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Exploring Recycled Brick Aggregate: A Viable Option for Low-Strength Structures

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Abstract: A comprehensive study was conducted to evaluate the feasibility of incorporating recycled brick aggregate (RBA) in concrete for construction purposes. Recycled bricks were collected from a variety of aged buildings and then processed accordingly into coarse aggregate for experimental testing. Unlike many other countries that rely on stone chips as aggregate, Bangladesh faces a shortage of natural stone, leading to the common use of brick chips in older structures. This study is particularly relevant in this context. The physical properties of RBA, such as specific gravity and absorption capacity, were thoroughly examined in this study. The research focuses the potential of RBA as a sustainable alternative for managing construction and demolition waste. Key experimental findings reveal that RBA can be effectively use in concrete, though its performance mostly depends on the water-to-cement (W/C) ratio. Optimizing the W/C ratio notably enhances the mechanical characteristics like compressive and tensile strengths, making RBA suitable for low- to medium-strength applications. The study confirms that recycled brick aggregate can provide comparable performance to conventional aggregates when properly assessed and utilized, with the concrete showing better results at a W/C ratio of 0.45. Overall, RBA offers the potential to produce concrete in the medium-low strength range of 20–30 MPa, making it a viable option for various structural applications.

Keywords: *Recycled brick, recycled brick aggregate, compressive strength, low-strength*

Introduction: Concrete is vastly used in civil engineering field for the purpose of construction of such infrastructure like roads, bridges, and dams. It is crucial in determining the material's properties because the aggregate constitutes approximately 75% of concrete's volume [1-3]. The traditional concrete production has large environmental impact, which deeply relies on aggregate extraction process, has led to increased interest in using recycled aggregate (RA) from demolished concrete [4]. Middle East and other rapidly emerging region have structures which are reaching the end of their service life, resulting in concrete rubble that can be repurposed as RA [5]. This sort of practice addresses environmental concerns while conserving natural aggregate resources. The incorporation of RA into concrete mixes generally diminishes environmental impact by about 1–7% compared to conventional concrete manufacture methods [6]. Recycled aggregate concrete (RAC) is gaining attention in both academic research and practical applications, with many countries implementing RA to effectively manage waste and lessen the environmental footprint of traditional concrete production in vast construction industry [5].

In Bangladesh, clay brick plays a decisive role in the rapidly increasing construction industry. Globally, the average annual consumption rate of concrete is about 2.5 tons per person, totalling 17.5 billion tons for the worldwide population [7]. Manufacturing this huge amount of concrete needs roughly about 2.62 billion tons of cement, 13.12 billion tons of aggregate, and 1.75 billion tons of water [2,5]. Aggregates are usually obtained through quarrying, river gravel extraction, fragmentation of boulder, or crushing clay bricks. Having the significant role of aggregates, recycling bricks for construction industry in Bangladesh offers considerable potential for conserving natural resources. Numerous historic buildings in Bangladesh are made of brick and brick aggregate concrete, providing a decisive source of aggregate from demolition waste. Recent research has explored the possibility of using recycled brick aggregate concrete as coarse aggregate [8]. An illustration of the manufacturing process of recycled brick aggregate is given in figure 1, showing the key phases involved in transforming demolished brick material into usable coarse aggregate.

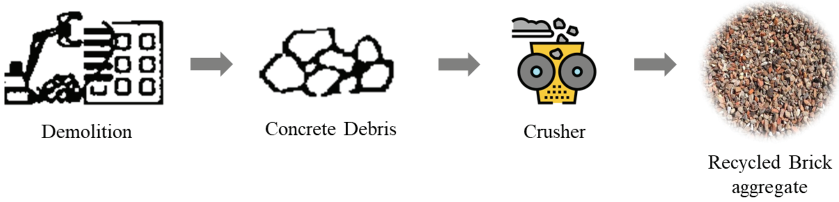

Fig. 1: Manufacturing process of recycled brick aggregate

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Roughly 60 to 70 percent of recycled concrete is normally repurposed as subbase aggregate for road construction, which results in about a 20% reduction in the consumption of conventional aggregates [9,10]. If the technology for recycling aggregates were fully implemented, it could potentially eliminate the need for virgin aggregates altogether by using recycled concrete for new construction. In Bangladesh, the growing volume of recycled concrete is primarily due to aging infrastructure and the replacement of low-rise buildings with taller ones spurred by a real estate boom. This increase in recycled concrete presents significant disposal challenges for developers [9]. However, utilizing this material in new construction projects could mitigate disposal issues, decrease the demand for new aggregates, and conserve natural resources. Although many older buildings in Bangladesh incorporated brick chips as coarse aggregate in concrete, most existing research on recycled concrete has concentrated on stone chips [11-14]. This underscores the necessity for research focused specifically on recycled concrete using brick-based aggregates, which is the aim of this study.

Hence, there is a significant opportunity for further research to enhance our understanding of recycled brick aggregate concrete. A comparative analysis of the properties of crushed fresh clay brick versus recycled brick aggregate concrete could yield valuable insights into the viability of using recycled brick as a coarse aggregate. This study aims to assess the performance of recycled brick and its aggregates and compare these findings with those of fresh brick and its aggregates.

Materials & Methods: The purpose of this study was to evaluate the mechanical properties of concrete containing recycled brick aggregate (RBA) and to compare these characteristics with those of concrete made with conventional fresh brick aggregate (FBA). The aggregates undertook testing for fresh properties like absorption capacity and specific gravity. Specific gravity and absorption capacity were calculated following ASTM C128-03. For assessment purposes, FBA, which is commonly used in Bangladesh and is superior to second and third-class brick aggregates, was selected together with RBA. Concrete specimens were casted with water-to-cement (w/c) ratios of 0.45 and 0.50 for both types of aggregates. **Table 1** provides the mixture proportions for FBA and RBA. Concrete cylinders, having 150 mm in diameter and 300 mm in height, were cast in accordance with ASTM C39-03 standards for compressive strength testing. Besides, the split tensile strength was assessed using 150 × 300 mm cylinders, following ASTM C496 standards. After casting, the cylindrical specimens were demoulded after one day and subsequently cured in an open chamber. Compressive strength test was performed for all the specimens were at 7, 14, and 28 days while the splitting tensile test were conducted only for 7 and 28 days. **Figure 2** illustrates the compression testing procedure used in this study.

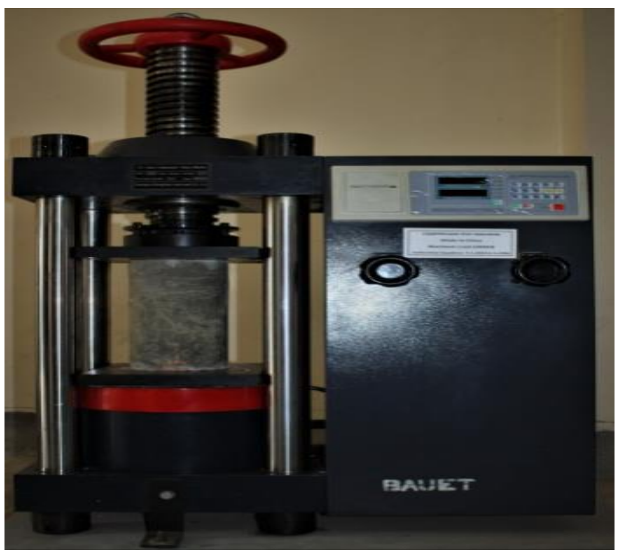

Fig. 2: Compression testing machine used in this study.

The experimental plan involved preparing two concrete mixtures with different water-to-cement (w/c) ratios of 0.50 and 0.45. The variations in aggregate content (cement, fine aggregate, and coarse aggregate) were adjusted accordingly to sustain the target workability and desired characteristics of the concrete. The mixtures merged a combination of fine brick aggregate (FBA) and recycled brick aggregate (RBA) as replacements for traditional fine and coarse aggregates. For the mixture with a w/c ratio of 0.50, the proportions of FBA and RBA were 720 kg/m³ and 1150 kg/m³ separately, with 180 kg/m³ of water. For the mixture with a w/c ratio of 0.45, the FBA and RBA proportions were 700 kg/m³ and 1100 kg/m³ correspondingly, with 180 kg/m³ of water. This setup permitted for comparison of the mechanical properties and performance of concrete formed with different water-to-cement ratios, keeping other variables constant.

Table 1. Mix Proportions of FBA and RBA used in this study.

		Unit content (kg/m^3)			
Case	**W/C**	**C**	**FA**	**CA**	**W**
FBA and RBA	0.50	360	720	1150	180
FBA and RBA	0.45	400	700	1100	180

Where, W = water; C = cement; CA = coarse aggregate; FA = fine aggregate.

Result and Discussions:

Physical properties

Bulk specific gravity of recycled brick aggregate: The bulk specific gravity (BSG) of aggregate made with recycled brick is a distinctive character which is important for assessing the material's density and porosity. BSG values for RBA can vary depending on the original brick composition, the crushing method employed, and any contaminants existing. Typically, BSG values for recycled brick aggregates decrease within the range of approximately 2.0 to 2.4, which is comparable to those of natural aggregates. These values are decisive for defining the aggregate's density and its suitability for various construction and concrete production applications. **Figure 3** reveals that the bulk specific gravity of RBA was higher than 1.5 but less than 2.0, closely matching the specific gravity of Fresh Brick Aggregate (FBA), which was 1.83. Previous studies stated bulk specific gravity values of 1.7 and 1.61 for recycled brick aggregate, respectively, which are alike to those of RBA [14,15]. Although these values are lower than the 2.5 to 2.9 range typically required for road pavement construction, RBA are still appropriate for other applications. They can be effectively used in concrete mix designs, water filtration systems, slope stabilization projects, railway bedding, and sub-base road construction materials [16,17].

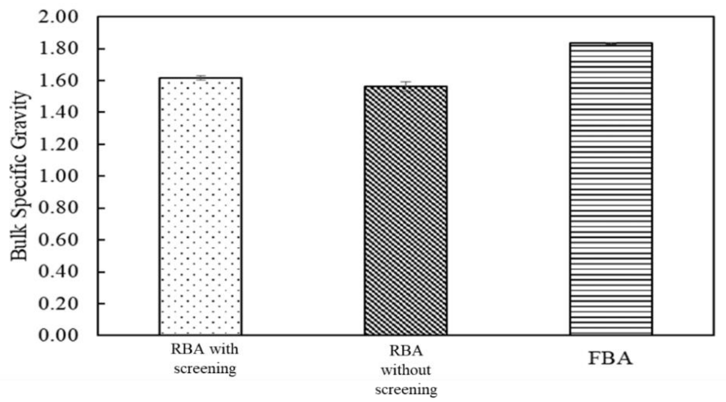

Fig. 3: Bulk specific gravity of RBA and FBA.

Absorption capacity of recycled brick aggregate: Recycled Brick Aggregate (RBA) and Fresh Brick Aggregate (FBA) show substantial alterations in their absorption characteristics, which has the ability to influence their efficiency in concrete applications. RBA, derived from demolished buildings, typically has higher absorption rates due to residual mortar and the effects of weathering. The extraction process naturally begins with a detailed site assessment to assess the potential for recycling materials [9,13]. During the demolition phase, efforts are made to distinct recyclable materials from non-recyclable ones, often involving manual sorting and the use of dedicated equipment. The extracted materials, including concrete and bricks, are then crushed using mechanical crushers, followed by screening to separate different sizes and remove impurities [9]. To confirm that the RBA meets specified standards for use in concrete mixtures, it undergoes quality control measures. Finally, the processed RBA is stored and made available for using in construction projects. This high absorption rate needs careful consideration during concrete mix design to address potential water demand issues and maintain consistent performance. In contrast, FBA, which is precisely produced for construction purposes, has lower absorption rates and a smoother surface texture, enhancing the workability and durability of concrete [18]. While RBA contributes to environmental sustainability by recycling materials, FBA offers better consistency and uniformity in concrete performance. The selection between RBA and FBA depends on the specific requirements of the project, environmental considerations, and the anticipated long-term durability of the concrete structure. As illustrated in **figure 4**, the absorption capacity of both RBA and FBA is compared, with RBA further divided into two categories: screened RBA, which has been processed to remove impurities, and unscreened RBA, which contains various particles from the demolition process [13,17].

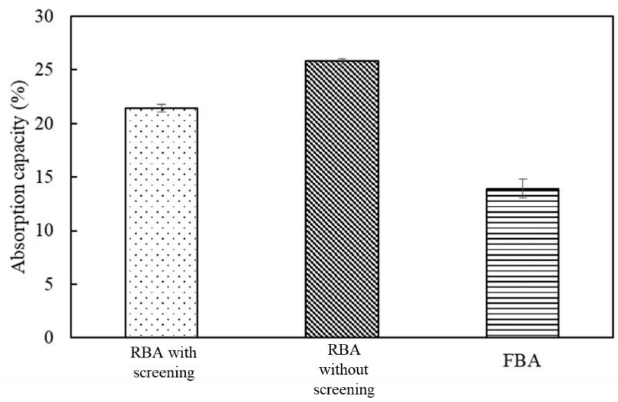

Fig. 4: Absorption measurements of RBA and FBA.

Figure 4 shows that the absorption properties of both screened and unscreened Recycled Brick Aggregate (RBA) exceeds that of Fresh Brick Aggregate (FBA), which has an absorption capacity of 14.44%. However, these absorption values range between 12% and 24% by weight fall well within the allowable range set by the Local Government Engineering Department (LGED) [19]. Specifically, the absorption capacities of screened and unscreened RBA were 7.48% and 11.91% higher, respectively, than that of FBA, which had an absorption capacity of 13.92%, as illustrated in the figure. The absorption capacity of screened RBA is comparable to that of refractory brick from a demolished cold storage building, which was reported to be 19.1% [9,10]. To minimize water absorption in RBA, effective strategies include selecting RBA that is clean and free from residual mortar, employing pre-soaking techniques or water-reducing agents during mixing, and optimizing the water-to-cement ratio in concrete mixes. Proper curing practices are also crucial, as they help maintain adequate moisture levels during the initial hydration phase, thus improving the durability and performance of RBA in the applications of construction industry.

Mechanical properties

Compressive strength of fresh and recycled brick aggregate concrete: Figure 5 illustrates the compressive strength results of concrete specimens at 7, 14, and 28 days, with each data point representing the average of three cylinders per mix. Previous studies shows that the compressive strength amplified with longer curing times. At the 7-day, the compressive strength of concrete made with Recycled Brick Aggregate (RBA) was closely equal to that made with Fresh Brick Aggregate (FBA). However, by 14 days, FBA demonstrated around a 25% greater upsurge in strength compared to RBA, and this trend continued at 28 days, with FBA showing a 23% higher strength increase than RBA. At 28-day compressive strength of RBA is approximately 1.7 times its strength at 7 days [9,13,14]. This pattern indicates that the compressive strength of RBA at 14 and 28 days is comparatively stable. Findings from previous research on RBA concrete demonstrate that the compressive strength of FBA aligns well with RBA which attains similar strength within 7 days, its overall strength is lower compared to FBA [9].

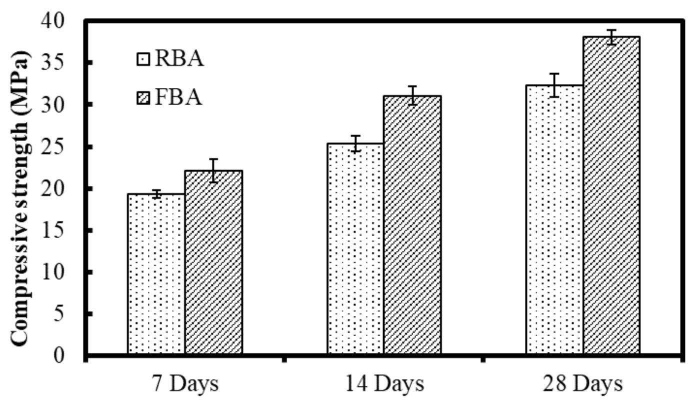

Fig. 5: Compressive strength of RBA and FBA.

The residual cement dust on the recycled aggregate (RA) severely distresses the aggregate's structural integrity. By incorporating cementitious materials this sort of undesirable effect on the concrete's mechanical properties can be mitigated. Concrete's strength is enhanced through the pozzolanic reaction, wherein calcium hydroxide from hydrated cement reacts with silicates to produce calcium silicate hydrate (CSH) gel, thereby improving overall strength [8,20,21]. The observed development in strength gain is largely owing to the late reaction of Fresh Brick Aggregate (FA), which contributes to the steady development of concrete strength over time. When the RBA is well-graded and devoid of contaminants like residual cement dust then the concrete made with recycled brick aggregate (RBA) can achieve compressive strength almost similar to that of fresh brick aggregate (FBA). This study focuses on these findings by investigating the precise aspects inducing compressive strength in RBA concrete. The quantification of strength reduction attributed to residual cement dust on the recycled aggregate is one of the key findings from this research. The overall strength of the concrete mixes reducing due to this contamination which shown to conciliation the structural integrity of the RBA. Particularly, these findings identify the integration of suitable cementitious materials can significantly alleviate this adverse effect. Such materials accelerate strength enhancement through pozzolanic reactions, where calcium hydroxide from hydrated cement reacts with silicates to yield calcium silicate hydrate (CSH) gel, which increasing the mechanical performance of the concrete [20,21]. Also, for supporting the long-term progress of compressive strength the consistent curing conditions for both RBA and FBA concrete specimens is ultimate necessary which is highlighted this study. This feature highlights the requirement of optimal curing practices to ensure that RBA concrete attains strength levels comparable to those of FBA over time [16,22].

In summary, this study contributes valuable insights by illuminating the detrimental influences of residual cement dust and the beneficial effects of cementitious materials while previous studies have demonstrated the potential for RBA to contest the compressive strength of FBA. These findings offer practical guidance for optimizing RBA concrete mixes and strengthen the possibility of RBA as a sustainable alternative in concrete production to increase their overall performance.

Splitting Tensile Strength of RBA and FBA: Figure 6 presents the results obtained from splitting tensile strength taken at 7 and 28 days. Results obtained from the experimental results as showed in figure 6, that the tensile strength of concrete made with recycled brick aggregate (RBA) is consistently lower than that of concrete using fresh brick aggregate (FBA). Precisely, at 28 days, concrete with FBA showed a tensile strength of 4.1 MPa, while RBA concrete demonstrated a reduced tensile strength of 3.2 MPa. This tendency of reduction in tensile strength in RBA concrete can be attributed to numerous aspects. Recycled brick aggregate (RBA) may pose challenges in concrete applications due to its probability of weaker bonding with the cement matrix, enlarged porosity, and higher water absorption, which can poorly affect the overall strength and water-cement ratio [23,24].

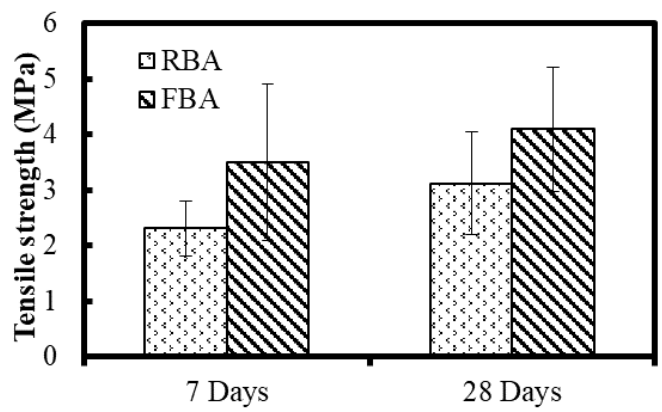

Fig. 6: Indication of tensile strength of RBA and FBA.

Moreover, dissimilarities in surface roughness, residual mortar exists in aggregate particles, microcracks from the recycling method can further reduce the concrete's structural integrity [6]. Also, different thermal and moisture expansion properties, the uneven quality of recycled aggregates and the existence of impurities can significantly weaken the concrete tensile strength properties. The alkali-silica reaction (ASR) potential in recycled bricks can also cause expansion and cracking, further weakening tensile strength [25]. Several approaches can be employed to address these issues and alleviate the reduced tensile strength when using RBA in concrete. To boost up the performance of recycled brick aggregate (RBA) in concrete several techniques can be applied like optimization of the sorting, cleaning processes to eliminate impurities, adjusting mix designs to lower the ratio of water to cement, and applying surface treatments to expand the interfacial bonding between cement matrix and aggregate. These viable approaches strengthen the mechanical properties of the concrete and promote more sustainable construction practices by effectively utilizing recycled materials.

The Failure Pattern of the Specimens of FBA and RBA: As illustrated in figure 7, the failure patterns spotted in concrete cylinders composed of recycled brick aggregate (RBA) and fresh brick aggregate (FBA), disclose different mechanisms influenced by the inherent properties of these materials. RBA concrete generally develops brittle cracks along shear planes which demonstrates shear failure. This sort of failure pattern happens due to the compromised interfacial transition zone (ITZ) formed between the residual old mortar adhering to the recycled aggregates and the new mortar matrix. The declining interfacial bond significantly weakens leading to less favourable performance under load compared to FBA concrete, which benefits from a more robust and cohesive matrix [26]. The presence of old mortar within the concrete generates inconsistencies and weak points, leading to a reduced capacity to resist shear forces and resulting in brittle failure modes [27]. In contrast, FBA concrete shows less distinct shear failure due to the robust and more consistent ITZ between the fresh brick aggregates and the new mortar [5,7-9]. Fresh aggregates contribute to a more even and robust concrete structure, permitting the structure having greater load resistance and a more ductile response under stress. By ensuring overall performance without enduring sudden brittle failure FBA concrete can withstand higher shear forces. RBA concrete is more susceptible to the columnar failure, where vertical splitting occurs along the length of the cylinder. The irregularities and weaker properties inherent in the recycled aggregates dominate this type of failure mode.

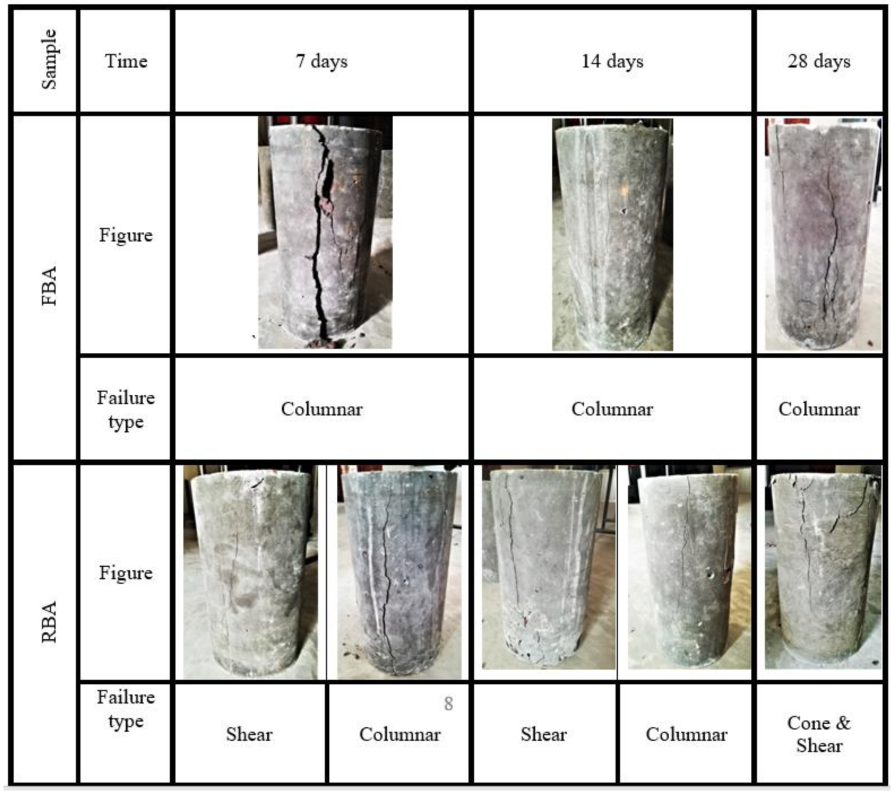

Fig. 7: Different types of failure patterns of RBA and FBA.

Uneven stress distribution is the one of the key reasons for this kind of failure mode in RBA concrete which arises from the irregular shape and results in reducing the strength of the recycled aggregates. Such kind of imperfections can generate stress concentrations that trigger vertical cracks when the specimen subjected to compressive loads. Although FBA concrete is still vulnerable to columnar failure under extreme loads, usually demonstrates a more detailed and less brittle failure response, which is mainly due to the consistency and strength of fresh aggregates [28]. Cone-shaped fractures alongside shear planes is another failure mode observed in RBA concrete which is a combination of cone and shear failure. This complex pattern creates multiple cracks which is due to the presence of both compressive and shear stresses [29]. Though under high stress such failures can also occur in FBA concrete, they are less common and more predictable, strengthening the superior performance, consistency, and reliability of fresh aggregates in structural applications [27,30]. Overall, due to the discrepancies inherent in recycled materials, RBA concrete exhibits a broader range of failure mechanisms that are less predictable. Compared to the traditional aggregates this variability underscores the material's relative weaknesses [31]. On the other hand, FBA concrete has the ability to perform more consistent and comparative predictable failure patterns, highlighting the increase structural integrity and reliability. These benefits making FBA a more suitable choice for applications requiring higher strength and stability. [8,11,13]. Thus, from the shear and columnar failures which are observed from the experimental fracture patterns in RBA concrete, endorse its appropriateness for low-strength structural applications. Although RBA remains feasible for non-critical structural uses, such as road sub-base layers, slope stabilization, and small-scale load-bearing components. Ability of reducing construction waste and conserving natural resources, RBA plays a crucial role in addressing environmental challenges by recycling materials from demolished structures. Therefore, for both sustainable building practices and resource conservation, RBA offers a practical and eco-friendly solution for low-strength concrete applications.

Conclusions: To minimize the increasing volumes of construction and demolition waste, the incorporation of recycled brick aggregate (RBA) in concrete production offers a viable sustainable approach. This study revealed some key insights for construction industry specially in concrete technology. Absorption capacity has a direct impact on the performance of concrete mixes, was found higher compared to the first-class brick aggregates commonly used in Bangladesh. Although concrete produced with RBA displayed lower compressive strength at a water-to-cement (W/C) ratio of 0.50, reducing the W/C ratio to 0.45 markedly enhanced both compressive and tensile strengths, underscoring the critical role of mix optimization when incorporating

RBA. Moreover, the bulk specific gravity of RBA closely matched that of fresh brick aggregates, which is in line with findings from previous studies, supporting its potential as a viable construction material. The strength range of 20-32 MPa makes RBA particularly suitable for low-strength structural applications like railway ballast as well as sub-base layers in road construction, where strength requirements are less critical but sustainability and cost-efficiency are prioritized. The crucial distinctive character like resource competency and material innovation makes RBA an attractive choice for sustainable construction projects. Tailored mix design approach and absorption properties are the key findings from this study which underscore RBA's potential as an eco-friendly substitute in concrete production. So, advancing in sustainable building practices, by optimizing these above-mentioned features, RBA can be well employed in targeted civil engineering applications.

Limitations and Recommendations: Prioritizing the resource conservation, RBA assists in minimizing the strain on disposing landfills while offering a viable alternative to traditional aggregates in various concrete uses. This practice contributes to waste reduction as well as supports environmentally responsible construction methods by promoting a circular economy within the construction industry. Nonetheless, this study has some certain limitations. Based on demolition waste, the discrepancy in the quality of recycled brick aggregates (RBA), which can significantly vary for the different characteristics was not fully investigated. To enhance RBA's performance, especially in reducing its absorption capacity, techniques such as using plasticizer admixtures, pre-saturating the aggregate, or applying water-reducing chemicals can be employed. Further exploration into the long-term durability, together with freeze-thaw resistance and shrinkage behaviour, would offer valuable understandings for the wide-ranging implementation of RBA in more demanding construction scenarios.

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