Physical and mechanical behaviors of waste paper reinforced mortar

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الخلاصة

في هذا البحث تم دراسة تأثير إضافة مخلفات الورق كألياف في مونة السمنت حيث تم جمع المخلفات الورقية من قارضات الورق المستخدمة في المكاتب. الدراسة تمت على نماذج من مونة السمنت. تم اضافة المخلفات الورقية بنسب مختلفة (0. 5% ، 1. 0%،1. 5%،2. 0%،2. 5%،3. 0%) وزنا مع استخدام المعجل الفائق بنسبة 2% من وزن السمنت ومقارنة النتائج مع الخلطة المرجعية. تم اجراء الفحوص الفيزيائية على نماذج المونة كمقاومة الانضغاط ومعاير الكسر والكثافة والامتصاص. النتائج اظهرت ان اضافة مخلفات الورق الى الخلطة قللت من مقاومة الانضغاط ومن قيمة معاير الكسر وزادت من امتصاص الماء وقللت من الكثافة لذا يمكن اعتبارها خرسانة إنشائية خفيفة الوزن. النتائج اثبتت ايضا ان اضافة الياف مخلفات الورق قللت من تشظي نماذج المونة وان النماذج المحتوية على مخلفات الورق تحافظ على شكلها الاصلي بعد الفشل مقارنة مع الخلطة المرجعية وان الشقوق رفيعة جدا في حالة الكسر، كذلك فان النماذج بعد الفشل ممكن ان تتحمل تحميل الى حد 93% من حمل الفشل اذا ما تعرضت الى اعادة التحميل.

الكلمات المفتاحية

المخلفات الورقية، المعجل الفائق، مقاومة الإنضغاط.

Abstract

This study investigated the use of waste papers as fiber reinforced mortar. The fibers have been collected from office paper shredders. Investigation was carried out on cement mortar samples. Different percentages of fibers i. e., 0. 5%, 1. 0%, 1. 5%, 2. 0%, 2. 5% and 3% by weight with the addition of super plasticizer by 2% of the weight of cement and compare the results with control mix. Mechanical properties such as compressive strength, flexure, density and water absorption were measured. The results indicated that the addition of waste paper decreases the compressive and flexural strength, increases water absorption and reduces the density so it could be considered as structurally lightweight concrete mortars. The results revealed that the addition of waste paper fibers reduces defragment of mortar and the samples with fibers keep their original shape after failure and the crack are very thin compared to control mix. Moreover they could sustain loads up to 93% of the failure load if they are subjected to preloading condition.

Keyword

compressive strength, super plasticizer, waste papers.

1. Introduction

Significant opportunity exists to reduce greenhouse gases (GHG) emissions through the development of energy aware construction materials. This can be achieved by maximizing the use of waste products, now merely used as landfill. The advantages of using wastes are twofold: firstly, the use of row natural resources is reduced, and secondly, wastes are being disposed of in a safe, effective and environmentally friendly manner. This advantageous solution has inspired an impressive volume of research and development. Work is being conducted worldwide on the use of recycled materials [1].

Concrete is the most widely used construction material in the world due to its high compressive strength, long service life, and low cost. However, concrete has inherent disadvantages of low tensile strength and crack resistance. To improve such weaknesses of the material, numerous studies have been performed on the use of waste materials as an addition to concrete mixes. Wastepaper has been used as building materials for decades, especially in cementitious matrices, and since then a lot of research has been conducted to develop the mechanical properties of the composite like compressive, tensile, flexural strength, and etc. Most of the published works on recycling of papers are from paper mill. Balwaik and Raut [2], investigated the use of paper-mill pulp as a replacement of cement up to 20% by weight, the results showed that the compressive, splitting tensile and flexural strength increased up to 10% addition of waste paper pulp and further increased in waste paper pulp reduces the strengths gradually. Mohamed and Fang [3] studied the use of paper-mill residuals collected from a wastewater treatment-plant as an addition in concrete mix with fly ash as a replacement for Portland cement, compressive, splitting tensile, flexural strength and rapid chlorides permeability test were carried out to evaluate the mechanical properties of the composite, the results revealed that concrete containing paper-mill residuals showed improvement in the durability test results when PC was replaced with class F fly ash. Shukeri and Abdul Ghani [4] studied the use of wastepaper as additional materials in concrete mixes and basic strength characteristics such as compressive strength, splitting tensile, flexural, and water absorption were determined and compared with a control mix. It was shown that the addition of wastepaper reduces the mechanical strength of concrete and increases water absorption properly. Fadila, Suleiman and Noordin [5] investigated the use of paper fibers with other mixture of lightweigh foamed concrete to produce a good lightweight concrete in terms of tensile strength, compressive strength and absorption of noise. R. Srinivasan, Sathya and Palanisamy [6] investigated the use of paper industry waste (Hypo Sludge) as partial replacement by replacing cement via different percentages of Hypo Sludge to produce low coast concrete, the results showed that compressive strength increased up to 40% replacement while split tensile strength have been decreased and the coast of concrete should be low accordingly. Pitroda, Zala and Umrigar [7] investigated the durability of concrete using Hypo Sludge as partial replacement of cement, physical properties as water absorption and sorptivity have been performed on different grade mixes, the results showed a low water absorption and low sorptivity of Hypo Sludge concrete at 10% replacement.

The aim of this study is to investigate the influence of the use of shredded waste paper on the properties of mortar. This is achieved by examining physical and mechanical properties of mortars containing waste paper in different percentages and compares the results with the original mix.

2. Experimental program

The key materials in this study were cement, sand, waste paper and super plasticizer. The cement used was ordinary Portland cement (PC) typically produced in Iraq. Uncrushed, quartzitic, natural sand with maximum size of (4. 75mm) the grading of the sand is shown in Table (1). Shredded waste paper used collected from office paper shredders used as fibers in mortar mix as shown in Fig.(1). Super plasticizer of type (structuro 502) has been added to the mixes with fibers. The specifications of super plasticizer are indicated in Table (2).

Table (1): Grading of fine aggregates.

Sieve size (mm)	% passing
4. 75	100
2. 36	65
1. 18	50
0. 600	35
0. 300	8
0. 150	0

Fig.(1): Waste paper fibers.

Table (2): Specifications of super plasticizer

Appearance:	Light brown coloured liquid
pH value:	6. 5
S. G. @ 20 0 C	1. 06 ±0. 02
Chloride content:	Nill
Alkali content:	Typical less than 1. 5 gm Na2O Equivalent per liter of admixture

3. Mortar mixture, proportions, sample preparation and testing methods.

The experimental study was developed with a typical mortar mix proportions of (1:2) cement to sand by weight with (w/c) ratio equals to (0. 4) was taken as reference mortar. Different percentages of waste paper fibers were added i. e. (0. 5, 1, 1. 5, 2, 2. 5 and 3) percent by weight of the total mix. Due to the high water absorption of the fibers, the (w/c) ratio has been increased gradually from 0.4 to the control mix up to (0. 6) to the mix with (3%) fibers. Super plasticizer has been added to mixes with fibers by (2%) of the weight of cement. The mixing process and sample preparation was according to ASTM C305 [8]. With the mixer in the operating position first the water and the super plasticizer were poured into the bowel of the electrical mechanical mixer while cement, sand and fibers were mixed together manually in a separate container in their dry state then they were introduced into the bowel and the mixer was turned on for about 30s then the mixer was stopped for 30s, then the mixing is continued for 1 min. The mixing state was carefully observed, and neither fiber balling nor any abnormalities were observed. Then the mortar has been molded in cubical molds of 50*50*50 mm and prismatic molds of 40*40*160 mm and they covered with cling film, after a day they were demoulded and cured in water until the time of testing.

4. Physical and mechanical properties

Characterization of the behavior of the mortar was performed through measurements of properties of this product in its hardened state. It involved the determination of density, absorption, mechanical strength (flexure and compression). The compressive strength of hardened mortars was performed on 50*50*50 mm cubs according to ASTM C109 [9] at ages 7 and 28 days. The mortar density and absorption was determined on 50*50*50 mm cubes at age of 28. The flexure strength was determined on 40*40*160mm mortar prisms at age of 28 days according to ASTM C 348 [10]. All the testing measurements were obtained from three samples, and the average of three samples was presented and discussed in the study.

5. Results and discussion

Determination of wet density, dry density and absorption.

The specimens were immersed in water at room temperature for 24 h. The specimens weights were recorded while suspended and completely submerged in water as (*Wi*). The specimens were removed from water and water allowed to drain for one min then the saturated weight was determined and recorded as (*Ws*). All specimens were dried in a ventilated oven for not less than 24 h at 105^0C. The weights of dried specimens were recorded as (*Wd*) (oven-dry weight). The wet density, dry density and absorption were calculated as:

The results of the hardened mortars wet, dry density and absorption are represented in Table (3) shown below.

Table (3): Mortars wet density, dry density and absorption.

Fibers %	0%	0. 5%	1. 0%	1. 5%	2. 0%	2. 5%	3. 0%
w/c	0. 4	0. 4	0. 45	0. 5	0. 5	0. 55	0. 6
Wet density(kg/m3)	2058	1977	1931	1852	1863	1818	1704
Dry density(kg/m3)	1989	1909	1862	1749	1727	1682	1534
Absorption %	3. 5	3. 7	4. 3	5. 8	6. 0	8. 1	12. 0

The results have shown that the addition of fibers causes a significant decrease in densities and an increase in the absorption percentages due to the porous structure of the mortars with fibers. Wet density has been decreases from (2058 kg/m3) for control mix to (1704 kg/m3) for mix with 3% fibers while dry density has been decreases from (1989 kg/m3) for control mix to (1534 kg/m3) for mix with 3% fibers. Absorption has been increased from (3.5%) for control mix to (12.0%) for mix with 3% fibers. As concrete density decreases thermal conductivity decreases. Figs.(3), (4) and (5) show the density and water absorption results.

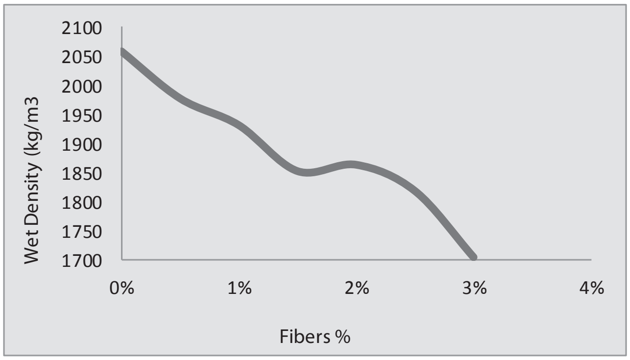

Fig.(3): Wet density of mortar.

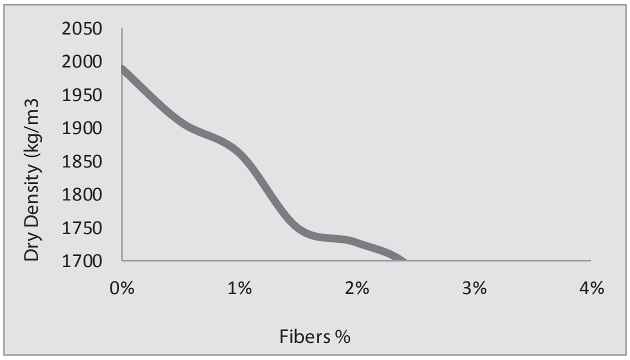

Fig.(4): Dry density of mortar.

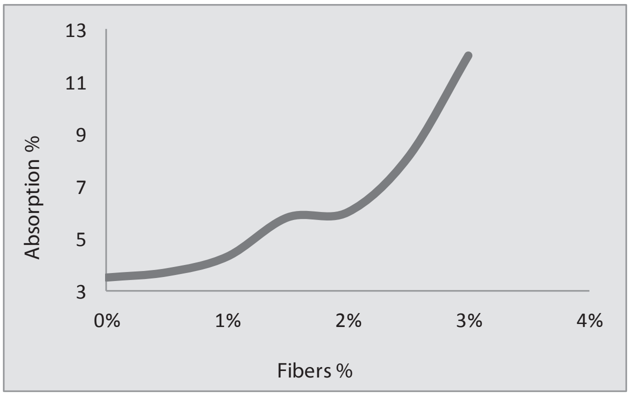

Fig.(5): Water absorption of mortar.

6. Mortar compressive strength

The results of compressive strength presented in Table (4) indicates that the addition of fiber reduces the compressive strength at 7 days from 63.7 (N/mm^2) for the control mix to 7.8 (N/mm^2) for mix with 3% fibers and at 28 days the compressive strength has been decreases from 69.7 (N/mm^2) for the control mix to 15.3 (N/mm^2) for mix with 3% fibers. There is a significant increase in compressive strength from 7 days to 28 days due to the hydration of cement in the mortar matrix.

ACI Committee definition states that compressive strength of a structural lightweight concrete at 28 days should be higher than 15-17 (N/mm^2) and air dry unit weight of structural lightweight concrete should be lower than 1850 kg/m3 (ACI Committee 213R, 1987) [12]. From Table (3) mortar with (1.5, 2.0, 2.5 and 3%) fibers could be classified as structural lightweight concrete mortars. From compressive strength test we can find that the failure modes of the samples is different i. e. the original mix sample has been damaged after failure while samples with fibers keep their original shapes after failure as shown in Fig.(8) that's due to the fibrous effect of the waste papers. Figs.(6) and (7) and show the results of the compressive strength tests.

Table (4): Mortars' compressive and flexural strengths.

Fibers %	0%	0. 5%	1. 0%	1. 5%	2. 0%	2. 5%	3. 0%
w/c	0. 4	0. 4	0. 45	0. 5	0. 5	0. 55	0. 6
Comp. strength (N/mm^2) at 7 days	63. 7	32. 2	23. 8	25. 7	14. 4	12. 9	7. 8
Comp. strength(N/mm^2) At 28 days	69. 7	39. 2	28. 6	30	19. 8	16. 2	15. 3
Modulus of rupture(N/mm^2)	8. 4	7. 8	6. 8	6. 3	6. 0	5. 3	3. 8
Compressive strength(preloading) (N/mm^2) at 28 days	1. 0	24. 5	23. 6	23. 4	17. 6	13. 6	14. 2

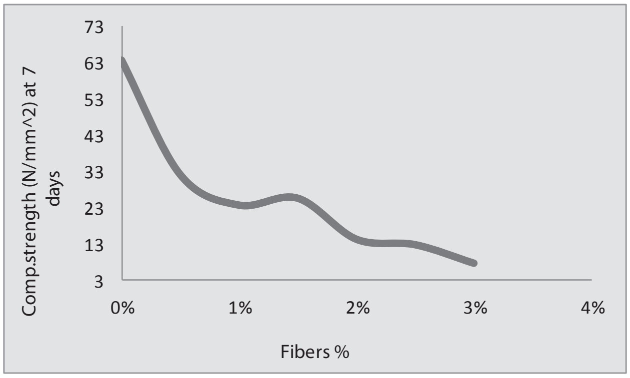

Fig.(6): Strength at 7 days compressive.

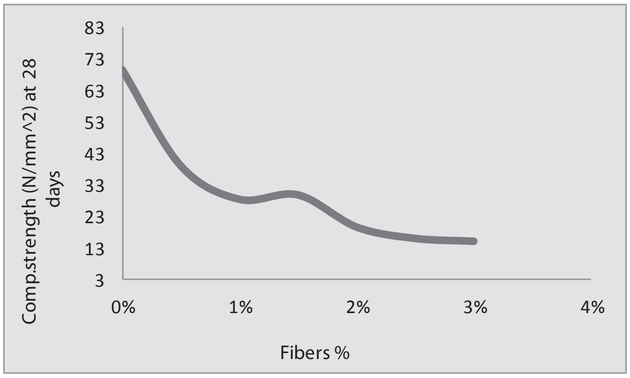

Fig.(7): Compressive strength at 28 days.

Fig.(8): Failure modes of mortar after compressive strength test, the left sample is for original mix, the middle is for mix with1. 5%fibers and the right one is for mix with 3%fibers.

7. flexural strength

Table (4) represents the average values of flexural strength for the mortars. The results show that the addition of fibers has been decreased the flexural strength as shown in Fig.(9) With the increase of fiber content we can find that the samples fail without rupture and the cracks are very small compared to the control mix as shown in Fig.(10).

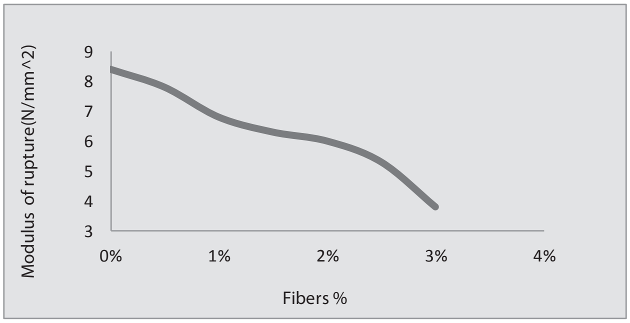

Fig.(9): Modulus of rupture.

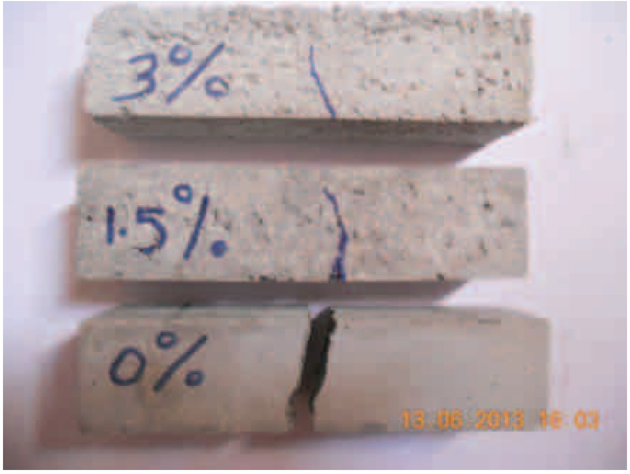

Fig.(10): Failure modes of mortar after flexural strength test.

8. Preloading

Samples with waste paper fibers could sustain loads after failure up to 93% of the failure load if they are subjected to preloading while the original mix does not, the results of preloading are indicated in Table (4).

Ultrasonic test

The ultrasonic test has been performed according to ASTM C597 [13] on three samples of 50*50*50mm using the ultrasonic device. Table (5) shows the results of ultrasonic test. Fig.(11) shows relationship between the fibers content and pulse velocity, were the velocity increased up 0. 5% fibers then it has been decreases by further increase of fibers.

Table (5): Relationship between fibers% and pulse velocity.

Fibers %	0%	0. 5%	1. 0%	1. 5%	2. 0%	2. 5%	3. 0%
Velocity (km/s)	2. 882	3. 175	3. 129	3. 136	2. 833	2. 463	2. 377

Conclusions

Based on results presented in this paper the following conclusions were made:

1. Generally, the compressive and flexural strength decreased by the addition of waste paper, but up to 3% addition of waste paper the mortar still behaves as structurally concrete mortar.
2. Most suiTable mix proportions is the 1. 5 to 3. 0 % of waste paper to be structurally lightweight concrete mortar.
3. There was an increase in water absorption of the concrete mixes as the content of the waste paper increased. This is expected since more amount of waste paper will involve in the hydration process. Therefore, additional amount of water was required for cement hydration. However; higher water content decreases the strength of concrete.
4. The addition of waste paper produces a porous structure mortar so that its density decreases gradually. The resulting mortar could be considered as thermally insulating mortar.
5. Mortar samples with waste paper could sustain loads if they are subjected to preloading after failure so they could absorb energy if they are subjected to dynamic loading.
6. The addition of waste paper prevents defragment of the sample when subjected to compressive loading, that mortar samples with waste paper keep their original shapes after failure compared to the original mix and the cracks are very thin in flexure.
7. Waste paper fibers occupy large volume in concrete mix that leads to an economic benefit by reducing cement demand in the mix and reducing the overall costs.
8. Use of waste paper in concrete can save paper industry disposal costs and produces a ‘greener’ concrete for construction.

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