Production of Hybrid Fiber Green Concrete Using Date Palm Fiber and Tires Wire Waste

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Abstract – In recent decades, researchers have begun to investigate innovative sustainable construction materials for the development of greener and more environmentally friendly infrastructures. The main purpose of this article is to investigate the possibility of employing date palm tree waste as a natural fiber and tires wire waste in concrete. Date palm fibers are a common agricultural waste in Middle Eastern nations, particularly in Egypt. As a result, this research examined the engineering properties of high-strength concrete using date palm fibers, as well as the performance of tires wire waste. The concrete samples were made using 0.0% and 0.50 by volume of date palm, 1.0 % of tires wire waste and (0.50%+0.50%), (0.5%+1.0%) and (0.75%+0.75%) by volume of date palm and tires wire waste respectively. Six concrete mixtures were made in total. Compressive strength test, flexural strength test and splitting tensile strength test were conducted. Moreover density, ultrasonic pulse velocity (UPV) and water absorption capability were determined.

***Keywords**:* date palm fiber, tires wire waste, high-strength concrete, Compressive strength, splitting tensile strength

I. Introduction

Environmental pollution is a crucial cause of climate change that may lead to a risk to human health. Hence, the efficient management of waste materials is essential for a smooth industrial revolution [1,2]. Researchers have recently concentrated on waste materials by converting them into wealth, such as energy production [3–5]. Further, waste materials might be reprocessed and reused to advance other valuable materials [6–8]. Infrastructure construction materials, particularly concrete, have been integrated with waste materials as critical components for several years [9–11]. Numerous studies have incorporated waste materials into concrete, such as gravel aggregates substituted by plastics [12], rubber [13], bottle glass [14], and recycled concrete aggregates [15]. Applying natural fibers as a construction material requires a unique challenge in the modern construction industry. Natural fibers have encountered the task of emerging new methods to simplify the usages of natural fibers in the fabrication of construction materials, where their benefits consent to compete efficiently [16–18]. The extraordinary challenges for the researcher are fiber quality, orientation and distribution, fiber strength, fiber humidity, fiber hydrophilicity, concerns of compatibility, and fiber degradation during chemical processing [19]. The application of natural fibers is more advantageous as fibers are locally accessible in abundance, are cost-effective, have small energy utilization during the process and permit a decrease in impacts on the environment. Aslam et al. observed that the addition of 2% coconut fibers in waste glass concrete improved the density by 20% and enhanced the mechanical strength [20]. Palm fibers have strand textures with distinct properties such as being low-cost, available in some regions, lightweight, and durable [21]. Fibers extracted from rotten palm trees are found to have low tensile strength, brittle behavior, low elasticity modulus, and very high water absorption capacity [22]. Several studies have incorporated natural fibers into construction materials [23–27]. For instance, Minke [28] observed that the addition of natural fibers into clay materials such as coir, animal or human hair, agave, sisal, straw, and bamboo might help in decreasing the shrinkage due to the dilution of the clay content as well as the definite amount of water immersed by the pores of the fiber. Taallah, Bachir, et al. [29] investigated the mechanical and hygroscopicity characteristics of compressed earth blocks occupied by date palm fibers to ensure the use of local building materials and support for low-cost housing in rural areas. Rokbi M. et al. [30] investigated developing and characterizing a polymer-reinforced concrete with date palm fibers. Their study used three sizes (short, very short, or mixed) of date palm fibers as a reinforcement. The experimental outcomes showed that the compressive and flexural strength were improved in some specimens. The study concluded that the strength improvement or degradation was attributed to the nature (treated or untreated) and the fibers' size (short, very short, or mixed). Since a lack of information on the engineering characteristics of the agro-waste date palm fiber-reinforced high-strength concrete found in the literature, the objective of this study is to examine the engineering characteristics of the date palm fiber-reinforced concrete in all aspects and make comparisons with conventional steel and polypropylene fibrous concrete.

II. Materials and Specimens Preparation

I.1. Materials

I.1.1. Cement

This study used ordinary Portland cement

Type-I for fabricating the high-strength date palm, steel, and polypropylene fibrous concrete specimens. The fineness and specific gravity of the cement were 410 m2/kg and 3.15, respectively. The cement contained 59% C3S, 12.10% C2S, 10.60% C3A, and 10.4% C4AF, as reported by the manufacturer [31] and confirmed with ASTM C 150 [32]. The chemical composition of the cement is recorded in Table 1.

TABLE 1. CEMENT CHEMICAL COMPOSITION.

Chemical Compound	Weight (%)
Cao	63.83
SiO2	19.70
Al2O3	6.25
Fe2O3	3.45
SO3	2.25
LOI	1.52
K2O	1.08
MgO	0.97
Insoluble	0.95

I.1.2. Aggregates.

The fine aggregate consists of natural dune sand with maximum particles passing through sieve No.4. More information about the fine aggregate used herein can be seen in previous work by the authors [31]. The coarser aggregate was a crushed stone with a maximum size of 20 mm used for manufacturing the high-strength date palm, steel, and polypropylene fibrous concrete. The physical characteristics of the fine and coarse aggregates are exhibited in Table 2.

TABLE 2. PHYSICAL CHARACTERISTICS OF THE AGGREGATES

Type of Aggregate	Bulk Density (kg/m^3)	Specific Gravity	Fineness Modulus	Absorption (%)
Fine	1535.74	2.67	2.23	1.31
Coarse	1630.00	2.77	7.34	0.69

I.1.3. Water and Superplasticizer

The filtered tap water was utilized as a fundamental element in manufacturing the high-strength date palm and polypropylene fibrous concrete and curing concrete. The properties of the water have accomplished the requirement of fabricating high-strength fibrous concrete with ASTM C1602/C1602M [33]. Super Plasticizers (SP) are well-known as great water reducers for manufacturing high-strength fibrous concrete. Sika Viscocrete, constructed on polycarboxylate ether (PCE), was employed as an SP for water reducers in this study.

I.1.4. Date Palm Fibers

The date palm fibers were obtained from Egypt's date palm trees are aged between 15 and 25 years old, which signifies one of the best available diversities and are accountable for significant agricultural waste production. These date palm fibers were manually collected from the palm trees. The date palm fibers are sited around the tree's trunk in a bidirectional form, comprised of two or three layers packed and superimposed. The collected raw date palm fibers had different diameters and lengths. Figure 1 shows the process of collecting the raw date palm material and turning it into fibers. The date palm fibers were cured chemically with 3% concentrations of analytical Sodium Hydroxide to eliminate any possible impurities from the surfaces of the fibers, and this chemical treatment also enhanced their matrix compatibility [34]. Afterward, the fibers were immersed in sulfuric acid (0.5% concentration) and washed with deionized (DI) water. Finally, the fibers were dried by sunlight and manually cut into 60 mm lengths with varying diameters. The physical properties of date palm fibers are revealed in Table 3.

TABLE 3. PHYSICAL PROPERTIES OF DATE PALM FIBERS

Length (mm)	Diameter (mm)	Density (kg/m^3)	Tensile Strength (MPa)	Elongatic (%)	Absorption (%)
60	0.1-1.0	1.30	240±30	12±2	5.00±2

Fig. 1. Date palm fibers as an agro-waste material.

I.1.5. Steel Tires Wire

There have been efforts to use different waste materials in concrete. One of these is the wastes arising from tires that have expired. The chemical composition and storage problems of car tires pose a problem worldwide. Tires are not biodegradable. Especially in case of the stocking stage, they can cause viral and bacterial diseases to multiply. The environmental problems caused by around 50 million waste tires annually in the Egypt alone are significant. Similarly, a significant portion (estimated 50%) of the one billion tires that complete their service life in the world every year is addressed through incineration. However, the accumulation of worn-out tires creates health and fire hazards. Therefore, these wastes should be used in a more sustainable way. It is possible to use waste car tires as fuel in cement factories, to be used instead of aggregate in asphalt and concrete, and to use in industry by separating the steel fibers in tires. Steel wire recovered in this way in Europe amounts to over 500,000 tons per year.

I.2. Specimens Preparation.

The waste of marble and granite was used as a partial replacement for natural sand in concrete. Compressive, tensile, and flexural forces were studied after 7 days and 28 days. Concrete was prepared by substituting marble and granite powder as a partial substitute for 0%, 10% and 20% sand.of weight according to the following table.

TABLE 4. MIXING RATIO OF DATE PALM AND STEEL TIRE WIRE

Mix	Cemen (kg)	Sand (m^3)	Gravel (m^3)	Water (L)	Date palm (Kg)	Steel tire (kg)
Control	350	0.38	0.76	164.5	-	-
Mix. (1)	350	0.38	0.76	164.5	-	3.5
Mix. (2)	350	0.38	0.76	164.5	1.75	-
Mix. (3)	350	0.38	0.76	164.5	1.75	1.75
Mix. (4)	350	0.38	0.76	164.5	2.625	2.625
Mix. (5)	350	0.38	0.76	164.5	1.75	3.5

III. TESTING METHODS

III.1. Compressive Strength Test

The specimens were tested according to ECP 2020 [36] under the compression load utilizing a 2000 kN capability of a mechanical compression testing machine (MATEST) with a loading rate of 0.0167 kN/sec. The size of the cube specimens was 50 × 50 × 50 mm^3. The specimens were tested after the 28-day curing regimen. Prior to testing, the specimens were kept at ambient temperature (23 ◦C ± 2 ◦C) for 24 h. Three specimens were tested for each mixture, and the average values were reported.

Specimens	Compressive Strength (MPa)
Control	278
Mix. (1)	290
Mix. (2)	336
Mix. (3)	336.67
Mix. (4)	320.67
Mix. (5)	326.6

II.2. Flexural Strength Test

The flexural strength of specimens was executed under a four-point loading arrangement that was implemented as per the ECP 2020 [37], which was applied through a Universal Instron machine (400 kN loading capacity) with a constant loading rate of 1.0 mm/min. This experiment also assessed the modulus of rupture (MOR). The displacement of the 100 × 100 × 500 mm3 was computed utilizing a Linear variable displacement transducer (LVDT) attached to the center of the prism specimens. The applied load and displacement were automatically recorded in the TDS-530 data logger during the execution of the experiment on the samples. The recorded results were transferred from the data logger to a computer to analyze the load-displacement graphs.

Specimens	Flexural Strength (MPa)
Control	4.2
Mix. (1)	7.2
Mix. (2)	4.23
Mix. (3)	7.2
Mix. (4)	7.21
Mix. (5)	7.43

II.3. Splitting Tensile Strength Test

The splitting tensile strengths of specimens were assessed at 28-days. The cylindrical specimens with dimensions of 100 mm diameter and 200 mm height and experiments were executed following ECP 2020 [38].

Specimens	Tensile Strength (MPa)
Control	58.5
Mix. (1)	74.67
Mix. (2)	123.23
Mix. (3)	139.79
Mix. (4)	145.5
Mix. (5)	141.5

II.4. Youngs Modulus

The mechanical property of a material to withstand the compression or the elongation with respect to its length.

It is denoted as E or Y.

Young’s Modulus (also referred to as the Elastic Modulus or Tensile Modulus), is a measure of mechanical properties of linear elastic solids like rods, wires, and such. Other numbers measure the elastic properties of a material, like Bulk modulus and shear modulus, but the value of Young’s Modulus is most commonly used. This is because it gives us information about the tensile elasticity of a material (ability to deform along an axis).

Young’s modulus describes the relationship between stress (force per unit area) and strain (proportional deformation in an object). The Young’s modulus is named after the British scientist Thomas Young. A solid object deforms when a particular load is applied to it. The body regains its original shape when the pressure is removed if the object is elastic. Many materials are not linear and elastic beyond a small amount of deformation. The constant Young’s modulus applies only to linear elastic substances.

Specimen	Max. Load (kN)	Max. Stress	Strain	Modulus of elasticity
Control	522	29.4	0.000312	31400
Mix. (1)	553.2	30.7	0.000225	45667
Mix. (2)	641	35.5	0.00042	27650
Mix. (3)	643.24	36.6	0.00033	36400
Mix. (4)	611.7	34.2	0.00029	39230
Mix. (5)	623.1	34.7	0.000271	41550

IV. Conclusion

1- The operational performance of concrete increased in tensile strength by 127% when adding palm fibers only, and increased by 210% when adding tire wire, and reached its highest number when adding rubber wire and palm fibers by 1% and 0.5%, and reached 238%.

2- The performance of concrete increased in pressure by 104% when palm fibers were added only, and increased by 120% when tire wire was added, and it reached its highest number when rubber wire and palm fibers were added by 1% and 0.5%, and it reached 121%.

3- The flexural performance of concrete increased by 104% when palm fibers were added only, and it increased by 171% when the frame wire was added.

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