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Properties of Concrete Incorporating Recycled Post-Consumer Environmental Wastes

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Abstract: The use of sustainable technologies such as supplementary cementitious materials, and/or recycled post-consumer environmental wastes is widely used in concrete industry in the last decade. This paper presents the results of a laboratory investigation of normal concrete containing sustainable technologies. Twenty one mixtures (21) were prepared with different combinations of silica fume, fly ash, olive's seed ash, and corncob ash (CCA). Fresh and hardened concrete properties were measured, as expected the inclusion of the sustainable technologies affected both fresh and hardened concrete properties. Based on the results obtained in this study and the analyses conducted, the following observations were drawn: replacing the cement by olive's seed ash or CCA has a significant effect on fresh concrete workability. Olive's seed ash increased the slump by more than 200 % compared to the control mixtures. The compressive strength of mixtures containing olive's seed ash showed by 45 and 75 % decrease compared to the control mixtures. The 28 days compressive strength of mixtures produced by CCA of 10 % replacement decreased by 41 % compared to the control mixture.

Keywords: normal concrete, silica fume, fly ash, olive's seed ash, corncob ash.

1. Introduction

Few and very limited papers found in the literature use the olive's seed ash and corncob ash (CCA) in conventional concrete industry. The following section summarizes the up-to-date literature focusing on the behavior of concrete incorporating such recycled post-consumer environmental wastes.

The main goal and challenge for the coming century, is to design a smaller and shallower reinforced concrete sections and for taking into consideration the economic aspects. Nowadays, the material engineers are investigating new concrete mixtures with different admixtures to reach the outmost performance and durability for severe environmental conditions. The waste-by-products and recycled materials are under a big push to be added to the conventional concrete ingredients and to replace cement content, keeping the strength and durability close to the desired specifications. The workability is considered an important factor when concrete mixtures are designed; especially in some applications where members are heavily reinforced. Thus, to lessen any difficulties associated with concrete placement in congested reinforced concrete members, concrete mixtures should be designed to workable. The sustainability of concrete members also is strongly related to global warming, which is a major problem for today's infrastructures. One of the most sustainable tools is the supplementary cementitious and recycled materials (SCMs) to be buried in concrete mixtures as attractive options to achieve green concrete.

The mechanical properties of kenaf fiber reinforced concrete (KFRC) are studied by Elsaid et al. (2011). The study showed the findings of an experimental research program that was conducted to study the mechanical properties of a natural fiber reinforced concrete (FRC), which is produced using the bast fibers of the kenaf plant. The fiber volume contents were taken 1.2 and 2.4 %. The compressive strength, modulus of elasticity, splitting tensile strength and modulus of rupture of KFRC specimens are measured and compared to the properties of plain concrete control specimens. The experimental results indicate that the mechanical properties of KFRC are comparable to those of plain concrete control specimens, particularly when accounting for the effect of the increased w/c ratio required producing workable KFRC. Further, more distributed cracking was found and higher toughness than plain concrete. In general KFRC specimens exhibited more ductile behavior with greater energy absorption and more well distributed cracking patterns, which is typical for KFRC.

Coconut fibers are one of the highest toughness natural fibers. The mechanical and dynamic properties of coconut fiber reinforced concrete (CFRC) members are performed by Ali et al. (2012). The damping ratio and fundamental frequency of simply supported CFRC beams are determined experimentally as well. The influence of 1, 2, 3 and

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5 % fiber contents by mass of cement and fiber lengths of 2.5, 5 and 7.5 cm is investigated and all the results were compared to plain normal concrete. Damping of CFRC beams increases while their fundamental frequency decreases with structural damage, Ali et al. (2012). CFRC with higher fiber content has a higher damping but lower dynamic and static modulus of elasticity. It is found that CFRC with a fiber length of 5 cm and a fiber content of 5 % has the best properties to be used in normal low cost concrete structures.

The mechanical properties of four types of date palm surface fibers on reinforced concrete were investigated by Kriker et al. (2005). The volume fraction and the length of fibers reinforcement were 2–3 % and 15–60 mm respectively. Increasing the length and percentage of fiber-reinforcement in both water and hot dry curing, was found to improve the post-crack flexural strength and the toughness coefficients, but decreased the first crack and the compressive strengths. In hot-dry climate a decrease of first crack strength with ageing was observed for each concrete type. Water curing decreased the global degree of the voids and cracks with time for each concrete type, but increased it in hot-dry climate.

Corncob is the waste-by-product obtained from corn, which is considered one of the most important cereal crops in Egypt. According to food and agriculture organization (FAO) data, 589 million tons of maize was produced worldwide in the year 2000. The United States was the largest maize producer having 43 % of world production. The effect of using CCA (pozzolanic waste-by-product of corncobs) as a cost-effective additive in blended cement is conducted by Adesanya (1996). The effects of the blended cement in various concrete mixtures were analyzed. The results show that replacing 20 through 50 % respectively of ordinary portland cement by weight with CCA produces stabilized clay and laterite exhibiting greater strength. The results also indicate that replacing 20 % of cement with CCA in conventional concrete mixtures improves water absorption and durability. It is also found that there is no significant difference between the strength of concrete produced with 0.0 and 20 % CCA as a partial cement replacement.

Adesanya and Raheem (2009a) attempted to convert waste-by-product into useful material for the construction industry, the study considered the use of CCA as a pozzolan in cement production. The chemical composition of CCA was investigated and used for replacing 0, 2, 4, 6, 8, 10, 15, 20 and 25 %

Table 1 Mixtures matrix.

Mixture	Replacement material	No. of specimens		% of cement replaced
		Cubes (150 × 150 × 150) mm	Cylinders (200 × 400) mm	
M1	Control mixture	6	3	0
M2	Silica fume	6	3	5
M3	Silica fume	6	3	10
M4	Silica fume	6	3	15
M5	Silica fume	6	3	20
M6	Silica fume	6	3	30
M7	Olive's seed ash	6	3	5
M8	Olive's seed ash	6	3	10
M9	Olive's seed ash	6	3	15
M10	Olive's seed ash	6	3	20
M11	Olive's seed ash	6	3	30
M12	Corncob ash	6	3	5
M13	Corncob ash	6	3	10
M14	Corncob ash	6	3	15
M15	Corncob ash	6	3	20
M16	Corncob ash	6	3	30
M17	Fly ash	6	3	5
M18	Fly ash	6	3	10
M19	Fly ash	6	3	15
M20	Fly ash	6	3	20
M21	Fly ash	6	3	30

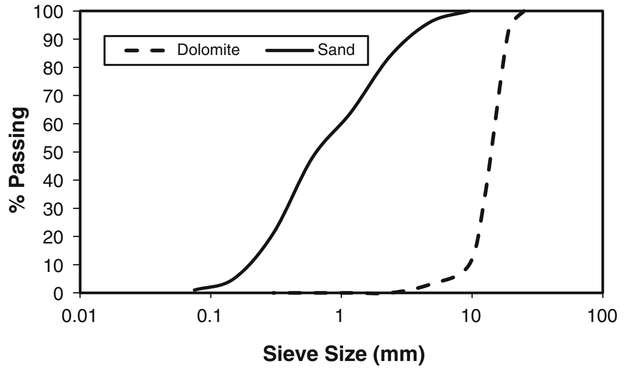

Fig. 1 Coarse and fine aggregates gradation.

by weight of ordinary portland cement clinker with CCA. The 0 % cement replacement was used as a control mixture. The results showed that CCA is a suitable material for use as a pozzolan as it satisfied the minimum requirement of combined SiO_2 and Al_2O_3 of more than 70 %, which means a good pozzolan to manufacturer blended cement. The blended cements produced also satisfied both NIS 439 (2000) and ASTM C 150 requirements especially at lower levels (<15 %) of CCA percentage replacement. Based on the test results, it was concluded that CCA could be suitably used in blended cement production. Adesanya and Raheem (2009b, 2010), performed an investigation on the workability, Durability, and compressive strength characteristics of CCA blended cement concrete. The study showed that only up to 8 % CCA substitution is adequate where the blended cement is to be used for structural concrete. The resistance of the mortar cubes to chemical attack was improved as the addition of CCA up to 15 % replacement level, and caused a decrease in permeability and reduction in weight loss due to reaction of the specimens with HCL and H_2SO_4 acid water. The improvement was up to about 50 % for HCL and 40 % for H_2SO_4 acid water (Jorge et al. 2012).

2. Objectives and Tasks

The objective of this study is to investigate the effect of sustainable technologies, silica fume, fly ash, olive's seed ash, and CCA, on fresh and hardened properties of conventional concrete. To achieve this objective the following two main tasks were performed:

1. *Mixture preparations* Table 1 summarizes the mixture proportions matrix used in this study. A total of 21

Table 2 Compositions and proportion of all mixtures.

Mixture	Total CMs (kg/m^3)	Cementitious materials (CMs) (kg/m^3)				
		Cement	Silica fume	Olive's seed ash	Corn cob ash	Fly ash
M1	400	400	0	0	0	0
M2	400	380	20	0	0	0
M3	400	360	40	0	0	0
M4	400	340	60	0	0	0
M5	400	320	80	0	0	0
M6	400	280	120	0	0	0
M7	400	380	0	20	0	0
M8	400	360	0	40	0	0
M9	400	340	0	60	0	0
M10	400	320	0	80	0	0
M11	400	280	0	120	0	0
M12	400	380	0	0	20	0
M13	400	360	0	0	40	0
M14	400	340	0	0	60	0
M15	400	320	0	0	80	0
M16	400	280	0	0	120	0
M17	400	380	0	0	0	20
M18	400	360	0	0	0	40
M19	400	340	0	0	0	60
M20	400	320	0	0	0	80
M21	400	280	0	0	0	120

Table 3 Mechanical and fresh properties of all mixtures.

Mixtures	Compressive strength, F_{cu} (kg/cm^2)		Tensile strength, F_t (kg/cm^2)	Slump (cm)
	7 days	28 days		
M1	217.6	312.8	20.3	7.3
M2	228.1	309.8	25.3	8.0
M3	213.0	285.6	44.3	7.6
M4	164.7	300.8	17.9	6.4
M5	205.3	309.8	16.9	5.8
M6	178.7	264.4	15.0	5.3
M7	131.3	225.6	8.9	9.0
M8	106.3	189.3	15.0	16.0
M9	92.3	175.5	3.9	16.0
M10	58.1	95.2	8.9	17.5
M11	47.1	77.1	2.9	19.0
M12	99.5	200.6	8.5	12.0
M13	82.4	144.8	5.7	14.0
M14	55.6	98.6	25.6	7.4
M15	35.0	69.8	23.1	8.0
M16	23.7	53.7	24.2	9.0
M17	250.3	352.4	19.5	9.6
M18	178.4	260.6	12.9	10.0
M19	155.0	250.0	22.0	8.8
M20	147.0	230.0	15.0	9.5
M21	115.0	223.0	15.0	10.0

mixtures were prepared, and were selected such that a comparison of the effect of silica fume, fly ash, olive's seed ash, and the CCA on can be studied.

2. *Laboratory testing* The experimental program in this study included measuring the concrete workability through the standard slump test as a measure of fresh property. The hardened properties were studied by performing the standard compressive strength test at 7 and 28 days, and split tensile strength at 28 days.

3. Experimental Program

3.1 Materials and Mixture Proportions

Crushed dolomite aggregate with nominal maximum aggregate size of 20 mm and well-graded local sand were used as coarse and fine aggregates (FAs), respectively. The aggregate gradation is performed according to ASTM C136 and illustrated in Fig. 1. The relative specific gravity and compacted density at saturated surface dry condition of the coarse aggregate (CA) were 2.64 and 1.7, respectively, whereas FA had a relative specific gravity of 2.73, and compacted density of 1.55, and a fineness modulus of 3.07. Type I Portland cement having a specific gravity of 3.15, initial and final setting times are 3.14, and 143 min, respectively and conforming to ASTM C150 requirements. Different binders incorporating ASTM Type I cement and SCMs including class C fly ash, and silica fume (SF) were also used in all mixtures other than the controls. All SCMs, including fly ash and silica fume, conform to ASTM C618 and ASTM C1240 standards, respectively. The fly ash and SF specific gravity values of 2.6, and 2.2, respectively. Table 2 shows all proportions of all concrete mixtures. The water-to-cement ratio of 0.50 was kept constant for all mixtures. The coarse and FA weights were also kept constant, and taken as 1070 and 710 kg/m^3 respectively.

The corncob was produced by grinding dried corncobs to about 6.00 mm diameter to enhance adequate combustion and to reduce the carbon content which affects the pozzolanic properties. The ground corncobs were burnt in open air using a local furnace. A measured quantity of corncob was collected, sprinkled with a kerosene fuel and set on fire. The temperature of the corncob was measured during burning as it turned from cob to burn and to powder to with

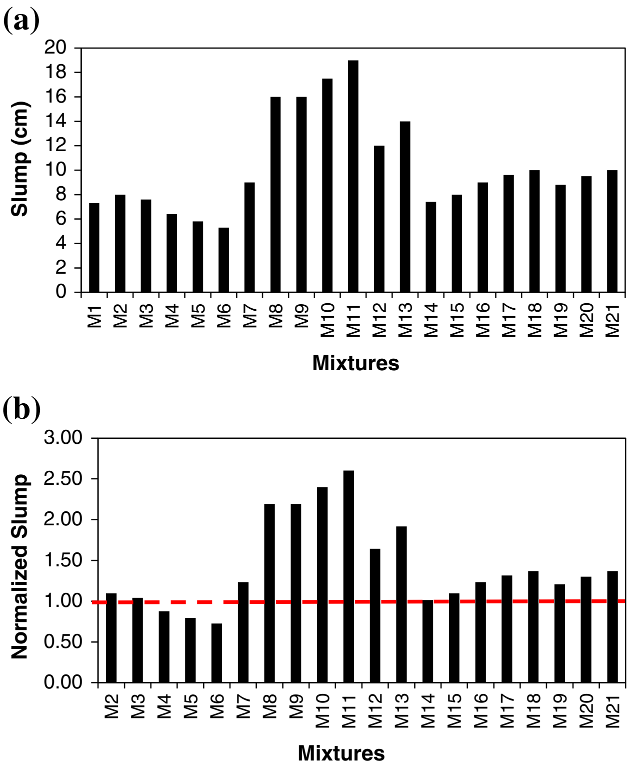

Fig. 2 **a** Slump for all mixtures. **b** Normalized slump for all mixtures.

a measured temperature of 600 °C in about 10 h. Olive's seeds were also prepared by washing at first then drying by placing the seeds in the oven for 24 h at temperature of 40 °C. The second stage was grinding the dried seeds on three stages till it reaches the ash sizes. The compacted bulk and loose densities were measured to be 735 and 705 kg/ m^3, respectively. The specific gravity was measured and taken as 1.25.

3.2 Testing Procedure of all Mixtures

Testing was carried out in two different phases. The first phase consisted of evaluating the properties of all fresh concrete mixtures to ensure that the concrete is workable, they were assessed using the standard slump test (ASTM C143). In the second phase, the compressive and split tensile strengths of all concrete mixtures were measured at various ages (7 and 28 days) to investigate the effect of using SCMs on the hardened concrete properties. The compressive strength was conducted on (150 × 150 × 150) mm cubes (Egyptian code standards) and cylindrical specimens of 200 mm diameter and 400 mm height were used to perform the split tension test.

4. Test Results and Discussion

4.1 Freshly Mixed Concrete

The slump test was performed for all mixtures and the results are summarized in Table 3. It is clear that mixture (M11), which has 30 % of cement, replaced by olive's seed ash experienced the largest slump value. Figure 2a shows the effect of different SCMs on the slump values for all mixtures. The least slump value is found to be for mixture (M16), which has 30 % of cement, was replaced by CCA.

It is also noticed that replacing the cement by olive's seed ash and CCA has a significant effect on concrete workability. It is shown that the olive's seed ash increased the slump by more than 200 % compared to the control mixture (M1). The effect of replacing cement by fly ash is much less than other cementitious materials. Figure 2b shows the normalized slump of all mixtures compared to the control case, and it shows that as the SF content increases, the slum decreases. The results showed that the concrete slump increased by an average of 38 % as the CCA content increased from 5 to

Fig. 3 Slump for mixtures with different cement replacement.

Fig. 4 Concrete cubes preparation, curing, and under compression testing.

30 %, indicating that concrete becomes more workable, meaning that more water is required to make the mixtures more workable. Figure 3 shows the slump test performed for some mixtures.

5. Mechanical Properties of Hardened Concrete

5.1 Effect of SCMs on the Compressive Strength

The preparation of concrete cubes, curing and the compressive test of one of the samples are shown in Fig. 4. Figure 5 summarizes the effect of the inclusion of silica fume, olive's seed ash, CCA, and fly ash in all mixtures. The addition of SF with 5, 10, 15, 20 and 30 % in mixtures M2 through M6 has significant effect on the 7 and 28 days compressive strength. The 7 days compressive strength of the mixture that has 10 % SF (M3) was 97.9 % of the control mixture strength (M1), while the 28 days strength was 91.3 % of the control mixture strength respectively. The effect of olive's seed ash on the compressive strength is shown in Fig. 5b. The olive's seed ash replaced the cement content by 5, 10, 15, 20 and 30 %, respectively. The compressive strength of the mixture that has 5 % olive's seeds (M7) decreased by 39.7 and 27.9 % at 7 and 28 days compared to the control mixtures, respectively. It is concluded that the chemical composition of olive's seed ash must be investigated to address its effect on the hydration process. The CCA effect on the compressive strength is investigated by replacing the cement content by 5, 10, 15, 20, and 30 %. The 30 % replacing decreased significantly the compressive strength compared to the control mixture (M1). The CCA will be considered an emerging waste-by-product material in the near future, but it is recommended to limit of replacement to be 15 % as a result of the present study. The replacement of cement by 5 and 15 % of CCA (M12 and M14) decreased the 28 days compressive strength by 35.9 and 68.5 % compared to the control mixture as shown in Fig. 5c. Figure 5d shows the effect of fly ash replacement on the compressive strength at 7 and 28 days. The replacement ratios were 5, 10, 15, 20 and 30 % from the cement weight. The compressive strength increased by 13 % due to a 5 % of cement replacement, however increasing the fly ash content to 30 % affect adversely the compressive strength as shown in Fig. 5d.

The effect of percentage replacement and mixture proportions on the compressive strength of concrete at the curing ages of 7 and 28 days are presented in Fig. 6a, b respectively. The results at 7 days for 5, 10, 15, 20, and 30 % mixture proportions are presented in Fig. 6a. The compressive strength is found to be decreasing as the percentage of cement replacement is increasing and that for the results at 7 and 28 days as well. The recorded observations indicate that blended cement concrete especially with olive's seed ash and CCA gain strength slowly at early curing age. The present study results are in agreement with the findings from previous studies, which stated that pozzolanic reaction at room temperature is slow, thus a longer curing period is needed to observe its positive effects.

5.2 Effect of SCMs on the Tensile Strength

Split tensile test with typical failure mode is shown in Fig. 7. The results are arranged to study the effect of replacing cement partially by silica fume, olive's seed ash, CCA, and fly ash in ordinary Portland concrete. The results clearly indicate that the split tensile strength dropped due to the addition of all SCMs. Two different trends were dictated

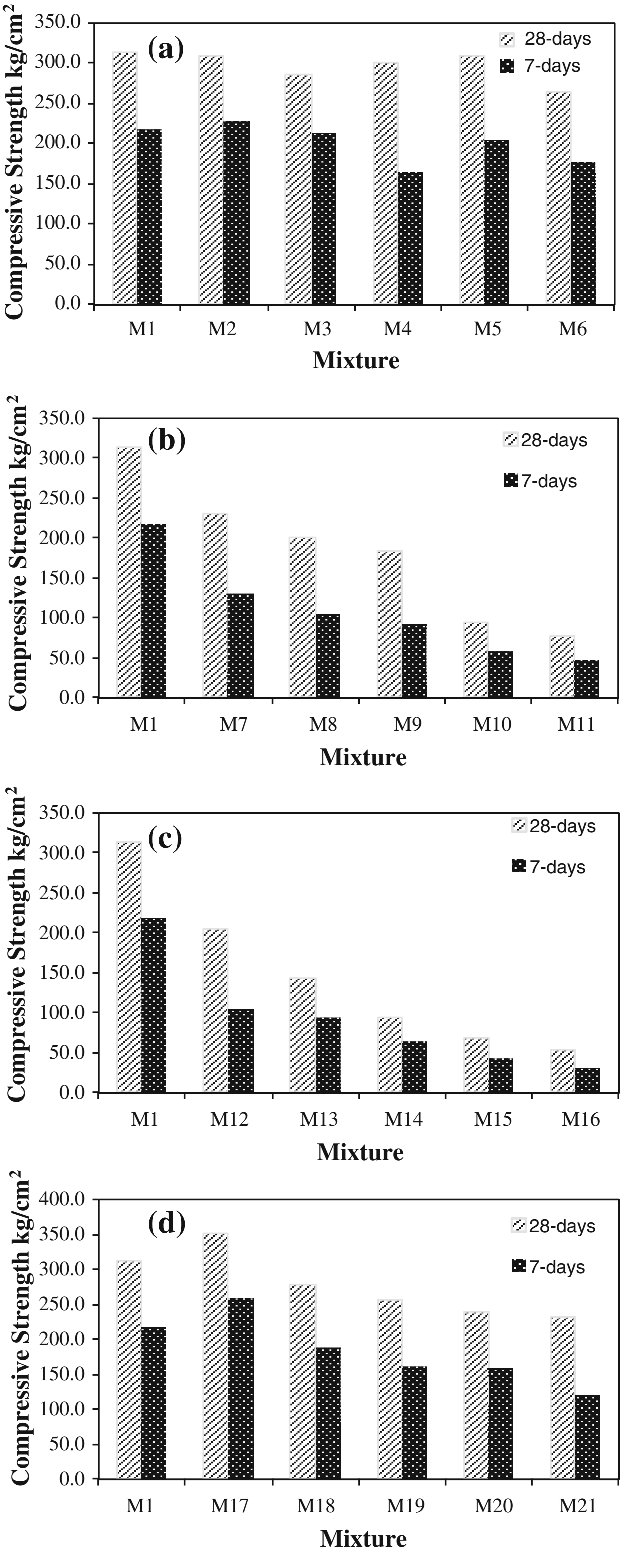

Fig. 5 Compressive strength at 7 and 28 days: **a** Silica fume, **b** Olive's seed ash, **c** Corncob ash, **d** Fly ash.

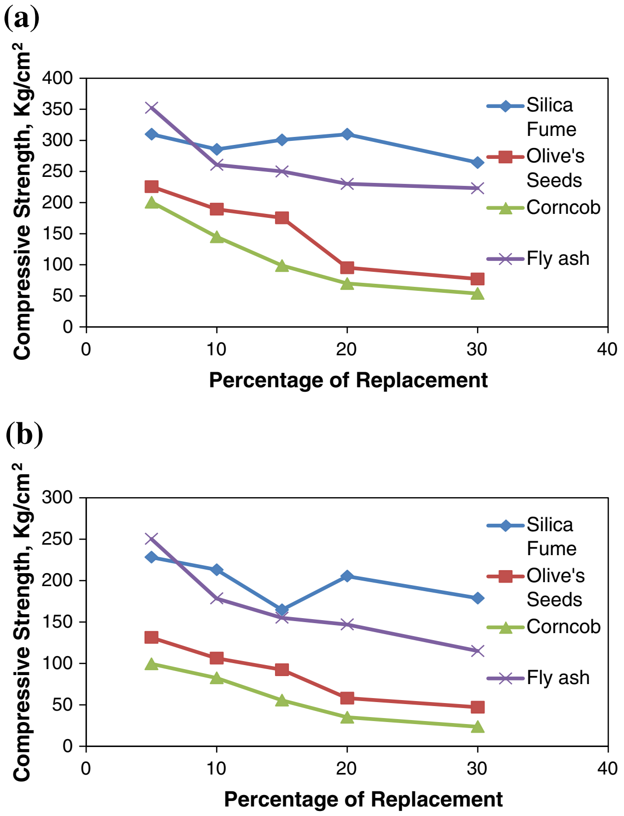

Fig. 6 **a** Effect of cement replacement ratios on the compressive strength of concrete cubes at age 28 days. **b** Effect of cement replacement ratios on the compressive strength of concrete cubes at age 7 days.

in the split tensile strength reduction. In the case of mixtures with silica fume, the tensile strength decreased by increasing the percentage cement replacement from 5 to 10 %. The present study results indicate that the optimum parentage of SF to be used is 5 %. All other supplementary materials affect adversely the tensile strength as shown in Fig. 8.

6. Summary and Concluding Remarks

Twenty-one (21) conventional concrete mixtures incorporating different proportions of silica fume, olives's seed ash, CCA, and fly ash were prepared and tested. The results of this study indicated a general trend of significant drop in concrete strength with the increase of some of the SCMs cement replacement. Based on the results obtained in this study and the analyses conducted, the following observations were drawn:

1. Replacing the cement by the olive's seed ash and the CCA has a significant effect on concrete workability.
2. Olive's seed ash increased the slump by more than 200 % compared to the control mixtures.
3. The 28 days compressive strength of mixtures containing 30 % replacement of olive's seed ash showed a 75 % decrease compared to the control mixture.
4. The 28 days compressive strength of mixtures produced by 5 and 30 % of cement replacement by CCA decreased from 35.9 to 82.8 %, compared to the control mixture, respectively.
5. The present study concludes that a further study should be investigated on the chemical composition of olive's seeds and CCA, to emphasize the effect of those materials on the hydration process.

Fig. 7 Split tensile strength test.

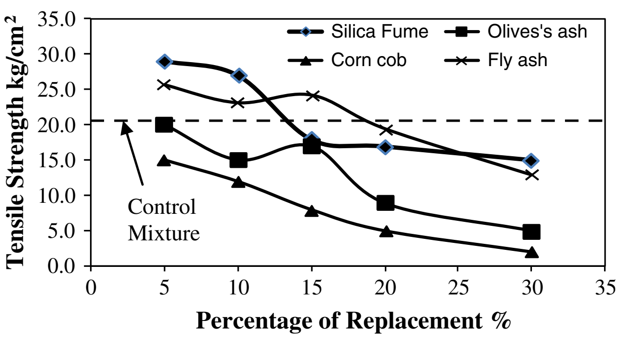

Fig. 8 Split tensile strength for all mixtures with different percentage of cement replacement.

6. The present study recommends the concrete includes olive's seeds and CCA not to be used in any structural members unless a durability study is performed.

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