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ENHANCED PERFORMANCE OF BRICK AGGREGATE CONCRETE USING PARTIAL SUBSTITUTION OF SAND WITH WASTE GLASS AND FLAX FIBER INTRUSION

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Abstract- This paper addresses the growing concern over the depletion of natural resources and the environmental impact of their extraction in the construction industry. The study examined the impact of incorporating flax fiber (FF) and waste glass fine aggregates (WGFA) on the mechanical properties of recycled brick aggregate concrete. The investigation focuses on the compression, split-tensile and flexural strength of the modified concrete. The results demonstrate that the incorporation of FF and WGFA substitution can enhance the mechanical properties of brick aggregate concrete, with the 1% fiber and 50% WGFA mix showing promising results in terms of compressive strength, and the 2% fiber and 50% WGFA mix showing promising results in terms of split tensile and flexural strength.

Keywords- Concrete, Flax fiber, Mechanical properties, Recycled brick aggregate, Waste glass

1 Introduction

Concrete is widely used in construction due to its high strength and durability. As urbanization and development continue, there is an increasing demand for concrete as a construction material. However, the production of concrete alone consumes 33% of construction minerals, and the depletion of natural resources and the environmental impact caused by their extraction are significant concerns [1]. To address these concerns, alternative materials for partial or full replacement of naturally available materials in the construction industry are being explored. Recycled waste materials have been extensively researched for their potential application in concrete as substitutes for natural aggregate. Broken bricks from construction and demolition waste, which account for a significant portion of landfill waste, have been found to produce concrete with reasonably high strength and lower water permeability compared to artificial aggregate concrete. Crushed brick waste when utilized in concrete has been found to produce concrete with reasonably high strength and lower water permeability compared to artificial aggregate concrete [2]. While Gayarre et al. [3] discovered that the addition of recycled brick aggregates (ReBA) results in poor performance in terms of shrinkage and creep, it still falls within the acceptable limits for structural concrete. Additionally, Zhao et al. [4] reported that the inclusion of ReBA in concrete significantly improves its resistance against the effects of freeze and thaw actions. Thus, despite these limitations, the utilization of brick in concrete up to a certain limit as a coarse aggregate presents a sustainable approach to reducing the demand for natural resources.

Researchers have also investigated the use of discarded glass as a substitute for natural fine aggregates in concrete [5], [6]. While glass powder can improve concrete properties due to its pozzolanic characteristics, its reactivity is influenced by its size, shape, porosity, and solid phases. Silica in glass reacts with calcium hydrates ($Ca(OH)_2$) to generate calcium silicate hydrate (CSH) [7]. Additionally, it has been discovered that glass exhibits pozzolanic qualities when the particle size is less than 150 m. However, as particle size decreases, pozzolanic behaviors improve, i.e., 35 m outperforms 150 m [8]. Increasing the amount of waste glass (WG) aggregate up to 60% can boost compressive strength, but excessive use can weaken adhesion between the waste glass aggregate and the cement paste, leading to lower compressive strength in concrete with waste glass aggregate [9]. Moreover, fiber-reinforced cementitious composites have proved effective in enhancing the strength and ductility of concrete. Various synthetic fibers, such as polypropylene, nylon, glass, polyester, basalt, carbon, and steel fibers, can be utilized in concrete with appropriate sizes, types, aspect ratios, and fractions with respect to volume. Nowadays, the potential of natural fibers is being studied for their use in cementitious materials [10]. One promising natural fiber for incorporation in concrete is flax fiber (FF), which is produced from the stem of the flax plant. Amjad et al. found that addition of sisal fibers can significantly enhance the resistance of concrete against tensile stresses [1]. Another study conducted my Amjad et al. also found similar results [2]. A study conducted by Femandez [11] optimized flax fiber reinforced concrete to encourage the use of natural fibers in buildings. The study sought the optimum length and optimum ratio of FF in concrete to harvest its maximum benefits. The length of fiber was optimized at 3 cm. Tensile and compression tests were performed on cylindrical specimens and small beams were cast for a three-point bending test. Results displayed substantial enhancement occurred in the strength and toughness of FF-reinforced concrete. Similarly, Momina et al. [12] reported that the incorporation of 0.3% flax fiber with a length of 25 mm led to an approximately 4.5% enhancement in compressive strength. Thus, significant literature is available that supports that the addition of fibers in concrete can potentially improve the properties of concrete. However, literature related to the conjunction use of FF reinforcement and recycled glass powder as partial replacement of sand in ReBA concrete is not available. This study aims to investigate the mechanical properties of ReBA concrete that has glass powder as a partial replacement for sand and reinforced with FF. The mechanical properties were evaluated in terms of compressive and tensile strength.

2 Material and Experiments

The materials included Bestway Cement Type-1 Ordinary Portland Cement, Lawrencepur sand as the fine aggregate, and locally available Margalla crush as the coarse aggregate, meeting ASTM guidelines [13]–[16]. To obtain recycled brick coarse aggregate, waste bricks were obtained from the local demolished masonry structure and then were crushed in the crusher machine up to the size of 0.5 inches and down. The gradations of brick aggregates were done the same as that of natural coarse aggregates. Similarly, WG was collected from dump sites and scrap shops and then was broken down into smaller pieces and further ground into finer particles for its utilization as a partial substitution of sand, as illustrated in Figure 1. Table 1 and Table 2 provide the chemical constituents of the cement, properties of the fine aggregates, and properties of the coarse aggregate, respectively. The WG fine aggregate (WGFA) obtained was also examined through X-ray fluorescence (XRF), revealing its pozzolanic nature as depicted in Table 3 [6].

Table 1: Chemical Composition of Bestway Cement

CaO	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**SO_3**	**MgO**	**K_2O**	**Na_2O**
64.52	21.25	4.96	3.15	2.81	2.51	0.62	0.18

Table 2: Properties of fine aggregate and coarse aggregates

	Fineness Modulus	**Absorption (%)**	**Bulk Specific Gravity (SSD)**	**Size (mm)**
Sand	2.90	2.04	2.75	
WGFA	2.44	-	2.68	
Natural coarse aggregate	-	0.72	2.68	12.5
ReBA	-	13.44	1.92	12.5

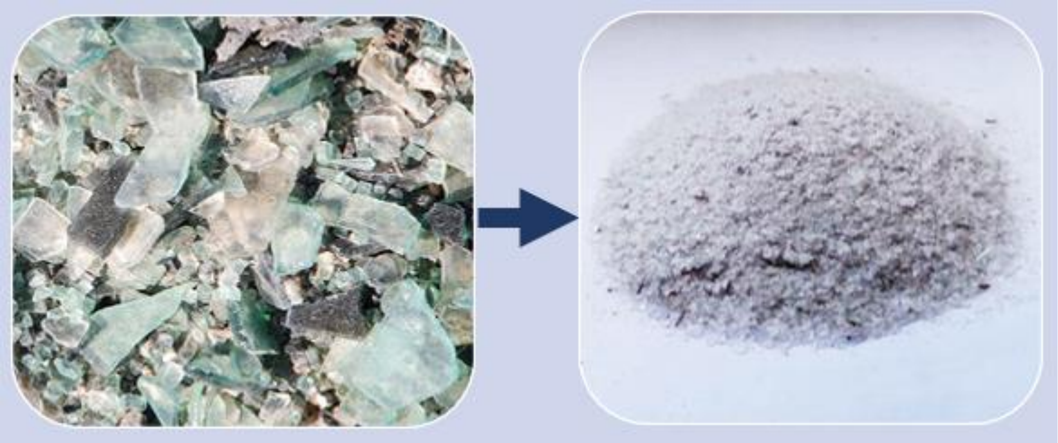

Figure 1: Preparing WGFA

Table 3: Chemical composition of WGFA

SiO_2	CaO	Al_2O_3	MgO	Fe_2O_3	Na_2O	K_2O	SO_3
68.82	18.02	2.25	1.59	1.03	5.72	0.43	2.14

Based on previous literature [10], [12], the FF was cut to an optimal length of 25 mm to be used in the cementitious mix as shown in Figure 2. The FF fiber exhibits an absorption capacity of 92% and a density of 1420 kg/m^3.

Figure 2:Visual of FF

2.1 Concrete Mix Proportions and Specimen Preparation

A total of 13 different concrete formulations were prepared, with one being a controlled mix without any recycled brick aggregate while the remaining having WGFA and FF as listed in Table 4. The concrete mix ratio used in all formulations was 1:1.3:1.9 (cement: fine aggregate: coarse aggregate), and the w/c was 0.45. To optimize the utilization of ReBA, the current research utilized a replacement ratio of up to 25%, which has been reported to have no significant negative effects on structural concrete [2]. All concrete mixes were supplemented with *Chemrite SP-303* superplasticizer at a weight percentage of approximately 1% to produce workable mixes.

Table 4: Concrete mix proportions

Mixes	**Cement (kg/m3)**	**w/c**	**Sand (Kg/m^3)**	**WGFA (Kg/m^3)**	**Natural Coarse Aggregate (Kg/m^3)**	**ReBA (Kg/m^3)**	**FF (Kg/m^3)**
CM	439.55	0.45	571.42	-	835.15	-	-
RBCM	439.55	0.45	571.42	-	626.36	208.79	-
RBCM10WG	439.55	0.45	542.85	28.57	626.36	208.79	-
RBCM25WG	439.55	0.45	514.28	57.14	626.36	208.79	-
RBCM50WG	439.55	0.45	457.14	114.28	626.36	208.79	-
RBCM1FF	439.55	0.45	571.42	-	626.36	208.79	4.39
RBCM1FF10WG	439.55	0.45	542.85	28.57	626.36	208.79	4.39
RBCM1FF25WG	439.55	0.45	514.28	57.14	626.36	208.79	4.39
RBCM1FF50WG	439.55	0.45	457.14	114.28	626.36	208.79	4.39
RBCM2FF	439.55	0.45	571.42	-	626.36	208.79	8.78
RBCM2FF10WG	439.55	0.45	542.85	28.57	626.36	208.79	8.78
RBCM2FF25WG	439.55	0.45	514.28	57.14	626.36	208.79	8.78
RBCM2FF50WG	439.55	0.45	457.14	114.28	626.36	208.79	8.78

All materials were carefully weighed according to the designated mix design and then dry-mixed in an electronic concrete mixer for a period of 2 to 3 minutes. Water was subsequently added, and the wet mixing process was continued for an additional 2 to 3 minutes. For each formulation, eight P.C.C. cylinders measuring 100 mm in diameter and 200 mm in height and two rectangular beamlets measuring 100x100x400 mm^3 were cast. After casting, the samples were left to dry-cure in moulds for 24 hours, under a temperature of 20±2 °C. At the end of the 24-hour curing period, the specimens were removed from their respective moulds and then placed in a water curing tank, maintained at a relative humidity of 100% at room temperature (23±2°C), and left to cure for the respective days.

2.2 *Testing Procedure*

The mechanical properties of the hardened formulated mixes were assessed in compression, tension, and flexural loadings. To determine the compressive strength, 100x200 mm^3 cylindrical samples were tested using the ASTM C39 method after 28 and 120 days. Splitting tensile strength, an indirect measure of tensile strength was evaluated by following the ASTM C469 guidelines on three 100x200 mm^3 cylindrical samples at 28 and 120 days. Flexural strength, which affects structural performance under bending, was also determined by utilizing the ASTM guidelines after 28 and 120 days on 100x100x400 mm^3 concrete prisms.

3 Results and Discussion

3.1 *Compressive Strength*

Figure 4 illustrates the compression strength of all the prepared concrete mixes at the 28th and 120th days of testing age. The inclusion of ReBA leads to a reduction in compressive strength owing to the inferior morphology of the bricks, which consequently affect the compression strength [4]. An increase in compressive strength was observed with an increase in testing age which was attributed to the progressive hydration reactions and the pozzolanic nature of the WGFA. Both the 28th and 120th day compression strengths of the prepared concrete mixes demonstrated an increase in strength due to the addition of WGFA. This was attributed to the angular structure of the WGFA particles, which promotes better bonding with the adjacent cement matrix. Additionally, the pozzolanic reactivity of the WGFA may also contribute to this effect [9]. The compressive strength of the 1% fiber-reinforced concrete mixes was enhanced due to the reinforcement effect of the fibers. Conversely, the compressive strength of the 2% fiber-reinforced mixes was decreased because, at higher fractions, the dispersion became much more difficult, resulting in the formation of agglomerates in the concrete mixture, thereby reducing the compression strength [17]. Among all the prepared mixtures, the mixture with 1% fiber and 50% WGFA exhibited superior performance, demonstrating the least reduction in compressive strength of approximately 3.5% and 3.1% at the 28th and 120th day of testing age, respectively, in comparison to the virgin concrete.

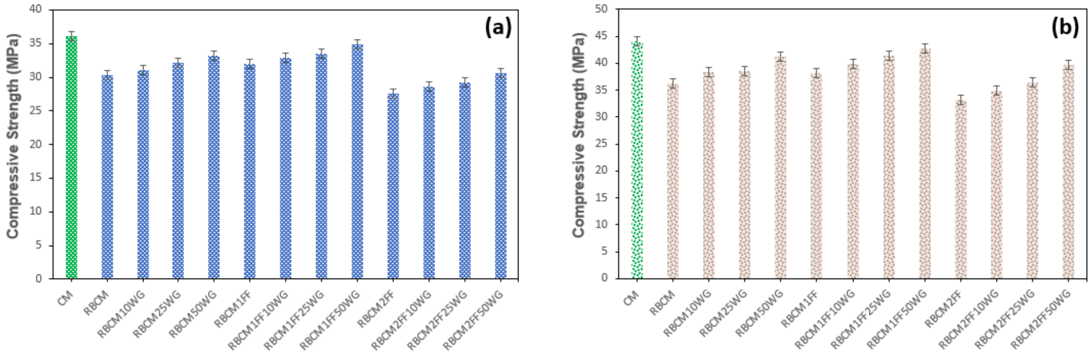

Figure 3: Compression strength of the formulated mixtures (a) 28th day (b) 120th day

3.2 Split-tensile Strength

The 28th and 120th day split tensile strength of all formulated concrete mixes is presented in Figure 4. As expected, the incorporation of recycled brick aggregate in the mixture was found to cause a reduction in split tensile strength due to the presence of voids and cracks in the brick aggregate. Results show that an enhancement in split tensile strength was observed as the testing age increased. This improvement can be attributed to the progressive hydration reactions and pozzolanic nature of waste glass fine aggregate (WGFA) used in the mixes. The results for split tensile strength were found to be similar to the ones observed for compression strength. Both the 28th and 120th day split tensile strength of the formulated concrete mixes demonstrated an increase in strength due to the addition of WGFA. This was due to the improved bond formation between the cement-WGFA interface and the pozzolanic reactivity exhibited by WGFA [9]. In contrast to the results observed for compression strength, where 2% FF-intruded mixes exhibited a decrease in split tensile strength, the split tensile strength of the formulated mixes still increased when FF content increased from 1% to 2%. This is because in the case of split tension the fiber reinforcement significantly dominates providing the confinement effect to concrete. These findings are consistent with those reported in previous literature [10], [17]. The study found that the mix with 2% FF and 50% WGFA outperformed all other formulations, exhibiting a 6.0% and 7.4% increase in split tensile strength at the 28th and 120th day of testing age, respectively, compared to the virgin concrete.

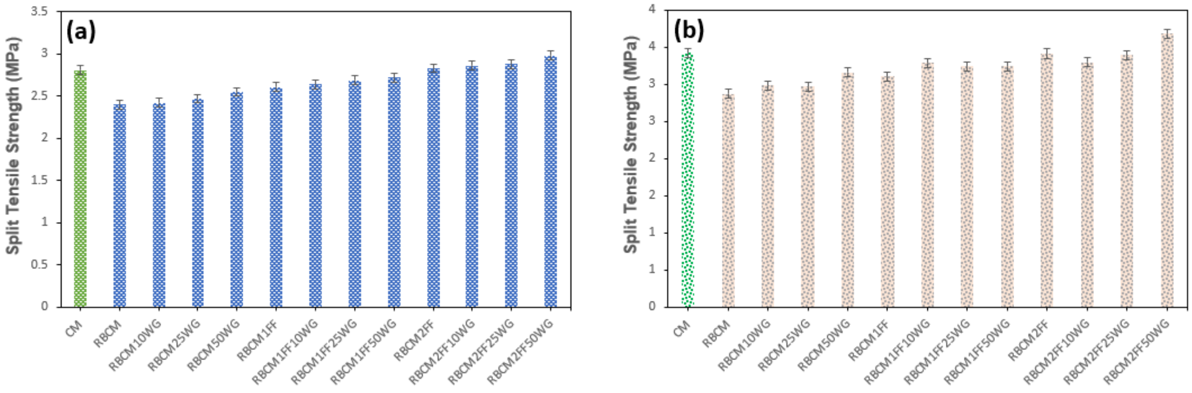

Figure 4: Split tensile strength of the formulated mixtures (a) 28th day (b) 120th day

3.3 Flexural Strength

Figure 5 presents the flexural strength of all formulated concrete mixes at the 28th and 120th days of testing age. The addition of WGFA and FF to the concrete mixes resulted in a similar trend in flexural strength as observed for split tensile strength, and the reasons explained earlier are also applicable to flexural strength. Among all the formulated mixes, the combination of 2% FF and 50% WGFA exhibited the best performance, demonstrating the least reduction in flexural strength of approximately 2.4% and 1.9% at the 28th and 120th day of testing age, respectively, compared to the virgin concrete.

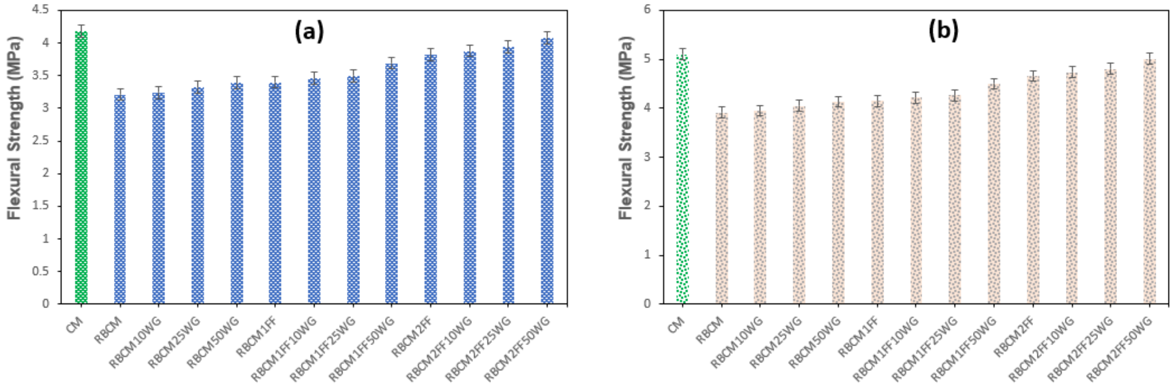

Figure 5: Flexural strength of the formulated mixtures (a) 28th day (b) 120th day

3.4 Practical Applications

The practical applications of enhancing the performance of brick aggregate concrete through the partial substitution of sand with waste glass and flax fiber intrusion are diverse and offer several benefits to construction projects. One significant advantage is the promotion of sustainable construction practices. By incorporating waste glass and flax fibers, this approach contributes to waste reduction and resource conservation. It enables the utilization of waste materials that would otherwise end up in landfills, effectively reducing the environmental burden associated with construction activities. Moreover, the addition of waste glass and flax fibers enhances the strength and durability of the concrete. Waste glass particles contribute to the overall strength of the concrete matrix, improving its load-bearing capacity. Flax fibers, on the other hand, act as reinforcement within the concrete, reducing the likelihood of cracks and enhancing its resistance to external forces, such as impact or cyclic loading. This results in more robust and long-lasting structures, reducing the need for frequent repairs or replacements. Another practical application is the improvement of thermal insulation properties. Waste glass exhibits insulating characteristics, making it suitable for applications where thermal efficiency is desired. By substituting sand with waste glass, the thermal conductivity of the concrete can be reduced, enhancing its insulation capabilities. This is particularly beneficial in regions with extreme weather conditions, as it helps regulate indoor temperatures, reduces energy consumption for heating or cooling, and contributes to energy-efficient building design. In terms of environmental impact, the use of waste glass and flax fibers helps to reduce carbon emissions and conserve natural resources. By incorporating waste materials into the concrete mix, the demand for virgin materials, is reduced. This lowers the environmental footprint associated with extraction and transportation, while also preserving natural ecosystems and minimizing habitat destruction. Furthermore, the application of waste glass and flax fibers can lead to potential cost savings. If waste glass and flax fibers are readily available as byproducts or waste materials in the local area, they can be obtained at lower costs compared to traditional raw materials. This can contribute to overall project cost reduction, making it an economically viable option for construction projects.

4 Conclusions

The following conclusions were drawn based on the findings of this research:

- With the inclusion of 1% FF and 50% WGFA substitution, the reduction in compressive strength was minimal at around 3.1% on the 120th day testing age.
- However, in terms of split tensile strength, the mix containing 2% fiber and 50% WGFA surpassed the virgin concrete, with an increase of 7.4% observed on the 120th day of testing.
- The reduction in flexural strength was minimal in the mix containing 2% fiber and 50% WGFA, which exhibited a decrease of approximately 1.9% on the 120th day of testing, in contrast to the virgin concrete.
- The enhanced performance of brick aggregate concrete through the partial substitution of sand with waste glass and flax fiber intrusion offers practical applications with numerous benefits for construction projects.

Thus, by incorporating waste materials and natural fibers, it promotes sustainability by reducing waste, conserving resources, and minimizing environmental impact. The addition of waste glass and flax fibers improves the strength and durability of the concrete, resulting in more robust structures with reduced maintenance needs.

It is recommended to extend this study in order to investigate the performance of this type of concrete under different environmental conditions, such as hot, cold, dry, wet, and cyclic dry-wet conditions.

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