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EVALUATING THE FLEXURAL PERFORMANCE OF FUNCTIONALLY GRADED CONCRETE USING STEEL FIBRES AND RECYCLED AGGREGATES

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Abstract- The objective of this research is to compare the flexural performance of functionally graded concrete (FGC) to that of conventional Steel fibres reinforced concrete (SFRC). In this study, four concrete mixes were prepared, containing one SFRC mix, and three combinations of FGC mixes. The hooked end steel fibres were used in 0.75 % of the total mix volume in the SFRC and FGC mixes. In FGC mixes, recycled plastic aggregates (RPA) and recycled concrete aggregates (RCA) have been substituted for natural aggregates by 15% by weight. Under third-point loading, the flexural performance of beam-shaped specimens with the dimensions of 100x100x500mm was assessed. In addition, an Ultrasonic pulse velocity test was conducted on cubic specimens having dimensions of 100x100x 100mm to find the quality of concrete under the influence of steel fibres and recycled aggregates. According to the findings, FGC has a lower post-cracking flexural efficiency than ordinary SFRC. Furthermore, UPV values of FGC are higher than conventional SFRC. This research reveals the economic advantages of using the functionally graded materials (FGMs) concept to minimize the use of fibres.

Keywords- Recycled concrete aggregate, Recycled plastic aggregate, functionally graded concrete, Steel fibres reinforced concrete, Sustainability.

1 Introduction

Nowadays concrete is globally used for construction purposes. The high compressive strength, workability, and durability of ordinary Portland cement concrete (PCC) are some of the recognition factors. The PCC contributes satisfactory performance in the compression zone and no requirement of giving fibres as reinforced in this zone. It is, however, a brittle material with poor tension efficiency (about 10% of compressive strength) [1].To avoid the brittleness of PCC, various types of fibres are frequently utilized as reinforcement. Fibre-reinforced concretes (FRC) can boost the concrete's toughness, flexural strength, and failure mode [1]. Multi-scale fibres with macro fibre and calcium carbonate (CaCO3) whisker (CW) will increase the mechanical properties and peak strain energy of cementitious composites substantially [2], [3]. Besides, numerous studies have revealed that fibres might somewhat or entirely replace conventional reinforcement [4]. According to researchers, the dispersion of fibres over the entire volume of the concrete portion makes it uneconomical material [5]. In order to minimize the use of fibres, functionally graded concrete (FGC) was introduced. Functionally graded materials (FGMs) were first suggested by materials scientists in 1984 [6]. Functionally Graded concrete (FGC) is a layer-by-layer fabrication technique that produced with a gradation in mechanical properties to achieve an intended function. On the other hand, large volumes of waste are dumbed such as plastics and demolition wastes which badly affect the natural environment. Electronic waste in developing countries has the potential to damage people's health and cause pollution [7]. The idea of reusing demolition waste and plastics to generate RCA and RPA is strongly recommended to solve these issues.

The addition of fibres to ordinary PCC will increase its flexural strength. Substituting natural aggregates for recycled aggregates (RCA and RPA) in concrete can help to limit environmental harm. Due to its ecological and economic benefits, Almeshal et al.presented a study of 103 articles and concluded that reusing plastic waste in the manufacture of concrete or mortar appears to be an environmentally sustainable alternative for getting rid of plastic waste [8]. Recycled concrete aggregates make up a large portion of building and demolition waste, and their recycling is important for long-term construction sustainability [9]. A functionally graded concrete (FGC) concept was developed to combine the benefits of fibres and recycled aggregates. FGMs have the ability to combine different materials to form a continuous monolithic structure [10].In comparison to a standard single-layered lining, the outcomes show that functionally graded lining has a higher elastic ultimate bearing potential [11]. Further study shows that under cyclic loading FGC performs better than ordinary FRC [12].

The aim of this study is to compare the flexural performance of functionally graded concrete (FGC) by using Steel fibres and recycled aggregates (RPA, RCA) to that of conventional SFRC. There is a lack of research on the effects of combining recycled aggregates and fibres [13]. Therefore in this research three types of aggregates were used: natural coarse aggregate (NCA), recycled concrete aggregate (RCA), and recycled plastic aggregate (RPA).In this study, steel was used as fibre-reinforced material. This study presents the models of steel fibre reinforced concrete (SFRC) (A) and FGC concrete mixes (B, C, D). FGC mixes consists of Portland cement concrete (PCC) +SFRC (B), recycled concrete aggregate (RCA) +SFRC (C) and recycled plastic aggregate concrete (RPAC) +SFRC (D). As a reference mix, the SFRC mix was used. The basic third-point loading test was executed to compare the flexural performance of FRC and FGC. Whereas, the Ultrasonic pulse velocity test was performed to determine concrete's quality under the influence of fibres and recycled aggregates. The results of each mix are discussed, and conclusions are presented.

2 Experimental Procedures

2.1 Materials

Ordinary Portland Cement (OPC) according to ASTM C-150 was utilized in this study. And ordinary drinkable water was chosen. As a fine aggregate, Natural sand of the Lawrencepur brand was used. Three types of coarse aggregates were used: natural coarse aggregate (NCA), recycled concrete aggregate (RCA), and recycled plastic aggregate (RPA). The NCA of the Margalla brand was used. Recycled concrete aggregate (RCA) was obtained through the manual crushing of tested specimens of concrete. As a plastic aggregate, recycled electronic waste (E-waste) was used. Fig 2(a) depicts the E-waste aggregate. The particle size distributions (PSDs) are shown in Fig 1.

In this study Steel fibre (MasterFibre S 65) was used as reinforcement. The MasterFibre S 65 is a hooked end that complies with ASTM A820, Type 1. The length (L) of this fibre is 35 mm, the aspect ratio (L/D) is 64 and the tensile strength is 1345 MPa. Bonding agent 'ULTRA SBR latex' complying with ASTM C1059-86 was utilized. It was produced in the ratio of SBR: water: cement 1:1:3. Fig 2(b) depicts the steel fibres utilized in this study.

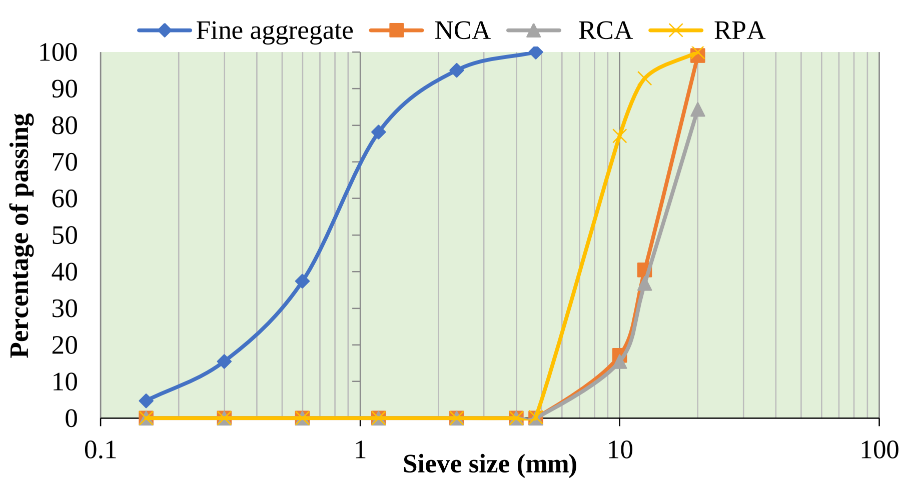


Figure 1: Particle size distributions (PSDs) of fine aggregates, NCA, RCA and RPA

2.2 Concrete mixes and testing procedures

Figure 3 depicts the models of four concrete mixes used in this research. These models consist of steel fibre reinforced concrete (SFRC) (A) and functionally graded concrete (FGC) mixes (B, C, D). FGC is made up of two layers of equal thickness. FGC group embraces Portland cement concrete (PCC) +SFRC (B), recycled concrete aggregate (RCA) +SFRC (C) and recycled plastic aggregate concrete (RPAC) +SFRC (D). Steel fibres were used to strengthen the bottom layer of all FGC mixes. Because concrete pavements are often bent, and thus the upper and lower layers are subjected to compression and tension, respectively [14]. Subsequently, PCC carries comparatively little tension loads; therefore, the reinforcement is only needed in the lower layer. All FGC mixes were compared to the SFRC mix, which was used as a reference mix.

To make the concrete mixes mentioned above, a total of four mix designs are required as shown in table 1. A 0.5 ratio of water to cement was selected. Steel fibres accounted for 59 kg/m3 of the total (0.75 percent in volume). Previous research has shown that when the fibres are between 0.5 and 1 percent of the concrete volume, there is a greater increase in residual flexure strength [15]. Furthermore, Debieb et al. reported an increase in compressive and flexural strength, especially at the 10% and 20% replacement levels [16]. As a result, the substitution percentage by weight of the natural coarse aggregates with recycled aggregates (RCA, RPA) was set at 15% in this study, and steel fibres accounting for 0.75 percent of concrete volume.

(a) (b)

Figure 2: (a) The prepared E-waste aggregates and (b) the used Steel fibres

A mechanical mixer was used to mix the concrete. The mixing process consists of two stages: the first stage involved the mixing of fine and coarse aggregates with half percent water for 4 minutes; the second stage involved the mixing of cement with the remaining half percent water for another 4 minutes. During the second level, steel fibres were added. The FGC mixtures were mixed for 8 minutes, while the SFRC mixtures were mixed for 12 minutes.

2.3 Production of concrete samples

Prismatic (100x100x500mm) samples were cast to test the flexural performance of the concrete mixes. Besides, an Ultrasonic pulse velocity test was also performed on cubic specimens having dimensions of 100x100x100mm to estimate the quality of concrete under the influence of recycled aggregates and steel fibres. The upper and bottom layers were defined using moulds (Fig 4. a-b). The bottom layer of concrete was mixed and cast according to the defined mark, then vibrated for 25 seconds. After that, a bonding agent (ULTRA SBR latex) was produced in the ratio of SBR: water: cement (1:1:3) and applied to the surface (Fig. 4. c-d). When a bonding agent becomes effective second layer (upper layer) of concrete was cast about 25 minutes later, up to the mould height (Fig. 4. e-f). The vibration of the top layer was decreased by 50 percent to prevent a mixture of the layers. A total of 12 prismatic and 12 cubic samples were made. After casting, all specimens were demoulded for 24 hours and cured for 28 days in water at room temperature (approximately 20 °C). A flexural strength test was used to assess the mechanical performance of steel fibres reinforced concrete (SFRC) and functionally graded concrete (FGC). Whereas, to ensure the quality and uniformity of concrete the Ultrasonic pulse velocity test was carried out.

Table 1- Mix designs (kg/m3)

Mixes ID	Cement	Water	Fine Aggregate	Coarse Aggregates			Fibres
				NCA	RCA	RPA	
Portland cement concrete(PCC)	422	211	672	1344	-	-	-
recycled plastic aggregate concrete(RPA)	422	211	672	1142	-	78	-
recycled concrete aggregate(RCA)	422	211	672	1142	202	-	-
steel fibre reinforced concrete (SFRC)	422	211	672	1344	-	-	59

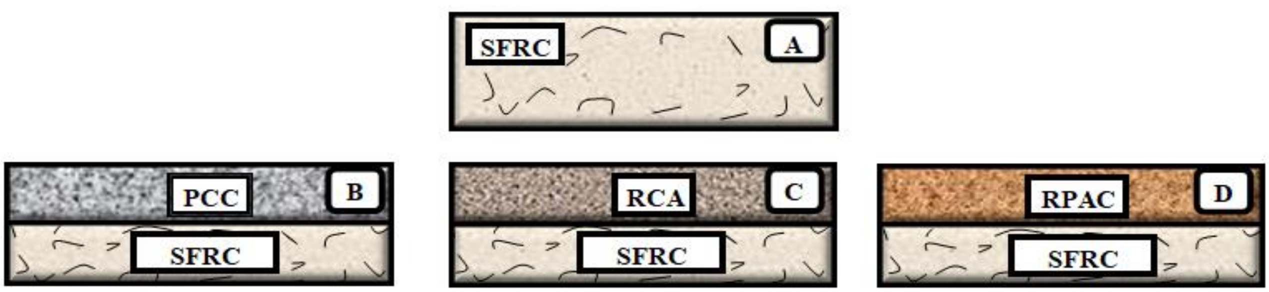


Figure 3: concrete mixes considered in this study

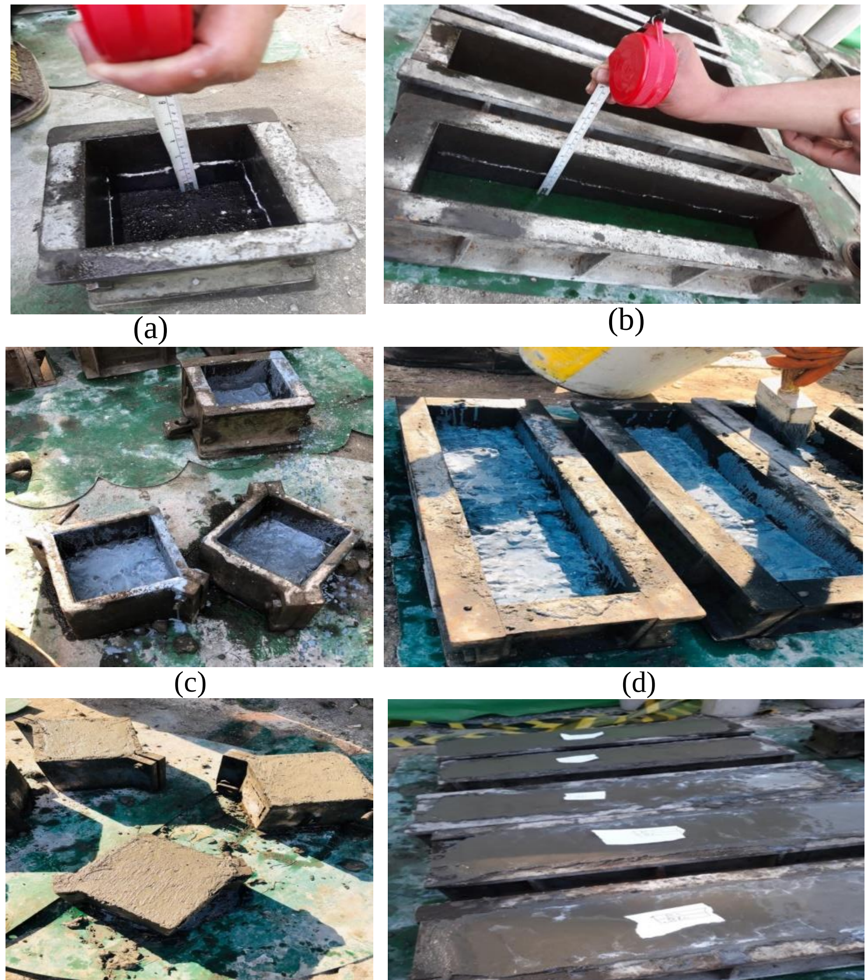
2.4 Flexural strength test

Modulus of rupture (MR) is another name for this examination. Under third-point loading at a rate of 0.5mm/minute, the flexural strength test was executed on beam-shaped specimens with dimensions of 100x100x500mm, as per ASTM C78 [17]. During the testing, flexural behavior and the crack pattern was being observed. Three samples were cast for each blend. Figure 5(a) depicts the prismatic sample being tested. Since fractures begin in the tension zone in the middle third of the span length, the formula for calculating the modulus of rupture (MR) is as follows:

$$f_r = \frac{P_u l}{bd^2} \qquad (1)$$

2.5 Ultrasonic pulse velocity (UPV) test

Non-destructive ultrasonic pulse velocity measurements are used to interpret concrete insufficiencies, such as non-uniformity and crack presence. This test was carried out on three cubic specimens, each measuring 100x100x100mm. Figure 5(b) depicts the cubic sample testing. This test is performed by sending an ultrasonic pulse through the concrete to be tested and measuring the time it takes for the pulse to pass through the structure. The values of ultrasonic pulse velocity were taken from the Ultrasonic Non-destructive Tester in accordance with ASTM C597-09 [18].



(a) (b) (c) (d) (e) (f)

Figure 4: Moulds are marked to define the upper and bottom layers: (a) cubic sample (b) Prismatic sample. The casting of the bottom layer along with an application of ULTRA SBR latex: (c) cubic sample, (d) Prismatic sample; and after casting of the upper layer (e) cubic sample, (f) Prismatic sample.

(a) (b)

Figure 5: (a) flexural strength testing and (b) UPV testing

3 Results and discussion

3.1 Flexural strength

Flexure strength results (mean value) of all concrete mixes (SFRC and FGC) are presented in fig.6. All of the FGC mixes were compared to the conventional SFRC mix. Eq. (2) can be used to calculate relative strength, from which the difference in strength can be calculated. The differences in flexural strength between FGC mixes and SFRC are thoroughly explained.

$$(f_{FGC} / f_{SFRC}) \times 100 \quad (2)$$

Figure 6 shows a comparison of steel fibres reinforced concrete (SFRC) and functionally graded concrete (FGC). PCC + SFRC mix has 5.5 % more flexural strength than traditional SFRC, RCA +SFRC mix has 1.8 % more flexure strength, and RPAC + SFRC mix has 13.3 % lower flexure strength. The best FGC mix was PCC + SFRC, which provided 5.5 % more flexural strength than conventional SFRC. Using recycled concrete aggregate (RCA) in concrete, on the other hand, helps to save the world by reducing the capacity of construction waste that closes up in landfills [19]. Therefore, FGC compositions of replaced recycled aggregates (RCA, RPAC) cast in the upper layer, combined with a bottom layer of fibres reinforced concrete, will eliminate environmental waste, thus leading to sustainable growth.

Cement optimization, serviceability performance, and an FGC member having the same deflection strength as a homogeneous component are just a few of the benefits of the FGC [20]. Concrete's functional gradation can be linked to a reduction in the element's mass and the formation of multifunctional properties [21]. As a result, using FGC in new construction can increase PCC's post-cracking behavior. Furthermore, the FGC concept in new construction is much more effective in bending members, enabling us to reduce the use of fibres that precede society's economic growth.

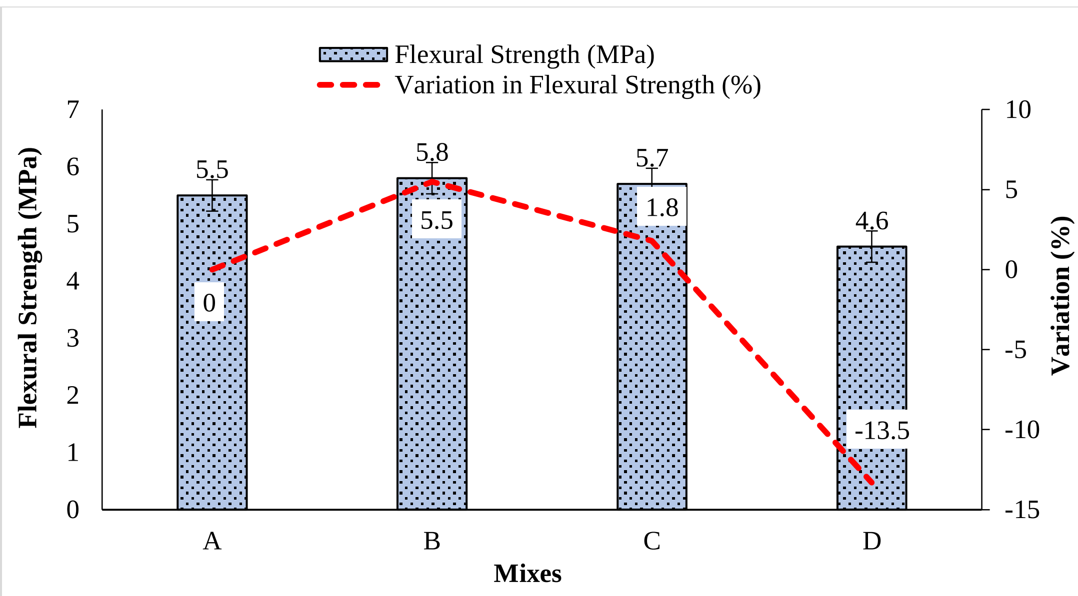


Figure 6: Flexure strength comparison of SFRC and FGC mixes

3.2 Ultrasonic pulse velocity (UPV) test

The UPV test was used to measure concrete's consistency under the influence of steel fibres and recycled aggregates. The UPV test results are presented in Figure 7. As suggested that Concrete has good durability when its pulse velocity value varies between 3660–4575 m/s [22]. Higher velocities indicate good material quality and consistency, while slower velocities can reveal concrete with numerous cracks or voids [23]. From the results, it can be observed that all calculated values are within the range indicated, which confirms the quality of both SFRC and FGC. Furthermore, the SFRC mix exhibits a lower UPV value than all FGC mixes. All FGC mixes have higher velocities than the SFRC mix because if we use FGC instead of SFRC, it will use fewer fibres. If the amount of fibres is reduced, then there will be fewer pores in the concrete and its UPV value will be greater. The results are in good agreement with the findings of L. Li.[24], who reported that the addition of fibres and calcium carbonate whisker (CW) decrease the ultrasonic pulse velocity (UPV) value. Finally, it has been concluded that FGC increases the quality and durability of concrete as compared to SFRC.

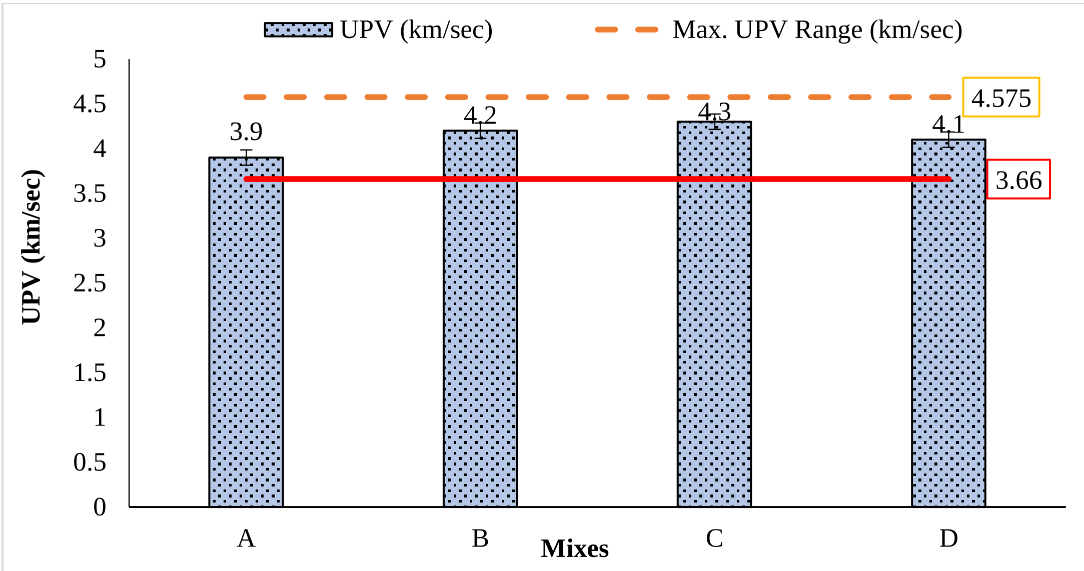


Figure 7: UPV test values of SFRC and FGC mixes

4 Conclusion

The experimental investigation conducted on the mechanical performance of Steel fibres reinforced concrete (SFRC) and functionally graded concrete (FGC) yielded the following conclusion.

- The mix PPC+SFRC and RCA+SFRC exhibit higher flexural strength compared to SFRC. While the flexural performance of RPAC+SFRC is lower than SFRC.
- The FGC combination of PCC+SFRC has a 5.5 % higher strength compared to the traditional SFRC.
- As compared to conventional SFRC, the FGC mix of RCA+SFRC has 1.8 % higher flexure strength, and the RPAC + SFRC mix has 13.3 % lower flexure strength.
- The strongest FGC mix combination is PCC+SFRC, which offers 5.5 % more flexure strength than traditional SFRC. Therefore, the FGC mix possessing PCC+SFRC is more effective and cost-efficient in bending members by reducing the fibres content.
- The ultrasonic pulse velocities of all FGC mixes are higher than the SFRC mix which ensures the concrete's consistency and uniformity.
- The FGC method, on the other hand, allows us to use fibres in one layer and cast the second layer from recycled aggregates concrete (RCA, RPA). It can support us in recycling everyday plastic waste and reusing demolished concrete as an aggregate substitute in new concrete in a cost-effective (environmentally friendly) manner.

In comparison to traditional SFRC, functionally graded concrete (FGC) is more efficient in flexural strength. As a result, FGC is suggested for the flexural member. However, utilizing different fibres, waste materials, and aspect ratios need to be examined along with the cost analysis to assess the FGC's performance.

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