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Effect of Surface-Treated Date Palm Rachis and Geogrid Reinforcement on High-Strength Self-Compacting Concrete Slabs

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ABSTRACT: The growing environmental concerns and increasing cost of conventional construction materials have intensified the need for sustainable and economical alternatives in concrete construction. This study investigates the flexural behavior of high-strength self-compacting concrete (HSSCC) slabs reinforced with alternative reinforcement systems, namely date palm rachis and geogrids. To enhance the bond characteristics between the reinforcements and the concrete matrix, surface treatments were applied using polyester resin mixed with fine sand, coarse sand, or fine glass powder.A series of slab specimens was cast and tested under flexural loading to evaluate load–deflection behavior and ultimate load capacity. The results were compared with those of an unreinforced control slab. The control specimen exhibited brittle behavior, failing at an ultimate load of approximately 9.9 kN with a limited deflection of about 4.3 mm. Slabs reinforced with untreated palm rachis showed only marginal improvement, reaching an ultimate load of approximately 10.2 kN. Surface treatment significantly enhanced the flexural performance of palm-rachis-reinforced slabs. Fine sand coating resulted in the highest ductility, with a maximum deflection of about 15.2 mm, while coarse sand coating provided the best overall performance, combining stable crack propagation with the highest ultimate load of approximately 13.1 kN. Palm rachis coated with fine glass powder exhibited increased stiffness accompanied by reduced deflection capacity. Geogrid reinforcement mainly contributed to improving flexural strength. Fine sand–coated geogrids achieved the highest ultimate load among geogrid specimens (≈11.4 kN), whereas coarse sand coating led to minor strength enhancement. Conversely, fine glass–coated geogrids showed excessive deflection (≈15.9 mm) and a considerable reduction in ultimate load (≈6.5 kN).

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1. INTRODUCTION

A new challenge for the construction industry is the increasing costs of traditional building materials and the economic and environmental sustainability concerns surrounding them [1]. Worldwide, the most commonly used construction material is concrete due to its compressive strength, durability, and availability of the raw materials. Compression strength can be increased even further, although concrete tends to be brittle and can crack and shrink. Historically, this has been counterbalanced by steel reinforcement to provide the necessary compressive strength and structural integrity. However, steel comes with its own costs, which negatively impact its effective use, including increased costs to reinforce, increased corrosion, and significant environmental emissions due to steel production [2]. Reinforced concrete structures also experience increased costs to maintain during their lifecycle due to the corrosion of the reinforcing steel. The economic and environmental sustainability of construction has to be addressed in the face of the global demand to provide cheap, rapid construction to developing nations like India. Rising global inflation to provide cheap construction and the increasing price of energy during the global migration to provide affordable housing have also emphasized the need for sustainable construction materials.[3] As a result, there has been a growing interest in the research fields aimed at the use of odd and renewable materials that help reduce the dependency on steel, reduce costs for construction, and reduce environmental harms, while still keeping the structural performance within reasonable bounds. Along with the economic difficulty within the construction industry, the improper management of agricultural by-products has become a pressing environmental and public health concern within developing countries, including India. Agricultural wastes are produced in large amounts every year [4]. Poor management of this kind of waste goes through a process of open burning, land-filling, and uncontrolled dumping. These actions are the cause of pollution in the air, contamination of the land, and the generation of greenhouse gases. To exemplify this, in Egypt, there are large amounts of agricultural residues every year, including rice straw, palm waste, and other biomass materials of biomass. A large part of these residues are burned in order to reduce costs, which greatly harms the environment. In the palm waste, the date palm tree residuals are a large part of the waste, and these are a very notable and underutilized palm waste [5]. Date palm trees are cultivated in large quantities across the Middle East, North Africa, and parts of Asia. There are millions of date palm trees in the regions of the Middle East and North Africa that are in the arid and semi-arid regions [6].

In recent decades, countries like Libya and Egypt have witnessed a considerable increase in the number of date palms. The increase in palm trees is accompanied by the generation of considerable amounts of fibrous wastes, such as palm fronds, leaves, and rachises [7]. While some agro-industrial enterprises have started to use palm by-products for the generation of energy, the production of some feed for animals, and the creation of products similar to timber, a significant portion of palm by-products remains underused. The recycling of palm by-products for use as construction materials helps to mitigate environmental pollution and offers inexpensive construction materials to the construction industry. This practice also demonstrates adherence to sustainable development principles and the circular economy by recycling waste materials into usable products. In recent years, several studies have focused on the use of natural fibers in the production of composites for cement-based products [8]. The attention the fibers have received is predominantly because of the natural fibers' biodegradability, availability, low cost, and mechanical properties. Numerous studies have shown that the inclusion of natural fibers in the composite mix improves the overall flexural strength of the composite, as well as its toughness, and its resistance to cracking and post-cracking. Among natural fibers, date palm, sisal, jute, and bamboo fibers are more energy efficient because they are renewable resources as opposed to conventional steel fibers. In rural and semi-urban regions, the incorporation of natural fibers into cement-based composites has the potential to improve levels of sustainability, as well as reduce construction expenditures, which is especially beneficial in areas with low-rise buildings [9].

The potential of date palm fibers to enhance the flexural strength and ductility of concrete, and to improve other mechanical traits of concrete, is noteworthy. A number of studies have shown that the effectiveness of date palm fibers in making these modifications depend on a number of attributes, such as, the length of the fibers, the amount added, the surface structure of the fibers, and the fiber processing method [10]. While chemical modification may enhance fiber-matrix interaction, such chemicals are often not environmentally friendly, opposing the objectives of green construction. Furthermore, the absence of a uniform processing standard and the diverse attributes of the fibers, limit their large scale use. However, date palm fibers have the potential to contribute to green construction, especially when modified and treated using more contemporary and environmentally friendly methods to enhance their mechanical properties especially concrete's [11].

Geogrids, a type of geosynthetic, have historically been used in transportation and geotechnical engineering for applications such as soil stabilization, retaining structures, and pavement reinforcement. Geogrids, made of geosynthetic polymers such as polyester, polypropylene, and polyethylene, have a high strength to weight ratio, with good corrosion resistance, and are easy to handle and install. Advancements in polymer processing techniques such as tensile drawing and bonding methods have made it possible to manufacture geogrids with increased mechanical performance suitable for structural applications [12]. In recent years, researchers have examined the viability of substituting or complementing geogrids as reinforcement in concrete elements with traditional steel reinforcements. Experimental studies have indicated that geogrid-reinforced concrete has better performance in flexural behavior, crack control, energy absorption capacity, and ductility compared to plain concrete. Although geogrids do not always result in an increase in the ultimate load-carrying capacity in conjunction with steel reinforcements, they do improve the ductile response and post-cracking behavior of concrete elements [13]. Various studies have been conducted using different types of geogrids, which include uniaxial, biaxial, and triaxial configurations. Biaxial geogrids have been reported to have better performance for the reason that they can better control and distribute stresses in multiple directions than other types. This demonstrates that geogrids have the potential to be used as sustainable reinforcement alternatives, especially in environments where reinforcement corrosion and durability are concerns [14].

Although there is a growing amount of literature on geogrid-reinforced concrete and natural-fiber-reinforced concrete, there are still some research gaps. Most studies have conducted research on these materials independently, and there is a research gap on using geogrids and agricultural waste fibers in concrete systems. [15, 16] In addition, most research has centered its attention on individual mechanical properties of some laboratory-scale specimens, remaining unclear on the materials' structural performance and functional applicability in real-world construction. Processing and optimizing treatments of date palm fibers for structural applications remain notably underexplored, especially on an industrial scale. Furthermore, comprehensive research on the sustainable alternatives to steel reinforcement in developing countries, which face the most extreme cost and waste management problems, has been scarce. Therefore, the research aims to examine integrated reinforcement strategies employing agricultural waste fibers [17-21], polymeric geogrids, and locally sourced fibers to improve the mechanical properties, durability, and overall sustainability of concrete structures. This has the potential to make significant strides in decreasing the use of non-renewable materials, reducing the overall construction costs, lessening the negative environmental impacts, and providing innovative solutions to the developing and rural areas for their sustainable and affordable infrastructural development.

This research, by examining agricultural waste reinforced date palm rachis and polymeric geogrids as potential substitutes for the conventional reinforcement systems in HSSCC slabs, addresses the structural performance and sustainability of conventional concrete reinforcement systems. Furthermore, examining such materials sheds light on the influence of surface treatment methods on bond behavior, flexural strength, ductility, and failure mechanisms. The results show that natural materials can be made to perform competitively if stress transfer and crack control are optimized through appropriate surface modification. Furthermore, the study shows the promise of date palm rachis, a plentiful and inexpensive agricultural waste by-product, as a reinforcement alternative that is environmentally and economically better than using steel. This further develops eco-efficient construction materials and encourages the development of inexpensive, durable, and sustainable concrete systems, especially where greater ductility and controlled failure are desired.

2. Experimental program

2.1. Raw materials

All raw materials used in this study shown in Figure 1 were carefully selected to ensure consistency, performance, and sustainability of the results. Ordinary Portland cement (OPC) of grade 52.5N, locally manufactured, was used as the primary binder. Silica fume was incorporated as a supplementary cementitious material to enhance the mechanical properties, cohesiveness, and durability of concrete. Crushed coarse aggregates of suitable grading and free from deleterious substances were employed to ensure adequate strength and workability. Potable water that complied with standard requirements was used for mixing. A high-range water-reducing admixture (superplasticizer) compatible with self-compacting concrete was added to reduce the water–cement ratio and improve the flowability and homogeneity. Date palm rachis, an abundant agricultural by-product, was cleaned, treated, and used as a natural reinforcement in both longitudinal and transverse configurations to improve the crack resistance and ductility of plain concrete. In addition, a polymer-based geogrid was incorporated as an internal reinforcement system because of its high tensile strength, corrosion resistance, and effective load transfer characteristics. Polyester resin (ES-11-56) was used to treat the palm rachis to enhance the interfacial bonding with the cementitious matrix and improve durability [22].

Figure 1. Raw materials used in HSSCC

2.2. Preparation of Polyester-Filler Binder

The polyester binder used for the surface treatment was first modified to obtain a workable consistency suitable for coating reinforcement materials. A filler material contained in a green glass bottle was added to the polyester resin at a dosage of 20 g per 360 g of polyester. The mixture was thoroughly blended until a relatively fluid and homogeneous state was achieved, allowing it to be effectively applied during the subsequent preparation stages. Owing to the rapid polymerization and hardening characteristics of the polyester–filler mixture, special care was taken to use the mixture immediately after preparation. In several instances, the mixture began to harden inside the container before application, transforming into a plastic mass. Therefore, all coating operations were performed promptly to ensure proper impregnation and surface coverage before the onset of the setting. This polyester mixture served as the primary bonding agent for both palm rachis and geogrid surface treatments. aggregate. Therefore, only the coarse asphalt fraction was selected for incorporation into the prepacked concrete mixtures.

2.3. Preparation and Surface Treatment of Date Palm Rachis

Date palm rachis intended for use as natural reinforcement was first cut to the required dimensions according to the specimen geometry. After cutting, the rachis surfaces were treated to enhance their bonding performance with the concrete matrix. The prepared polyester–filler mixture was applied as a coating layer, and while still fresh, granular materials were bonded to the surface to increase its roughness and mechanical interlocking. Three types of surface modifiers were used: fine sand passing a 0.6 mm sieve and retained on a 0.15 mm sieve, coarse sand passing a 0.6 mm sieve and retained on a 0.36 mm sieve, and glass powder passing a 1.18 mm sieve. These materials were uniformly distributed on the rachis surface to create a textured and heterogeneous interface. The objective of this treatment was to improve adhesion, reduce slippage, and enhance stress transfer between the palm rachis and the surrounding HSSCC. After coating, the treated rachis was left to harden before placement within the concrete specimens.

2.4. Preparation and Surface Treatment of Geogrid Reinforcement

In addition to palm rachis, geogrid reinforcement was surface-treated using a similar procedure to improve its interaction with the concrete matrix. The geogrid was completely wrapped with the prepared polyester–filler mixture to ensure full-surface coverage. While the polyester coating remained workable, fine sand, coarse sand, and glass powder with the same particle size distributions used for the palm rachis were bonded to the geogrid surface. The fine sand passed a 0.6 mm sieve and was retained on 0.15 mm, the coarse sand passed a 0.6 mm sieve and was retained on 0.36 mm, and the glass powder passed a 1.18 mm sieve. This treatment aims to transform the relatively smooth polymeric surface of the geogrid into a mechanically active interface capable of improving the bond strength and load transfer. The treated geogrid was allowed to harden before installation inside the concrete specimens.

2.5. Pre-Casting Preparation and Readiness for Concrete Placement

All reinforcement materials, including the treated date palm rachis and treated geogrid, were prepared before concrete mixing and casting as shown in **Figure 2**. This approach ensured that the surface treatments were fully hardened and stable before exposure to the highly flowable HSSCC mixture. Preparing the reinforcement in advance eliminated the risk of premature polyester setting during casting and ensured consistency among all specimens. The treated rachis and geogrid elements were subsequently positioned inside the molds according to the experimental layout before the pouring. The following images illustrate the palm rachis and geogrid after surface treatment and prior to placement in the HSSCC samples.

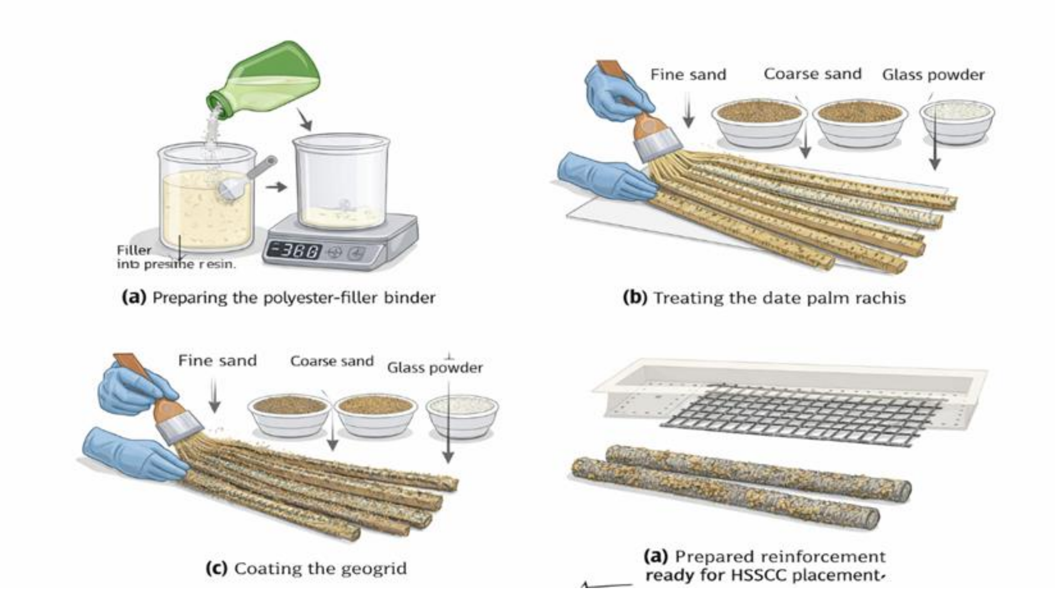

Figure 2: Preparation steps of Geogrid Reinforcement and Date Palm Rachis

2.6. Mixing proportions

The mixing proportions adopted in this study were designed to produce HSSCC with adequate flowability, stability, and superior mechanical performance. **Table 1** presents the detailed mix composition expressed in kg/m³. A relatively high cement content of 550 kg/m³ was used to achieve the required strength level, while silica fume was incorporated at 27.5 kg/m³ as a supplementary cementitious material to enhance the particle packing, strength development, and durability. Fine and coarse aggregates were used in equal proportions of 762 kg/m³ each to ensure a balanced aggregate skeleton and improve workability without any segregation. The total mixing water content was fixed at 184.8 kg/m³, resulting in a low water-to-binder ratio that was suitable for high-strength applications. A high-range water-reducing admixture (superplasticizer) was added at a dosage of 6.93 kg/m³ to improve the flowability, filling ability, and homogeneity of the concrete while maintaining a low water content. These proportions were selected to achieve a stable and cohesive HSSCC mixture capable of accommodating the embedded reinforcement without the need for external vibration [23-25].

Table 1. Mixing proportions

Material	**Proportion kg/m^3**
cement	550
Silica fume	27.5
Coarse aggregate	762
Fine aggregate	762
Water	184.8
Super plasticizer	6.93

2.7. Sample Coding and Identification System

To ensure clarity, consistency, and ease of comparison during testing and results discussion, a systematic coding scheme was adopted for all the specimens used in this study shown in **Table 2**. The control specimen without reinforcement was designated as sample (0). Specimens reinforced with date palm rachis were coded using the letter "A," while those reinforced with geogrid were coded using the letter "B". The numerical suffix indicates the type of surface treatment applied to the reinforcement: "0" refers to untreated reinforcement, "1" denotes coating with fine sand, "2" indicates coating with coarse sand, and "3" denotes coating with fine glass powder. Accordingly, samples A0–A3 correspond to palm rachis with different surface conditions, whereas samples B0–B3 represent geogrid reinforcements with the same range of surface treatments. This coding system was consistently applied throughout specimen preparation, testing, data analysis, and results discussion to facilitate the clear identification and direct comparison of the influence of the reinforcement type and surface treatment on the structural behavior of the concrete elements.

Table 2. Sample codes and reinforcement configurations

Sample Code	Type of reinforcement
0	No reinforcement (Control specimen)
A0	Palm rachis without surface treatment
A1	Palm rachis coated with fine sand
A2	Palm rachis coated with coarse sand
A3	Palm rachis coated with fine glass powder
B0	Geogrid without surface treatment
B1	Geogrid coated with fine sand
B2	Geogrid coated with coarse sand
B3	Geogrid coated with fine glass powder

2.8. Casting and curing

After preparing all constituent materials, HSSCC was mixed following a controlled sequence to ensure homogeneity and reproducibility. Before mixing, the mixer was thoroughly cleaned and washed to eliminate any residue from previous batches. Fine and coarse aggregates were first introduced into the mixer and dry mixed for approximately two minutes, followed by the addition of half of the cement content and mixing for one minute. Subsequently, the total amount of silica fume was added and mixed for another minute, after which the remaining cement was added and blended for an additional minute [24, 25]. The mixing water was divided into two equal portions; the first portion was combined with the superplasticizer and added to the mix, followed by mixing for approximately one minute, after which the second portion of water was added to achieve the desired consistency. The resulting HSSCC exhibited high cohesiveness, compactness, and stability, without visible segregation, as shown in **Figure 3**. The fresh concrete was discharged from the mixer using suitable tools and transported to the casting location using a bourette. Casting was performed by pouring concrete from a height of approximately 50 cm while maintaining an initial concrete cover of 1-2 cm before placing the reinforcement. The prepared reinforcement elements, namely the treated date palm rachis and treated geogrid, were positioned inside the molds, and the specimens were labeled according to the type of reinforcement used .

Figure 3. Casting procedures of prepacked HSC

3. TESTS

The flexural performance of the slab specimens was evaluated using a bending test to assess their load-carrying capacity, stiffness, and crack behavior. Each slab was positioned between two lower steel supports spaced 400 mm apart, and a single upper loading plate was applied at the mid-span. The load was applied vertically using a compression testing machine and increased incrementally as shown in **Figure 4**, with the applied load recorded in kilonewtons (kN). A dial gauge shown in Figure 4 was installed to measure the vertical deflection, where a steel reference piece was fixed beneath the slab and brought into contact with the dial gauge needle. Owing to testing constraints, deflection readings were taken at a distance of 0.25 L from the support and subsequently corrected to obtain the equivalent mid-span deflection. The load and deflection readings were recorded simultaneously at each 1 kN increment. The load corresponding to the first visible crack was noted, and loading was continued until the complete failure of the specimen occurred. After testing, each slab was visually inspected and photographed to document the crack patterns, crack propagation, and failure mode. The same testing procedure was repeated for all slab specimens to ensure consistency, after which the results, observations, and failure characteristics of each specimen were analyzed and discussed. Similar procedures were applied to the cube specimens for compressive strength evaluation.

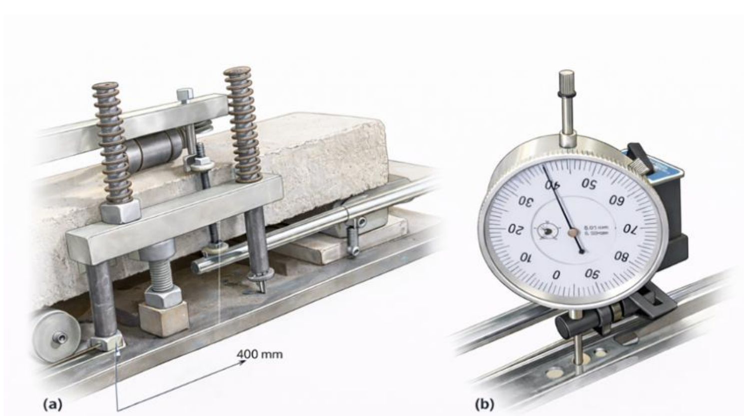

Figure 4. Flexural testing setup and deflection measurement

4. Results and discussion

4.1. Load-Deflection Response of the Control Specimen (Sample 0)

The load-deflection response of the control slab specimen (Sample 0), which contained no reinforcement shown in **Figure 5**, reflected the typical brittle behavior of plain high-strength self-compacting concrete. The experimental results showed that the specimen exhibited a relatively rapid increase in deflection during the initial stages of loading, indicating limited stiffness and the absence of internal mechanisms to restrain tensile cracking. With further load increments, the rate of deflection gradually decreased until the first visible cracking occurred, followed by a sudden loss of load-carrying capacity. The control slab reached ultimate failure at an applied load of approximately 9.9 kN, corresponding to a maximum recorded deflection of approximately 4.3 mm. The abrupt failure and limited deformation capacity observed in Sample (0) confirmed the inherently brittle nature of unreinforced concrete slabs under flexural loading. These results provide a baseline reference for evaluating the effectiveness of palm rachis and geogrid reinforcements in enhancing the flexural strength, stiffness, and ductility of the reinforced specimens.

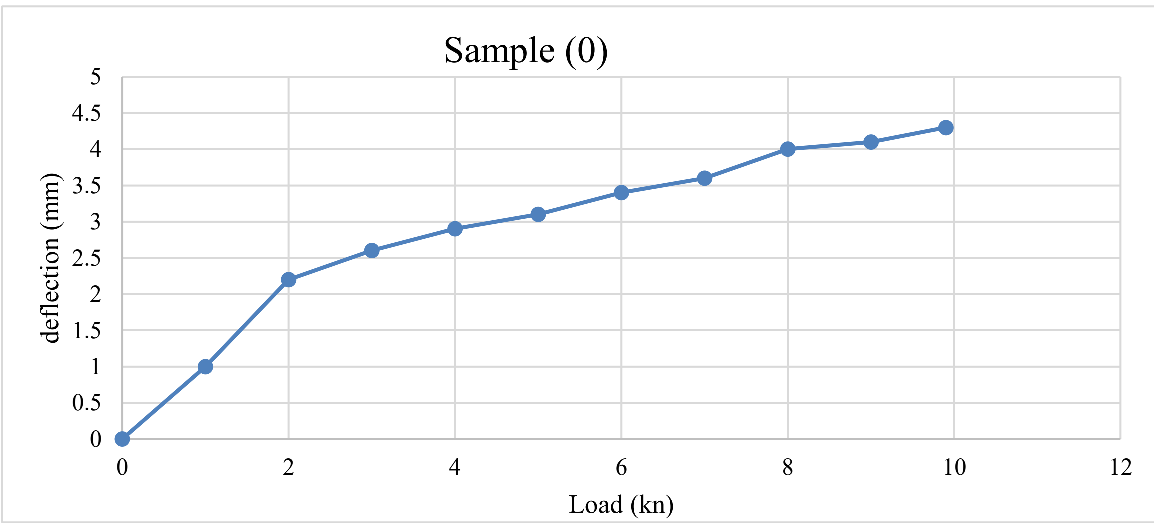

Figure 5. The load-deflection response of the control slab specimen (Sample 0)

4.2. Flexural Behavior of Palm Rachis Reinforced Slab without Surface Treatment (Sample A0)

The load-deflection behavior of Sample (A0), reinforced with untreated date palm rachis, shown in **Figure 6**, demonstrated a noticeable improvement compared to the control specimen, indicating the contribution of natural reinforcement even without surface treatment. During the initial loading stage, the deflection increased slowly, indicating an increase in stiffness relative to that of the unreinforced slab. As the applied load approached approximately 7 kN, a change in the slope of the load–deflection curve was observed, suggesting the initiation of microcracking and partial mobilization of the palm rachis to resist tensile stresses. Beyond this stage, the deflection continued to increase in a relatively steady manner until failure occurred at an ultimate load of approximately 10.2 kN, with a maximum recorded deflection of approximately 4.0 mm. Compared with the Sample (0), the A0 specimen exhibited a higher load-carrying capacity and a more gradual failure process, indicating improved ductility. However, the absence of surface treatment limited the bond efficiency between the palm rachis and concrete matrix, restricting the full utilization of the reinforcement capacity [26]. These results highlight that untreated palm rachis can enhance flexural performance to some extent; however, surface modification is expected to play a critical role in further improving stress transfer, crack control, and post-cracking behavior in reinforced slabs.

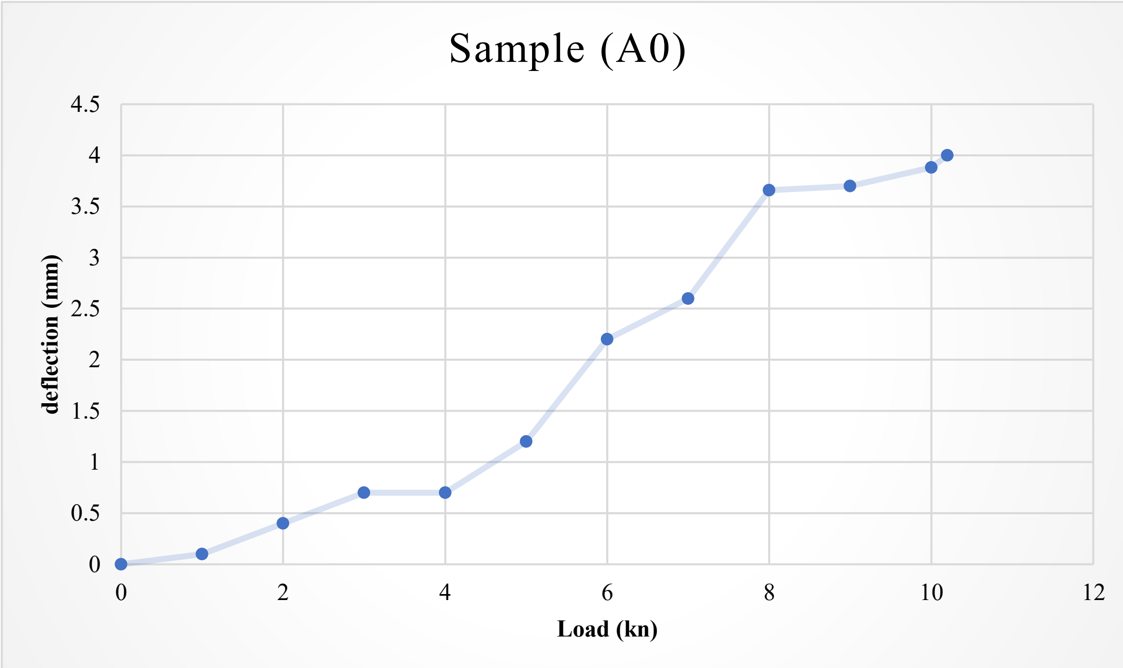

Figure 6. The load-deflection response of the control slab specimen (Sample A0)

4.3. Flexural Behavior of Palm Rachis Reinforced Slab Coated with Fine Sand (Sample A1)

Sample (A1), reinforced with date palm rachis coated with fine sand, exhibited a significant improvement in flexural performance compared to both the control specimen (Sample 0) and the untreated rachis specimen (Sample A0). At the early stages shown in **Figure 7** of loading, the slab showed very limited deflection, indicating enhanced stiffness and effective stress transfer between the concrete matrix and treated reinforcement. As the applied load approached approximately 10 kN, a noticeable increase in the deflection rate was observed, corresponding to the initiation and propagation of flexural cracking. The specimen reached an ultimate load of approximately 10.8 kN, accompanied by a substantially higher maximum deflection of approximately 15.2 mm, reflecting a pronounced improvement in ductility. The fine sand coating increased the surface roughness of the palm rachis, leading to stronger mechanical interlocking and improved bond characteristics with surrounding concrete. This enhanced bond delayed the crack localization and allowed the reinforcement to remain engaged over a wider deformation range. Compared to Sample (A0), Sample (A1) demonstrated not only a higher load-carrying capacity but also a markedly more ductile failure mode, highlighting the effectiveness of fine sand surface treatment in improving the crack control and post-cracking behavior of palm rachis-reinforced slabs [27].

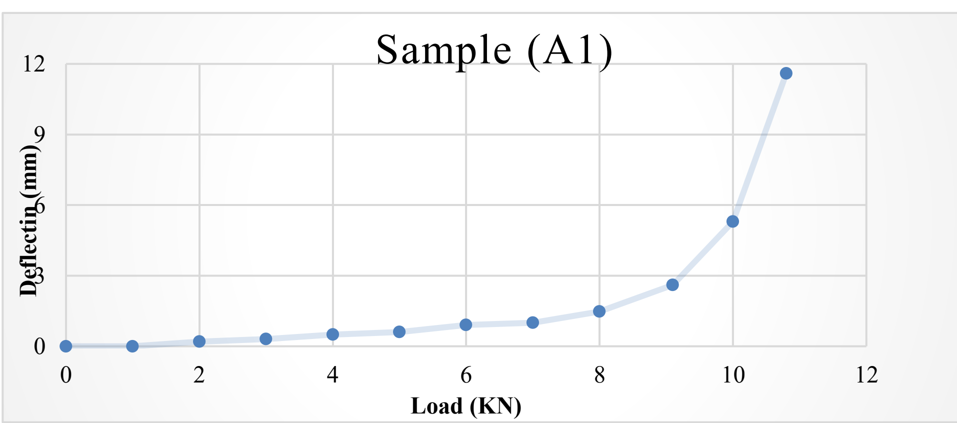

Figure 7. The load-deflection response of the control slab specimen (A1)

4.4. Flexural Behavior of Geogrid Reinforced Slab Coated with Fine Sand (Sample B1)

The flexural response of Sample (B1), reinforced with a geogrid coated with fine sand, exhibited a clear enhancement in load-carrying capacity and deformation behavior compared to the control specimen and several palm-rachis-reinforced slabs shown in **Figure 8**. In the initial stages of loading, the specimen showed minimal deflection, indicating high initial stiffness and effective engagement of the geogrid within the concrete matrix. As the applied load increased to approximately 8 kN, the deflection rate began to increase, reflecting the onset of cracking and progressive mobilization of the geogrid reinforcement. The slab sustained loading up to an ultimate load of approximately 11.4 kN, accompanied by a maximum deflection of approximately 7.3 mm. Compared with Sample (A1), Sample (B1) demonstrated a higher ultimate load but a lower maximum deflection, indicating a stiffer yet less ductile response. The fine sand coating enhanced the surface roughness of the geogrid ribs, improving the mechanical interlocking and bond efficiency with the surrounding concrete [28], which delayed crack propagation and improved stress redistribution. Overall, the behavior of Sample (B1) confirms the effectiveness of geogrid reinforcement combined with surface treatment in improving the flexural strength while maintaining controlled deformation and stable post-cracking behavior.

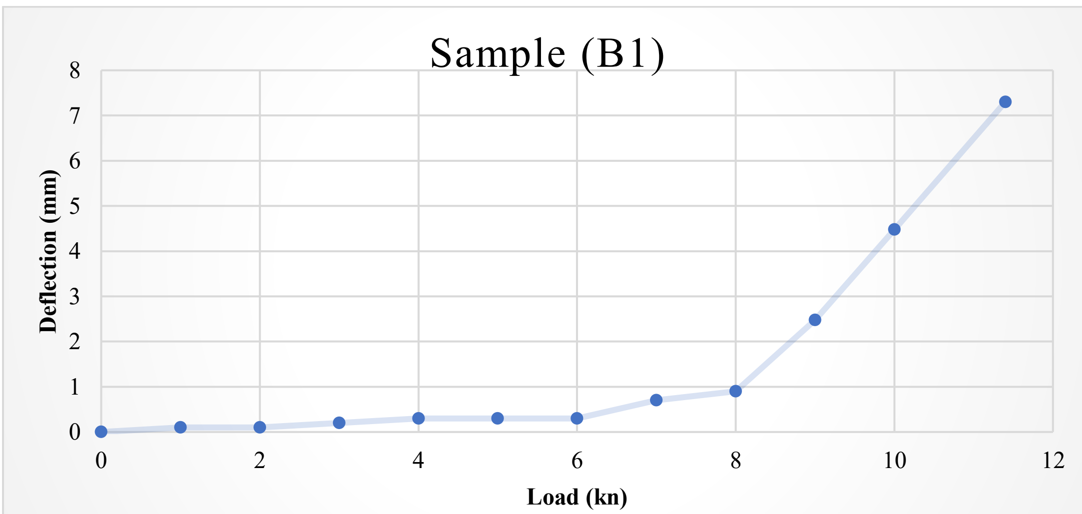

Figure 8. The load-deflection response of the control slab specimen (B1)

4.5. Flexural Behavior of Palm Rachis Reinforced Slab Coated with Coarse Sand (Sample A2)

Sample (A2), reinforced with date palm rachis coated with coarse sand, exhibited a marked enhancement in flexural capacity compared to both the untreated palm rachis specimen (Sample A0) and the fine sand-coated specimen (Sample A1) shown in **Figure 9**. During the initial loading stage, the slab exhibited a slow increase in deflection, indicating improved stiffness and effective load sharing between the concrete matrix and treated reinforcement. As the applied load reached approximately 3 kN, a noticeable increase in deflection was observed, which was attributed to the initiation of flexural microcracks. Between 3 and 8 kN, the deflection increased at a relatively controlled and gradual rate, reflecting stable crack propagation and efficient stress transfer. Beyond this range, the load–deflection response remained nearly steady until ultimate failure occurred at an applied load of approximately 13.1 kN, accompanied by a maximum deflection of approximately 10.35 mm. Compared with Sample (A1), Sample (A2) achieved a significantly higher ultimate load while maintaining substantial deformation capacity, indicating a balanced improvement in both strength and ductility. The use of coarse sand as a surface treatment enhanced the mechanical interlocking at the palm rachis–concrete interface, leading to improved bond performance, delayed crack localization, and more distributed cracking before failure [29].

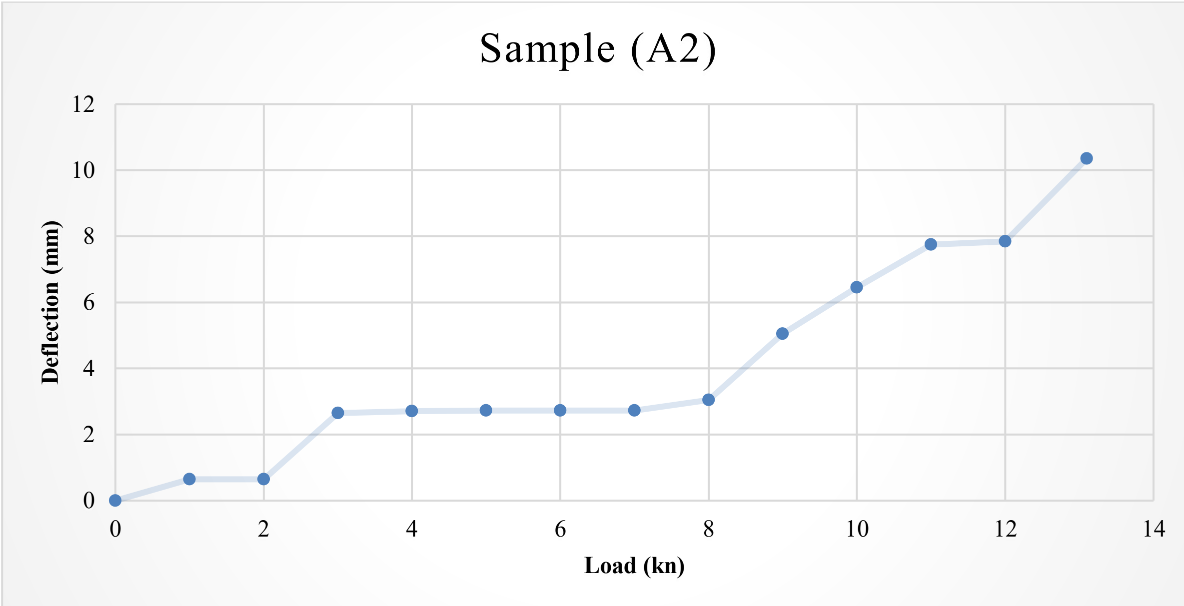

Figure 9. The load-deflection response of the control slab specimen (A2)

4.6. Flexural Behavior of Geogrid Reinforced Slab Coated with Coarse Sand (Sample B2)

Sample (B2), reinforced with a geogrid coated with coarse sand, showed a moderate improvement in flexural behavior compared to the control specimen, while exhibiting a stiffer response relative to the other reinforced slabs shown in **Figure 10**. In the initial stages of loading, the deflection increased slowly, indicating effective engagement of the geogrid reinforcement and good initial stiffness. As the applied load approached approximately 9 kN, the deflection rate began to increase, indicating the initiation of cracking and partial mobilization of the reinforcement. The slab failed at an ultimate load of approximately 10.2 kN, with a maximum recorded deflection of approximately 8.7 mm. Compared with Sample (B1), Sample (B2) exhibited a lower ultimate load and reduced deformation capacity, suggesting that the coarse sand coating, while improving surface roughness, resulted in less efficient stress transfer than fine sand. The overall response indicated that the coarse sand coating on the geogrid enhanced the flexural resistance compared to the uncoated specimens but provided a more restrained and less ductile behavior compared to the finer surface treatments [30].

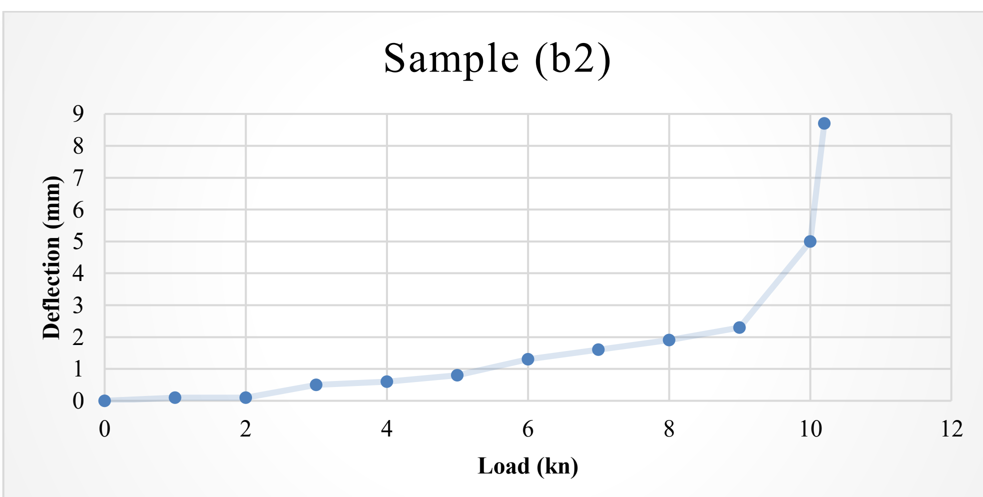

Figure 10. The load-deflection response of the control slab specimen (B2)

4.7. Flexural Behavior of Palm Rachis Reinforced Slab Coated with Fine Glass Powder (Sample A3)

The flexural response of Sample (A3) shown in **Figure 11**, reinforced with a date palm rachis coated with fine glass powder, demonstrated a significant enhancement in the load-carrying capacity combined with a controlled deformation behavior. Throughout the initial loading phase, the deflection increased gradually and in a near-linear proportion to the applied load, reflecting the stable stiffness and effective bond between the reinforcement and concrete matrix. As the load reached approximately 8 kN, cracking initiated, followed by a steady increase in deflection until ultimate failure occurred at an applied load of approximately 12.5 kN. The maximum recorded deflection at failure was approximately 4.9 mm, indicating a relatively stiff response compared with that of the other palm rachis-reinforced specimens. The fine glass powder coating improved the surface smoothness while still providing adequate mechanical interlocking, leading to enhanced stress transfer and delayed crack propagation. Compared to Samples (A1) and (A2), sample (A3) exhibited higher strength but reduced ductility, suggesting a shift toward strength-dominated behavior owing to the nature of the surface treatment.

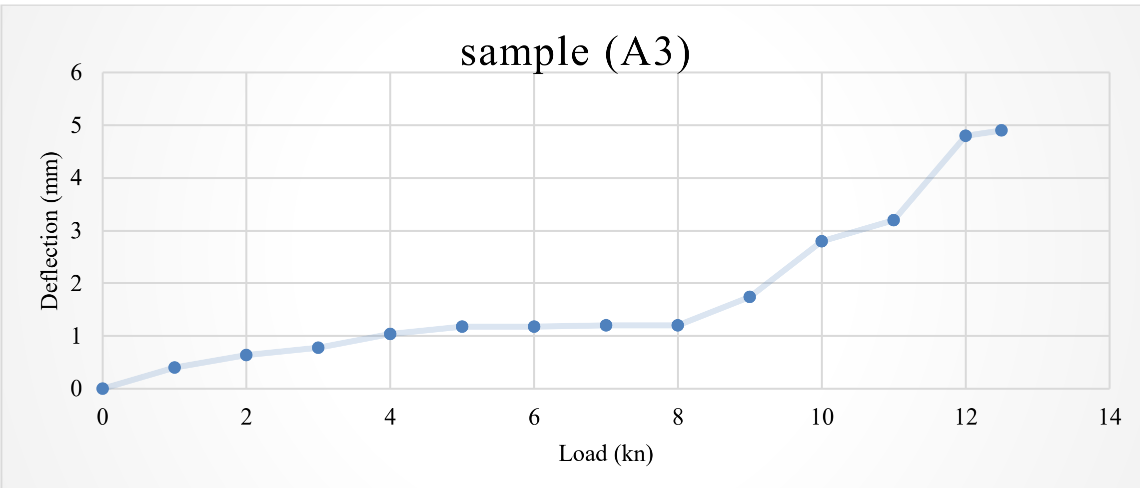

Figure 11. The load-deflection response of the control slab specimen (A3)

4.8. Flexural Behavior of Geogrid Reinforced Slab Coated with Fine Glass Powder (Sample B3)

Sample (B3), reinforced with a geogrid coated with fine glass powder, exhibited a distinctly different flexural response characterized by early stiffness followed by rapid deflection development prior to failure shown in Figure 12. During the early loading stages, the deflection increased slowly, indicating good initial stiffness and a strong bond at the reinforcement–concrete interface. However, as the applied load approached approximately 5 kN, the deflection rate increased sharply, indicating crack localization and reduced post-cracking restraint. The specimen failed at a relatively low ultimate load of approximately 6.5 kN, while exhibiting a very high maximum deflection of approximately 15.95 mm. This behavior indicates a highly ductile but low-strength response of the material. The fine glass coating on the geogrid enhanced the interfacial bonding but may have reduced the frictional resistance and stress redistribution capability after cracking, leading to early strength degradation. Compared with the other geogrid-reinforced specimens, Sample (B3) showed the highest deformation capacity but the lowest flexural strength, highlighting a clear trade-off between ductility and load-carrying capacity.

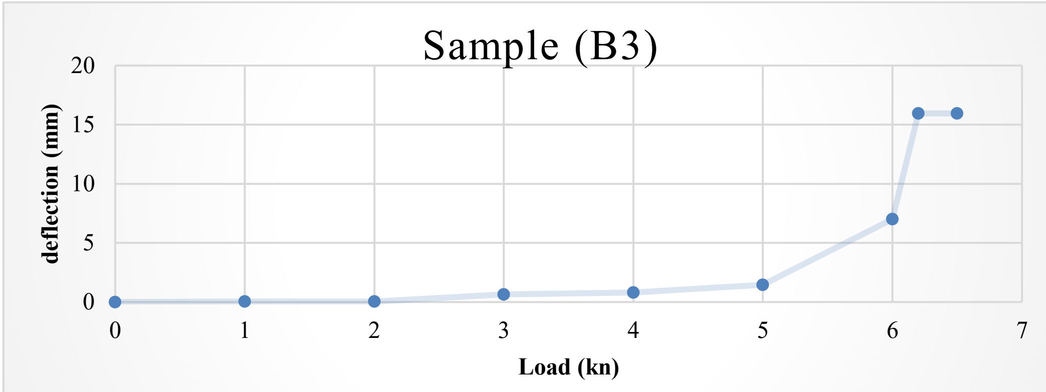

Figure 12: The load-deflection response of the control slab specimen (B3)

4.9. Comparative Flexural Performance and Reinforcement Mechanisms

A comprehensive comparison of the load-deflection behavior of all tested slab specimens revealed that both the type of reinforcement and surface treatment technique play decisive roles in controlling the flexural strength, stiffness, ductility, and failure mode. The control specimen (Sample 0) exhibited brittle behavior characterized by a low ultimate load and limited deformation capacity, serving as a baseline for evaluating the reinforcement efficiency. Introducing untreated palm rachis (A0) resulted in a moderate increase in the ultimate load and a more gradual failure process; however, the absence of surface treatment limited the bond efficiency and restricted stress transfer after cracking. Surface-treated palm rachis specimens demonstrated pronounced improvements, with the fine sand coating (A1) significantly enhancing ductility and post-cracking deformation capacity, whereas the coarse sand coating (A2) provided the best balance between strength and ductility, achieving the highest ultimate load among the palm-rachis-reinforced slabs. In contrast, the fine glass powder coating (A3) led to a strength-dominated response with reduced deformation capacity, indicating stiffer but less ductile behavior [30] .

The geogrid-reinforced specimens exhibited different performance trends as shown in **Figure 13**. The Fine sand–coated geogrid (B1) achieved the highest flexural strength among all tested specimens, reflecting superior tensile resistance and effective stress redistribution; however, its deformation capacity remained lower than that of palm-rachis-reinforced slabs. The Coarse sand–coated geogrid (B2) showed moderate strength enhancement with restrained ductility, whereas the fine glass–coated geogrid (B3) exhibited a highly ductile but low-strength response, characterized by early stiffness, followed by rapid deflection growth and premature strength degradation. Overall, palm rachis reinforcement was more effective in enhancing ductility and crack distribution, whereas geogrid reinforcement primarily contributed to an increased load-carrying capacity. Among all configurations, Sample A2 (palm rachis coated with coarse sand) demonstrated the most favorable overall performance by combining high flexural strength, stable crack propagation, and substantial deformation capacity, making it the optimal reinforcement solution within the scope of this study

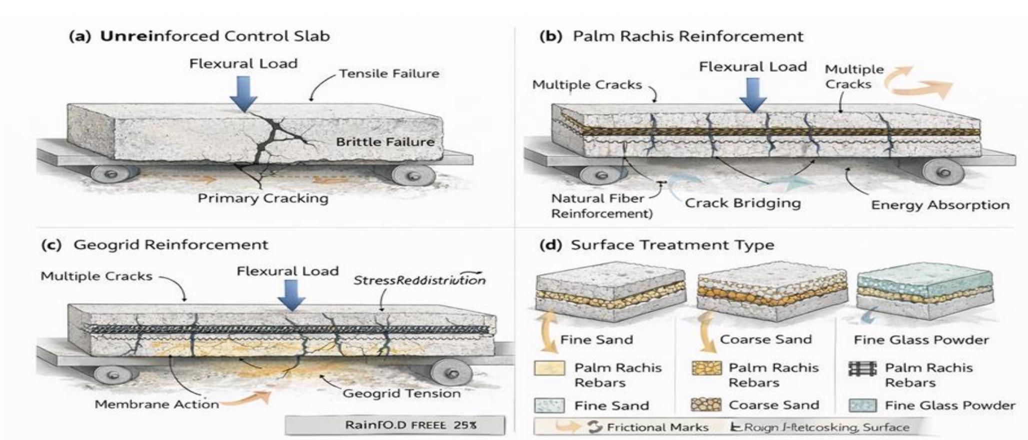

Figure 13. Reinforcement mechanism governing flexural behavior of reinforced slab

5. Conclusions

Based on the experimental results and comparative analysis of the flexural behavior of all tested specimens, the following conclusions can be drawn: The control specimen exhibited a brittle flexural behavior with a low load capacity and limited deformation. The use of untreated palm rachis improved ductility compared to the control slab but exhibited limited bond efficiency. Palm rachis coated with fine sand significantly enhanced the ductility and post-cracking deformation. Palm rachis coated with coarse sand achieved the highest flexural load with stable crack propagation. Palm rachis coated with fine glass powder increased stiffness but reduced the deformation capacity. The untreated geogrid increased the flexural strength but showed limited post-cracking efficiency. The Fine sand–coated geogrid exhibited the highest flexural strength among all the specimens. The Coarse sand–coated geogrid exhibited moderate strength with restrained ductility. The Fine glass–coated geogrid exhibited high deformation but low flexural strength. The palm rachis with a coarse sand coating offered the best overall balance between strength and ductility.

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No potential conflict of interest was reported by the author(s).

Reference

[1] A. Arora, A. Almujaddidi, F. Kianmofrad, B. Mobasher, N. Neithalath, Material design of economical ultra-high performance concrete (UHPC) and evaluation of their properties, Cement and Concrete Composites 104 (2019) 103346.

[2] J. Ryl, J. Wysocka, K. Darowicki, Determination of causes of accelerated local corrosion of austenitic steels in water supply systems, Construction and Building Materials 64 (2014) 246-252.

[3] C.J. Zega, Á.A.J.W.m. Di Maio, Use of recycled fine aggregate in concretes with durable requirements, 31(11) (2011) 2336-2340.

[4] B.S. Thomas, Green concrete partially comprised of rice husk ash as a supplementary cementitious material – A comprehensive review, Renewable and Sustainable Energy Reviews 82 (2018) 3913-3923.

[5] Z. Quanwei, C. Qi, A.H. AlAteah, A.M. Alfares, S. Alinsaif, S.A.J.R.o.A.M.S. Mostafa, AI-based prediction for the strength, cost, and sustainability of eggshell and date palm ash-blended concrete, 64(1) (2025) 20250113.

[6] W. Xu, T.Y. Lo, W. Wang, D. Ouyang, P. Wang, F. Xing, Pozzolanic Reactivity of Silica Fume and Ground Rice Husk Ash as Reactive Silica in a Cementitious System: A Comparative Study, Materials (Basel) 9(3) (2016).

[7] M. Adamu, H. Alanazi, Y.E. Ibrahim, M.J.C. Abdellatief, B. Materials, Mechanical, microstructural characteristics and sustainability analysis of concrete incorporating date palm ash and eggshell powder as ternary blends cementitious materials, 411 (2024) 134753.

[8] A. Tamimi, S.W. Tabsh, M.J.M. El-Emam, Pervious concrete made with recycled coarse aggregate and reinforced with date palm leaves fibers, 16(23) (2023) 7496.

[9] Y.E. Ibrahim, M. Adamu, M.L. Marouf, O.S. Ahmed, Q. Drmosh, M.A.J.B. Malik, Mechanical performance of date-palm-fiber-reinforced concrete containing silica fume, 12(10) (2022) 1642.

[10] D. Cui, L. Wang, C. Zhang, H. Xue, D. Gao, F.J.M. Chen, Dynamic splitting performance and energy dissipation of fiber-reinforced concrete under impact loading, 17(2) (2024) 421.

[11] A. Koutous, E.J.M.T.P. Hilali, A review on the use of date palm fibers to reinforce earth-based construction materials, (2023).

[12] P. Huali, M. Akbar, M.U. Arshid, Z.B. Mazhar, O. Guoqiang, T.O. Alshammari, A.M. Yosri, Seismic resilience of geogrid reinforced concrete earth-retaining wall of various incremental panels based on physical and numerical modelling, Structures, Elsevier, 2025, p. 107901.

[13] M.S. Moawad, A.M.J.A.E.J. El-Hanafy, Investigation of the effect of using geogrid, short glass, and steel fiber on the flexural failure of concrete beams, 68 (2023) 479-489.

[14] R.H. Bashir, B.S. Hamad, G.R.J.C.S.i.C.M. Chehab, Assessment of external and internal geogrid confinement of reinforced concrete columns, 20 (2024) e02974.

[15] M. Ozawa, S. Subedi Parajuli, Y. Uchida, B. Zhou, Preventive effects of polypropylene and jute fibers on spalling of UHPC at high temperatures in combination with waste porous ceramic fine aggregate as an internal curing material, Construction and Building Materials 206 (2019) 219-225.

[16] R. Xu, T. He, Y. Da, Y. Liu, J. Li, C. Chen, Utilizing wood fiber produced with wood waste to reinforce autoclaved aerated concrete, Construction and Building Materials 208 (2019) 242-249.
[17] W. Zhou, J. Mo, S. Xiang, L.J.C. Zeng, B. Materials, Impact of elevated temperatures on the mechanical properties and microstructure of waste rubber powder modified polypropylene fiber reinforced concrete, 392 (2023) 131982.
[18] A.H.J.C.S.i.C.M. AlAteah, Engineering characteristics of ultra-high performance basalt fiber concrete incorporating geranium plant waste, 19 (2023) e02618.
[19] B.A. Tayeh, A.A. Hakamy, M.S. Fattouh, S.A.J.C.S.i.C.M. Mostafa, The effect of using nano agriculture wastes on microstructure and electrochemical performance of ultra-high-performance fiber reinforced self-compacting concrete under normal and acceleration conditions, 18 (2023) e01721.
[20] Z. Guo, Q. Sun, L. Zhou, T. Jiang, C. Dong, Q.J.J.o.B.E. Zhang, Mechanical properties, durability and life-cycle assessment of waste plastic fiber reinforced sustainable recycled aggregate self-compacting concrete, (2024) 109683.
[21] S. Panda, A. Nanda, S.K. Panigrahi, Potential utilization of waste plastic in sustainable geopolymer concrete production: A review, J Environ Manage 366 (2024) 121705.
[22] A. Tripathi, A. Gupta, S. Bagchi, L. Mishra, A. Gautam, R.J.J.o.P. Madhok, Comparison of the effect of addition of cyanoacrylate, epoxy resin, and gum Arabic on surface hardness of die stone, 25(3) (2016) 235-240.
[23] A. Joshaghani, M. Balapour, M. Mashhadian, T. Ozbakkaloglu, Effects of nano-TiO2, nano-Al2O3, and nano-Fe2O3 on rheology, mechanical and durability properties of self-consolidating concrete (SCC): An experimental study, Construction and Building Materials 245 (2020) 118444.
[24] J. Wang, Q. Dai, R. Si, Y. Ma, S. Guo, Fresh and mechanical performance and freeze-thaw durability of steel fiber-reinforced rubber self-compacting concrete (SRSCC), Journal of Cleaner Production 277 (2020) 123180.
[25] F. Ergen, M.J.J.o.B.E. Katlav, Investigation of optimized machine learning models with PSO for forecasting the shear capacity of steel fiber-reinforced SCC beams with/out stirrups, 83 (2024) 108455.
[26] M. Adamu, A.N. Raut, Y.E. Ibrahim, H. Alanazi, O.S.J.S.R. Ahmed, Multi-criteria decision-based optimization and multivariable regression analysis of date palm fiber reinforced concrete modified with silica fume under normal and elevated temperatures, 15(1) (2025) 5902.
[27] M.H. Yassin, R.E. Lakys, Z.-E. Merouani, A. Jumah, M.H.J.S.R. Farhat, Performance analysis of palm tree microfibers in concrete, 15(1) (2025) 5128.
[28] M. Shokr, M. Meguid, S. Bhat, D.J.I.J.o.G. Malomo, G. Engineering, Experimental and Numerical Investigations of Slab-On-Grade Reinforced with Stiff and Ductile Geogrids, 11(2) (2025) 1-17.
[29] A. Kareem, S.S. Mehboob, D. Khan, Q.B.a.I.L. Qureshi, A. Rezzoug, K. Hayat, A. Ali, M.A.J.I.J.o.C.S. Mumtaz, Materials, A Review on Date Palm Fiber as a Sustainable Reinforcement for Concrete Applications, 19(1) (2025) 98.
[30] A.E.-R. Fares, H. Hassan, M.J.F. Arab, Flexural behavior of high strength self-compacted concrete slabs containing treated and untreated geogrid reinforcement, 8(4) (2020) 23.