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Research Paper

Behavior of Natural Fiber Reinforced Concrete Using Rice Straws

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ABSTRACT: *This research studies the behavior of concrete reinforced with rice straws as natural fibers. Specimens with different fibers percentages were casted and tested to determine the mechanical properties of rice straw reinforced concrete. A concrete mix with compressive strength 30 MPa was designed. Total of 27 standard cubes, 18 standard cylinders and 9 standard prisms were casted and tested. Specimens were divided into control mix and rice straws reinforced mixes. The specimens with fibers were casted using two different percentages of (1.5 and 2.5% by concrete volume), with the same fiber length which is 25 mm ± 5 mm. Concrete cubes were used to determine the compressive strength after 3, 7 and 28 days, cylinders were used to determine compressive strength and tensile splitting strength at age 28 days and prisms were used to determine the flexural strength after 28 days.*
It was found that using raw rice straw fibers in concrete reduced its workability despite using admixtures regarding the slump values due to the high absorption capacity of rice straws, as well as reducing concrete compressive strength. On the other hand, both tensile strength and flexural strength were improved. However, concrete with 1.5% fiber showed better mechanical properties than concrete with 2.5% fiber.
KEYWORDS: *Agricultural Waste; Natural Fibers; Rice Straw; Mechanical Properties*

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I. INTRODUCTION

The search for new sustainable building materials has become among the interests in the recent years by governments and industrial sectors. These new building materials should have certain advantages in terms of physical properties, mechanical properties, cost, and/or availability and sustainability [1]. This research trend coincides with the spread of concepts such as “Going Green” and “Eco-Friendly”, which refer to the protection of the environment, either by conserving the main natural resources or by controlling the causes of environmental pollution [2], [3]. Accordingly, new and innovative approaches for using agricultural waste in the construction industry have recently received a great attention. These approaches evolved to reduce the side effects of the current disposal methods of agricultural waste that can cause uncontrollable environmental pollution. One of these recent approaches is the use of agricultural residues as natural fibers among the ingredients for manufacturing the cement matrices for construction purposes [4].

Researchers have shown that some natural fibers can improve several important properties of fresh cement mix and final hardened concrete [5], [6]. In Egypt, rice straws, one of the rice crop residues, are locally available in huge amounts with low cost. Rice straws are usually burned and used as ash according to its high pozzolanic effect, which makes it suitable to be used as a cement replacement [7], but this burning process needs special equipment and proper plants to be done in a controlled environment to avoid air pollution [8]. Hence, the aim of this research is to investigate the usage of raw rice straws without burning as natural fibers in concrete as a sustainable building material by studying the mechanical properties of produced hardened concrete.

II. BACKGROUND

2.1 Mechanical and Physical Properties of Rice Straw Fibers

Factors such as origin and age of the plant, the surrounding climate and extraction method have effect on the properties of fibers [9], which subsequently, causes variation in the behavior of fibers in concrete [5]. Table 1 shows some physical and mechanical properties of rice straw fibers.

Table 1: Typical values of properties of rice straw fibers [10], [11].

Property	Value
Density	350-700 Kg/m^3
Water absorption	100 -200%
Tensile strength	435-450 MPa
Modulus of elasticity	24-26 GPa
Elongation at break	2-2.5%

2.2 Concrete Reinforced with rice straw Fibers

Recently, rice straw fibers are being used in concrete mixes to bridge the cracks caused by the applied loads to allow ductile failure of concrete, which in turn improves the toughness of the matrix and its post crack performance [12]. Recent studies showed that adding rice straw fibers would decrease the concrete strength, while the drying shrinkage and the time for cement hydration was increased [13].

A recent study by Rachana Shrestha on the effect of treated straw fibers on the mechanical and durability characteristics of concrete showed that adding dry raw rice straws absorbs high amount of water from concrete, which produces voids in the concrete, which results in lower compressive, flexural and splitting tensile strength. The density of voids is higher in case of dry raw straw reinforced concrete.

Another study showed that using raw rice straw fiber has and inhibitory effect on cement hydration and had marginal or even adverse effect on the mechanical properties of composites, on the contrary of using sodium hydroxide chemically treated fibers which enhanced composites flexural strength and compressive strength [14].

III. OBJECTIVES

In this research the main objective is to investigate the usage of rice straws as natural fibers in the cement- based mixes for construction applications as a renewable sources to reduce depletion of non-renewable sources and reduce the impact of the usual disposal methods of rice waste that cause environmental pollution.

IV. EXPERIMENTAL PROGRAM

4.1 Materials

Coarse Aggregate

In this study, crushed dolomite with 10 mm nominal maximum size and 4.7 fineness modulus was used. Its specific gravity is 2.73 and the absorption percentage is 1.91%. The aggregate is washed properly before being used to remove any dust or suspended materials.

Fine Aggregates

Harsh desert sand, clean and free of impurities was used, with fineness modulus equals 2.3 and specific gravity equals 2.5.

Cement

CEM I, conforming to ESS No 373/1991 was used. Its grade is 42.5 N and its specific gravity is 3.15.

Chemical Admixtures

Rice straw fibers are known for high absorption capacity as they can absorb mass of water greater than their own weight [10]. Hence, chemical admixtures had to be used to maintain the mix workability without increasing the water content. Superplasticizer that complies with ASTM C494 type F (Subsequently type A) was preferred to be used. So, superplasticizer having the commercial name (Addicrete BVF) was selected. It is produced by Chemicals of Modern Building (CMB) group for building chemicals. Its density is 1.18 ± 0.01 kg/l as per the product data sheet.

4.2 Fibers Preparation

Rice straws were brought from rice buddies in Dakahliya-Egypt. It was harvested during autumn season. Table 2 shows the properties of used rice straws. The straws were received in piles with original length around 30-50 cm, and then got manually cut to a length of 25 mm ± 5 mm. This length was chosen to avoid the tendency of fibers to form balls as showed in previous studies [13].

Table 2: Properties of Raw Rice Straw

Property	Specification
Specific Gravity	0.4
Density	398.9 Kg/m3
Moisture Content	6.58%
Porosity	84.21%

Fibers Water Absorption

Water absorption of raw fibers was determined to study the effect of the hydrophilicity of the fibers on the concrete mix. The fibers were soaked in water for 24 hours and then spread on a dry towel to let the surface dry and reach the Saturated-Surface Dry weight (WSSD), and then it was left in oven at temperature of 50°C for 24 hours until constant weight is reached to determine the oven dry weight (Woven dry). The absorption of fibers was represented as a ratio between WSSD and Woven-dry. It was found that the water absorption of the untreated fibers reached 123%, which is a high percentage that would cause reducing the free water content in concrete and that is why admixtures were used.

4.3 Preparation of Test Specimens

The concrete mix was designed to obtain a strength of 30 MPa. The test specimens were divided into plain concrete (without fibers) and concrete with raw fibers. The specimens contained fibers had two different percentages of fibers, 1.5% and 2.5%, with the same fibers length 25 mm ± 5 mm. This fibers length was selected to avoid the tendency of fibers to form balls according to previous studies [13].

The specimens casted for each mix were: 9 standard cubes to test the concrete compressive strength after 3, 7 and 28 days, 6 standard cylinders to determine cylinder compressive strength and tensile splitting strength after 28 days and 3 prisms of dimension 100x100x400 mm to determine the flexural strength at age 28 days.

Concrete Mixes Design and Mixing Procedures

Different concrete mixes were designed for each group of specimens according to ASTM C192/C192M – 2016. Superplasticizer was used with the mixes containing fibers. Its percentage in each mix was determined in respect to the fibers percentage, which is defined as superplasticizer/fibers ratio. The materials weight per one cubic meter are listed for all mixes in

Table 3.

For mixing process, dry ingredients were allowed to mix for 1 minute before adding water and superplasticizer. The fibers were added slowly in small quantities and had been separated by hand to ensure that no fibers balling took place due to the interlock between fibers. The process of adding the fibers took approximately 3-5 minutes. Then the superplasticizer was mixed with water and added gradually to the mix, and the ingredients were allowed to mix properly for about 4 minutes.

Table 3: Concrete Design Mix for Different Specimen Groups (1 m3)

Mix	Rice straw %	Adm. %	Cement (Kg)	Water (L)	FA (Kg)	CA (Kg)	Rice straw (Kg)	Admixture (L)	Slump (mm)
M0	0	0	384	227	574.9	1149.7	0	0	126
M1	1.5	0.9	384	227	559.2	1118.4	6	2.72	109
M3	2.5	1.5	384	227	548.8	1097.5	10	4.58	98

Concrete workability

The workability of concrete was determined by slump test according to ASTM C143 - 2015. The desired slump was 60 to 120 mm.

Table 3 and Figure 1 represent the slump values for different mixes. It shows that different volume fractions of fibers has an effect on the slump value. It was observed that increasing the percentage of fibers from 1.5% to 2.5% resulted in decreasing the slump despite using superplasticizer, due to the hydrophilic nature of rice straws fibers, which causes high water absorption from the mix [15].

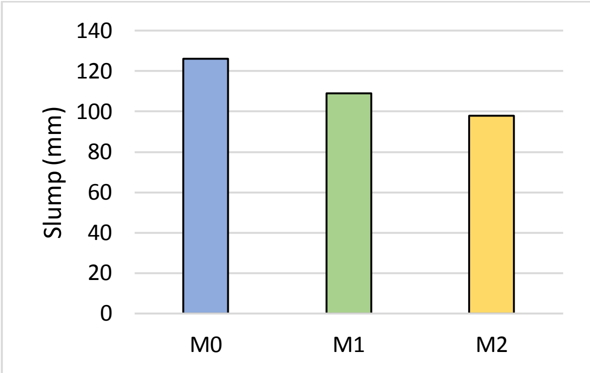

Figure 1: Slump values for different mixes

V. Testing And Results

5.1 Concrete compressive strength

Compression test was carried out with loading rate of 13.5 KN/s on both standard cubes of 150x150x150 mm and standard cylinders of 150 mm diameter and 300 mm length according to BS EN 12390-3-2019. The cubes were tested at 3, 7 and 28 days while the cylinders were tested at 28 days only.

Table 4 shows a summary of the results of compression test. It shows that adding rice straws fibers either treated or untreated to concrete decreased its compressive strength compared to the control mix. That was attributed to the presence of waxes which reduce the matrix interlock, as well as organic and inorganic components which chemically react with cement and would reduce its strength [16]. However, treated fibers gave better concrete compressive strength compared to untreated fibers; this was due to the removal of most of the surface substances such as waxes, mineral matters, organic and inorganic substances, and also increasing the fiber surface corrugation as shown in the SEM results, which in turn improved the fiber-matrix interaction resulting in improving the compressive strength. Figure 2, Figure 3, Figure 4 and Figure 5 shows the different compressive strength values for each mix at different ages.

Table 4: Concrete Compressive Strength

Mix	$F_{c\text{-cube}}$-3 days (Mpa)	$F_{c\text{-cube}}$-7 days (MPa)	$F_{c\text{-cube}}$-28 days (MPa)	$F'_{c\text{-cylinder}}$-28 days (MPa)	Strength Ratio cyl/cube
M0	14.72	28.92	36.15	28.58	0.80
M1	11.23	21.82	31.00	21.15	0.69
M2	9.61	17.16	24.71	16.05	0.65

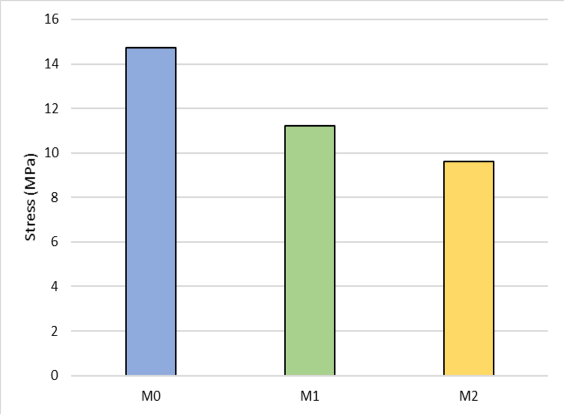

Figure 2: Cube average compressive strength at age 3 days

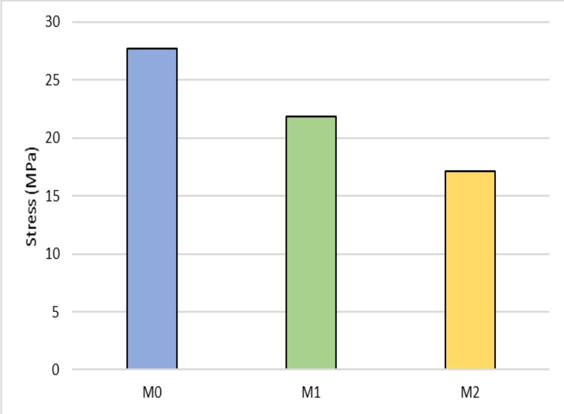

Figure 3: Cube average compressive strength at age 7 days

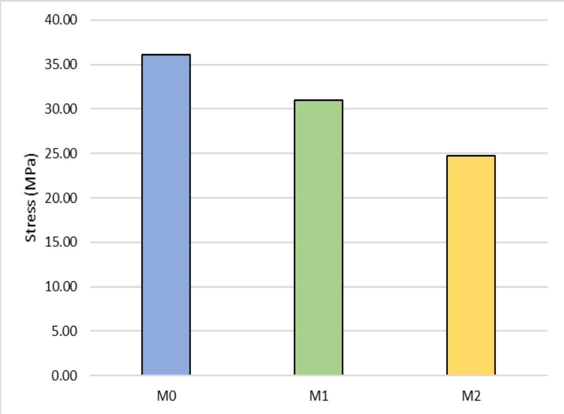

Figure 4: Cube average compressive strength at age 28 days

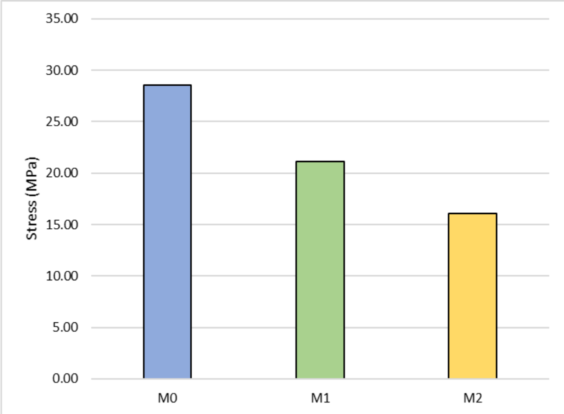

Figure 5: Cylinders average compressive strength at age 28 days

5.2 Tensile Splitting Strength

Tension splitting test was performed on 3 standard cylinders of each mix to indicate their tensile strength according to ASTM C496/C496M – 17. As shown in Table 5, mixes with fibers, either treated or untreated, gave higher tensile splitting strength compared to the control mix due to the high tensile strength of fibers. However, concrete with treated fibers showed better tensile splitting strength than this with untreated fibers as treated fibers have more corrugated surface, which improves the bond between the fibers and concrete.

Figure 6 shows a comparison between the tensile splitting strength results for different mixes at age 28 days.

Table 5: Tensile splitting strength

Mix	Splitting Strength F_{sp} (MPa)
M0	3.08
M1	3.38
M2	3.29

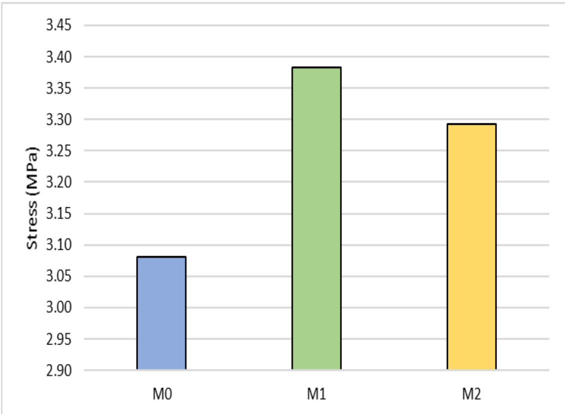

Figure 6: Average splitting tensile strength at age 28 days

5.3 Flexural Strength

Three-point bending test was performed on prisms with dimension of 100x100x400 mm to determine the flexural strength of different mixes according to ASTM C87/C87M-21. Table 6 and Figure 7 show the flexural strength of each mix. It was found that adding fibers to concrete enhanced the flexural strength of concrete compared to conventional concrete. Also the concrete with treated fibers showed better behavior than this with untreated fiber.

Table 6: Concrete flexural strength

Mix	Flexural Strength F_b (MPa)
M0	5.61
M1	7.58
M2	6.01

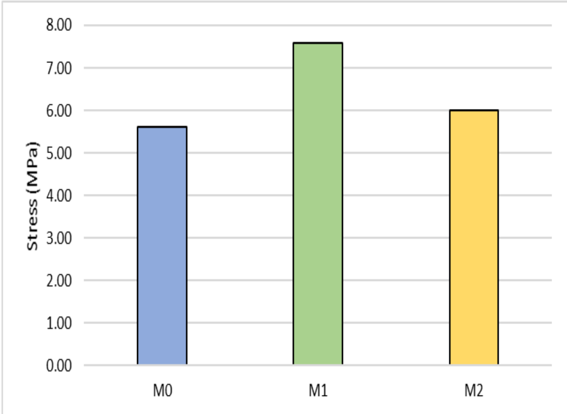

Figure 7: Average flexural strength at age 28 days

VI. CONCLUSION

In this research, rice straws fibers are being studied as natural fibers in concrete. Rice straws fibers have the advantages of being low cost and low density. The mechanical properties of concrete containing raw fibers are studied and compared to conventional concrete. The slump values of fresh concrete is reduced by adding fibers to the mix due to the high absorption capacity of fibers. The compressive strength of concrete is negatively affected by adding fibers due to the presence of waxes, which reduce the matrix interlock, as well as organic and inorganic components, which chemically react with cement and would reduce its strength. Both tensile strength and flexural strength are improved by adding fiber to concrete, that was attributed to the high tensile strength of rice straws fibers and the improved bond between the fibers surface and concrete. However, the optimum fibers volume friction among the two used amounts is 1.5% as it showed better mechanical properties in terms of compressive, tensile and flexural strength.

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