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Performance Studies on Glass Fiber Reinforced Recycled Aggregate Concrete

J. Sivamani*[a], M. P. Thiyaneswaran[b], K. S. Navaneethan[b]

[a] *Department of Civil Engineering, Sona College of Technology, Salem, Tamilnadu, India*
[b] *Department of Civil Engineering, Kongu School of Architecture, Perundurai, Tamilnadu, India*

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ABSTRACT

The utilization of fibers in the concrete reduces cracks, increases the energy absorption and concrete strength. The use of fine recycled aggregate (FRA) in concrete overcomes the scarcity of natural aggregates, however its deprived quality affects the concrete properties through development of cracks. This study investigates the effect of glass fiber (GF) utilization in reducing crack propagation using fine recycled aggregate (FRA) in the concreteThe coarse natural aggregate (CNA) was replaced with 10, 30, 50, 70, 90 and 100% of FRA and GF was added 0, 0.25, 0.5, 0.75, 1 and 1.5% by weight. The concrete mixtures with the optimal percentage of FRA and different percentages of GF were prepared by two-stage mixing approach (TSMA) and normal mixing approach (NMA) and tested for their fresh and hardened properties. The optimized mix was observed with 30% of FRA and 1% of GF prepared by TSMA, with a strength improvement of 11.3% compared to the control mix at 28 days. The study further investigated the practical suitability as a paver block for non-traffic and medium volume traffic applications as per IS 15658: 2006 and observed that minimum strength requirement of 40 MPa was achieved under both conditions with the optimized mix with an improvement of 17.4% compared to conventional paver block.

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1. INTRODUCTION

The generation of waste from construction industries has been increasing rapidly due to significant renovation in construction activities in recent decades. Various wastes from construction include concrete, steel, wood, metals etc., among which concrete fractions contribute to the higher volume. The production of construction waste is around 3 billion tons annually around the world [1]. Among the 3 billion tons, the maximum contribution ensued from developed countries due to its increased construction and rehabilitation activities. It is to be noted that only 40% of generated wastes were reutilized in the momentary application, and the remaining were dumped. Feasibly, the demand for natural aggregates was also increasing, prompting the use of sustainable waste materials as an alternative. The global construction aggregate market (GCAM) predicted an increase in the aggregate market to 6.8% from 2020 to 2030[1]. Statistics also ensure that the consumption of natural aggregate will rise from 43 to 63 billion tons[2], and the demand for natural aggregate will rise by 5.2% [2]. Thus, it could show a positive approach to use construction waste as a suitable replacement for natural aggregates.

Numerous studies were performed to explore the utilization of construction wastes as recycled aggregates in concrete. The recycled aggregates are the concrete proportions of the construction wastes consisting of natural aggregates with cement mortar smeared. Andal et al. [3] found that replacing CNA with 30% and 100% of coarse recycled aggregate (CRA) reduces the strength of recycled aggregate concrete (RAC) by 10.3% and 15.21%. The strength improvement was attributed to the increase in the pore size in CRA resulting from cement mortar on its surface. Koper et al. [4] used CRA obtained from mixes with various W/C ratios and observed that the CRA from higher W/C ratios exhibits inferior properties than those with lower W/C ratios.

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*Corresponding Author Institutional Email: *jagan.civil@sonatech.ac.in* (J. sivamani)

[1] https://www.futuremarketinsights.com
[2] https://www.globenewswire.com/

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Thomas et al. [5] used CRA in different volumetric fractions and observed that replacement of CRA beyond 25% increases the water absorption of RAC with a maximum of 29.41% at 100% replacement. Ozbakkaloglu et al. [6] observed that replacement of CRA beyond 25% reduces the strength by around 11% due to the increased perviousness of CRA ensuing from the adhered mortar on CRA. Similarly, Mi et al. [7] used CRA collected from a source with different concrete strength and observed that the strength of the source concrete is directly proportional to the quality of the CRA owing to the dense mortar adhered to the CRA. Lavado et al. [8] found that the slump loss in RAC increases with time due to the higher porosity characteristics of CRA. The study reported that a 6% slump loss at 30 minutes was increased to 63% at 90 minutes. It could be observed that the concrete properties with CRA were affected due to its inferior quality, which is mainly due to the recycling of construction wastes. The construction wastes are recycled into different fractions of varying sizes for their use as coarse or fine aggregates in concrete. During recycling, micro-cracks develop on the CRA, which expands with repeated recycling stages, resulting in higher water absorption and thus affecting the concrete [9-11]. The higher porous nature of CRA tends to absorb water from the concrete mix, which upon hardening, evaporates, resulting in void formation. Such higher porous concrete tends to exhibit minimum compressive and flexural strength. To counteract such reduced strength, adding fibers will be a viable option in addition to several pre-treatments methods.

Several fibers, such as steel, polypropylene (PP), glass etc., have been used in practice in recent times to improve the tensile property of concrete. Few researches have been developed using single and hybrid fibers in recycled aggregate concrete. Akca et al. [12] used 25 to 45% of CRA with 1% of optimized PP fibers and observed a 17% increase in strength with 1% of PP fibers and a 20% decrease in strength beyond 1.5% of PP fibers. Chan et al. [13] optimized 0.66% of polypropylene fiber with 100% of CRA and observed concrete mixes with CRA only tend to show lesser strength due to its higher perviousness; however, with PP fibers, significant improvement in flexural strength and elastic modulus was observed. Gao et al. [14] used steel fibers up to 2% with different percentages of CRA and found that with equivalent fiber content and compressive strength, replacement of CRA had a diminutive influence on the durability of the concrete. He et al. [15] used hybrid steel fibers and PP fibers and found that with 1.5% of hybrid steel fibers, the strength of the RAC was enhanced by 23%, but with 1.2% of PP fibers, the strength was reduced by 5.5%. Similarly Gao et al. [16] investigated different fibers such as steel, PP and basalt and FRA and observed a decrease in workability with an increase in fiber volume due to the higher surface area of fibers that occupies more mortar. The study also reported a higher strength of 6 MPa with 1.5% mild steel fibers, 3.15 MPa with 0.198% PP fibers, and 3.4 MPa with 0.15% of basalt fibers. Gyanendra Kumar et al. [17] reported that the use of optimized percentage of CRA (25%) and PP fibers (2%) improves the strength of RAC by 25.4% and shear strength by 30.8% due to the strong bond between the interface of cement paste and fibers. Juric et al. [18] observed that use of recycled GF polymer in the concrete increases the load bearing cpapcity of the member by 33% compared to conventional. Balamuralikrishnan et al. [19] used Alccofine (a high glass content reactive % material) as an alternative to cement and observed 17% strength improvement. Dadzie and Kaliluthin [20] used waste plastic bottles in the production of voided concrete slab and obsereved 13% reduction in the cost and subsequent CO_2 and embodied energy emissions. Sivamani et al. [21] used FRA and observed optimal replacement of 30% increases the strength by 7.85% and decreased by 23.5% with 100% replacement. Pawar et al. [22] analyzed the stress-strain behaviour of recycled aggregate concrete using stress-strain curve model and observed that the efficacy of model is similar in ascending and varying in descending portion for strength prediction.

The effectiveness of the research relies on its suitable practical applications. In such a case, Pederneiras et al. [23] used CRA obtained from the site and laboratory up to 60% and observed a strength of 40 MPa suitable for medium traffic conditions. However, Tam et al. [24] used both FRA and CRA and observed a 5% increase in water absorption, but with a prolonged curing period, the strength was found to be equivalent to the mix with CNA. It could be observed from the brief literature review that use of CRA in concrete creates voids due to higher porosity that weakens the concrete micro-structure. So, few fibers such as steel, PP and basalt fibers were commonly used with CRA in concrete. However, the effect of crimped GF with FRA and its practical suitability in traffic applications still needs to be reported. Thus, this study investigates the influence of 0.25, 0.5, 0.75, 1, and 1.5% crimped GF with 10, 30, 50, 70, 90 and 100% of FRA on the concrete properties and its suitability under different traffic volume conditions.

2. METHODOLOGY

2. 1 Materials

This study used ordinary portland cement of 43 grades collected from the local vendor as per ASTM C150. Locally available river sand with a relative particle size of 1.18 mm~2.36 mm was used as fine natural aggregate (FNA). The concrete waste from a demolished building in the institution with particle size equivalent to FNA was used as fine recycled aggregate (FRA). The huge boulders from the site were broken initially with a hammer and then crushed with a jaw crusher machine. It is then sieved with a mechanical sieve to obtain the particle size distribution equivalent to FNA. The FNA and FRA were pre-soaked separately for 24 hours and surface saturated for 3 hours before their use in the casting [11]. The photographic reflection of FNA and FRA is shown in Figure 1. The FNA was replaced with 10, 30, 50, 70, 90 and 100% of FRA by its volume. The coarse natural aggregate (CNA) was the river gravel with particle sizes ranging from 10 mm~20 mm. The gradation curves of FNA and FRA are shown in Figure 2. The glass fiber (GF) collected from the local vendor were chopped to an aspect ratio of 30 and was added in the weight fractions of 0.25, 0.5, 0.75, 1.0 and 1.5% in the concrete. The glass fiber is highly durable, do not corrode and has higher validity than other fibers. The visual and microscopic observation of fibers is shown in Figure 3. The properties of GF from the vendor are given in Table 1.

2. 2. Methodology

The concrete mixtures are prepared as per IS 10262 (2009) to achieve a target strength of 30 MPa. Table 2 shows the mix proportions adopted with suitable material quantities. The concrete mixtures prepared with different aggregates were labelled as FRA-a-x-y, where ‘a’ represents the percentage of FRA, ‘x’ represents the percentage of fiber and ‘y’ represents the method of mixing adopted.

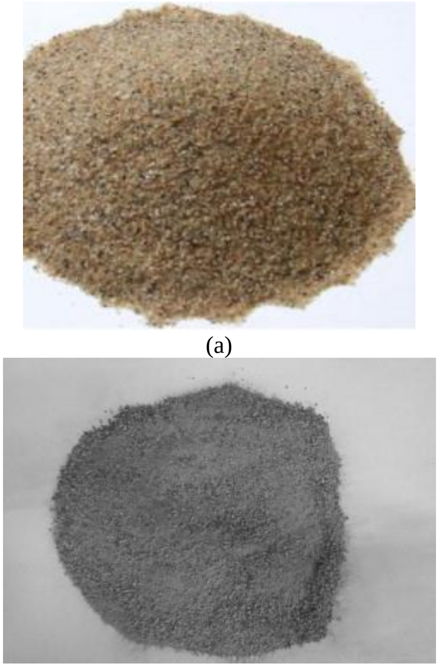
(a)

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Figure 1. Visual Observation (a) FNA (b) FRA

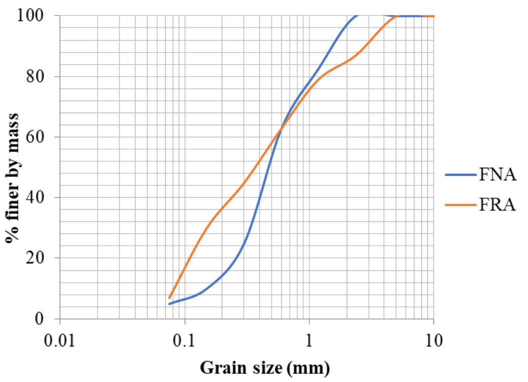
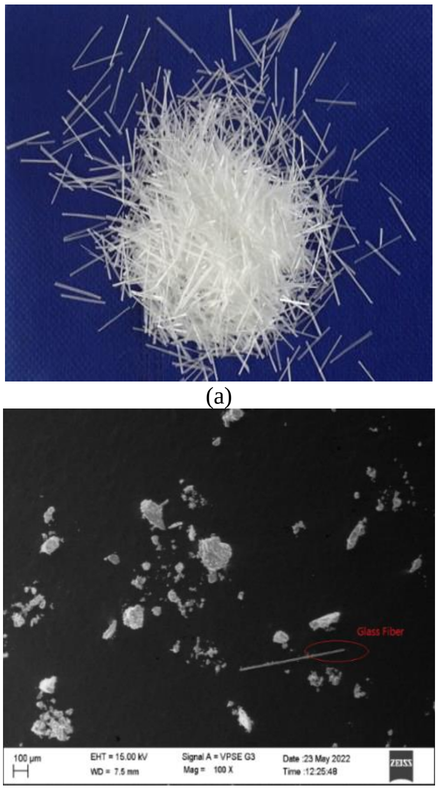


Figure 2. Gradation of fine aggregates



(a)

(b)

Figure 3. GF (a) Visual obervation (b) Microscopic observation

TABLE 1. Properties of GF

Fiber	Length (mm)	Aspect Ratio	Density (g/cm^3)	Elastic Modulus (GPa)
GF	18	30	0.84	70

For instance, the mix ID FRA-50-0.25-NMA indicates that the concrete mixture was prepared with 50% FRA and 0.25% GF by a normal mixing approach. In NMA, all the materials were added in suitable proportions and mixed well for 180 seconds to achieve uniform

TABLE 2. Concrete mix proportions (Optimized mixes)

Mix ID	(kg/m³)				
	CEMEN	FNA	FRA	CNA	Water
FRA-0-0-NMA	413	799	0	1029	186
FRA-30-0-NMA	413	559.	239.	1029	186
FRA-100-0-NMA	413	0	799	1029	186
FRA-30-1-NMA	413	559.	239.	1029	186
FRA-100-1-NMA	413	0	799	1029	186
FRA-0-0-TSMA	413	799	0	1029	186
FRA-30-0-TSMA	413	559.	239.	1029	186
FRA-100-0-TSMA	413	0	799	1029	186
FRA-30-1-TSMA	413	559.	239.	1029	186
FRA-100-1-TSMA	413	0	799	1029	186

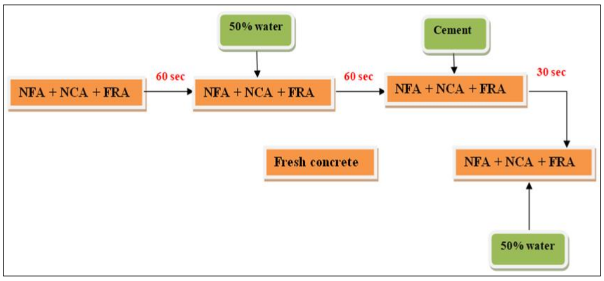


Figure 4. Schematic illustration of TSMA

blending. In TSMA, FNA, FRA, CNA and GF were added with half of the water and blended for 60 seconds. Following, cement was added and blended for 30 seconds, and the remaining 50% was added and mixed for 120 seconds [25]. The TSMA was uniquely adopted in the mixes with FRA as it tends to absorb excess water while mixing, affecting the workability of the concrete (Figure 4).

Initially, the concrete mixes were manufactured by NMA with different percentages of FRA to optimize the percentage of FRA, followed by the optimization of GF. The fresh concrete mixes prepared with optimized percentages of FRA and GF by both NMA and TSMA were tested for workability as per IS 1199 (1959). The fresh concrete was poured into moulds, vibrated and turned out into 150 mm cubes, 150 mm x 300 mm cylinders, and 500 mm x 100 mm x 100 mm prisms under laboratory conditions. The moulds were removed after 24 hours and tested for their hardened properties as per IS 516 (1959). The cubes were tested for compression, cylinders for tensile strength and elastic modulus and prism for flexural strength at 7, 14 and 28 days. The shear strength of the concrete was determined at 28 days [26]. All tests were conducted in trebles. It is essential for every research study to evaluate their suitability in real-time applications. In such perspective, the concrete mix with optimized FRA and GF was fabricated into hexagonal paver blocks (125 mm side area) and tested for non-traffic (60 mm thick) and medium volume (80 mm thick) traffic applications. For light volume non-traffic applications, the concrete mix was designed for M30 grade and for medium volume traffic applications, the concrete mix was designed for M40 grade. The paver blocks with varying thickness were tested for compressive strength at 28 days as per IS15658 (2006).

3. RESULTS AND DISCUSSIONS

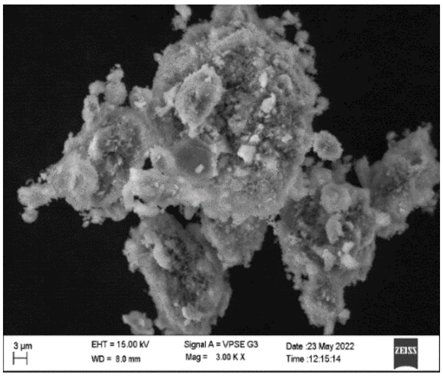
3. 1. Characteristics of Aggregates

Table 3 shows the properties of FNA, FRA and CRA used. The properties of aggregates were within the BIS limits (IS 383:2009). However, FRA's properties were inferior to FNA's due to its poor quality. The water absorption of FRA was 87% higher than FNA, and the density of FRA was 6.15% less compared to FNA. The higher porosity of FRA ensuing from the adhered mortar increases the water absorption and reduces the density [8, 10, 11]. Figure 5 shows the microstructure of FNA and FRA used in the study. The microstructure of FNA shows angular with flaky particles, whereas the microstructure of FRA, smearing of cement particles on the surface of it, causes an increase in porosity. Figure 6 shows the XRD patterns of FNA and FRA, and it is observed that the FNA shows higher silica and lesser calcite, whereas, in FRA, calcite is more than silica. The

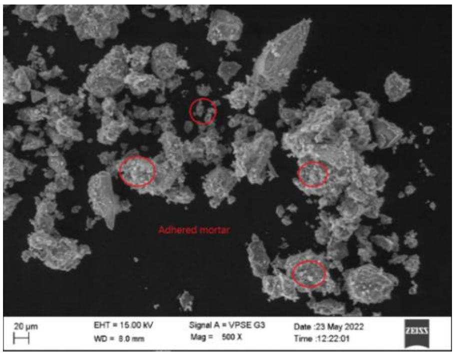
TABLE 3. Properties of aggregates

AGGREGATE	G	W.A (%)	C.V (%)	I.V (%)	D (kg/m³)
FNA	2.53	0.93	-	-	1526
FRA	2.41	7.12	-	-	1432
CNA	2.73	0.87	20.41	17.23	1978

G – specific gravity; W.A. – Water absorption; C.V – Crushing value; I.V – Impact value; D – Density

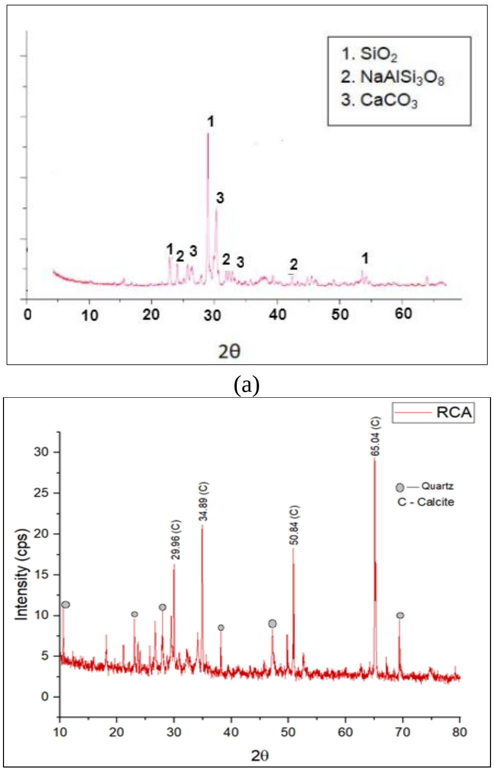


(a)



(b)

Figure 5. Microstructural images (a) FNA (b) FRA



(a)

(b)

Figure 6. XRD images (a) FNA (b) FRA

former favors the C-S-H formation, while the latter is due to the smearance of cement mortar on recycled aggregates.

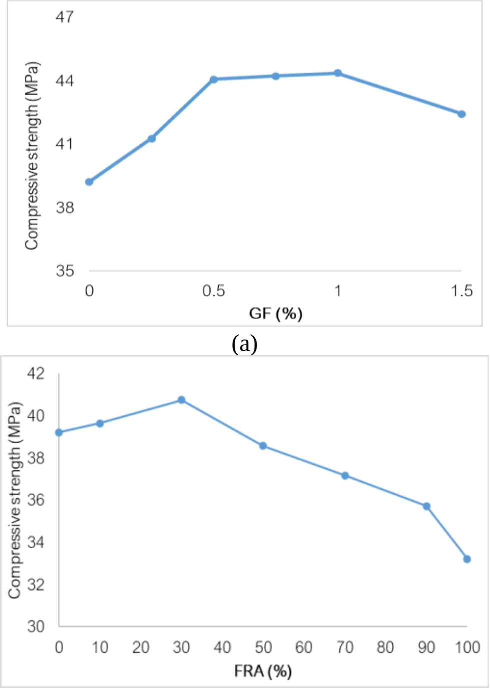
3. 2. Optimization of FRA and GF

Figure 7(a) shows the variation in strength with the addition of GF. The optimum GF was 1%, with an increase in strength of 11.6% at 28 days. The strength of concrete with 0.25%, 0.5% and 0.75% of GF was increased by 4.9%, 11% and 11.32%. An increase in strength mainly depends on the percentage of GF. The crack-arresting property of GF increases the energy absorption of the concrete and improves its strength [27]. Conversely, with 1.5% of GF, the strength was reduced by 7.5% at 28 days. The reason may be the wrapping of aggregate by excess GF weakening the interlocking bond or uneven orientation/dispersion of GF in concrete [28].

Figure 7(b) shows the variation in strength with the addition of FRA at 28 days. The strength of concrete with 10% and 30% of FRA was increased by 1.1% and 3.8%. It is observed that only minimum improvement in the strength was observed which is due to the higher angularity of particles resulting from the crushing process [11, 29]. However, with 50%, 70%, 90% and 100% of FRA, the strength of concrete was reduced by 1.6%, 5.2%, 8.9% and 15.3%. The reduction in the strength of concrete was mainly influenced by increase in the porosity of FRA as a result of cement mortar smeared on it [10, 30]. Various other factors such as source, size, age, percentage of mortar etc. influence the strength of RAC. The production of FRA involves series of crushing to reduce the large boulder construction wastes to finer particles. During recycling, micro-cracks develop on recycled aggregates which prolongs with an increase in the crushing stages causing higher porosity in FRA and reducing the strength of the concrete.

3. 3. Properties of Concrete with Optimized Mixes

It could be observed that 30% of FRA and 1% of GF tend to improve the strength of concrete individually.



(a)

(b)

Figure 7. (a) Variation in strength with GF (b) Variation in strength with FRA

However, the effect of GF on the properties of the concrete with FRA by NMA and TSMA is the main intend of the research. Ten different mixes by NMA and TSMA with optimized percentage of FRA and GF was considered to investigate the concrete properties.

3. 3. 1. Workability The workability of optimized concrete mixes is shown in Figure 8. It is observed that the workability of mixes with FRA decreases; however, with TSMA, the workability improves. The slump of NAC was found to be 70 mm; however, with 30% of FRA, the slump was reduced by 14.3%. Similarly, with 100% of FRA, the slump of RAC prepared by NMA reduced by 71.4%. The higher porosity of FRA absorbs mixing water reducing the required water for a homogenous concrete mixture and reducing the workability of concrete [31, 32]. Through TSMA, the workability of NAC was found to be 75 mm, and the slump of the mix with 30% and 100% of FRA was reduced by only 10% and 64%. The mechanism of adding water in two stages in TSMA overcomes the negative effect of higher water absorption of FRA and insufficient water during concrete mixing [11, 20]. The addition of fibers further tends to reduce the slump of the concrete mixes, irrespective of aggregate replacement. The slump of FRA-30-1-NMA was reduced by 18.6%, and the slump of FRA-30-1-TSMA was reduced by 15.7%. Similarly, the slump of FRA-100-1-NMA was reduced by 74.3%, and the slump of FRA-100-1-TSMA was reduced by 67.2%. The higher surface area of GF requires more mortar to wrap and thus reduces the slump of the concrete [14]. Nevertheless, the mix with equivalent fiber content prepared by TSMA shows little higher slump values due to the addition of water in two-stages during concrete mixing. Similar other studies [10, 19] show improvement in the workability of RAC due to the influence of TSMA.

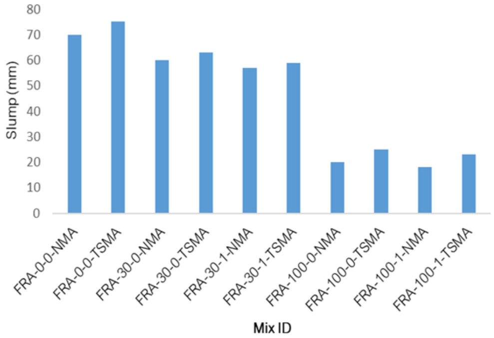


Figure 8. Workability of the mixes

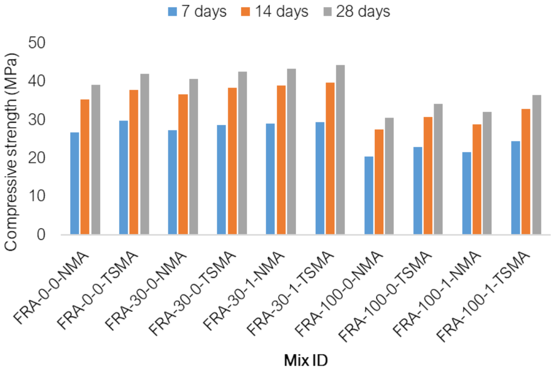


Figure 9. Compressive strength of the mixes

3. 3. 2. Compressive Strength The compressive strength of optimized mixes is shown in Figure 9. The control mix FRA-0-0-NMA shows a strength of 39.2 MPa at 28 days, which meets the required target strength of M30 grade concrete. However, the strength of the control mix by TSMA was further enhanced by 6.5% due to the effectiveness of the mixing technique. When FNA is replaced by 30% of FRA, the strength is improved by only 1.9% at 7 days and 3.8% at 28 days. With TSMA, the strength was further improved by only 6.4% at 7 days and 8% at 28 days. However, with 100% FRA, the strength was reduced by 19.6% at 7 days and 18.1% at 28 days. The strength reduction with excess FRA particles is due to its poor-quality ensuing from the smearing of cement particles. A similar improvement in strength was observed in the TSMA mix, even with 100% of FRA. Upon the addition of fibers, the strength of RAC increases up to 1%, beyond which it decreases. The maximum compressive strength was achieved at 1% of GF with 30% of FRA as 44.23 MPa at 28 days. It could be observed that the strength improvement was 11.3% compared to control concrete, and only a 3.6% improvement was observed with the addition of GF. The variation with the addition of GF was observed to be minimum, as GF does not significantly impact the strength of RAC [33].

The higher angularity and aspect ratio of GF forms a grid that bridges within the matrix and arrests the crack propagation further upon loading. Nevertheless, adding a higher percentage of GF causes uneven distribution of fibers leading to the localization of fibers to specific regions. Such characteristics lead to void formation, and thus the reduction in strength was observed. In addition, a higher percentage of GF consumes excess mortar due to its increased surface area, affecting the workability and strength of the concrete. However, minor variations in strength were observed in optimized mixes, even with 100% of FRA and optimized GF. The strength of FRA-100-1-NMA was reduced by only 19.4% at 7 days and 18.1% at 28 days, and the strength of FRA-100-1-TSMA was reduced by 8.9% at 7 days and 7.2% at 28 days.

The addition of GF has shown only minimal improvement in the concrete strength. Few studies on fiber-reinforced RAC infer that the elastic modulus of fibers influences concrete strength. He et al. [15] reported that adding 1.5% of steel fiber with an elastic modulus of 210 GPa shows a 23.2% improvement in strength, whereas the GF with the elastic modulus of 35 GPa reduces the strength by 5.5%. Furthermore, Gao et al. [16] used hook-end steel fiber, micro steel fiber, PP and basalt fiber (BF) and inferred that PP and BF show reduced strength compared to steel fibers due to their lower elastic modulus. Compared with steel and PP fiber, the elastic modulus of GF was lesser, resulting in minor strength improvement in the concrete.

3. 3. 3. Split Tensile Strength

The split tensile strength of the optimized mixes is shown in Figure 10. The variation in the trend of split tensile strength is similar to that of compressive strength for all optimized mixes. The tensile strength of control concrete with NMA and TSMA was 3.21 MPa and 3.47 MPa at 28 days. With 30% of FRA, the tensile strength was improved by only 4.5% for NMA mixes and 9.1% for TSMA mixes. However, with 100% FRA, the tensile strength was reduced by 22.7% for NMA mixes and 12.5% for TSMA mixes. The reason behind the variation in tensile strength with the addition of FRA and TSMA was equivalent to compressive strength.

Similar to compressive strength, the tensile strength of glass fiber-reinforced RAC tends to increase. The tensile strength of FRA-30-1-NMA and FRA-30-1-TSMA was improved by 11.32% and 12.5% at 28 days. However, with 100% FRA, the tensile strength was reduced by only 20.2% for NMA mixes and 11.2% for TSMA mixes. The addition of GF has a better influence on tensile strength than the compressive strength of RAC. When specimens are loaded for splitting, GF-oriented transverse to the longitudinal direction of the specimen acts as a link in effective load transfer carrying an additional load and thus improving the tensile strength of the concrete. In addition, localization of stress might occur in the mixes beyond the optimized percentage of GF, reducing the tensile strength of the concrete. Similar other study by Akca et al. [12] show influence of stress localization with the addition of excess fibers that affected the tensile strength of the concrete.

Besides the surface texture, dispersion, elastic modulus, and fiber orientation influence the concrete's strength. Figure 11(a) shows the effect of the orientation of GF on the concrete strength. It could be observed that fibers-oriented transverse to the direction of the applied load are subjected to tensile load. In contrast, those oriented along the applied load will compress rather than tension resulting in crumbling. This could reduce the strength as the fibers are strong in tension and weak in compression. Figure 11(b) shows the effect of excess GF on the concrete strength. The addition of excess GF causes uneven dispersion/accumulation of GF in a specific region leading to the localization of stress. This, in turn, causes void formation in that region resulting in a reduction in the concrete strength.

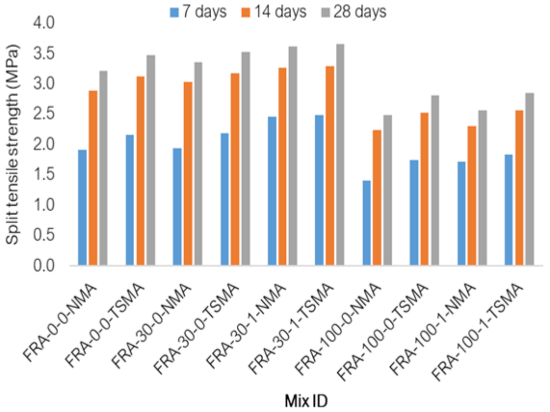
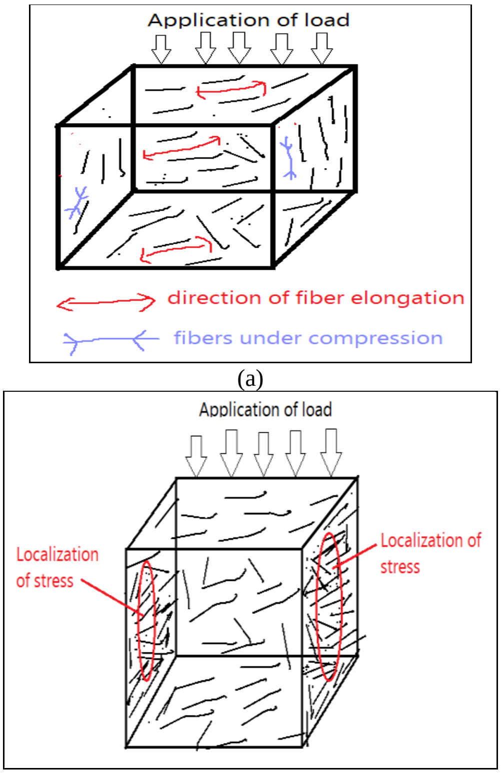


Figure 10. Split tensile strength of the mixes

3. 3. 4. Flexural Strength

The flexural strength of the optimized mixes is shown in Figure 12. The flexural strength of F-30-0-NMA and F-30-0-TSMA



(a)

(b)

Figure 11. Schematic illustration (a) Orientation of GF (b) uneven dispersion of GF

was 2.3% and 4.9% more compared to the control concrete. With 100% of FRA, the flexural strength of the F-30-0-NMA and F-30-0-TSMA was reduced by 14.3% and 11.1%. After adding GF, the strength of F-30-1-NMA and F-30-1-TSMA was further improved by 16.2% and 17.8%. For the mix with 100% of FRA, adding 1% of GF reduced the strength by only 12.4% and 10.3%. The variation of flexural strength was observed to be in a similar compressive and tensile strength tendency.

3. 3. 5. Shear Strength

The shear strength of the optimized mixes is shown in Figure 13. It could be observed that shear strength decreases with an increase in the FRA. The shear strength of the concrete with 30% FRA was improved by 2.5%, while with 100%, shear strength was reduced by 7.2%. The shear strength reduction with increased FRA is due to poor bonding characteristics between recycled aggregate and matrix resulting from adhered mortar [17]. After adding 1% of GF, the shear strength with 30% GF was increased by 3.6% and the shear strength with 100% of GF was reduced by only 2.2%. The addition of GF improves the bond characteristics by bridging the cement matrix firmly and improving the shear capacity of the concrete.

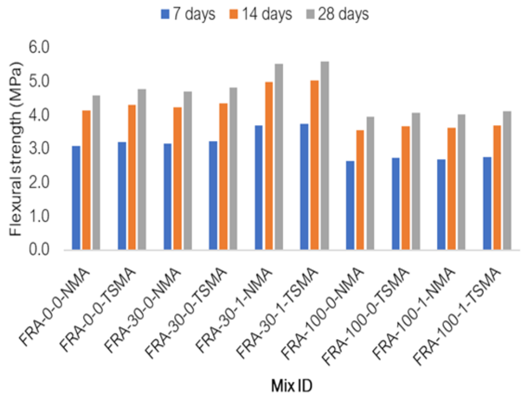


Figure 12. Flexural strength of mixes

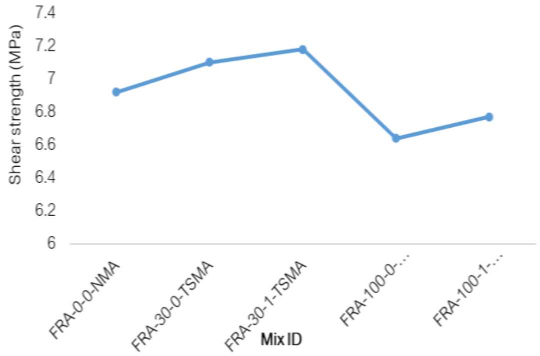


Figure 13. Shear strength of the mixes

3. 4. Effect of GF on the Performance of Paver Block

The influence of GF on RAC was observed to yield positive results with the mix containing optimized FRA of 30% and GF of 1% prepared by TSMA. So, the study evaluates the performance of paver blocks with glass fiber-reinforced RAC. Figure 14 shows the compressive strength of the paver block at 28 days. For non-traffic applications, the strength of FRA-30-0-TSMA was increased by 1.2% and the strength of FRA-100-0-TSMA was reduced by 21.7%. However, the strength of FRA-30-1-TSMA was increased by 4.5% and the strength of FRA-100-1-TSMA was reduced by only 17.4%. Similarly, for medium traffic applications, the strength of FRA-30-0-TSMA was increased by 1.9% and the strength of FRA-100-0-TSMA was reduced by 20.38%. However, the strength of FRA-30-1-TSMA was increased by 5.4% and the strength of FRA-100-1-TSMA was reduced by only 15.8%. It could be observed that the addition of GF tends to increase the strength of the paver block. Furthermore, for medium traffic volume applications, with optimized GF and FRA, the strength of paver blocks reaches a maximum of 46 MPa at 28 days, which is suitable for medium volume traffic applications. Such improvement is due to the tensile property of GF, but eventually, the strength improvement was minimum compared to other fibers owing to its low elastic modulus.

4. CONCLUSIONS

The effect of glass fiber (GF) on the hardened properties of recycled aggregate concrete (RAC) was studied and their practical suitability were evaluated with paver blocks for non-traffic and medium volume traffic conditions. The following recommendations were made as folows:

1. The inferior quality of FRA increases the water absorption and optimizes the replacement to 30%.

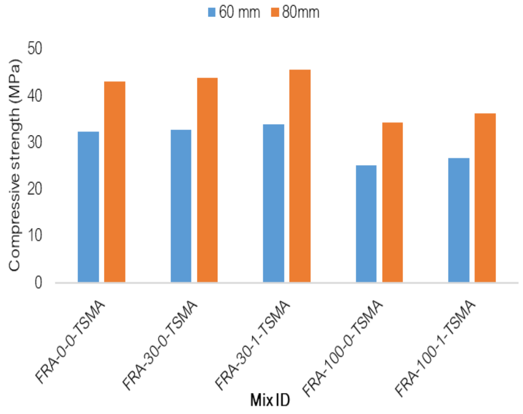


Figure 14. Compressive strength of paver block

2. The concrete mix prepared by two-stage mixing approach (TSMA) show 8% higher strength compared to normal mixing approach (NMA).
3. The concrete mix with 30% of FRA was increased by 8% while the mix with 100% of FRA was reduced by 7.1%.
4. The concrete mix with 1% of GF show 11.6% higher strength, beyond which it decreases due to pore formation resulting from the mortar covering the GF.
5. The concrete mix with optimized percentage of FRA and GF prepared by TSMA show 11.3% higher compressive strength, 12.5% higher tensile strength, 17.8% higher flexural strength and 3.6% increase in the shear strength of the concrete.
6. The paver block with optimized percentage of FRA and GF exhibit minimum strength of 33.9 MPa (non-traffic) and 45.6 MPa (medium traffic).

The research on the influence of GF on the recycled aggregate concrete tend to show better properties counteracting the negative effects of recycled aggregate concrete. However, the limitations are imposed on the utilization owing the glossy surface of GF and localization of stress leading to weaker bonding with recycled aggregate.

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Persian Abstract

چکیده

استفاده از الیاف در بتن باعث کاهش ترک ها، افزایش جذب انرژی و مقاومت بتن می شود .استفاده از سنگدانه های بازیافتی ریز (FRA) در بتن بر کمبود سنگدانه های طبیعی غلبه می کند، اما کیفیت ضعیف آن از طریق ایجاد ترک بر خواص بتن تأثیر می گذارد .این مطالعه به بررسی اثر استفاده از الیاف شیشه (GF) در کاهش انتشار ترک با استفاده از سنگدانه بازیافتی ریز (FRA) در بتن می‌پردازد GF 0، 0.25، 0.5، 0.75، 1 و 1.5 درصد وزنی اضافه شد .مخلوط‌های بتن با درصد بهینه FRA و درصدهای مختلف GF با روش اختلاط دو مرحله‌ای (TSMA) و روش اختلاط معمولی (NMA) تهیه و برای خواص تازه و سخت‌شده‌شان آزمایش شدند .مخلوط بهینه شده با FRA 30% و GF 1% تهیه شده توسط TSMA، با بهبود استحکام 11.3%در مقایسه با مخلوط شاهد در 28 روز مشاهده شد .این مطالعه بیشتر مناسب بودن عملی را به عنوان یک بلوک سنگفرش برای کاربردهای ترافیکی غیر ترافیکی و حجم متوسط طبق استاندارد IS 15658: 2006 بررسی کرد و در مقایسه با بلوک سنگفرش معمولی مشاهده کرد که حداقل مقاومت مورد نیاز 40 مگاپاسکال تحت هر دو شرایط با ترکیب بهینه با بهبود 17.4 درصد به دست آمد.