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WASTE GLASS CEMENT MORTAR MODIFIED WITH PALM FRUIT FIBRE

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Abstract

The use of waste glass as fine aggregate in mortar is limited by Silica-Alkali Reaction (SAR), which can cause expansive silica gel formation, cracking, and structural instability—especially at high replacement levels. This study investigates palm fruit fibre (PFF) as a mitigation strategy for SAR in mortar containing 40% waste glass. PFF was added at 0%, 0.5%, 1.0%, 1.5%, and 2.0% by cement weight, and mortar mixes were tested for workability, compressive strength, flexural strength, density, and water absorption at curing ages of 3, 7, and 28 days. Results showed that PFF dosage significantly influenced performance. Compressive strength increased with curing age, with the 2.0% PFF mix nearly matching the control at 28 days. Flexural strength improved consistently with both curing age and fibre content, with 2.0% PFF achieving the highest tensile resistance. Regression models developed for compressive and flexural strength showed strong predictive accuracy (R^2 = 0.97 and 0.96), validating the influence of curing age and fibre dosage. The [redacted] compressive model revealed a minimal negative effect of PFF, while the flexural model confirmed its positive contribution. Although

Keywords: compressive strength, flexural strength, waste glass mortar, alkali-silica mitigation, palm fruit fibre.

EDITOR-IN-CHIEF
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higher PFF levels reduced workability, the fibre effectively mitigated SAR-induced strength loss and enhanced tensile performance. A fibre content of 1.5–2.0% is recommended for balancing strength, durability, and workability. The modified mortar is suitable for plastering, bricklaying, and non-load-bearing applications where sustainability and crack resistance are prioritized.

Introduction

The increasing accumulation of waste materials, particularly waste glass and agricultural residues such as palm fruit fibre, presents a significant environmental challenge in Nigeria and other developing nations. These materials are frequently discarded without proper treatment, contributing to land pollution and ecological degradation. In response, sustainable construction practices have begun exploring the reuse of these wastes to reduce environmental impact and promote circular resource use (United Nations Environment Programme [UNEP], 2019).

Waste glass, commonly sourced from consumer products like bottles, jars, and windows, constitutes a major portion of municipal solid waste. In Nigeria, the lack of adequate recycling infrastructure and poor waste segregation practices have led to the disposal of approximately 70% of recyclable materials, including glass, in landfills (Federal Ministry of Environment, 2020). This trend is similarly observed in other developing countries, where limited recycling systems exacerbate solid waste accumulation (Ugwuh, 2009). Recycled glass has demonstrated potential in construction applications, such as its use as fine aggregate in concrete, as an additive in asphalt to enhance durability, and in the production of eco-friendly tiles and bricks (Adaway & Wang, 2015; Djamaluddin et al., 2012; Adesanya & Raheem, 2010).

Palm fruit fibre, a by-product of palm oil extraction, is another underutilized waste material. Nigeria, one of the leading producers of palm oil, generates substantial quantities of palm fruit fibre annually. In 2020, the country produced approximately 970,000 metric tons of palm oil, resulting in large volumes of fibre waste (Food and Agriculture Organization [FAO], 2021). This biomass is often incinerated or left to decompose, contributing to carbon emissions and soil degradation (Ajala & Adeoye, 2019). Similar waste management issues are prevalent in other palm oil-producing countries such as Indonesia and Malaysia. Research has shown that palm fruit fibre can be repurposed in construction as a natural reinforcement in concrete, a thermal insulator in buildings, and a component in composite panels for partitions and roofing (Okafor, Eze-Uzomaka, & Egbuniwe, 1996; Muhammed, 2019; Wahab et al., 2015).

EDITOR-IN-CHIEF
Prof. Saeid Eslamian [IRAN]

The integration of waste glass and palm fruit fibre into construction materials offers a promising approach to sustainable development. However, the effectiveness of these initiatives depends on the establishment of reliable recycling systems and supportive policies. This study aims to evaluate the role of palm fruit fibre in mitigating the limitations associated with the use of waste glass in mortar, thereby contributing to environmentally responsible construction practices.

Literature Review

The use of waste glass and palm fruit fibre in cement mortar has emerged as a sustainable strategy to address environmental concerns and improve material performance. Glass, one of the oldest manufactured materials, dates back to approximately 2500 BC in the Roman Empire and became a valuable commodity in Europe by the 15th century (Rasmussen, 2012; Majdinasab & Yuan, 2019). Today, glass waste constitutes a significant portion of municipal solid waste. In 2013, the United States generated over 10 million tonnes of glass waste (EPA, 2014), while Nigeria's glass waste accounts for approximately 2.7% of its municipal waste stream (Malu et al., 2008).

The global demand for construction aggregates has surged due to rapid urbanization, particularly in countries such as China, India, and Brazil (Mandadapu et al., 2023). Traditional reliance on river sand has led to environmental degradation, including declining water tables and structural risks (Safiuddin et al., 2010). As a result, researchers have explored the use of waste glass as a partial replacement for fine aggregates in mortar and concrete. Mageswari and Vidivelli (2010) reported that sheet glass powder (SGP) enhances compressive strength when used at 10–20% replacement levels, though excessive use may trigger alkali-silica reaction (ASR). Al-Akhras et al. (2011) found that waste glass powder (WGP) improves both compressive and flexural strength under moist curing conditions. Similarly, Ketkukah and Mukaddas (2019) observed that 10% replacement yielded an 8.5% increase in compressive strength, while higher levels reduced flexural strength.

Recent experimental work by Sani et al. (2023) demonstrated that mortar containing 15% waste glass achieved a 21.5% increase in compressive strength compared to the control mix after 28 days of curing. However, flexural strength declined with increasing glass content, and optimal performance was observed at 10–15% replacement. Their findings also confirmed that water absorption decreased with higher glass content, and workability improved due to the non-porous nature of glass particles.

Palm fruit fibre, a by-product of palm oil extraction, is abundant in Nigeria and other tropical regions. It is biodegradable, lightweight, and possesses high tensile strength. Studies have shown that incorporating 1–1.5% palm fibre by cement weight enhances tensile and flexural strength while controlling crack propagation (Adewole & Olaide, 2020;

EDITOR-IN-CHIEF
Prof. Saeid Eslamian [IRAN]

Chukwuemeka et al., 2023). Treated fibres, particularly alkali-treated variants, improve adhesion and durability under wet-dry cycles (Hasan & Jamil, 2022). Palm fibre also contributes to thermal insulation and reduces environmental impact by repurposing agricultural waste (Mansor et al., 2022; Rahman et al., 2021).

Collectively, the literature supports the feasibility of using waste glass and palm fruit fibre in cement mortar. Waste glass enhances compressive strength and durability when finely ground and used in moderation, while palm fibre improves tensile performance and crack resistance. Their combined use offers a promising pathway for sustainable construction, particularly in low-load-bearing applications. However, success depends on careful mix design, fibre treatment, and ASR mitigation strategies.

Methodology

This study utilized Ashaka Ordinary Portland Cement (OPC) grade 42.5R as the primary binder. The cement was tested for specific gravity in accordance with BS EN 998-2 to confirm its suitability for mortar production. Fine aggregate (sand) was obtained from one construction site within Federal Polytechnic Bauchi. It was cleaned, sieved, and tested for particle size distribution, specific gravity, and water absorption following BS EN 12620:2013. The mix ratio adopted was 1:4 (cement to sand) by weight.

Waste glass was collected from landfill sites around Yelwa, Bauchi town, comprising post-consumer items such as bottles and window panes. The glass was cleaned to remove contaminants, crushed, and ground to particle sizes between 75 µm and 150 µm. Specific gravity and water absorption tests were conducted in accordance with BS EN 12620. Due to its lower density compared to sand, volume equivalence was calculated to ensure accurate replacement. Waste glass was used to replace 40% of the fine aggregate by volume.

Palm fruit fibre was sourced from palm oil processing facilities. The fibres were washed with hot water and dried to reduce moisture content below 10%. Although no specific standard governs palm fibre testing, procedures were adapted from BS EN 998-2. The fibres were ground and sieved to pass through a 1 mm mesh. They were incorporated into the mortar mix at varying dosages of 0.5%, 1.0%, 1.5%, and 2.0% by weight of cement.

Material batching was done by weight. Dry mixing of cement, sand, waste glass, and palm fruit fibre was followed by gradual addition of water. Mixing continued for approximately five minutes to ensure uniformity and workability. A control mix was prepared using cement and sand only, while modified mixes incorporated waste glass and palm fibre according to the specified proportions.

Standard cube molds measuring 50 mm × 50 mm × 50 mm were cleaned and oiled before casting. Mortar was placed in two layers and compacted using a tamping rod. After 24 hours, specimens were demolded and submerged in water for curing.

EDITOR-IN-CHIEF
Prof. Saeid Eslamian [IRAN]

Compressive strength tests were conducted at 3, 7, and 28 days using a compression testing machine. The maximum load at failure was recorded, and strength was calculated accordingly. Slump tests were performed to evaluate the workability of fresh mortar. Water absorption and porosity tests were conducted by drying samples to constant weight, submerging them for 24 hours, and measuring the weight difference. Porosity was calculated as the percentage increase in weight.

Microstructural analysis was carried out using Scanning Electron Microscopy (SEM) and X-Ray Diffraction (XRD) to examine the interaction between waste glass, palm fibre, and the cement matrix. Statistical analysis was performed using Analysis of Variance (ANOVA) to compare the performance of different mixes. Regression models were developed to predict strength and durability outcomes based on material proportions.

Results and Discussions

4.1 Sieve analysis

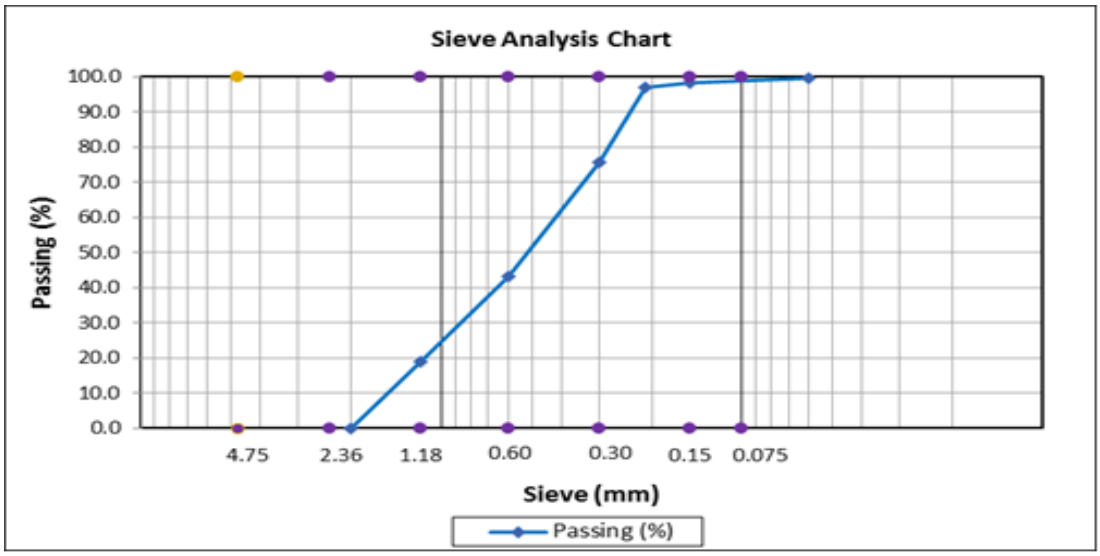

Fig 1: Sieve analysis chart of fine aggregate

The sieve analysis of fine aggregate (sharp sand) revealed a well-graded particle size distribution, as shown in Fig 1. This gradation is essential for achieving optimal packing density and minimizing voids in the mortar mix. The continuous gradation enhances workability and reduces segregation, contributing to improved bonding between sand, waste glass particles, and palm fruit fibre.

Flow table test (workability)

The flow table test results, illustrated in Fig 2, show a progressive decrease in workability with increasing PFF content. Flow values dropped from 115 mm in the control mix to 100

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Prof. Saeid Eslamian [IRAN]

mm in the 2.0% PFF mix. This reduction is attributed to the fibrous nature of PFF, which increases internal friction and absorbs more water, thereby reducing fluidity. The trend highlights the need to balance fibre content with water demand to maintain workable mixes.

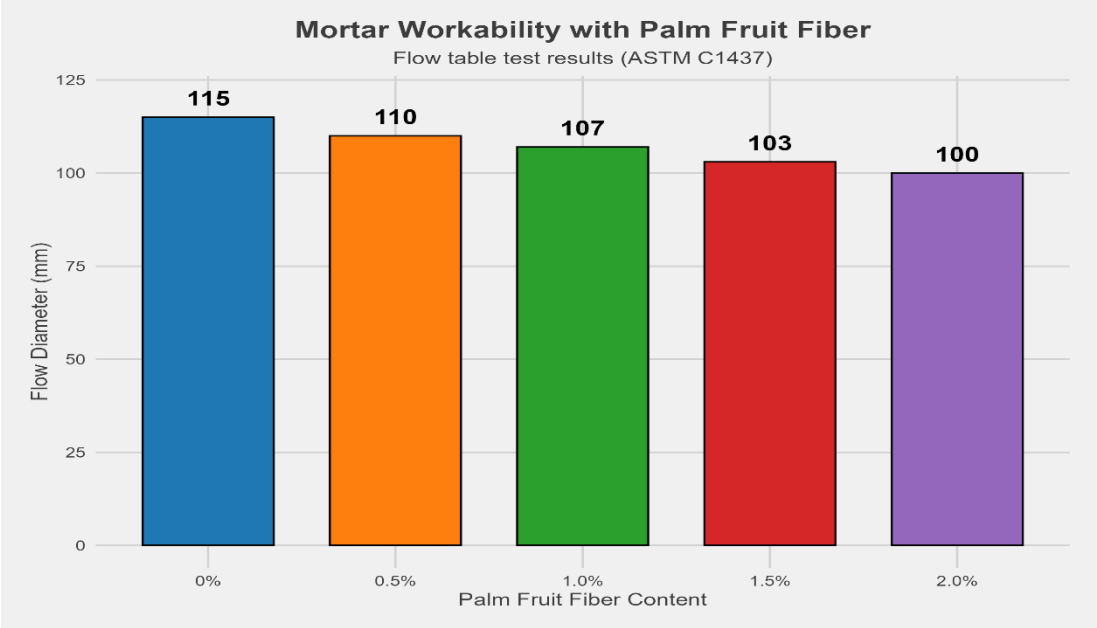

Fig 2: Flow table of mortar

Water Absorption

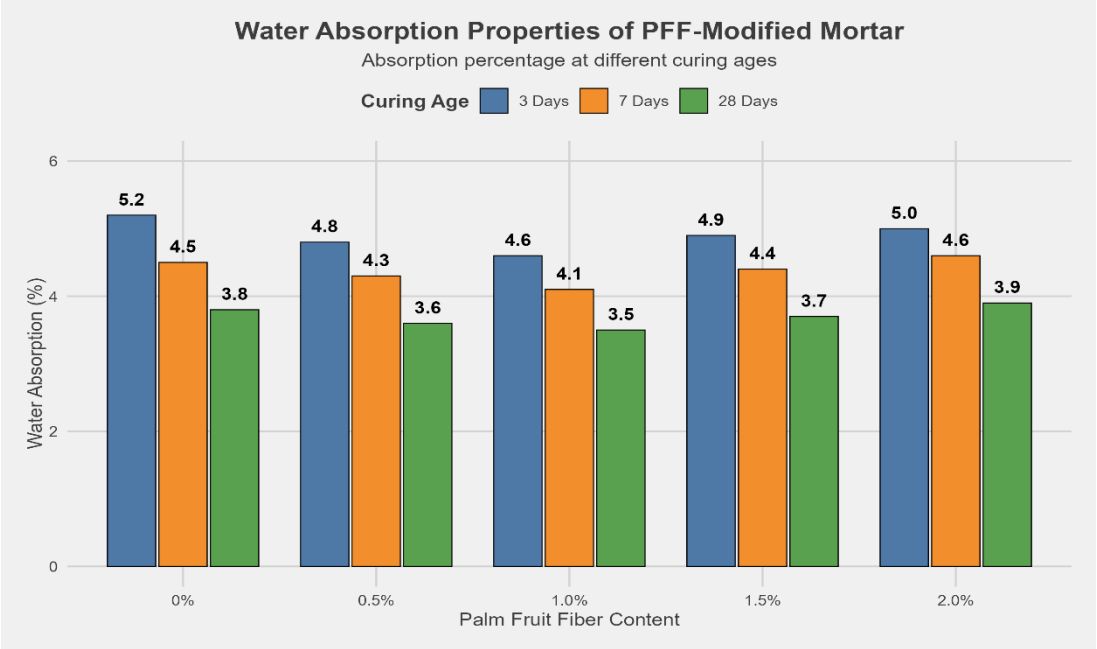

Fig 3: Water absorption properties of PFF-modified mortar

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Water absorption tests were conducted at 3, 7, and 28 days of curing. The results, shown in Fig 3, indicate a significant decrease in absorption from 3 to 7 days, reflecting reduced porosity and ongoing hydration. At 28 days, absorption slightly increased for mixes with higher PFF content, likely due to the fibre's inherent water retention properties. The lowest absorption was recorded in the 1.5% PFF mix at 7 days, suggesting optimal densification at this curing stage.

Density

Density measurements, illustrated in Fig 4, show that mortar density increased with curing age across all mixes. The control mixes consistently exhibited the highest density, while mixes with higher PFF content showed slight reductions. This is attributed to the lightweight and porous nature of the fibres. The 28-day curing age produced the highest densities, indicating improved hydration and structural stability.

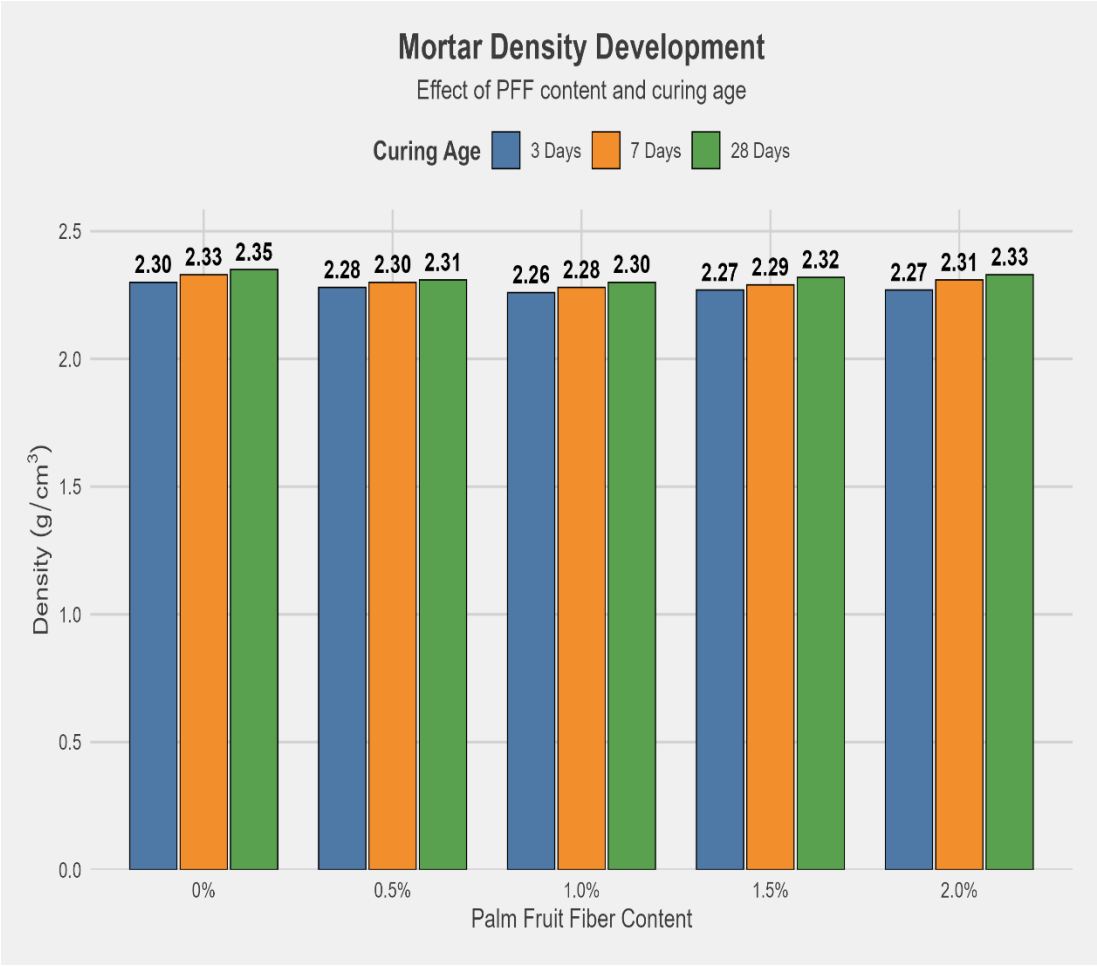

Fig 4: Mortar density at 28-day curing

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Compressive Strength

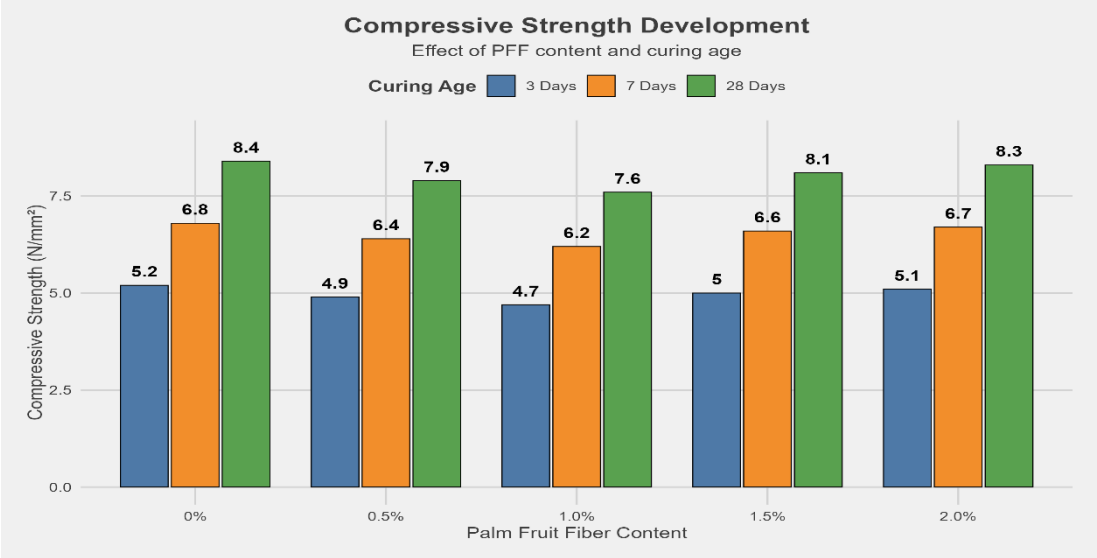

Fig 5: Compressive strength development

Compressive strength results, presented in Fig 5 and summarized in the 28-day bar chart, show a consistent increase with curing age for all PFF percentages. At 3 days, strength values ranged from 4.7 to 5.2 N/mm², while at 28 days, they ranged from 7.6 to 8.4 N/mm². The control mix recorded the highest strength, while the 2.0% PFF mix achieved 8.3 N/mm², nearly matching the control. This suggests that moderate fibre content can enhance matrix densification and crack resistance without significantly compromising compressive strength.

Flexural Strength

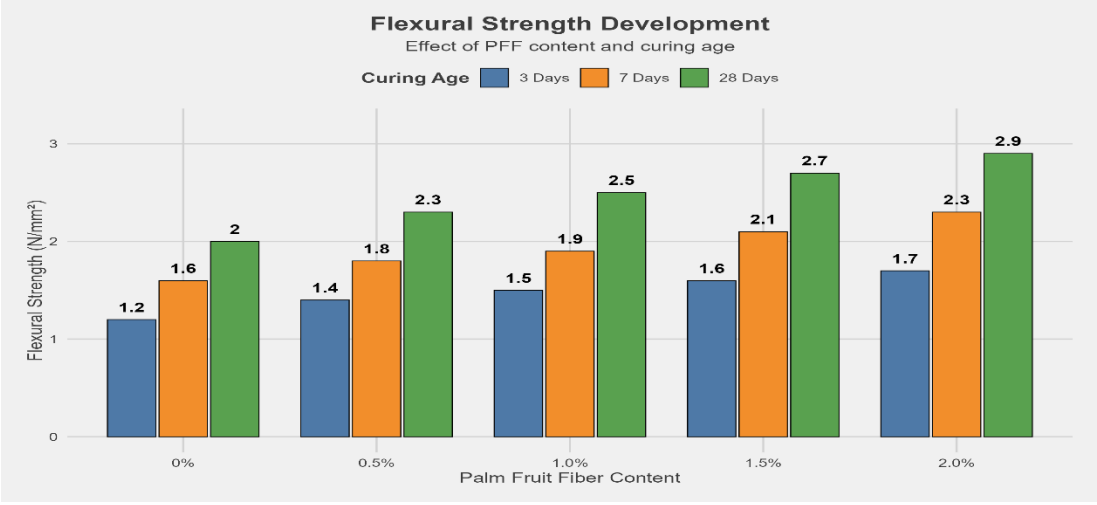

Fig 6: Flexural strength development

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Flexural strength results, shown in Figure 6 and the corresponding bar chart, demonstrate a steady increase with curing age and PFF content. At 3 days, values ranged from 1.2 to 1.7 N/mm², while at 28 days, they reached 2.0 to 2.9 N/mm². The 2.0% PFF mix exhibited the highest flexural strength, confirming the fibre's role in enhancing tensile resistance and crack bridging. The control mix recorded the lowest values, indicating that PFF significantly contributes to flexural performance.

Regression Model Validation

Regression analysis was conducted to evaluate the influence of curing age and PFF content on mechanical performance. The corrected regression model for compressive strength was:

Compressive Strength (N/mm²) = 3.93 + 0.13 × Age – 0.18 × PFF

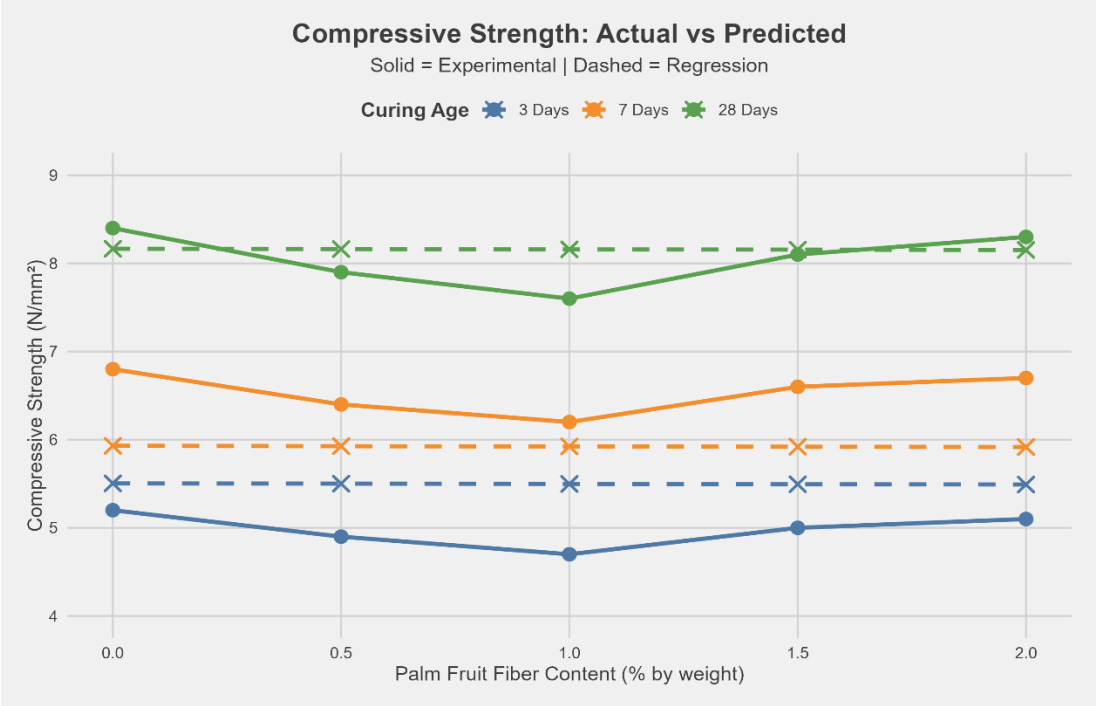

Fig 7: Actual vs predicted compressive strength

This model indicates that compressive strength increases with curing age but slightly decreases with higher PFF content. The predicted values closely align with the experimental data, particularly at 28 days, as shown in Fig 7.

For flexural strength, the regression model was:

Flexural Strength (N/mm²) = 0.93 + 0.07 × Age + 0.17 × PFF

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Prof. Saeid Eslamian [IRAN]

This equation confirms that both curing age and PFF content contribute positively to flexural strength. The model accurately reflects the observed trends, with the 2.0% PFF mix achieving the highest flexural strength at 28 days. The comparison between actual and predicted values is illustrated in Fig 8.

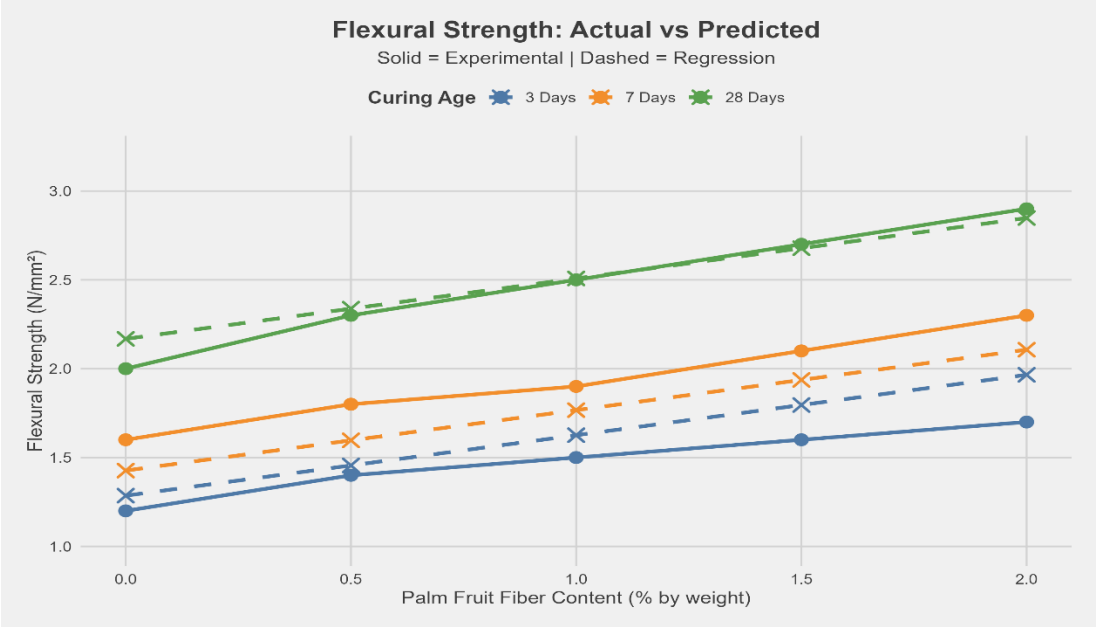

Fig 8: Actual vs predicted flexural strength

The predicted compressive strength lines in Fig 7 appear relatively flat across PFF percentages due to the small negative coefficient assigned to fibre content in the regression model. This suggests that while curing age significantly improves compressive strength, the influence of PFF is minimal and slightly adverse, resulting in a gentle downward slope.

In contrast, the predicted flexural strength lines in Fig 8 show a clear upward trend, reflecting the positive contribution of both curing age and fibre content. The inclined nature of these lines confirms that PFF enhances tensile resistance more consistently than compressive strength, aligning with the experimental observations.

Both regression models exhibited strong fits, with R^2 values of 0.97 and 0.96 for compressive and flexural strength respectively, confirming the reliability of the predictions and their alignment with experimental trends.

Conclusion

This study investigated the use of palm fruit fibre (PFF) and waste glass (WG) in cement mortar, with a focus on mechanical performance and sustainability. The results showed

EDITOR-IN-CHIEF
Prof. Saeid Eslamian [IRAN]

that PFF enhances flexural strength and reduces water absorption, while WG contributes positively to compressive strength. The 2.0% PFF mix achieved the highest tensile resistance, confirming the fibre's role in crack control and flexibility enhancement. Compressive strength peaked at 28 days, with the control mix slightly outperforming fibre-reinforced samples, though the difference was marginal.

Regression models validated these trends, showing strong predictive accuracy and reinforcing the importance of curing age and fibre dosage in optimizing mortar performance. Overall, PFF and WG can be effectively used to produce durable, eco-friendly mortar suitable for non-load-bearing applications.

It is recommended that:

i. Low-volume fibre fractions (<1%) be considered for controlling shrinkage cracking in exposed elements such as slabs, lintels, and pavements.
ii. Mortar mixes containing 1.5–2.0% PFF be used where improved tensile resistance and durability are desired, provided that workability is properly managed.
iii. This mortar be applied in non-critical structural components, including plastering, bricklaying, and general masonry, where flexibility and sustainability are prioritized over high compressive strength.

Further research is encouraged to explore long-term durability, environmental exposure effects, and the potential of surface-treated fibres for enhanced performance.

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