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Research Article

The Effect of Adding Different Types of Natural Fibers on Mechanical Properties and Impact Resistance of Concrete

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Abstract: The purpose of this study is to evaluate the effect of natural fibers: sisal and palm fibers on the different properties of concrete have been investigated through a number of tests. The properties investigated include compressive strength, flexural strength, splitting tensile strength and impact resistance of concrete. Sisal fiber has been used at three percentages of total mixture volume (0.6, 1.20 and 1.8%, respectively), while the palm fiber has been added in (2.5, 5.0 and 7.5%, respectively) by volume. The results of this study show that the concrete is reinforced with sisal and palm fibers improvement in flexural strength and in splitting tensile strength while no significant alteration in the compressive strength has occurred. The results also show improvements in the impact resistance of concrete by the addition of sisal and palm fibers which give maximum increase 114.3 and 285.7%, respectively for 1.8% sisal fiber and 7.5% palm fiber, respectively. The addition of sisal and palm fibres to the plain precast concrete slabs enhances the impact resistance and compensates for the decrease in depth for (500×500×40 mm). The important visual observation is that the predominant mode of failure in all fibers which has reinforced concrete slabs is fiber pull-out. Besides, it has been figured out that the slabs remain together in one piece. They are broken; though. The plain concrete slabs have been totally disintegrated and shattered.

Keywords: Impact resistance, mechanical properties, natural fibers, palm fibers, precast concrete slabs, sisal fiber

INTRODUCTION

Concrete is the most versatile material used in civil engineering structures. It is so simple and cheap that it can so easily be made by mixing aggregates, water and cement with unsophisticated equipment. Then, this mixture is poured or pumped virtually into any shape or section. Concrete is relatively strong in compression but weak in tension and tends to have brittle properties, because of the micro-cracks between the aggregate and the cement paste which tend to extend and contact with adjacent cracks when exposed to any tensile stress. The weakness in tension can be overcome by the use of conventional rod reinforcement and to some extent by the inclusion of a sufficient volume of certain fibers (Neville, 1995; Ahmed *et al*., 2006; Shetty, 2005).

The concept of using fibers to improve the characteristics of construction materials is very old. Early applications include addition of straw to mud bricks, horse hair to reinforce plaster and asbestos to reinforce pottery, use of continuous reinforcement in concrete (reinforced concrete) increases strength and ductility, but requires careful placement and labor skill (Wafa, 1990).

A large variety of fibers, include mineral fibers (glass; carbon; steel... etc.), organic manmade fibers (polypropylene; polyvinylene... etc.) and organic natural fibers (sisal, coconut fibers… etc.) have been used as reinforcement of composites (such as cement paste, mortar and/or concrete) to improve the tensile strength, shear strength, toughness, resistance to cracking, durability and to impart additional energy absorbing capability so as to transform a brittle material into a ductile material (Silva *et al*., 2011; Dawood and Ramli, 2012; Udoeyo and Adetifa, 2012; Oliveira and Gomes, 2011).

Recently, there has been resurgence of interest in using natural fibers of vegetable origin which are constituted of cellulose for fiber reinforcement of concrete in developing countries. This has been brought about by the energy crisis, a general oversupply and relatively cheap source of fibers and the need to reduce foreign reserve expenditure on importing other fibers.

Investigations have been carried out in many countries on various mechanical properties, physical performance and durability of concrete materials reinforced with natural fibers from coconut husk and trees sisal, sugarcane bagasse, jute, bamboo, wood and other vegetable fibers. These investigations have shown encouraging commercial prospects of this new distinct group of materials for application in low cost housing construction (Ahmad *et al*., 2001).

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The greatest advantage of reinforcement of concrete by natural fibers is the improvement of the impact and fatigue resistance. The disadvantages, however, is the difficulty to assess the exact magnitude of this improvement.

The aim of this experimental work is to study the effect of adding randomly distributed two types of natural fibers: Sisal Fiber (SF) and Palm Fiber (PF) on the properties of plain concrete. Many tests are required to be assessed in this experimental work such as: Compressive strength using (100 mm) cubes, flexural strength using (100×100×500 mm) simply supported prisms, splitting tensile strength using (100×200 mm) cylinders, impact resistance using precast slab (500×500×50 mm) and (500×500×40 mm). For impact resistance test, precast concrete slab with different thickness has been used (500×500×50 mm) and (500×500×40 mm) for economical purposes and for clarification of the benefit of using randomly distributed fiber in concrete.

METHODOLOGY

Materials: Materials used for the production of all concrete mixtures included Ordinary Portland Cement (OPC), fine aggregate, coarse aggregate with a maximum size of 12.5 mm, super plasticizer and two types of natural fibers sisal and palm fibers.

The natural fibers used in this study as shown in Fig. 1 are date-palm and sisal fibers. The palm fibers have been extracted from the leaf sheath of palm trees, which consist of fiber with various diameters. Cutting and hand picking operations on the sheath have been also used to obtain fiber of (40 mm) length.

The fiber has been added at proportions (2.5, 5.0 and 7.5%, respectively) by volume of total mixture. But the sisal fiber has been extracted from bundles of 1.5 m length, cut into (40 mm) length and added at proportions of (0.6, 1.2 and 1.8%, respectively) by volume of total mixture. Table 1 shows some properties of the fibers. All the fibers' types have been washed by tap water and added to the mixture of saturated surface dry conditions.

Preparation of specimens: The reference concrete mixture is designed according to the British method B.S. 1881. All mixtures have been designed to have a 28-day cubic compressive strength of 35 MPa. After many trials, one mixture proportion has been used in this study (1:1.36:2.2) (cement: sand: gravel) by weight. Cement content was (440 kg/m^3) and w/c ratio was (0.43) to give a slump of (85±5) mm.

Super-plasticizer has been used to maintain specific slump for all mixtures. The mixtures have been batched in a rotary mixer of 0.1 m^3. The dry constituent cement, sand and aggregate are initially mixed for 1 min then the required amount of water is added and the whole mixture constituents are mixed for another minute. The fibers are then added for a period ranging from 1 to 3 min depending on the amount of fiber. The super plasticizer added in steps, then the whole constituents mixed for proper time until a uniform dispersion of fibers is achieved.

(a) Sisal fiber

(b) Palm fiber

Fig. 1: Photograph picture of sisal and palm fibers

Table 1: Properties of the used natural fibers

Properties	Fibers types	
	Sisal	Palm
Density (kg/m^3)	1330	670
Water absorption after 24 h (%)	110	224
Modulus of elasticity (MPa)	38	35
Ultimate tensile strength (MPa)	600-700	143-180

Over mixing is avoided because the fiber may suffer damage and loss of strength. Such procedure results in good dispersion of fibers and it prevents balling problems. To obtain a fair face casting and to facilitate remolding, the moulds are thoroughly oiled before casting. Casting is carried out for each 50 mm depth of concrete. A vibrating table is used throughout this study. Each layer is vibrated for 20 sec, to avoid any segregation. The surface of the concrete is then struck by using trowel. The specimens are covered with nylon sheets to prevent evaporation of water from concrete and stored under laboratory condition. The specimens are remolded after 24 h and stored in water to have a relatively constant temperature about 21±2°C until the time of testing.

Testing procedure of all mixtures: The workability of the fresh concrete is measured by using the standard slump test apparatus. The slump test was carried out according to B.S.1881:1952. The internal surface of the mold was thoroughly cleaned and freed from superfluous moisture before conducting the test. The mold was placed on a smooth, horizontal, rigid and

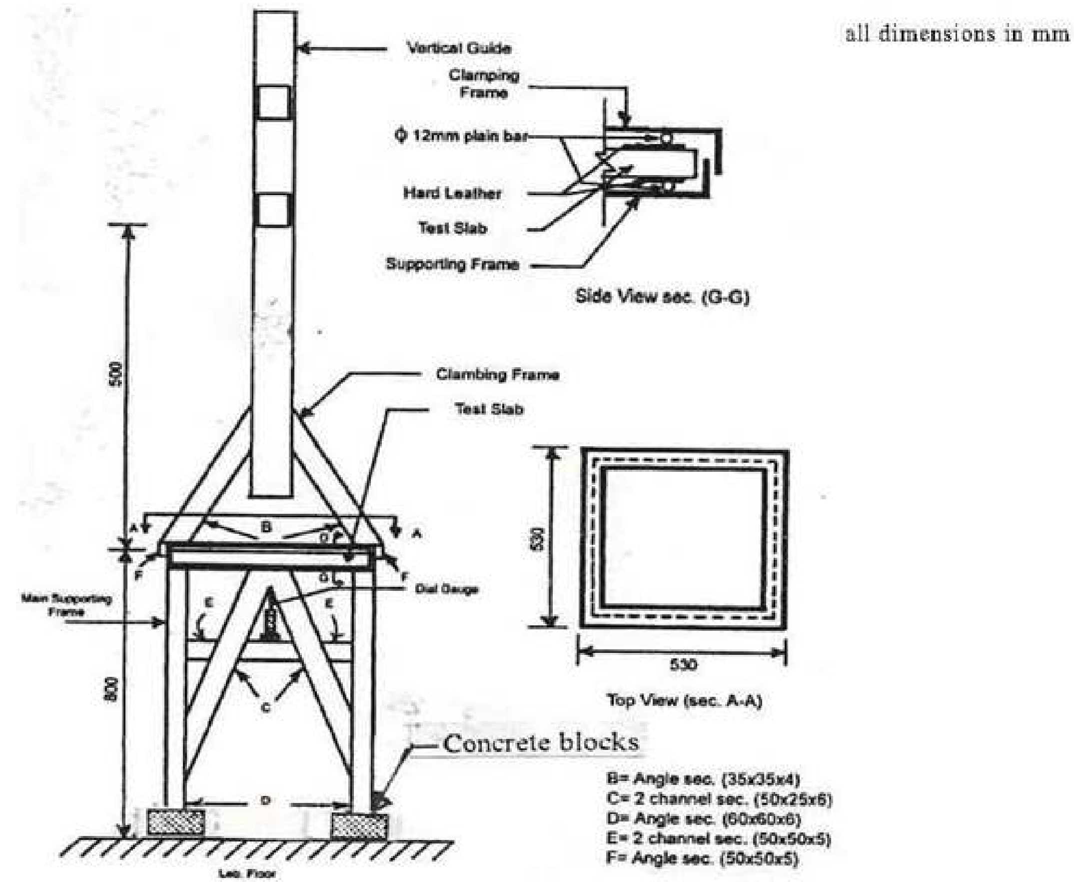

Fig. 2: Schematic shows the apparatus of impact resistance test

nonabsorbent surface metal plate and then filled with four layers. Each layer is one-fourth the mold height and was tamped with 25 strokes of the rounded end of a tamping rod. The strokes were distributed in a uniform manner over the cross-section of the mold and for the subsequent layers, penetrated into the underlying layer. The mold was removed from the concrete by raising it in a vertical manner and then allowing the concrete to subside. The slump was then measured immediately by determining the difference between the height of the mold and the highest point of the specimen.

The compressive strength test is determined according to B.S.1881: part 116:1989 using 100 mm^3. The compressive strength cubes have been tested using (ELE-Digital Elect.2000) at loading rate of 15 MPa/min.

Flexural strength has been carried out on (100×100×500 mm) simply supported prisms with clear span of 400 mm under one point loading according to B.S.1881: part 112:1989.

The splitting tensile strength is determined according to B.S.1881: part117: 1989, using (100×200 mm) cylinders. The splitting tensile strength cylinders have been tested using (ELE-Digital Elect. 2000). The average splitting strength of three cylinders is recorded for each test.

The average of three samples has been adopted at each test. The results of all specimens of plain concrete and fiber reinforced concrete stored in water have been tested at various ages (7 and 28 days).

The impact resistance of fiber reinforced concrete can be measured by a test method that is simple and easy to carry out. It has been developed by ACI Committee 544 (1986), which recommends the use of repeated impact "drop weight test to estimate this important property". In this study a simple repeated drop-weight impact testing apparatus is developed as shown in Fig. 2 in which the impact resistance of the precast slabs can be evaluated in terms of the number of blows required to cause failure, the apparatus mainly consists of three parts which are described as follows.

The main supported frame: A steel frame is strong enough to be held rigidly during impact load, the columns of the base are fixed in concrete to insure the stability of the frame during test. The specimens are placed in position in the testing frame using a continuous square steel angle to provide simply supported boundary conditions in all four sides of the specimen.

Drop weight guide system: A tube of circular section with an inside diameter of 105 mm, is held vertically above the center of the slab using four arms fixed to the steel frame so as to allow vertical movement only. This tube is used to drop the falling mass from a control height of (1.5 m) with accurate guideless.

Striker: A falling ball with a mass of (1.25 kg) and diameter of (94 mm) is used as a striker which is repeatedly dropped throughout the guide system on to the slab until failure.

EXPERIMENTAL RESULTS AND DISCUSSION

The performance of the sisal and palm fibers is estimated by determining the slumps, compressive strengths, tensile strengths, splitting strengths and impact resistance of the concrete specimens cast from the sisal and palm fibers.

Testing of slump: The slump cone test is adopted to assess the workability of plain and fiber reinforced concrete the test results are presented in Table 2.

Regarding the results, it has been seen that the fiber volume fraction increases, the dosage of super-plasticizer also increases for all types of fiber reinforced concrete mixtures (SF and PF). This happens due to the high cohesion of mixtures containing higher volume fraction, which is compatible with the observation made by Jorillo and Shimizu (1992).

The addition of fibers to plain concrete increases the stability and the cohesion of the mixture. This results in the reduction of the mixtures workability. This outcome concurs with Aboud (1980), he claimed that fibers tend to reduce the workability of concrete and additional air is entrained in the mixture. To overcome this problem in this study, fibers in saturated surface dry condition are used to maintain specific w/c ratio and polycarboxylic ether formulation which is known commercially as Glenium sky 777 is used as super-plasticizer to improve the workability of fiber mixtures.

Testing of compressive strength: Table 3 presents the average values of compressive strength results and their standard deviation values determined for concrete at different fibers's types and contents.

The results presented in Table 3 show that the fibers addition causes a small increase in compressive strength. This increment does not exceed 10% even for PF.5 at 28 days. The increase in compressive strength is due to the uniform dispersion of fibers in the matrix without curling and fiber balling. This agreed with the conclusion made by Jorillo and Shimizu (1992).

Testing of flexural strength: Table 4 presents the average values of flexural strength results and their standard deviation values of control concretes and concretes containing different types and contents fibers.

Table 2: Slump of concrete mixtures

Mixture designation	Fiber volume (%)	Super-plasticizer * (%)	Slump (mm)
R	0.0	0.00	80
SF	0.6	0.47	82
	1.2	0.84	85
	1.8	2.20	80
PF	2.5	0.41	83
	5.0	0.73	85
	7.5	1.30	88

*: By weight of cement

Table 3: Compressive strength of specimens at different fiber content and type

Mixture designation	Fiber volume (%)	Compressive strength (MPa), 7 days	S.D.	Compressive strength (MPa), 28 days	S.D.
R	0.0	23.40	0.98	39.4	0.49
SF	0.6	24.45	0.45	39.7	0.41
	1.2	26.50	0.65	40.7	0.25
	1.8	24.30	0.67	39.1	0.33
PF	2.5	26.20	0.74	39.6	0.16
	5.0	30.80	0.65	43.3	0.98
	7.5	27.60	0.90	41.1	0.90

S.D.: Standard deviation

Table 4: Flexural strength of specimens at different fiber content and type

Mixture designation	Fiber volume (%)	Flexural strength (MPa), 7 days	S.D.	Flexural strength (MPa), 28 days	S.D.
R	0.0	2.70	0.16	3.18	0.12
SF	0.6	2.82	0.10	3.78	0.15
	1.2	4.68	0.22	5.58	0.11
	1.8	4.50	0.20	4.80	0.17
PF	2.5	3.46	0.17	4.71	0.25
	5.0	4.47	0.02	5.65	0.12
	7.5	4.25	0.20	5.22	0.10

S.D.: Standard deviation

From these results, it can be observed that the flexural strength increases as age increase and the maximum increases are (75.47%) and (77.67%) for SF1.2 and PF5.0 respectively compared with plain concrete tested at the same period of 28-day. The flexural strength of plain concrete is improved by the addition of both natural fibers and it increases up to 1.2 and 5% (by volume) for SF and PF concrete mixtures respectively then it decreases as fiber volume fraction increases. This can be attributed to the curling and bundling of fibers during the mixture which limits the effectiveness of the entire length in transmitting stresses. This observation goes with Ramirez (1992).

Testing of splitting tensile strength: The splitting tensile strength results for specimens of plain concrete and fiber reinforced concrete are given in Table 5. From these results, it can be observed that the splitting strength increases as age increases. The maximum increase for SF1.2 and PF5.0 was 48.61 and 24.3%, respectively compared with plain concrete tested at the same period of 28-day.

The splitting tensile strength of plain concrete is improved by the addition of both natural fibers and it increases up to 1.2 and 5% (by volume) for SF and PF concrete mixtures respectively then it decreases as fiber volume fraction increases. This can be attributed to the

Table 5: Splitting strength of specimens at different fiber content and type

Mixture designation	Fiber volume (%)	Splitting strength (MPa), 7 days	S.D.	Splitting strength (MPa), 28 days	S.D.
R	0.0	1.28	0.11	2.51	0.22
SF	0.6	2.50	0.15	2.97	0.10
	1.2	2.74	0.03	3.73	0.02
	1.8	2.39	0.10	2.63	0.02
PF	2.5	2.16	0.13	2.77	0.07
	5.0	2.45	0.04	3.12	0.11
	7.5	2.33	0.14	2.95	0.12

S.D.: Standard deviation

Table 6: Impact resistance results of precast concrete slabs

Mixture designation	Fiber volume (%)	Dimension (mm)	No. of blows
R	0.0	(500×500×50)	14
SF	0.6	(500×500×40)	20
	1.2	(500×500×40)	30
	1.8	(500×500×40)	35
PF	2.5	(500×500×40)	24
	5.0	(500×500×40)	40
	7.5	(500×500×40)	54

(A) Precast concrete slab reinforced with 1.8% by volume of sisal fiber

(B) Precast concrete slab reinforced with 7.5% by volume of palm fiber

Fig. 3: Failure of precast concrete slabs with and without fibers

segregation problems as a result of insufficient compaction of the higher fiber volume mixtures. It is seen that, segregation of fibers is avoided; the increasing volume percentage of fibers more or less linearly increases the strength of the composite (ACI Committee 544, 1986).

Testing of impact resistance: The results of the impact resistance in terms of the number of blows of precast concrete slabs are shown in Table 6. From these results the following observations can be made:

- The impact resistance of precast plain concrete slabs is improved and increased by the addition of both natural fibers.
- The impact resistance of (500×500×40 mm) precast slabs is higher than the impact resistance of plain concrete slabs of (500×500×50 mm).
- The addition of both natural fibers to the precast concrete slab improves the impact resistance and compensates for the decrease in depth for (500×500×40 mm). The increase in the impact resistance is 150 and 285.7%, respectively for SF1.8 and PF7.5, respectively compared with plain concrete slabs of (500×500×50 mm) tested at the same period of 28-day.
- The important visual observation can be inferred from the Fig. 3A and B is that the predominant mode of failure in all fiber reinforced concrete slabs is fiber pull-out. It is also observation that the slabs remain together in one piece. They are broken, though. The plain concrete slabs, however, exhibit total disintegration and shattering. This point is compatible with the conclusion made by Ramaswamy and Krishnamoorthy (1983).

CONCLUSION

From the experimental results of this study, the following conclusions can be drawn:

- The addition of fiber reduces the workability of all concrete mixtures. To compensate for the reduction in workability, super-plasticizer is used in different dosages between 0.47 to 2.2% for SF concrete mixtures and between 0.41 to 1.3% for PF concrete mixtures.
- The addition of sisal fiber does not significantly alter the compressive strength of plain concrete mixtures. But the compressive strength decreases as fiber volume fraction increases.
- The addition of sisal fiber improves the flexural strength and the splitting strength of plain concrete.
- The mechanical properties of plain concrete are enhanced and improved by the addition of (1.2%)

by volume of sisal fiber and the percentages of increase are (3.3%) for compressive, (75.47%) for flexural and (48.61%) for splitting tensile.

- The mechanical properties of plain concrete are enhanced and improved by the addition of (5.0%) by volume of palm fiber and the percentages of increase are (9.89%) for compressive, (77.67%) for flexural and (24.3%) for splitting tensile.
- The addition of sisal and palm fibers to the plain precast concrete slabs improved the impact resistance and compensates for the decrease in depth for (500×500×40 mm).
- The maximum increase in impact resistance of plain concrete slab is (114.3%) and (285.7%) for SF1.8 and PF7.5, respectively.
- The addition of both natural fibers to the precast concrete slabs of (500×500×40 mm) compensates for the reduction in them thickness and improves their impact resistance. This intern provides an economical production of precast concrete slabs.
- The important visual observation is that the predominant mode of failure in all fiber reinforced concrete slabs is fiber pull-out. It is also observed that the slabs remain together in one piece. They are broken, though. The plain concrete slabs, however, exhibit total disintegration and shattering.

RECOMMENDATIONS

More experimental work is needed in the future to efficiently evaluate:

- The effect of fungi and insects on the sisal and palm fiber reinforced concrete.
- The microstructure properties of sisal and palm fiber reinforced concrete in different soaking periods.
- The durability of sisal and palm fibers reinforced concrete.
- Possibilities of improving and enhancing the performance of sisal and palm fibers reinforced concrete by using natural pozzolanic materials.

ABBREVIATIONS

R = Reference concrete
SF = Sisal fiber
PF = Palm fiber

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