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ENHANCING OF CYLINDERS CONCRETE CONFINED WITH HYBRID SISAL AND GLASS FIBER REINFORCED POLYMER

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Abstract: This study evaluates the effectiveness of a hybrid composite as an option for enhancing concrete structures. Concrete cylinders were wrapping with a combination of natural and synthetic fibers. A total of fifteen cylindrical specimens were prepared the concrete in the 25 MPa range and tested under axial compression load. Three specimens were used as control specimens and the remaining twelve specimens were encapsulated with strips of sisal fabric and glass fibers. Three variables were taken, including the complete encapsulation, spacing, and orientation of the hybrid fiber strips of sisal and glass fibers. The results found that combining sisal fibers with glass fibers increased the energy absorption properties of the encapsulated concrete and improved the axial compression performance. The strength of all specimens wrapping with sisal-glass fibers increased compared to the uncoated specimens, especially the fully coated specimens where the compressive strength increased by about 79%. This work demonstrates that the use of HSGFRP can be an effective way to strengthen concrete structures.
Keywords: Ultimate load, Confined, Strengthening, Hybrid fiber composites, FRP, HSGFRP

1. Introduction

Concrete stands as a crucial construction material widely utilized in various structural frameworks due to its easy availability, relatively low cost of its components, ease of manufacturing, flexibility, and other advantages over different construction materials. Concrete structures may encounter structural flaws and damages throughout the entire construction process and during their operational life, stemming from problems related to design failures (Bossio et al., 2019), inadequate reinforcement, and exposure to hostile environments, resulting in the corrosion of reinforcement steel or concrete. Therefore, to maintain the integrity of these structures, substantial research has been undertaken to develop effective and economical reinforcement techniques that ensure safety standards and serviceability (De Lorenzis et al., 2001; Venkiteela et al., 2017; Truong et al., 2017; Hussain et al., 2020). This includes the prevalent application of fiber-reinforced polymers (FRPs) as enhancement materials for concrete. The outstanding properties of FRPs, such as high tensile strength, impressive strength-to-weight ratio, resistance to corrosion, simple installation, and elevated specific strength, render them the most frequently utilized material for strengthening structures. The application of fiber-reinforced polymers for reinforcing various structural elements began in Switzerland in 1984 (Meier et al., 1992), where tests were conducted on carbon fiber reinforced concrete beams. Following the success of this experiment, numerous studies and research indicated that external reinforcement with FRPs can considerably enhance the load-bearing capacity of concrete columns as well. In these studies, various types of FRPs have been employed to strengthen concrete columns, including carbon fiber reinforced polymers (CFRP) (Xiao & Wu, 2000; Park et al., 2008; Chaallal et al., 2003; Issa et al., 2009; Tanaka et al., 1994), glass fiber reinforced polymers (GFRP) (Triantafyllou et al., 2015; Kumutha et al., 2007; Silva & Rodrigues, 2006). Previous research has contributed to enhancing the efficiency of techniques using these innovative materials in reinforcing columns in concrete structures. These FRPs enhance the concrete column's ability to withstand compressive loads and absorb energy. Since the production of synthetic FRPs requires high energy. However, natural FRPs are preferred from a sustainability perspective. Natural FRPs have drawbacks, such as increasing the surface area of the column and having lower to moderate tensile strength compared to synthetic FRPs. The elevated expense serves as a constraining element, prompting initiatives to development composites from alternative substances. Natural fibers such as sisal, jute, flax, and others (Sen & Paul, 2015; Padanattil et al., 2019; Xian et al., 2013; Yan & Chouw, 2013; Yan & Chouw, 2014). Were comparison for enhancing concrete structures, In contrast to synthetic fibers, natural fibers offer a lower density, moderate tensile and bending characteristics, and a reduced cost. Therefore, few investigations have indicated that combining synthetic FRPs with natural FRPs can enhance the performance attributes of the FRPs to reach the expected outcomes ((Wu et al., 2009; Ramesh et al., 2013; Padanattil et al., 2017; Wahab et al., 2019).

2. Experimental Program

2.1 Concrete

The concrete mixture was employed to obtain the desired range of unwrapping concrete strength, as shown in Table 1. Mixture was created in the laboratory by a mechanical mixer. The compressive strength of concrete utilized for the study was 25 MPa.

Table 1. Concrete mix proportion

Cement kg/m^3	**Fine aggregate kg/m^3**	**Coarse aggregate kg/m^3**	**Water Ltr/m^3**
350	700	1050	192.5

2.2 Properties of sisal and glass fibre

The sisal glass used in this study is illustrated in Figures (1&2). Properties of SFRP and GFRP material are provided in Tables (2&3).

Table 2. Physical and chemical of sisal fibre)

Physical state	**Solid**
Relative Density	1.32-1.5 g/cc
(Solubility wt.% in water)	76.7%
Tensile strength	400-700 N/mpa

Table 3. Physical and chemical of glass fibre

Physical state	**Solid**
Appearance / Color	White or off white
Odor	Odorless
Relative Density	2.6-2.7 g/cc (bare glass)
(Solubility wt.% in water)	Insoluble
Freezing / Melting Point	> ، 1400*F (800*C)
Percent Solid	100

Figure 1. Shows the Sisal fiber

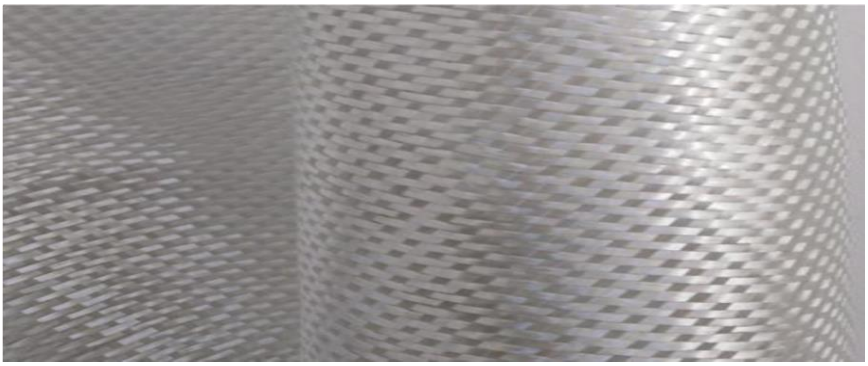

Figure 2. Glass fiber sheet roll (Structure wrap)

2.3 Epoxy resin

In this experiment, a two-part high performance and easily applicable epoxy resin bonding agent Sikadur® - 32 complies to ASTM C 881 type II as shown in Figure (3). It is made of a resin (Part A) and a hardener (Part B). As instructed by the manufacturer, Part A and Part B are combined in a 2:1 weight ratio. It can effortlessly be applied using a brush or roller. The epoxy resin is provided by the manufacturer and is represented in Table (4).

Table 4. Mechanical properties of epoxy resin

Sikadur® - 32	
Tensile Strength	18-20 N/mm^2
Compressive Strength	50-60 N/mm^2
Flexural Strength	30-35 N/mm^2
Bond strength to concrete	2.5-3 N/mm^2

Figure 3. Epoxy resin (Sikadur®-32)

2.4 Fabrication of specimens

The study involved the fabrication of twelve cylindrical concrete specimens, each measuring 100 mm × 200 mm, constructed in the Structural Engineering Laboratory of Bani-Waleed University in Libya. The Ordinary Portland Cement, sand, coarse aggregates of 14 mm were utilized in creating the concrete cylinders. Two batches of concrete mixes were used to cast all the fifteen specimens after 28 days water curing compressive strength was 25 MPa (ASTM, 2006), the cylinders were dried after removing from water for 180 days. The priority in wrapping was given to sisal fibers because are weak in corrosion resistance, and afterwards, they were wrapping with glass fiber sheets. This study investigation explored three variables: full confinement wrapping, spacing (40 mm and 120 mm), and the orientation of HSGFRP strips (0°, 90°). Detailed specifications of the specimens are presented in Figure (4) and Table (5).

2.5 Installation of HSGFRP strips

Before installing the FRP sheets, the surfaces of the columns were mechanically cleaned and ground using a diamond cutter to remove the cement layer, loose and brittle materials, to achieve a flat and mouldable surface. Embedded dust particles were removed from the surface using a high-pressure air blower. The prepared surface must be clean and free of dust and impurities before applying the epoxy. The GFRP fabric cut into desired dimension using sharp scissors. After wards, the strips were stored and placed carefully without folding the fabric. Epoxy has two parts namely part A and part B. Stir each part thoroughly and add with a ratio of 1 (part A): 4 (part B) into a suitable mixing bucket. Mix the parts A and B jointly at least from 3 to 5 minutes using a mixing spindle attached to a low-speed electric drill until the mixture reaches a pliable consistency and a consistent grey colour. Fill the cracks and voids with the prepared epoxy. Next, apply the initial coat of epoxy onto the concrete surface, then proceed with the saturation process and the placement of the fiber sheets using resin. The specified amount of SFRP is then placed according to the weight, length, and width of the GFRP sheets, followed by another saturation with epoxy. The sheets were then rolled using decorative rollers along the direction of the fibers to remove excess epoxy.

2.6 Test Methodology

The concrete columns were subjected to compression load using a hydraulic machine of 2000 KN capacity. The load was applied at equal intervals (4.7 kN/sec) (ASTM, 2014). The specimens subject to axial compression load until failure.

Table 5. Nomenclature of HSGFRP Wrapped Concrete Cylinders Specimens

Specimen Designation	Full wrapped/ Spacing/ Orientation of SFRP&GFRP strips
C1	Control unwrapped plain concrete
CSG2	Full wrapped
CSG3	Wrapped with 40mm spacing
CSG4	Wrapped with 120mm spacing
CSG5	Wrapped with orientations 0^{o}, 90^{o} hoop direction strips

Figure 4. Wrapping Configuration

3. Results and Discussion

3.1 Failure Load and Modes of Failure

The control specimen C1 succumbed to compression at a failure load of 196.25 kN. Figure (4) depicts the failure patterns of the control and strengthen specimens. The wrapped specimen CSG2 experienced HSGFRP rupture along with compression failure at the upper end of the column, reaching a failure load of 351.5 KN. The specimens CSG3 and CSG4 encountered concrete crushing and HSGFRP wrapping rupture at ultimate compressive loads of 283.5 KN and 267.2 KN, respectively. The specimen CSG5 failed due to rupture of the lower strip of HSGFRP, and cracking occurred in the unconfined portion of concrete near the top of the column. The obtained gain in percentage of enhancement of compressive load of the repaired rectangular columns CSG2, CSG3, CSG4, and CSG5 was 79.00%, 44.60%, 36.00% and 45.60% greater over the control specimen. Table 6 and Figure 5 present the external reinforcing HSGFRP configurations and the experimental outcomes of both the control and enhanced specimens.

Table 6. Experimental results for cylinder concrete specimens

Specimen Designation	Axial Stress (N/mm²)	Failure Load (KN)	Increment (%)
C1	25.00	196.25	--
CSG2	44.75	351.5	79.00
CSG3	36.15	283.5	44.60
CSG4	34	267.2	36.00
CSG5	36.4	286	45.60

Figure 5. Failure modes of HSGFRP wrapped circular concrete

3.2 Test Parameters

This research examined three distinct factors specifically spacing, alignment, layer of HSGFRP strips, and slenderness ratio. The aim was not only to ascertain the maximum load-bearing capacity but also to determine the optimal wrapping pattern for the rehabilitated rectangular columns.

3.3 Effect of Full wrapped of HSGFRP

Figure (6) shows the ultimate compressive load for specimens with full wrapped of GFRP. The specimen CSG2 with full confined attained an enhancement of 79.00% greater than the control. It indicates that full wrapped of ultimate load could be achieved by fully strengthen of HSGFRP sheets.

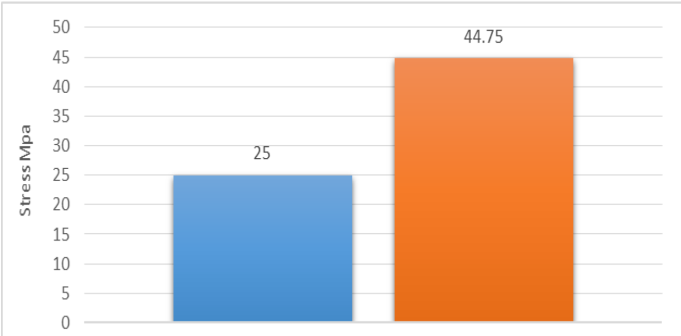

Figure 6. Comparison of compressive load with full wrapped of HSGFRP

3.4 Effect of Spacing of HSGFRP Strips

Figures 6 and 7 depict the comparison between specimens featuring varying spacing of SGFRP strips in series CSG3 and CSG4, respectively. From these figures, it is evident that specimen CSG3, which has a 40 mm strip spacing, attained an enhancement of 8.60% over specimen CSG4, which has strips spaced at 120 mm. Moreover, specimen CSG3 with 40 mm spacing achieved a 44.60% improvement compared to the control specimen C1. In a similar manner, the specimens CSG4 (strip spacing = 120 mm) demonstrated a 36.00% increase relative to the control specimen C1. It was observed that increasing the spacing between the strips results in a decline in the ultimate compressive load of the wrapped specimens.

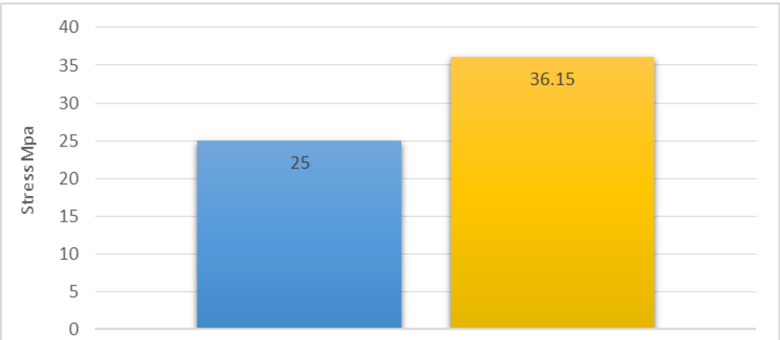

Figure 7. Comparison of compressive load with 40 mm spacing of HSGFRP strips

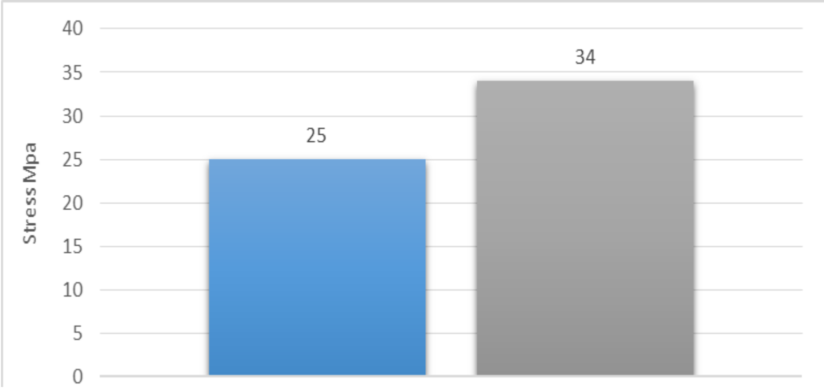

Figure 8. Comparison of compressive load with 120 mm interval of HSGFRP strips

3.5 Effect of Orientation of HSGFRP Strips

Figure (9) represents the comparison of ultimate compressive load for confined specimen with 0°,90° orientations. Specimen CSG5 strengthen strip orientation attained a gain in compressive load of approximately 45.6% greater than the control specimen. Results shows that specimen with orientation had better enhancement than control specimen.

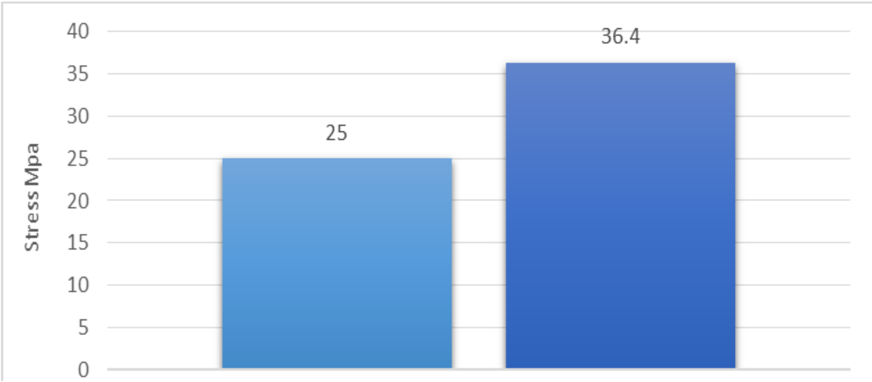

Figure 9. Comparison of compressive load with different fibre orientations

3. Conclusion

The results from the study on (HSGFRP) showed a significant improvement in compressive strength, the following conclusion are made:

(i) The samples reinforced with (HSGFRP) exhibited a notable improvement in compressive load resistance ranging from 36.00% to 79%, compared to the uncoated samples.

(ii) This study demonstrated the effectiveness of using (HSGFRP) in strengthening weak cylindrical columns; and

(iii) The findings demonstrated that the configuration and tilt of the reinforcement significantly influence the enhancement or reduction of the element's compressive strength.

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