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MECHANICAL PROPERTIES OF MİSCANTHUS REINFORCED CONCRETE

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ABSTRACT

There has been an increasing interest in the use of vegetable-fiber-reinforced structural concrete elements in many countries recently. Vegetable fibers facilitate the production of structural elements that are cheaper, lighter and they improve the mechanical properties of the cement, and provide aural and thermal insulation. Vegetable fibers are preferred because they increase the ductility of the material; this has the important effect of improving dissipation capacity when fissures occur. In addition, the manufacturing cost of this material is very low. In this study, cylinder and beam specimens were produced by using miscanthus (sinensis) as a plant fiber in the concrete. Ø15/30 cm cylinder specimens were subjected to compression tests and splitting tests. 5x15x75 cm beam specimens were subjected to bending tests. The granulometry of the aggregate was kept constant during the preparation process of the concrete mix, and the concrete was produced with a water-cement ratio of 0.5 having 450, 400 and 350 kg/m^3 cement dosages, and with various fiber ratios (0%, 2%, 4%, 6%).

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INTRODUCTION

Nowadays, the use of synthetic, mineral, or steel fiber reinforced concrete has become widespread in the production of structural elements. In particular, there is a long history of producing fiber-reinforced materials whose tensile strength is lower than compressive strength. The first example is bricks made from sun-baked soil, and there are various historical examples of construction materials incorporating plant fibers. More recently, the most common fiber-reinforced material was asbestos, after which steel, glass-wool, carbon, cellulose, nylon and polypropylene with other fibers were used. Different from those, in our day vegetable fibers have been also used. The main reason for using fiber is to reduce the brittleness of a material, and to increase ductility and therefore the dissipation capacity of a structural element under load. Vegetable fibers are produced in large amounts in tropical countries, especially in Brazil. The most common plant fibers are Manila hemp, sisal hemp, cannabis, coir, cotton and cannabis sativa. Manila and sisal hemp are classified as tight fibers due to their mature.

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Recently, cellulose vegetable fiber has been used to increase the ductility of concrete. Cellulose chains are in the form of microfibers. These chains combine in various sequences to create the structure of the fiber. Within the plant, fibers and cells are combined by lignin, which resists deformation of the fiber structure by the alkaline in cement (Coutts, 1982). Manila hemp, which is one of the most commonly used fibers, takes its strength from stem, leaf, and body. Its length varies between 1.2 and 4.5 m under normal circumstances. Manila hemp has great strength and elastic modulus, thanks to its quality and length, and is resistant to wear and deformation. Resistance to fungus can be enhanced by chemical substances. Manila is generally marketed at standard lengths. Sisal fibers are obtained by twisting the fibers of two tropical plants, sisal and henequen, of which sisal is more durable and effective and thus, as a result the fiber is named as sisal not henequen. The resulting fibers are 0.6–1.2 m in length. Sisal hemp is frequently preferred, because it has 80% of the strength of manila and is greatly resistant to seawater. Cannabis is planted in large quantities in many part of the world, and is a highly resilient plant. Cannabis was mostly used as fiber before the recognition of Manila. Today, it is mainly used in the construction of rope ladders, tightropes and tie rope. Cannabis has a much greater water-absorption capacity than dense fibers and it is the most preferred material used against water leakages. In addition, Cannabis sativa (also known as jute) is used as fiber. Coir rope, which is made from fibers of the coconut shell, has one-quarter the strength of cannabis and high elasticity. It is light that it does not sink in water. Cotton is produced from smooth white thread that is resistant to bending. Apart from these, cannabis sativa which is also named as jute is also used as vegetable fiber. In comparison to vegetable fibers, the tensile strength of synthetic nylon fibers is three times higher than Manila hemp. Synthetic fibers provide advantages such as resistance to impacts, tightness, tensibility, and returning to normal length. The diameters of vegetable fibers were found to range between 1/4 – 3 inches (6.35–76.2 mm) and perimeters were between 3/4 – 9 inches (19.1–229 mm). Since the tensile strength of vegetable fiber decreases after usage and due to weather conditions, care should be taken in the choice of application. The fiber may also be subject to impact, knotting and sharp twisting during the usage, which may reduce the strength by 50%. If the load to be carried safely by the fiber cannot be measured by spinners, it can be determined by approximate calculation, in which the safe load-bearing capacity is equal to the square of the fiber diameter. When the fiber diameter is calculated by inch, the unit of the load is ton. For example, the load to be carried safely by vegetable fiber whose diameter is 1/2 inch is 1/4 ton (Savastano, 1998). A previous study examined the main characteristics of transition regions in Portland cement mixtures that were prepared using asbestos and polypropylene mineral fibers; malva, sisal and coir vegetable fibers. The study examined both the effects of the transition region characteristics on the mixture's mechanical properties, and the effect of water–cement ratio on the mixture life. The transition region can be defined as the fiber–mixture interface at a thickness of 10–100 micrometers (μm), and has different characteristics from the mixture. Within the interface, the concentration and porosity of the Portland crystals are high. In order to ensure adhesion between fiber and cement paste, the porosity in the transition region and concentration of Portland crystals should be improved; as a result, adherence and endurance are increased (Savastano, 1997). In another study, the transition region of cellulosic fiber and cement mixture is examined. In this study, Portland concentration and porosity increase were recorded at the early hydration stage, after which hardening of the fiber by implementing different curing conditions was observed. Consequently, it was found that tensile strength was reduced due to fiber rupture in the mixture (Bentur, 1989). Weathering effect was examined in vegetable-fiber-reinforced mixtures, and as a result of these studies, ductility was found to decrease with increasing age. This was attributed to the organic structure of the fiber, which deteriorated in the alkaline cement environment. In time fiber lost its effect in the mixture. Thus, there are three important issues to be considered to ensure the structural integrity of vegetable fibers (Agopyan, 1992).

- Protection from the alkaline effect of water by ensuring non-leakage characteristics of the dry mixture,
- Steam-curing should be implemented at high pressure to ensure carbonation; silica fume should be added if necessary,
- Low-alkaline binders should be used.

Since the climate conditions of Sao Paulo, Brazil are convenient, the cost is reduced by 15% by using coir-fiber-reinforced cement mixtures in external panels. The effect of the water-cement ratio on tensile strength was determined by applied tests. The results showed that higher water/cement ratio reduced tensile strength. Variations in the material properties of the vegetable-fiber-reinforced concrete composite affect pipe surfaces, wall thickness, and endurance. Changes in surface permeability and wall thickness were observed by microscope in 8 cellulosic-fiber-reinforced samples. In order to compare the changes in the vegetable-fiber-reinforced concrete pipes eight reinforced concrete pipe samples were prepared. The various concrete samples were placed inside a stainless steel cage and released in the experimental environment. The strength characteristics of vegetable-fiber-reinforced concrete pipes were determined by applying load to the samples. In each of three months, 3 fiber reinforced concrete samples were taken from the experiment environment and compression load was applied. Behavior under this compression load was examined via diagrams of maximum load/day. The changes of strengths in the samples broken by the flexure test and maximum tensile capacity were determined. Comparison of the endurance of cellulose-fiber-reinforced concrete pipe exposed to acid attacks with that of reinforced concrete pipe showed that the properties of vegetable-fiber-reinforced concrete pipe material were affected much more under all experimental conditions. In addition, vegetable-fiber-reinforced concrete pipes showed sufficient endurance performance for the intended application (Fisher, 2001). Luiz C. Roma Jr. and colleagues have investigated mechanical, physical and thermal performance of roofing tiles produced with several formulations of cement-based matrices reinforced with sisal and eucalyptus fibers. The physical properties of the tiles were more influenced by the fiber content of the composite than by the type of reinforcement. The type of the fiber was the main variable for the achievement of the best results of mechanical properties. Exposure to tropical climate has caused a severe reduction in the mechanical properties of the composites (Luiz, 2008). Romildo D. Toledo Filho and colleagues presented several approaches used to improve the durability performance of mortar composites incorporating sisal and coconut fibres (Romildo, 2003). In this study "miscanthus" is used as vegetable fiber and changes in the mechanical properties of concrete have been examined. The reason for using miscanthus as a plant fiber is that it can be grown in the weather conditions of the city of Konya, Turkey. Miscanthus used in the experiments was fairly easily obtained from the fields in the campus area which are controlled by the Agricultural Engineering Faculty at Selcuk University, Konya. Since miscanthus is easily cultivated, its price is quite low.

EXPERIMENTAL STUDIES

Materials

Aggregates: Natural aggregate used in the experiments was obtained from Kayseri Koramaz Quarry; aggregate granulometry is shown in Figure-1 with the reference curves related to the ideal granulometry. Experiments were conducted according to standards TS 3529, TS EN 1097-6 and TS 130 in order to determine the properties of the aggregate. Accordingly, the all-in-aggregate fineness modulus was k=4.84; specific weight was 2490 kg/m^3; compressed unit weight was 1695 kg/m^3; and bulk weight was 1615 kg/m^3. Water absorption rate was 8.96% for fine aggregate and 2.09% for coarse aggregate.

Cement: Reinforced Portland cement with specific weight of 3.15 kg/dm^3 was used in the production of samples (CEM I 42.5 R). Table-1 shows the conformation of the cement to TS 19 (TS EN 197-1).

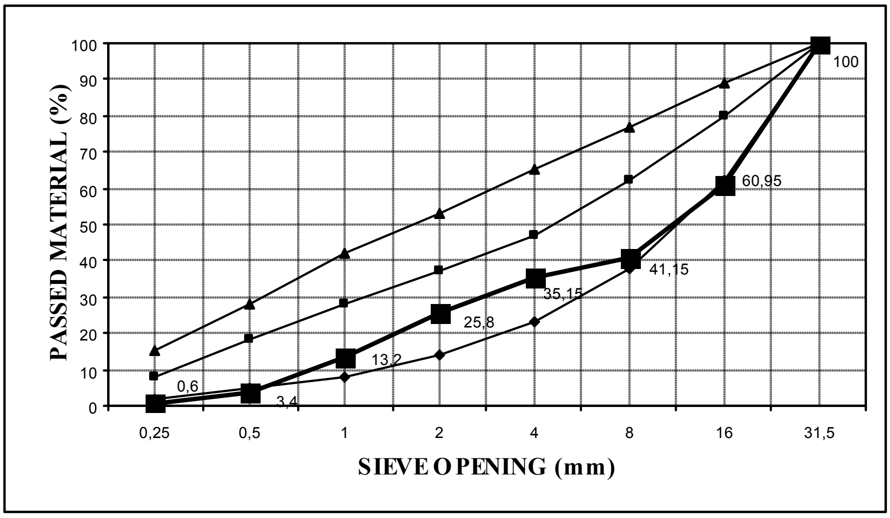

Figure 1. Aggregate granulometry

Table 1. Values of cement used in the experiment compared with TS 19 specifications

PROPERTY		TS19 specification	Experimental values
Setting	Startup time	≥1 hour	1 hour 16 minutes
	Finishing time	≤10 hour	4 hour 26 minutes
Volume expansion		≤10 mm	4 mm
Amount on 200-micron sieve		≤%1	%0.4
Amount on 90-micron sieve		≤%14	%9.3
Specific surface		≥%2400 cm^2/g	%2900 cm^2/g
Compressive strength (kg/cm^2)	7 days	210	228
	28 days	325	348
Tensile Strength under bending (kg/cm^2)	7 days	40	49
	28 days	55	65

Table 2. Physical and mechanical properties of the vegetable fiber used in the experiment

Properties	Density kg/m^3	Water absorption %	Unit elongation at reakage moment %	Tensile Strength MPa
Miscanthus	70	110.0	4.3	95-118

Table 3. Values of the compressive strength, splitting strength, tensile strength, modulus of elasticity, and energy absorption capacity.

MIXTURE		Compressive Strength (MPa)		Splitting Strength σ_Y (MPa)		Tensile Strength $\sigma_Y/1.5$ (MPa)		Modulus of elasticity (MPa)		Energy absorption Capacity (N mm)	
Dosage	Fiber ratio (%)	7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days
350	0	22,55	29,12	1,98	3,22	1,32	2,15	34515	37316	13,34	24,37
	2	24,88	30,09	1,94	2,50	1,29	1,67	35549	37697	11,58	21,16
	4	25,13	30,10	2,14	2,24	1,43	1,49	35657	37704	11,21	28,18
	6	26,93	31,47	2,17	3,13	1,44	2,09	36422	38237	10,92	29,94
400	0	23,06	33,13	2,17	2,70	1,44	1,80	34748	38867	11,39	27,26
	2	25,31	34,61	2,22	2,71	1,48	1,81	35736	39416	13,94	23,02
	4	26,78	34,65	2,30	2,94	1,53	1,96	36359	39431	5,91	19,29
	6	28,66	35,09	2,37	2,28	1,58	1,52	37128	39590	10,83	34,50
450	0	26,98	35,19	2,42	1,98	1,61	1,32	36443	39627	18,82	16,03
	2	27,59	37,39	2,44	3,30	1,62	2,20	36692	40418	14,17	15,26
	4	28,36	37,43	2,62	2,77	1,75	1,84	37009	40433	12,79	18,75
	6	28,88	37,94	2,65	3,20	1,76	2,13	37218	40610	10,33	22,15

Vegetable Fiber (Miscanthus): *Miscanthus giganteus* vegetable fiber was added to the concrete samples. Ground plant material which was obtained from Selcuk University, Faculty of Agriculture was stored in the laboratory. Particular care was taken to ensure that the material was dry and that shells were removed. The properties of the natural vegetable fiber used in the experiment are shown in Table 2 (Acaroğlu, 1998). In a previous study, cut; ground; and ground+cut; miscanthus (giganteus) fiber was used as concrete additive. As experimental studies found that using ground miscanthus material improved the strength properties of concrete, (Açıkel, 2005) in the present study, ground Miscanthus plant was added to the concrete samples at 0%, 2%, 4%, and 6% by volume. Figure 2 shows natural and ground states of *Miscanthus* plant.

Water: Erciyes University campus mains water which is drinkable was used in experiments as the mixture water.

Concrete Mixtures and Production: While preparing the concrete mixtures, the granulometry of the aggregate was kept constant, and the concrete was produced with a water-cement ratio of 0.50 having 450, 400 and 350kg/m^3 cement dosages, and with various fiber ratios (0, 2, 4, 6 %) according to TS 1247.

There have been 72 cylinder samples (3 samples for each ratio) which were tested on the 7th and 28th days of the experiment. A total of 80 experiment specimens were produced and 72 were cylinder samples with dimensions of ϕ15x30 cm. Two samples were produced for 7 days-old compressive strength experiment, one sample was produced for slitting experiment, and two samples were produced for 28 days-old compressive strength experiment. While producing samples, according to TS EN 12350-2, slump funnel test was carried out. Slump amount was found out between 70-110 mm. Concrete mixtures calculations were done according to absolute volume method. Fresh concrete was poured into formworks as three layers and each layer was skewered by 25 times and was tampered and compressed with plastic tamper. After all the formworks were completely filled, the surface of the fresh concrete was smoothed with a long float. The samples were kept in these formworks for 24 hours. After this process, the samples were removed out the formworks and they were kept in water which was at room temperature until the 7th and 28th days of the experiments. Sulphur tops were made for the cylinder samples that were going to be tested for compressive strength. There have been 8 prismatic beam samples with dimensions of 15x15x75 cm. They were produced having 400 kg/m^3 cement dosages and with various fiber ratios (0, 2, 4, 6%). These samples were subjected to flexural strength experiments. Fresh concrete was poured into prismatic beam formwork as three layers and each layer was skewered, tampered and compressed with plastic tamper. The consistency of the fresh concrete was determined according to TS EN 12350-2 for all the mixtures.

Experiments: For each type of mixtures, in compliance with TS EN 12390-3, at 7th day, and at 28th day of the experiment, cylinder samples were subjected to compressive strength tests (Figure 3); in compliance with TS EN 12390-6, at 28th day of the experiment, a cylinder sample was subjected to splitting tests (Figure 4). During the experiments, in order to measure the displacement values, a komparametre was placed. In compliance with TS EN 12390-5, at 28th day of the experiment prismatic beam samples were subjected to bending tests (Figure 5). For beam samples displacement values were periodically measured.

Figure 2. *Miscanthus & giganteus* plant material in natural and ground state

Figure 3. A ϕ15x30 cm cylindrical concrete specimen being subjected to pressure test

Figure 4. A ϕ15x30 cm cylindrical concrete specimen being subjected to splitting test

Figure 5. A 15x15x75 cm beam concrete specimen being subjected to bending test

Test Results: 7th and 28th day compressive strength test results; 7th and 28th day splitting strength test results; 7th and 28th day tensile strength test results; 7th and 28th day modulus of elasticity; and 7th and 28th day energy absorption capacity were all presented in Table 3.

RESULTS

In this study, mechanical properties of cylinder and beam specimens, which were produced with miscanthus reinforced concrete, were examined and the results obtained are summarized as follows; When the compressive strength test results were analyzed; for 7 days-old samples the increase of compressive strength was calculated about 8% in fiber reinforced (with 2% fiber ratio) concrete compared with fiber-free concrete; about 11% in fiber reinforced (with 4% fiber ratio) concrete compared with fiber-free concrete; and about 17% in fiber reinforced (with 6% fiber ratio) concrete compared with fiber-free concrete. For 28 days-old samples the increase of compressive strength was calculated about 5% in fiber reinforced (with 2% fiber ratio) concrete compared with fiber-free concrete; about 6% in fiber reinforced (with 4% fiber ratio) concrete compared with fiber-free concrete; and about 7% in fiber reinforced (with 6% fiber ratio) concrete compared with fiber-free concrete. When the splitting strength test results were analyzed; it can be seen that there has not been a significant contribution for splitting strength. Because in 7 days-old and 28 days-old samples, although the fiber ratio was increased, the splitting strength was relatively stable. When the values for the modulus of elasticity were analyzed; for 7 days-old and 28 days-old samples the increase of the modulus of elasticity was calculated about 1,2% in fiber reinforced (with 2% fiber ratio) concrete compared with fiber-free concrete; about 1,2 % in fiber reinforced (with 4% fiber ratio) concrete compared with fiber-free concrete; and about 2% in fiber reinforced concrete (with 6% fiber ratio) concrete compared with fiber-free concrete. In 28 days-old prismatic beam samples tensile strength values and energy absorption capacities (the area under the strength-displacement curves) were stable related to the increasing fiber ratios. At the end of the experiment, it was seen that, the vegetable fiber only contributed in the compressive and bending tensile strength of concrete. It has been concluded that; in order to achieve more specific evaluations, necessary investigations should be carried out about the durability of concrete.

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