Mechanical Strength Performance of Mortar Incorporating Recycled Grass Cutter String Fibre

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Abstract

The improper disposal of recycled grass cutter string (RGCS) fibre waste contributes to environmental pollution due to its long degradation period and limited recycling practices. This study investigated the feasibility of utilising RGCS fibre as a sustainable reinforcement material in mortar. Specifically, the effects of fibre length (10, 20, and 30 mm) and fibre volume fraction (0.15%, 0.225%, and 0.30%) on the compressive, splitting tensile, and flexural strengths of mortar were evaluated, and the optimum fibre combination was identified. Mortar specimens incorporating RGCS fibres were prepared and tested in accordance with relevant standards. The results showed that the inclusion of RGCS fibres generally enhanced the splitting tensile and flexural strengths of mortar, while the effect on compressive strength depended on fibre length and content. The highest splitting tensile strength was achieved by mix M2A (20 mm, 0.15%), whereas mix M3A (30 mm, 0.15%) recorded the highest flexural strength. The findings indicate that fibre lengths of 20-30 mm at a volume fraction of 0.15% provide the most favourable overall mechanical performance by improving crack-bridging capability and resistance to crack propagation. This study demonstrates the potential of RGCS fibre as a sustainable alternative reinforcement material for mortar, while promoting the beneficial reuse of nylon waste. The findings can be applied in masonry mortar, plastering works, repair materials, and precast non-structural construction elements.

Keywords: Compressive, Flexural, Mechanical Properties, Mortar, Recycled Grass, Cutter String Fibre

1.0 Introduction

Mortar, a composite material consisting of cement, fine aggregate, and water, is an essential component in masonry construction, where it is primarily used to bond building units and fill gaps between building blocks [1]. It is strong in compression but does not perform well under tension. Synthetic and natural fibres are often added to improve the lacking properties. Fibre reinforcement has been a valuable choice for construction projects that demand superior performance and sustainability benefits. Various kinds of fibres such as steel, polypropylene and nylon are commonly used, each providing distinct advantages [2]. The construction industry comprises 36% of global energy use and 40% of total carbon dioxide emissions. Building works also contribute up to 40% of solid waste generation and 30% of global raw materials [3]. The growing focus on sustainability in construction underscores the importance of using recycled materials for their substantial environmental and economic benefits [4].

Recycled grass cutter string (RGCS) fibre is typically made from nylon, resilient and flexible against wear and environmental degradation [5]. A lack of proper waste management can be observed where RGCS were left behind by lawn workers around the grass area. The decomposition time of nylon varies based on temperature, humidity and type of nylon, with estimates ranging from 30 to 40 years or longer, emphasising the need for effective recycling solutions [6]. Nylon fibres bridge cracks by holding the material together and preventing further crack propagation when the structure experiences bending forces, improving overall durability, tensile distribution and crack resistance of the structure [7], [8], [9]. Previous studies have reported that the incorporation of nylon fibres enhances the splitting tensile and flexural strengths of cementitious composites [10], [11], [12], [13], [14]. Despite these promising findings, studies focusing specifically on RGCS fibres remain scarce. In particular, the influence of RGCS fibre length and fibre volume fraction on the mechanical performance of cement mortar has not been comprehensively investigated.

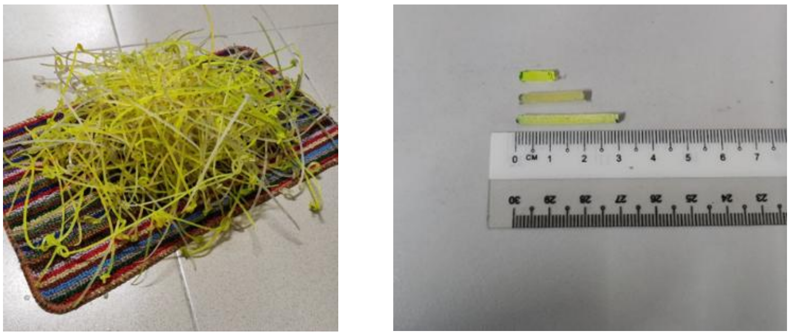
Therefore, this study aims to evaluate the feasibility of incorporating recycled grass cutter string fibres into cement mortar as a sustainable fibre reinforcement material. This study specifically investigates the effect of different RGCS fibre lengths and fibre volume fractions on the compressive, flexural, and splitting tensile strengths of mortar. Furthermore, the optimum combination of fibre length and fibre content is identified to maximise the mechanical performance of fibre-reinforced mortar while promoting the sustainable reutilisation of nylon waste.

2.0 Methodology

This study adopted an experimental approach to evaluate the feasibility of incorporating RGCS fibres as reinforcement in cement mortar. The methodology consisted of material preparation and characterisation, mortar mix design, specimen fabrication, and mechanical performance evaluation. Mortar mixtures containing different RGCS fibre lengths (10 mm, 20 mm, and 30 mm) and fibre volume fractions (0.15%, 0.225%, and 0.30%) were prepared and compared with a control mixture without fibre reinforcement. The mechanical performance of the hardened mortar was assessed through density, compressive strength, splitting tensile strength, and flexural strength tests in accordance with the relevant British Standards. The experimental procedures adopted in this study are described in the following sections.

2.1 Materials

The materials used in this study consisted of cement, fine aggregate (sand), water and recycled grass cutter string (RGCS). Ordinary Portland Cement (OPC) manufactured by Tasek Corporation Berhad, conforming to MS EN 197-1:2014 [15], was used as the binding material. Natural river sand and potable water were obtained from the Advanced Materials Engineering Laboratory, Universiti Tun Hussein Onn Malaysia (UTHM). Discarded grass cutter strings were collected from lawn maintenance areas within the UTHM campus. The collected strings were thoroughly cleaned using a detergent solution to remove adhered soil and other contaminants before being rinsed with clean water and air-dried. After drying, the RGCS fibres (Type 6 nylon-Polyamide 6 or PA6) were manually cut into three lengths of 10 mm, 20 mm, and 30 mm, as illustrated in Figure 1. The fibres were subsequently weighed according to the required dosage for each mortar mixture before mixing.



(a) (b)

Figure 1: (a) Cleaning and air-drying of RGCS; (b) RGCS fibres cut into lengths of 10 mm, 20 mm, and 30 mm

2.2 Mix Design

The mortar mix has a cement-to-sand ratio of 1:3 (by weight). A high degree of workability is required to achieve minimum compaction; therefore, a water-to-cement ratio of 0.7 is used. Ten mortar mixtures were prepared, comprising one control mixture without fibre reinforcement and nine fibre-reinforced mixtures incorporating different combinations of RGCS fibre length and fibre volume fraction.

The RGCS fibres were incorporated at volume fractions of 0.15%, 0.225%, and 0.30%, with fibre lengths of 10 mm, 20 mm, and 30 mm. The mix proportions are presented in Table 1. The mixture identification system consisted of the mixture designation (M), followed by the fibre length category (1 = 10 mm, 2 = 20 mm, and 3 = 30 mm) and the fibre content (A = 0.15%, B = 0.225%, and C = 0.30%). For example, Mix M1A denotes mortar containing 10 mm RGCS fibres at a volume fraction of 0.15%.

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Table 1: Mix proportions of mortar containing recycled grass cutter string fibres

Mix ID	Sand (kg)	Cement (kg)	Water to cement ratio	Percentage of RGCS fibre (%)	Length of RGCS fibre (mm)
M0	33	11	0.7	-	-
M1A	33	11	0.7	0.15	10
M1B	33	11	0.7	0.225	10
M1C	33	11	0.7	0.30	10
M2A	33	11	0.7	0.15	20
M2B	33	11	0.7	0.225	20
M2C	33	11	0.7	0.30	20
M3A	33	11	0.7	0.15	30
M3B	33	11	0.7	0.225	30
M3C	33	11	0.7	0.30	30

2.3 Material Characterisation

The physical properties of the constituent materials were characterised before specimen preparation. The particle size distribution of the sand was determined through sieve analysis in accordance with BS EN 12620:2002 [16] and BS 882:1992 [17]. Approximately 1 kg of sand was used for the grading analysis.

The tensile properties of the RGCS fibres were evaluated using a Universal Testing Machine (UTM) in accordance with BS EN 10002-1:2001 [18]. To assess the influence of environmental exposure, fibres representing three ageing conditions, namely fresh, moderately weathered, and severely weathered, were tested. The tensile strength obtained from this characterisation was used to evaluate the suitability of RGCS fibres as reinforcement in cement mortar.

2.4 Fresh Mortar Testing

The workability of the fresh mortar mixtures was evaluated using the slump test. The test was performed for each mixture immediately after mixing to determine the influence of RGCS fibre length and fibre content on mortar consistency. The test procedure was conducted following the relevant standard method, and the measured slump values were recorded for subsequent analysis.

2.5 Hardened Mortar Testing

The mechanical performance of the hardened mortar was evaluated through density, compressive strength, splitting tensile strength, and flexural strength tests after curing. The density of the hardened mortar specimens was determined to evaluate the influence of RGCS fibres on the compactness of the mortar matrix. Compressive strength was determined using cube specimens measuring 100 mm × 100 mm × 100 mm in accordance with BS EN 12390-3:2002 [22]. Nine cube specimens were prepared for each mixture, with three specimens tested after 7, 14, and 28 days of water curing. Splitting tensile strength was evaluated using cylindrical specimens with dimensions of 100 mm diameter × 200 mm height following BS EN 12390-6 [23]. Two specimens were prepared for each mixture and tested after 28 days of curing. Flexural strength was determined using prism specimens measuring 100 mm × 100 mm × 400 mm in accordance with BS EN 12390-5 [24]. Two prism specimens were prepared for each mixture and tested after 28 days of curing.

For compressive strength, nine cubes with dimensions of 100 mm x 100 mm x 100 mm for each mix design were prepared. The compressive strength test was conducted on the 7, 14, and 28 days, with three cube specimens per mix for each respective day. The mortar cubes were tested using a compression testing machine in compliance with BS EN 12390-3:2002 [22].

For splitting tensile strength, two cylinders with dimensions of 100 mm diameter x 200 mm length for each mix design were prepared. The splitting tensile strength test is conducted on the 28-day, two-cylinder specimens per mix. The mortar cylinders are tested using a compression testing machine in compliance with BS EN 12390-6 [23].

For flexural strength, two prisms with dimensions of 100 mm x 100 mm x 400 mm were prepared for each mix design. The flexural strength test was conducted at 28 days, with two prism specimens per mix. The mortar prisms were tested using a flexural testing machine in compliance with BS EN 12390-5 [24]. Table 2 summarises the specimen dimensions and the number of specimens for each test.

Table 2: Number and dimensions of test specimens prepared for each mortar mixture

Mix Id	No. of specimens for cube (100mm x 100mm x 100mm)	No. of specimens for cylinder (100mm x 200mm)	No. of specimens for prism (100mm x 100mm x 400mm)
M0	9	2	2
M1A	9	2	2
M1B	9	2	2
M1C	9	2	2
M2A	9	2	2
M2B	9	2	2
M2C	9	2	2
M3A	9	2	2
M3B	9	2	2
M3C	9	2	2
Total	90	20	20

3.0 Results and Discussion

3.1 Material Characterisation

The tensile strength of recycled grass cutter string (RGCS) fibres was evaluated under three ageing conditions, namely fresh, moderately weathered, and severely weathered. The results showed that the fresh RGCS fibres exhibited the highest average tensile strength of 158 N/mm². As the degree of weathering increased, the tensile strength progressively decreased to 131 N/mm² for moderately weathered fibres and 108 N/mm² for severely weathered fibres. This represents an overall reduction of approximately 32% from the fresh condition to the severely weathered condition. The deterioration in tensile strength can be attributed to the degradation of the nylon polymer caused by prolonged exposure to environmental factors such as ultraviolet (UV) radiation, moisture, temperature fluctuations, and oxidation. These factors weaken the polymer chains, resulting in reduced tensile capacity and mechanical performance [19]. Despite the reduction in strength, the weathered RGCS fibres retained sufficient tensile capacity to function as crack-bridging reinforcement in cement mortar, demonstrating their potential for sustainable reuse in construction applications. The tensile strength of RGCS fibres decreased with increasing weathering exposure, indicating degradation of the nylon material due to environmental effects. Nevertheless, even severely weathered fibres retained sufficient tensile capacity to function as crack-bridging reinforcement in mortar, demonstrating their potential for sustainable reuse.

3.2 Fresh Mortar Properties

The workability of the fresh mortar mixtures was evaluated using the slump test, and the results are presented in Figure 2.

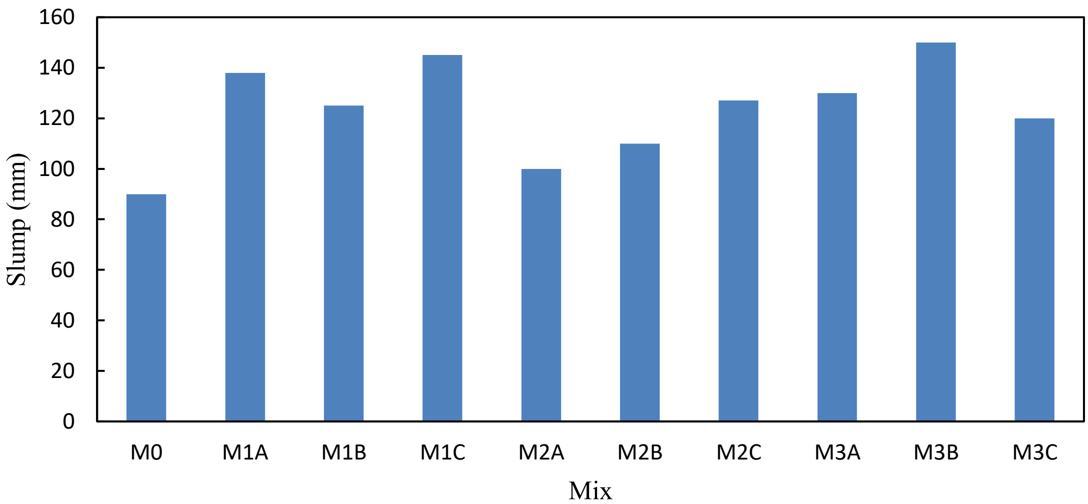

Figure 2: Slump test of fresh mortar mixtures

The control mixture (M0) recorded the lowest slump value of 90 mm, indicating lower workability in the absence of fibre reinforcement. In general, all mortar mixtures incorporating RGCS fibres exhibited higher slump values than the control mixture, suggesting that the inclusion of RGCS fibres improved the workability of the fresh mortar. This behaviour may be attributed to the relatively smooth surface texture and low water absorption of nylon fibres, which minimise the amount of mixing water absorbed by the fibres and allow more free water to remain within the mortar matrix.

Among the fibre lengths investigated, the mixtures containing 10 mm RGCS fibres exhibited the highest average slump values. The improved workability can be attributed to the shorter fibres being more uniformly dispersed throughout the mortar, resulting in less interference with the movement of the fresh mix. Similar observations have been reported in previous studies, which demonstrated that shorter synthetic fibres are less likely to become entangled during mixing and therefore provide better workability than longer fibres [20].

In contrast, mixtures reinforced with 20 mm fibres generally produced lower slump values than those containing 10 mm and 30 mm fibres. The intermediate fibre length may have generated greater internal resistance during mixing, thereby restricting the flowability of the mortar. Nevertheless, an increasing trend in slump was observed as the fibre dosage increased from M2A to M3B, with M3B recording the highest slump value of 150 mm. However, the slump decreased for M3C, which contained 30 mm fibres at a volume fraction of 0.30%. The reduction in workability at this higher fibre dosage is likely attributable to fibre agglomeration (balling), where the long fibres became entangled during mixing, reducing mortar homogeneity and restricting its flow [21].

Overall, the results indicate that both fibre length and fibre content influence the workability of fresh mortar. The incorporation of RGCS fibres generally improved workability compared to the control mix, primarily due to the good dispersion characteristics of shorter fibres. However, increasing the fibre content, particularly for longer fibres, tended to reduce workability as a result of fibre entanglement, agglomeration, and increased internal resistance during mixing.

3.3 Compressive Strength

The compressive strength development of the mortar specimens at curing ages of 7, 14, and 28 days is presented in Figure 3. Overall, the incorporation of recycled grass cutter string (RGCS) fibres influenced the compressive strength of mortar, with the effect depending on both the fibre length and fibre volume fraction. While certain fibre-reinforced mixtures exhibited slight reductions in compressive strength compared with the control mix (M0), selected combinations of fibre length and dosage resulted in measurable improvements, indicating that the compressive performance of mortar is highly dependent on achieving an optimum balance between fibre geometry and fibre content.

Among all mixtures, M1C, containing 10 mm RGCS fibres at a volume fraction of 0.30%, achieved the highest 28-day compressive strength of 33.77 MPa, representing an approximately 11% increase compared with the control mix (30.50 MPa). This improvement suggests that the shorter fibres were more uniformly dispersed within the cement matrix, enabling effective restraint of microcrack initiation and propagation under compressive loading. A homogeneous fibre distribution enhances stress transfer across the matrix and delays crack coalescence, thereby improving the overall load-carrying capacity of the mortar. Similar improvements in compressive strength have been reported for nylon fibre-reinforced cementitious composites, where well-dispersed fibres contributed to improved matrix integrity and crack resistance [10], [11].

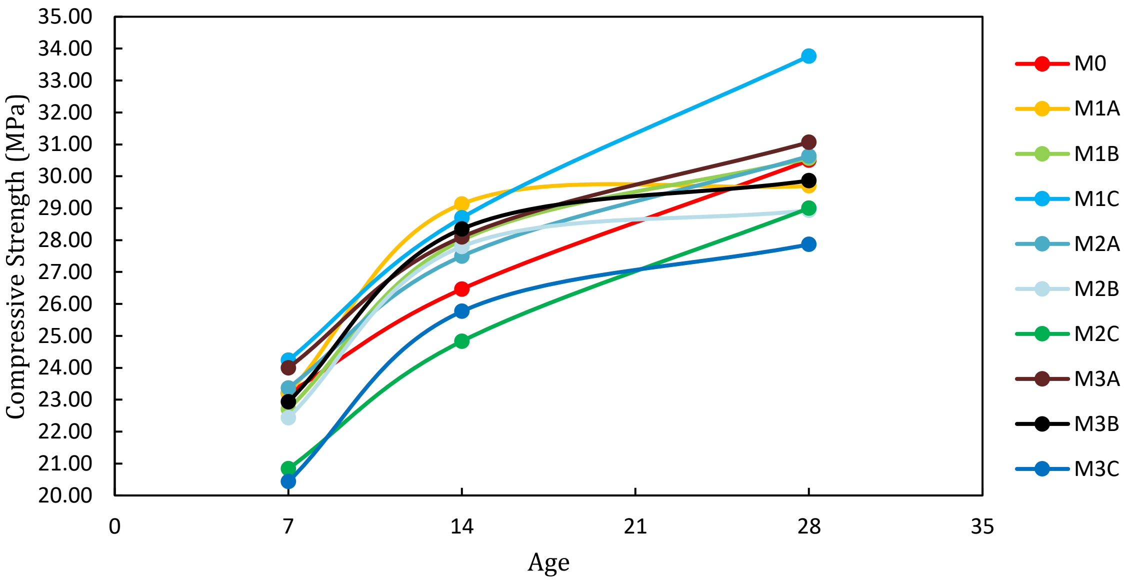

Figure 3: Compressive strength development of hardened mortar at 7, 14, and 28 days

In contrast, mixtures containing 20 mm (M2C) and 30 mm (M3C) fibres at 0.30% exhibited lower compressive strengths than the control mix. This reduction is likely due to fibre agglomeration and increased internal voids caused by the higher dosage of longer fibres, which reduced matrix compactness and weakened the fibre–matrix bond. Similar trends have been reported in previous studies, where excessive fibre content reduced compressive strength because of poor workability and increased porosity [11], [13], [14].

At the 28-day curing age, only M1C, M2A, and M3A achieved compressive strengths exceeding that of the control mix, indicating that the effectiveness of RGCS fibres depends on achieving an optimum combination of fibre length and fibre content. The compressive strength of mortar depended on the fibre length and volume fraction. Optimum fibre combinations (M1C, M2A, and M3A) enhanced compressive strength, whereas higher dosages of longer fibres generally reduced strength due to poor dispersion and increased void formation.

3.4 Splitting Tensile Strength

The splitting tensile strength results are shown in Figure 4, the overall results showed improvement in tensile strength with the addition of RGCS fibre.

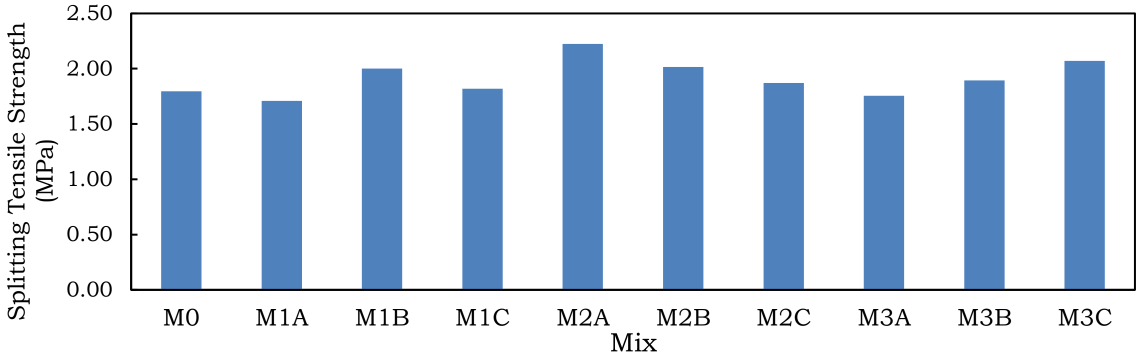

Figure 4: Splitting tensile strength of hardened mortar after 28 days

The addition of RGCS fibres generally enhanced the splitting tensile strength of mortar through improved crack-bridging action. Among all mixtures, M2A (20 mm, 0.15%) achieved the highest splitting tensile strength of 2.23 MPa, representing a 24% improvement over the control mix, indicating that a moderate fibre length at a low dosage provides the optimum balance between effective crack bridging and good fibre dispersion. In contrast, higher fibre contents or longer fibres produced less significant improvements due to reduced dispersion efficiency and potential fibre clustering.

3.5 Flexural Strength

The flexural strength results are shown in Figure 5, the addition of RGCS fibre into the mortar mix generally improved its performance compared to the control mix which recorded a flexural strength of 3.80 MPa.

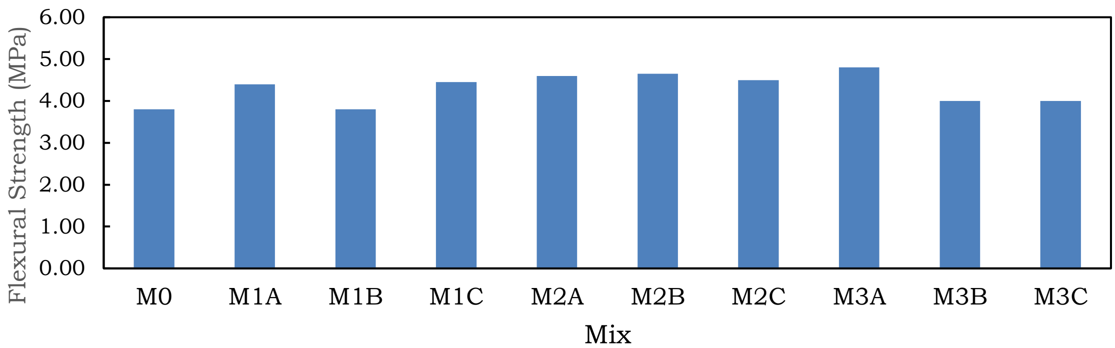

Figure 5: Flexural strength of hardened mortar after 28 days

For mixes with 10 mm fibre, M1A achieved a strength of 4.40 MPa, which is a 16% improvement. However, M1B showed no change compared to the control mix, while M1C showed an increment of 17%. The inconsistent results for mixes with 10 mm fibre indicate that while 10 mm fibres may be an advantage, their effectiveness may decrease due to poor fibre distribution. Mixes with 20 mm fibres presented the most consistent and effective performance. M2A, M2B and M2C recorded flexural strengths of 4.60 MPa, 4.65 MPa and 4.50 MPa respectively, showing constant improvements over the control mix. These results indicate that 20 mm fibre length is suitable for improving flexural strength regardless of the percentage. M3A achieved the highest flexural strength of 4.80 MPa among all mixes, representing a 26% increase over the control mix. However, M3B and M3C both recorded only 4.00 MPa which is a 5% improvement. This trend suggests that longer fibres are more effective at lower percentages and may cause fibre balling or poor dispersion when added excessively. RGCS fibres improved the flexural performance of mortar, with most fibre-reinforced mixtures outperforming the control mix. The best result was obtained by M3A (30 mm, 0.15%), indicating that longer fibres are more effective in resisting bending-induced crack propagation when used at an appropriate dosage.

3.6 Ratio Between Splitting Tensile Strength and Compressive Strength

Table 3 shows the ratio between splitting tensile strength and compressive strength at 28 days.

Table 3: Ratio between splitting tensile strength and compressive strength

Mix Id	Splitting tensile strength at 28 days (MPa)	Compressive strength at 28 days (MPa)	Ratio between splitting tensile and compressive strength
M0	1.80	30.50	0.059
M1A	1.71	29.70	0.058
M1B	2.00	30.57	0.065
M1C	1.82	33.77	0.054
M2A	2.23	30.63	0.073
M2B	2.02	28.93	0.070
M2C	1.87	29.00	0.064
M3A	1.76	31.07	0.056
M3B	1.90	29.87	0.063
M3C	2.07	27.87	0.074

Most of the mixes with RGCS fibre showed an increased ratio compared to the control mix. The highest ratio was recorded in M3C, which is 0.074, followed by M2A and M2B, which are 0.073 and 0.070, respectively. Longer fibres tend to achieve higher ratios and are more effective in enhancing tensile capacity relative to compressive strength, due to their ability to bridge cracks and absorb tensile stress. Shorter fibres showed lower ratios, which may be due to insufficient fibre engagement across cracks. The tensile-to-compressive strength ratio increased for most fibre-reinforced mixtures, demonstrating that RGCS fibres contributed more significantly to tensile resistance than compressive resistance. Higher ratios observed in mixtures containing longer fibres indicate improved crack-bridging efficiency and stress transfer across the mortar matrix.

3.7 Ratio Between Flexural Strength and Compressive Strength

Table 4 shows the ratio between flexural strength and compressive strength at 28 days.

Table 4: Ratio between flexural strength and compressive strength

Mix Id	Flexural strength at 28 days (MPa)	Compressive strength at 28 days (MPa)	Ratio between flexural and compressive strength
M0	3.80	30.50	0.125
M1A	4.40	29.70	0.148
M1B	3.80	30.57	0.124
M1C	4.45	33.77	0.132
M2A	4.60	30.63	0.150
M2B	4.65	28.93	0.161
M2C	4.50	29.00	0.155
M3A	4.80	31.07	0.155
M3B	4.00	29.87	0.134
M3C	4.00	27.87	0.144

The control mix, M0 recorded a ratio of 0.125 which serves as the baseline for comparison. The trend suggests that 20 mm fibres are overall effective in achieving optimal strength enhancement, maybe due to their suitable length for dispersion and effective crack bridging. Mixes with 30 mm fibres such as M3A and M3C also produced high ratios but may face challenges such as fibre balling if not properly mixed. 10 mm fibre mixes produced inconsistent results with M1B showing no improvement in the ratio, possibly due to ineffective crack-bridging capabilities due to the short length. The flexural-to-compressive strength ratio was generally enhanced by the addition of RGCS fibres, particularly for mixtures containing 20 mm and 30 mm fibres. This finding suggests that these fibre lengths provide a favourable balance between fibre dispersion and crack-arresting capability, leading to improved flexural performance relative to compressive strength.

4.0 Conclusion

The results demonstrated that the mechanical performance of mortar is influenced by both the length and volume fraction of recycled grass cutter string (RGCS) fibres. The incorporation of RGCS fibres generally enhanced the splitting tensile and flexural strengths of mortar, while compressive strength was maintained or slightly improved only for selected mixtures. Longer fibres (20 mm and 30 mm) were more effective than 10 mm fibres in improving tensile-related properties. Among the mixtures investigated, 20 mm and 30 mm fibres at a volume fraction of 0.15% provided the most favourable overall mechanical performance. Therefore, RGCS fibre can be considered a viable and sustainable reinforcement material for mortar, particularly when used at an optimum fibre length of 20-30 mm and a fibre content of 0.15%.

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Author Contributions

Chai Teck Jung: Conceptualisation, Methodology, Design, Data Analysis, Original Manuscript Draft Preparation;
Wu Shanshan: Methodology, Design, Data Analysis, Manuscript Improvement;
Koh Heng Boon: Conceptualisation, Methodology, Design, Data Collection, Validation, Data Analysis, Manuscript Reviewing and Editing.

Conflicts of Interest

This manuscript has not been published elsewhere and is not under consideration by other journals. All authors have approved the review, agree with its submission, and declare no conflict of interest in the manuscript.

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