Applied Chemical Engineering (2024) Volume 7 Issue 3 ISSN: 2578-2010 (O)
doi: 10.59429/ace.v7i3.5571

RESEARCH ARTICLE

Behavior of pavement concrete mixture with cellulose materials in the severe environments for sustainability purposes

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ARTICLE INFO

Received: 12 November 2024
Accepted: 16 December 2024
Available online: 25 December 2024

ABSTRACT

Concrete mixture is commonly prepared from cement, sand, gravel, and water to obtain the available mix that is easy to work. However, it can be prepared with different materials for better sustainable properties that are appropriate for the severe environments. Meanwhile, the concrete for highway pavement must be prepared with high-performance properties due to dramatic high traffic load and the adverse environmental effects in recent years. The main aim of this study is to evaluate the effect of incorporating biomass waste on concrete performance. This study consisted of the production of concrete mixtures with different percentages of Papyrus Fibers (PF), Date Seeds (DS), and Olive Seeds (OS) after they were converted into powders and mixed with cement in proportions of (3, 5, 7) % by weight of cement. The samples were evaluated for compressive strength after (7, 14, and 28) of curing. The compressive strength was compared with the controlled mix. Results showed that the compressive strength of the mixture comprising PF exhibited (30, 34, 37) MPa at 28 days for percentages of (3, 5, 7) %, respectively, compared with the control mix (namely, 32 MPa). For other additives, DS exhibited (31, 28, 22) MPa, and OS (20, 18, 15) at the same curing ages and the same percentage of additives. Furthermore, the abrasion resistance test results of the 28 days cured samples with different cellulose additive types highlighted that decrement trend exists in the abrasion resistance for both wear depth and weight loss with the addition of OS (5 and 7) % or DS (3, 5 and 7) % and the decrement rate reach above (23%). Thus, adding biomass additives can improve the mechanical and durability properties if accurate optimizing percentages is comprised.

Keywords: Sustainability; Cellulose Materials; Concrete pavement; Concrete pavement; Compressive strength; Papyrus fibers; Date seeds; Olive seeds

1. Introduction

Annually, large quantities of concrete, almost higher than 10 billion tons, are reproduced to realize the requirements of construction works. Therefore, ordinary portland cement concrete is considered a high exhaustion construction material worldwide compared to other materials. That is regarding to their unique properties in terms of durability, strength, simplicity of getting the raw materials, and economical usage[1,2]. Therefore, it has a significant function in the infrastructure of the buildings in the world as it is the backbone of all construction works used for different applications such as roads, bridges decks, and other structures. Commonly, concrete mixtures fabricated depend on two significant materials, i.e., aggregates and paste[2]. The aggregates generally compose a large portion of the mixture, about (60-70) % of the total volume of concrete. It also usually includes various sizes of aggregate particles, i.e., coarse and fine aggregates, along with sand. At the same time, the paste is collected from water and Portland cement[3]. Nevertheless, using concrete with ordinary Portland cement offers weak properties, e.g., considerable shrinkage, weak resistances, such as tensile, flexural, and chemical, and slow hardening[4,5]. Moreover, the production process of concrete mixtures generally requires a large consumption of energy and raw materials and is accompanied by high CO_2 emissions. Besides the waste resulting from the destruction of constructions, making it seems less convenient to the environmental requirements. Therefore, researchers tend to comprise admixtures through the output process of concrete mixtures to overcome the shortage properties of traditional mixtures[6-10]. The late trend of researchers to get a mixture possess superior properties by offering good resistances and fewer pollution problems, by following the basis of "green rating building" has become of attention for the infrastructure of buildings[2,7]. Therefore, some researchers suggest inserting wastes and agriculture materials through the production of concrete mixtures as a cement or sand replacement to get a mixture closest to the environment. From waste materials, such as post-consumer glass, silica fume, fly ash, recycled tires, recycled concrete, plastics, etc., and from various agricultural materials such as natural fibers, corn cob, coconut shell, oil palm shell, pistachio shell, rice husks, etc., were used for the same purpose[11-13]. Among these materials, many researchers encourage the combination of natural fibers into concrete mixtures due to their positive impact on the mechanical and durability properties of concrete mixtures, besides their availability[14-16]. For example, Sivaraja et al.[15], in their research, said that usage of natural fibers increase the internal friction within the mixture and reinforcing it by prolong a 3D network that in turn creates a high-strength mixture. They also try to investigate the profit of two natural fibers, sugarcane bagasse, and coconut coir, on the mechanical performance of concrete mixtures over three curing ages (28 days, 1, and 2 years). The obtained results indicate that these fibers strengthen the mixture against compression, flexural, modulus of rupture, and split tensile strength. Otherwise, others such as Almograbi[17] study the utilization of date palm seeds (DPS) as an alternative to coarse aggregates for some particular structures of lightweight concrete. It has been renowned that DPS plays a good role in constructing lightweight concrete as a coarse aggregate in its structure. Consequently, the durability is regarded as one of the most important properties during its service life. Also, he investigates the effect of DPS on the durability properties of the concrete mixture. He observed that mixture durability enhanced after incorporating DPS as an alternative to coarse aggregate in terms of permeability and water absorption[17]. In another study conducted by Eisa[18], he tried to employ olive's seed ash, and corncob ash (CCA) as cement-replacement materials. He found that incorporating these materials influences the behavior of concrete mixture in terms of compressive strength at various levels. As the compressive strength was lowered by above 40% after adding the olive's seed ash in contrast with the control mixture. While when replacing cement with 10% of CCA, it appeared that the compression strength declined by no more than 41%.

Different kinds of biomass wastes contain cellulose materials such as papyrus fibers, date seeds, and olive seeds, and these wastes are available in hot and dry weather regions widely. Hence, there is necessity to get rid of this wastes. Therefore, this research aims to improve the pavement concrete mixture performance by adding cellulose materials to support sustainability in severe environments. Therefore, the sand was replaced using different cellulose materials, e.g., date seed ash, olive seed ash, and natural reed papyrus fibers, to produce a lightweight concrete mixture of altered compressive strength and abrasion loss resistances.

2. Materials and methods

2.1. Materials and procedure

The materials adopted in this research were type (V) of sulfate resistance Portland cement (SRC), standard sand, crushed gravel, water, and additives: include different kinds of Cellulose materials (e.g., papyrus fibers, date seeds, olive seeds).

The physical and chemical properties of SRC are presented in **Table 1 and 2**. The illustrated results observed that it satisfies the requirements of Iraqi Specifications No. 5/1984[11]. Moreover, **Table 3 and 4** provide the gradation adopted for sand and coarse aggregate, respectively. The grading of the fine aggregate and coarse aggregate are illustrated in **Figure 1 and 2**.

Table 1. Physical Properties of (SRC) Cement **%.**

Physical Properties	Sample	Table Limits according to IQS
Initial setting time(min)	00.45(Min.)	105
Finale setting time (hour: min)	10:00(Max.)	3:20
Fineness in Blaine m^2/kg	250(Min.)	315
23(Min.), 34.5(Min)	28.04	Compressive strength MPA at 7 days, 28 days

Table 2. Chemical Properties of (SRC) Cement %.

Oxide	Test result sample	Limits according to IQS
CaO%	62.54	-
SiO_2%	19.82	-
Al_2O_3%	3.05	-
Fe_2O_3%	4.91	-
MgO%	3.10	≤5%
SO3%	1.54	≤2.5%if C_3A<5% or≤2.8 if C_3A>5%
Loss on ignition%	2.26	<=4%
Total	96.97	-
F.CaO	2.80	-
Insoluble residue	0.73	≤1.5%
L.S. F	0.95	0.66-1.02
C_3S%	62.05	-
C_2S%	9.51	-
C_3A%	1.25	≤3.5%
C_4AF%	14.51	-

Table 3. The Grading of Natural Sand According to Iraqi Specification.

Sieve size (mm)	**Passing accumulates %**	**Percent passing accumulates limit of zone II of IQS 45/1984**
10	100	100
4.75	99	90-100
2.36	87	75-100
1.18	76	55-90
0.6	47	35-59
0.3	18	8-30
0.15	6.4	0-10
0.075	1.2	0-3

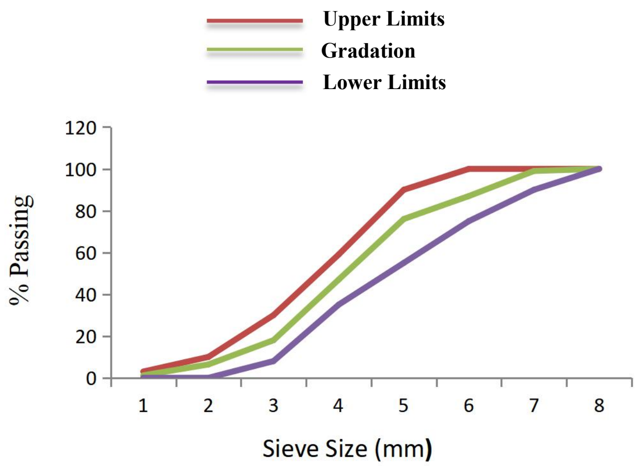

Figure 1. Fine Aggregate Grading

Table 4. The Grading of Coarse Aggregate, According to Iraqi Specification

Sieve Size mm	**Passing Accumulate %**	**Specification IQS 45/1984 Standard regime 5-20**
37.5	100	100
20	98	95-100
10	56	30-60
5	1.6	0-10

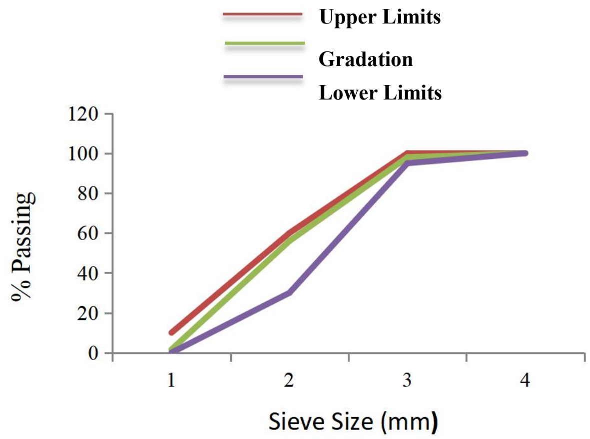

Figure 2. Coarse Aggregate Grading.

Furthermore, the papyrus fibers (PF) were used here with different dosages as a reinforcement material besides the original concrete mixture components (i.e., cement, sand, gravel, and water). Along with the date and olive seed powders that are adopted as sand-replacement materials. The following sections describe the preparation of these modifiers.

2.1.1. Preparation of papyrus fiber (PF) powder

Initially, papyrus was collected from the Marshes in the south of Iraq, then the process of extraction of pulp and fiber was done. After that, it was chopped into segments with lengths ranging between 10 and 50 and 2 mm in diameter. Then dried in a 100 C oven for 20 min and used for the required purpose. Figure 3 offers the preparation of PF.

Figure 3. Preparation of Papyrus Fibers.

2.1.2. Preparation of date seed (DS) and olive seed (OS) powders

Plant residues from date palms and olive trees were collected. Seeds have a color ranging from red to brown when ripe, and it is almost spherical, ellipsoid, or elongated in shape. Each date palm and olive tree consist of a hard seed into it. The chemical composition of the olive seed obtained is shown in Table 5. The seeds can be collected, cleaned, and immersed in water for one hour and dried in the oven for 30 minutes at 100 ° C. It is manually ground into a fine powder, as represented in Figure 4 and 5. Moreover, Table 6 and 7 summarize the acceptable gradation for each material according to the Iraqi Specification Zone II of IQS 45/1984.

Figure 4. The Preparation of Date Seeds Before and After grindings.

Figure 5. Preparation of The Olive Seeds Before and After grindings.

Table 5. Chemical composition of the olive seed.

	Ext. EtOH %	Ext. AQ %	Ashes %	Lignin %	Hemicellulose %	α-cellulose %
Olive Seed	1.13	0.015	2.10	13.80	24.91	58.64

Table 6. The Grading of Date Seeds according to Iraqi Specification.

Sieve size (mm)	Passing accumulate %	Percent passing accumulate limit of Zone II of IQS 45/1984
10	100	100
4.75	98	90-100
2.36	85	75-100
1.18	77	55-90
0.6	48	35-59
0.3	20	8-30
0.15	7.3	0-10
0.075	1.2	0-3

Table 7. The Grading of Olive Seed s According to Iraqi Specification.

Sieve size (mm)	Passing accumulate %	Percent passing accumulate limit of Zone II of IQS 45/1984
10	100	100
4.75	97	90-100
2.36	85	75-100
1.18	72	55-90
0.6	45	35-59

0.3	18	8-30
0.15	6.1	0-10
0.075	1.3	0-3

2.2. Concrete mix

Four types of concrete mixtures were prepared in this investigation, its ratio and weight were fixed for all mixtures and concerning C30 (according to the requirement of highway concrete pavement). The first one is the control mixture denoted by (M0), the second type (M (1,2,3) PF) is the mixture with reed papyrus fiber (PF), the last two types (M (1,2,3) DS) and (M (1,2,3) OS) are the mixtures with date seeds (DS) powder and olive seeds (OS) respectively.

The mixture was poured into steel molds for 24h; then, the samples were removed from the mold and placed in the maturation basin for (7,14, and 28) days to prepare it for the compressive strength and abrasion resistance tests at 28 days according to the required standards. The samples were exposed to the air for a short time to be dried, then subjected to the required test. Table 8 provides information on the quantities required to prepare the concrete mixtures.

Table 8. Materials amounts adopted in this research.

Mixtures	Additive amount, %	PF weight, g	DS weight, g	OS weight, g	Cement weight, g	Sand weight, g	Gravel weight, g	Water weight, g
M0	0	0	0	0	11.22	25.00	45	6000
M1PF	0.0003	7.65	0	0	11.22	25.49	45	6000
M2PF	0.0005	12.75	0	0	11.22	25.48	45	6000
M3PF	0.0007	17.85	0	0	11.22	25.48	45	6000
M1DS	3	0	765	0	11.22	24.74	45	6000
M2DS	5	0	1275	0	11.22	24.23	45	6000
M3DS	7	0	1785	0	11.22	23.72	45	6000
M1OS	3	0	0	765	11.22	24.74	45	6000
M2OS	5	0	0	1275	11.22	24.23	45	6000
M3OS	7	0	0	1785	11.22	23.72	45	6000

2.3. Compression strength test

Compression strength represents one of the essential tests for concrete mixtures. The test was conducted by 2000 kN standard testing machine and casting cubic samples possess a dimension of (150×150×150) mm, as shown in **Figure 6 and 7**, then cured at three different periods, i.e., 7, 14, and 28 days. After that, it was subjected to a vertical compression load to verify the variation in the concrete mixture's ability against compression.

Figure 6. Concrete cubes after compression test with no access to the Failure Condition.

Figure 7. The concrete cubes after the compression test with failure condition for papyrus fibers.

2.4. Abrasion resistance tests

Cylindrical specimens of 152 mm diameter × 75 mm height were cast for each concrete mixture to assess the faculty mixtures against abrasion resistance. After casting, all the prepared samples were de-molded after 24 hr. and placed inside the curing bath according to ASTM C944M-12[19]. Then, samples were subjected to 197 N ± 3 N vertical load, which provides a speed of about 200-rpm rotary by using the rotary cutter device shown in **Figure 8**. The weight loss of each concrete specimen was recorded after 2 min, as well the wear depth was measured by an electronic digital caliper.

Figure 8. The rotary cutter device for evaluating the abrasion resistance and the electronic digital caliber.

3. Result and discussion

Figure 9 shows images obtained with the use of scanning electron microscope for the control sample and 0.7% PF sample. This new concrete mixture structure altered the concrete properties of compression compressive strength and abrasion resistance, producing enhanced outcomes.

a **b**

Figure 9. Scanning electron microscopy (SEM) images of (a) control sample and (b) 0.7% PF sample.

3.1. Compression strength results

Figure 10 displays the compressive strength results as a function of curing time for the control mixture. It was observed that the value of compressive strength increases with respect to curing time, and it reached more than (30) MPa after (28) days of curing. This result is in agreement with the Iraqi specification for highway concrete pavement.

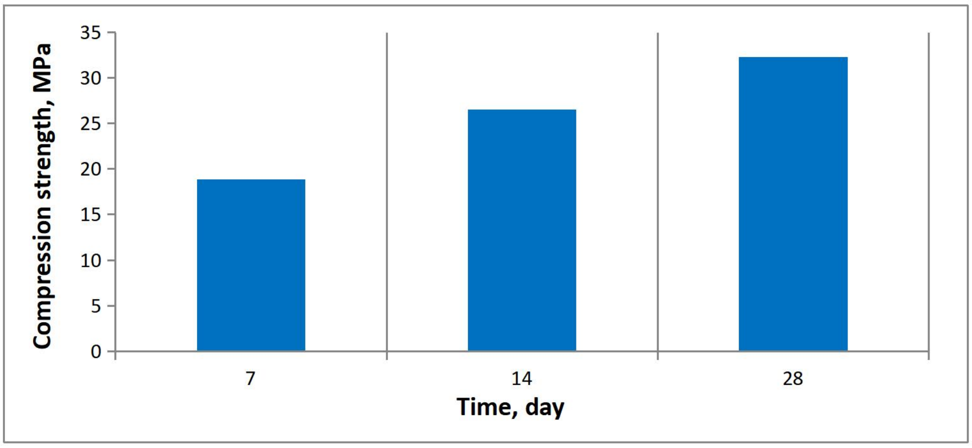

Figure 10. The relation between the compressive strength and curing time of control samples.

Figure 11 demonstrates the effect of PF on the compressive strength of the concrete mixture. The results clarify the incidence of a gradual increment into compressive strength of concrete mixture after insertion of PF for percentage (0.3, 0.5, 0.7) %. Results display that the compressive strength of PF mixtures reached its summit by about 37 MPa when comprising the 0.7% PF (i.e., M3PF) at 28 days of curing. As it achieved an enhancement in compressive strength by approximately 15%. This regard to the superior properties of PF, which work on increasing the bonding at the interface between mixture components and PF by extending a 3D network and raising the mixture reinforcement. Then assist the mixture to overcome the compression failure. The results obtained for PF mixture are coincide with that observed by Sivaraja et al.[15].

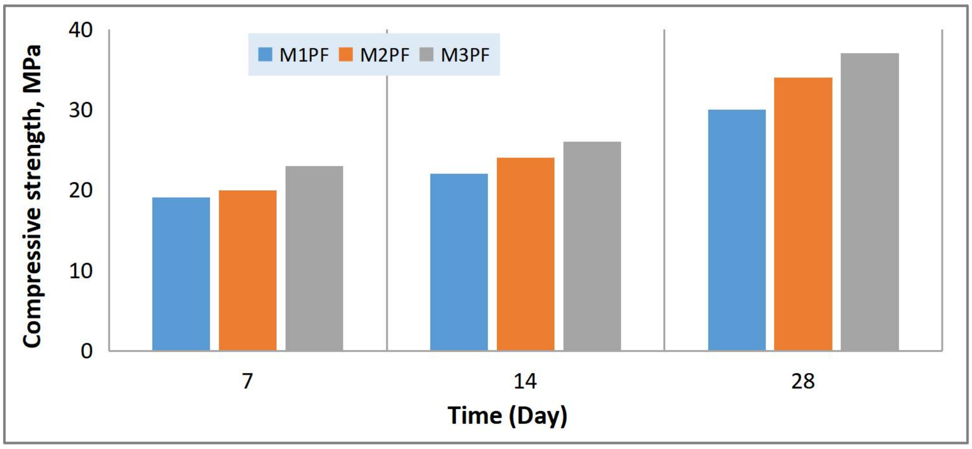

Figure 11. The relation between the compressive strength and curing time of modified samples by reeds papyrus fibers.

While the mixtures fabricated using DS and OS offered a reverse trend. As cleared in **Figure 12 and 13**, the employment of these materials causes a noticeable shortage in the capability of mixture against compression with respect to both additive dosage and curing time. Nevertheless, at 28 days of curing presents a higher compression strength, and only the mixtures contain 3% of DS and OS. As the compression strength reached to 31 MPa and 20 MPa for the M1DS and M1OS concrete mixtures, respectively. Even though, it still lower than the control mixture, as the strength declined by about 5% and 38% for M1DS and M1OS, respectively in contrast with control mixture. The deficiency in strength for mixtures with DS and OS with respect to their contents is attributed to the intersects of ash particles between each other and their domination in the mixture skeleton. That, in turn, caused a scarcity in the hydration reaction in the mortar and reduced the cohesion between cement mortar and date seed or olive seed ashes. The results are reconcile with that obtained by Danso[20] and Nasir et al.[21].

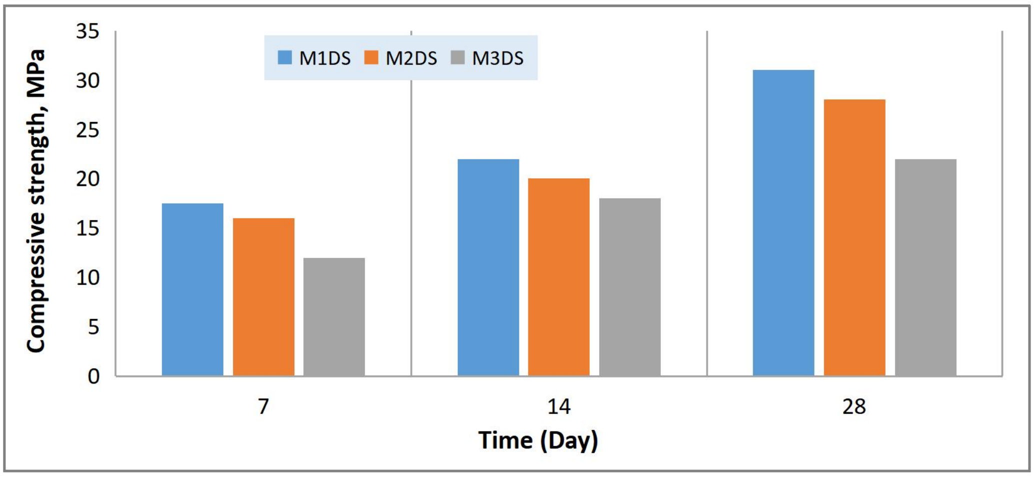

Figure 12. Relation between the compressive strength and curing time of DS modified samples.

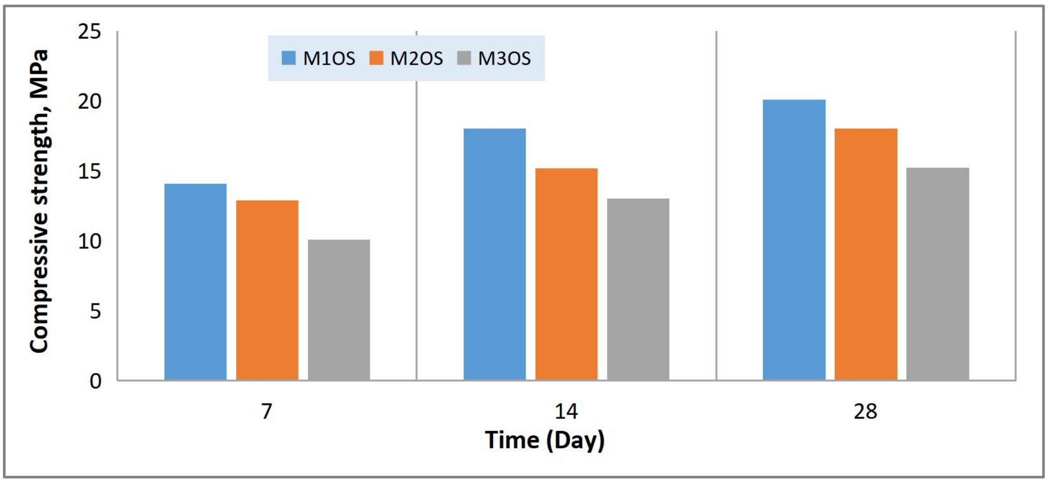

Figure 13. Relation between the compressive strength and curing time of OS modified samples.

3.2. Abrasion resistance results

Abrasion resistance results as a function of wear depth (WD) and weight loss (WL) at 28 days of curing of all concrete mixtures, i.e., CM and DS, OS modified concrete mixtures were presented in Figure 14 and 15. Results indicate that the supplement of modifiers in the concrete mixture significantly impacts the faculty of concrete mixtures to withstand abrasion loss but with various levels. It's clear that the mixture fabricated using PF eliminates the amount of WD and WL dramatically, in contrast with the remaining modifiers. As the use of fiber reduces each of WD and WL by above 35% at M3PF. This return to the faculty of fiber to prolong a 3D network within the mixture medium, that lead to strengthen the interlock between PF other mixture components, thereafter rise the resistance of the mixture against abrasion.

Whereas blending the OS and DS along with other components of concrete mixture didn't gain the mixture evident improvement. Reversely, they contributed to raising both WD and WL with respect to additive dosage and exceeded the control mixture level, especially at the higher modifier dosage. However, the minimum level of WD and WL for OS mixtures reached 20% for M2OS and 2% for M1OS, respectively. While an increment occurred in the magnitude of WD and WL for DS mixtures even when using 3% DS, and the rise overrun the control mixture by 10% and 20% for M1DS, respectively. This behavior is related to the reduction of cohesion between mixture components and DS or OS additive due to the occurrence of a high connection between ash particles that causes a debonding with mixture components. Besides the porosity nature of ash itself, which acquires the mixture an increment in the percentage of pores, that weaken its ability to withstand abrasion. Abrasion results of all mixtures appear in agreement with that observed by Atis et al.[16].

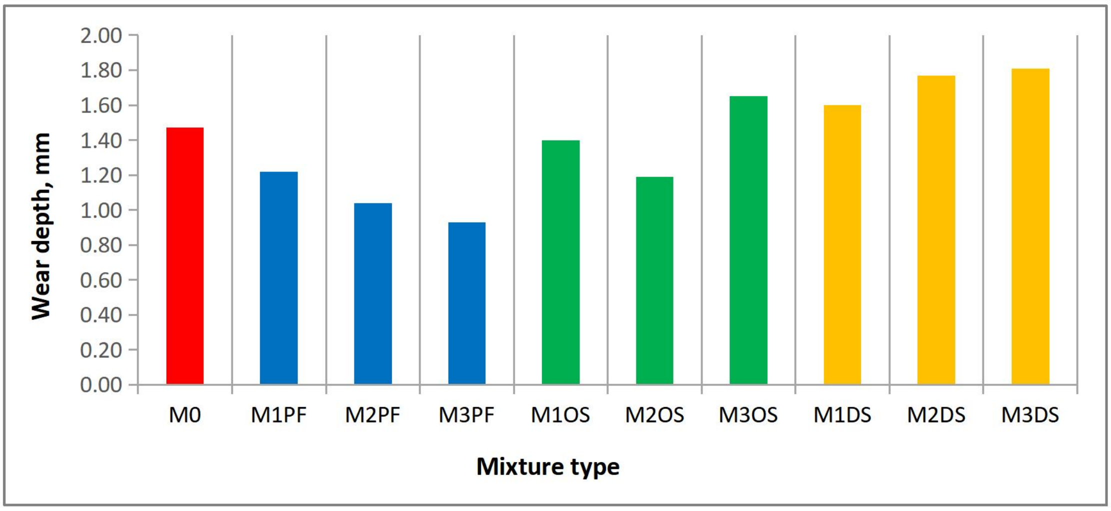

Figure 14. Wear depth of all concrete mixtures at 28 days curing.

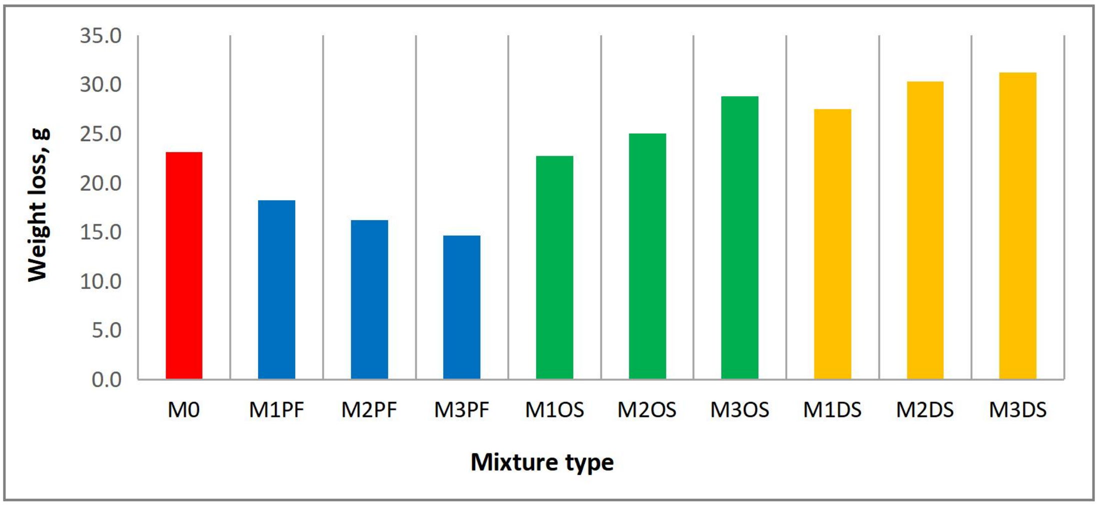

Figure 15. Weight loss of all concrete mixtures at 28 days curing.

4. Conclusion

The present study tends to determine the variation in compressive strength and abrasion resistance of different additives (papyrus fibers, date seeds, and olive seeds) for improving the sustainable properties that can be suitable in severe environments. The new concrete mixture structure altered the concrete properties of compression compressive strength and abrasion resistance, generating heightened consequences. Hence, the adjustable properties after involving these additives became more applicable. Findings showed that relatively minor responsiveness was observed when using OS products than other modifiers in terms of compression strength. At the same time, DS displayed a lower resistance against abrasion. PF can strengthen the concrete mixture and get an excellent result using this additive, even in low and high ratios. Increment of compressive strength and decrement of abrasion resistance for concrete mixtures reinforced by PF gives a good indication to be used for highway concrete pavement. Accordingly, an improvement in the concrete mixture properties was achieved in the presence of cellulose materials in which adding PF increased the compressive strength of the concrete mixture to about 15% for 0.7% PF and 28 days of curing, and PF declined abrasion weight and depth by above 35% at 0.7% PF and 28 days of curing. In addition, combining DS and OS seeds with the concrete mixture ingredients gives a weak resistance to the mixtures. That indicates that these materials cannot be used to enhance the strength of the concrete mixture. Thus, adding DS lowered the compressive strength of the concrete mixture to nearly 5%, while OS reduced it by about 38%, and in the case of abrasion loss the comprising of DS resulted in an increment of 10% and 20% for wear depth and weight loss, respectively. In comparison, OS reduced these properties at a specific moment by about 20% and 2%, respectively.

Acknowledgments

The authors thank the department of Environmental Engineering, Faculty of Engineering, University of Babylon, Iraq for supporting this research.

Conflict of interest

The authors declare no conflict of interest.

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