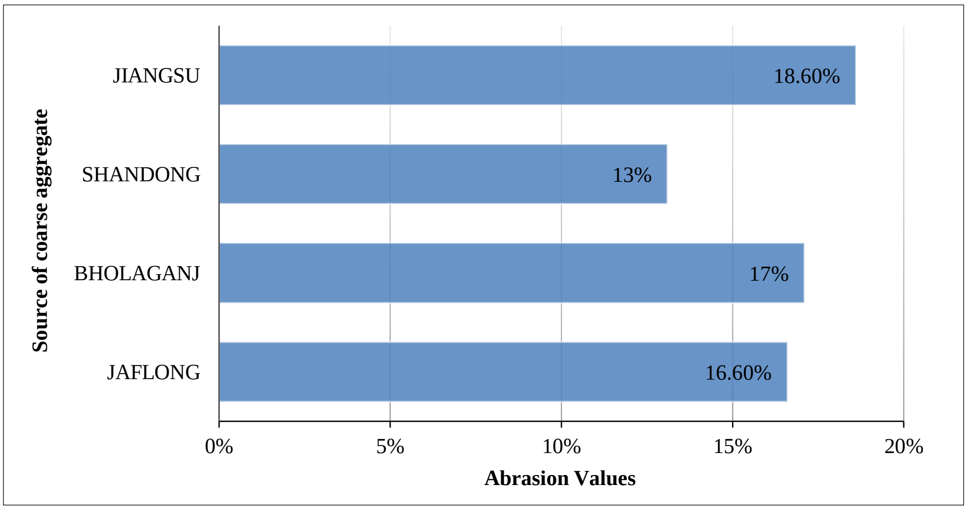


Figure 6. Abrasion values of coarse aggregate

Figure 7 shows bar graphs of apparent specific gravity and specific gravity (OD and SSD-based) about the CA source. With values of 3.67 and 3.75, respectively, the OD and SSD mass weights in Shandong, Jiangsu, were more significant than the others. Bholaganj CA had OD-specific and SSD mass values of 3.41 and 3.6, respectively. Once more, the apparent specific gravity was 4.11 in Jaflong's coarse aggregate and 3.81 in Jiangsu's coarse aggregate.

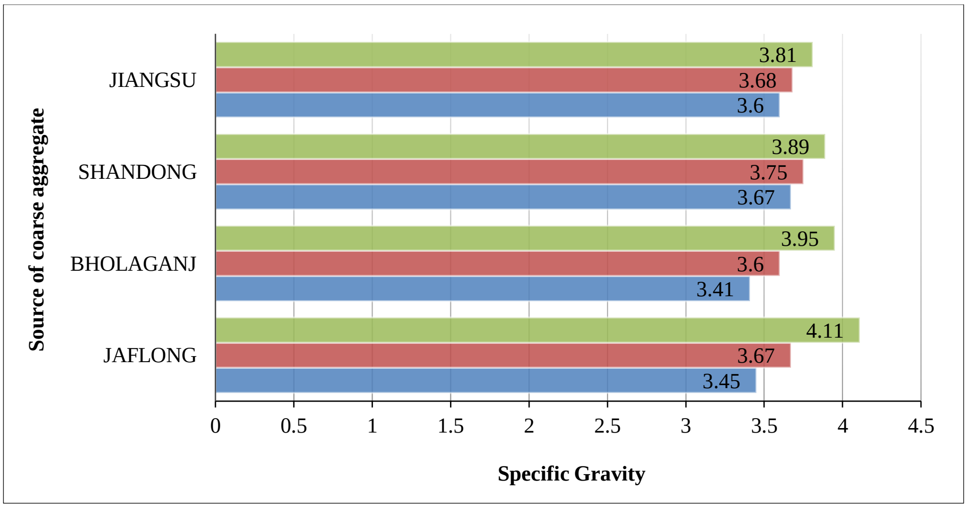


Figure 7. The specific gravity of coarse aggregate

Figure 8 shows the uptake of CA from various sources. Jaflong CA had the highest absorption rate of 10.47%, Jiangsu CA had the lowest absorption rate of 4.16%, and Shandong CA had similar values.

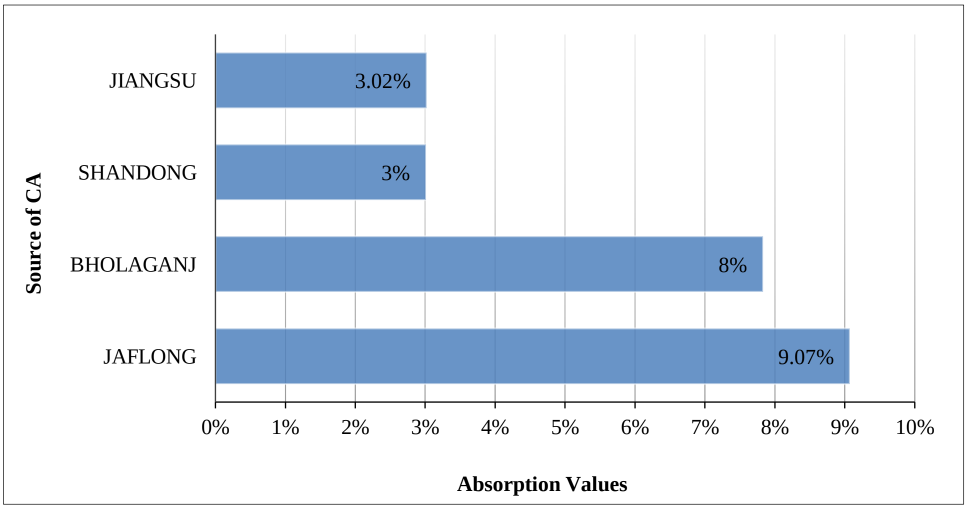


Figure 8. Absorption values of coarse aggregate

Figure 9 displays the unit weights of CA from various sources. In Shandong, CA, unit weight values were discovered to be 1769 kg/m^3, while in Jaflong, CA, they were 1603 kg/m^3. Figure 10 demonstrates that the void rate was highest in Jaflong, CA (11.63%) and lowest in Shandong, CA (5.23%).

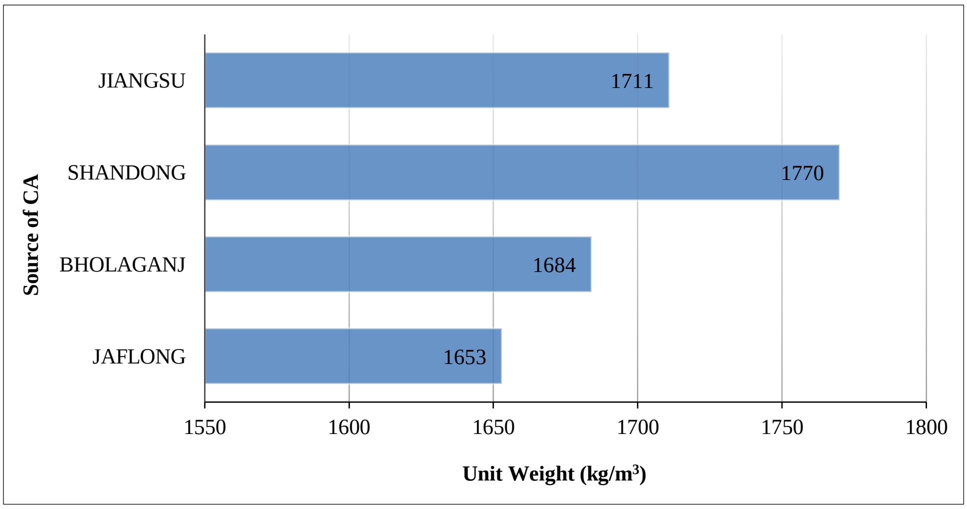


Figure 9. Unit weight of coarse aggregate

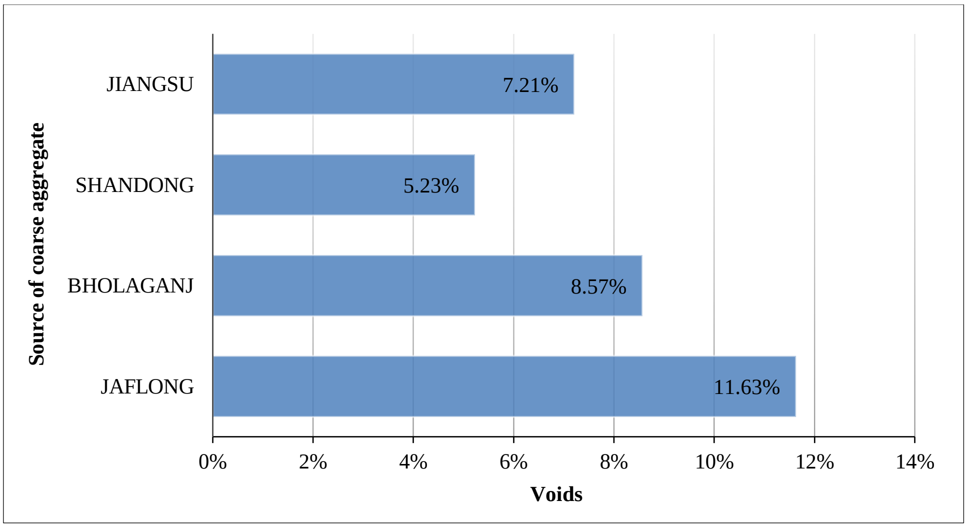


Figure 10. Void % of coarse aggregate

Figure 11 displays the AIV variation for several CA sources. AIV measured 25.5% in Jaflong, California, where it was most significant, and 12.1% in Shandong's coarse aggregate, where it was lowest. ACV alterations for the four different forms of CA are shown in Figure 12. Compared to other CAs, the CA of Jaflong had the highest ACV, at 29.85%, virtually matching the CA of Jiangsu, while the CA of Shandong had the lowest, at 14.1%.

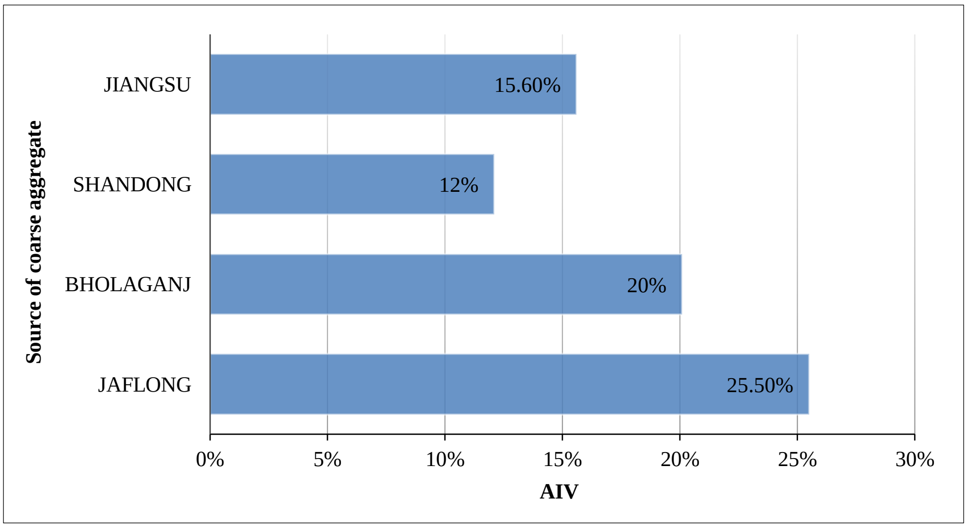


Figure 11. AIV of coarse aggregate

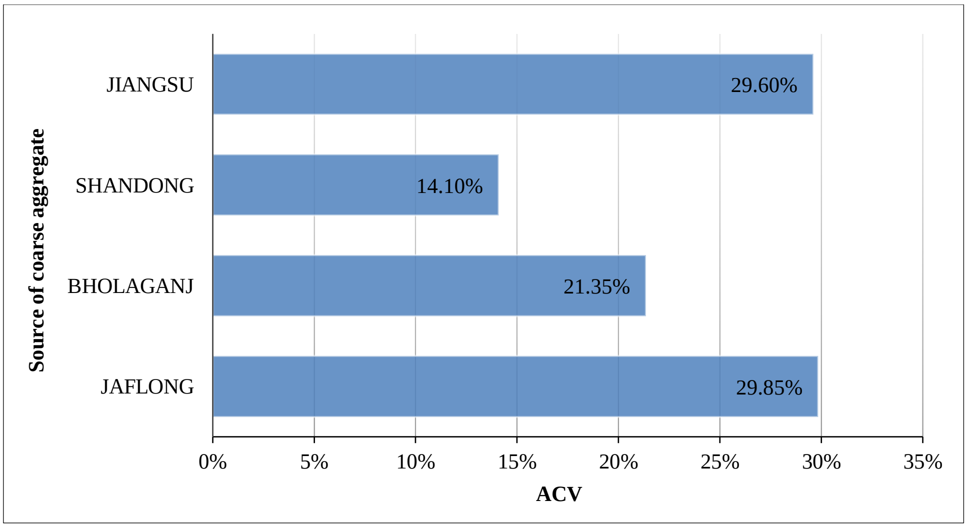


Figure 12. ACV of coarse aggregate

Figure 13 displays concrete compressive strength for different CA locations with test results of other days. Concrete cylinder made by Jaflong CA has the highest compressive strength while Shandong CA has the lowest compressive strength.

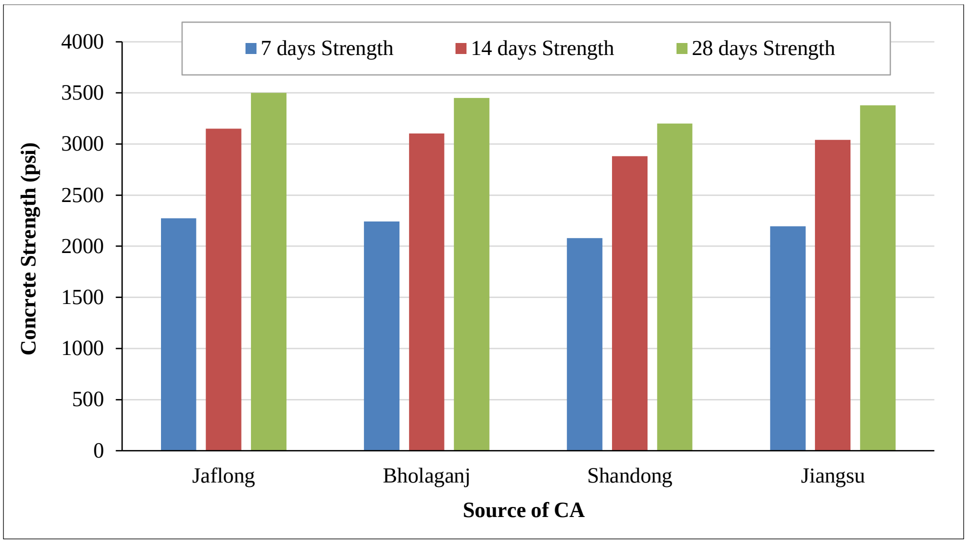


Figure 13. Concrete strength value

Concrete cylinder made by Jaflong CA has the highest compressive strength while Shandong CA has the lowest compressive strength.

4. Conclusion

This paper investigated the effect of aggregate type on the compressive strength of concrete and its permeability. For this purpose, different aggregates from other locations were used in the concrete mixtures. In addition, various properties of the aggregates, including ACV, AIV, gradation, absorption, abrasion, specific gravity, voids, and unit weight, were studied. Coarse aggregates were collected from four prominent sources: Jaflong and Bholaganj (Bangladesh), Shandong, and Jiangsu (China). The FM value of Shandong CA was observed to be less than that of others due to its being less coarse. Particle size was more significant than others and found the highest FM value for Bholaganj, CA. From this test, it's observed that the value of the coarse aggregate's fineness modulus is significantly influenced by particle size. The CA of Jiangsu has the highest abrasion value; it has higher toughness than other sources. The CA of Shandong absorbed less water than any other source; it has the highest specific gravity value. Less void space for water has been found for Shandong CA because it has less FM, and its absorption is lower than that of other sources. Aggregates became smaller voids between the particles when the value of FM was reduced. Because Shandong CA included fewer slums than other sources of CA, it had the most significant average unit weight. The lower FM content may account for the decreased voids compared to other CAs. Jaflong CA can absorb more impact load compared to other CA sources and showed the highest AIV value. It also revealed a significant value for abrasion and FM. A higher value of FM means that the aggregates are coarser and can withstand high loading. The abrasion value was reduced, resulting in a reduced AIV value. Compared to other CA sources, Jaflong CA can absorb compressive load better, and it's observed that it has the highest ACV value. According to this research, Jaflong CA can provide more compressive strength than other sources of CA.

4.1. Recommendation and Further Work

Recommendations for future work include optimizing aggregate mixtures, exploring alternative sources, and conducting long-term performance studies. Additionally, implementing advanced testing methods and validating findings in real-world applications, possibly through collaboration with industry experts, would enhance the practical implications of the research.

5. Declarations

5.1. Author Contributions

Conceptualization, K.H. and R.M.; methodology, K.C. and R.M.; software, K.H.; validation, A.A. and R.H.; formal analysis, K.H. and R.M.; investigation, K.C.; resources, R.H.; data curation, A.A.; writing—original draft preparation, K.C.; writing—review and editing, K.H.; visualization, A.A.; supervision, R.H.; project administration, K.H., R.M., and K.C. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in the article.

5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

5.4. Conflicts of Interest

The authors declare no conflict of interest.

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