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DRYING SHRINKAGE OF CEMENT MORTAR REINFORCED WITH WASTE OFFICE PAPER FIBERS

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ABSTRACT

In this investigation, the influence of using waste office paper fibers (WOPF) on the behavior of drying shrinkage in cement mortar have been presented**.** Cement mortar specimens size of (25×25×285) mm and a length change measuring apparatus including a dial gauge capable of measuring the length accurately to ±0.002 mm have been used to study free drying shrinkage of cement mortar according to ASTM C596 – 01 method. The workability of cement mortar reinforced with WOPF was assessed by using flow table test method. WOPF was added to the cement mortar in five ratios (0.2%, 0.4%, 0.6%, 0.8%, and 1%) by weight of cement with two categories. In first one WOPF added after being soaked in water for 24 hours while in the second one WOPF added after being soaked in cooking oil for 48 hours. The total mixes were 10 in addition to the reference mix (the 11th mix) which is made without WOPF. The results of the study indicated that the increase in WOPF ratio led to reduce in workability. In first category, when WOPF ratio increased to 0.4%, the flow percent still within 110±5%, and when WOPF ratio increased to 0.6% and above the flow percent clearly reduced. While in second category, when WOPF added, the flow percent dropped obviously for all ratios. Drying shrinkage percent increased when WOPF was added to mixes compared with reference mix for all ratios used in both categories except the fifth ratio (i.e. WOPF 1%) in which the drying shrinkage percent decreased at age of drying 11, 18, 25 days for first category and at age of 18 and 25 days for second category. Drying shrinkage percent of mixes has equal ratio of WOPF in the both categories had the same tendency in variation with time. The loss of weight percent variation for all the mixes is approximately linear. The loss of weight percent of category I is more than that of category II.

KEYWORDS: Drying shrinkage; Waste office paper fibers; Oil cooking; Cement mortar; Workability of cement mortar

انكماش الجفاف لمونة السمنت المسلحة بألياف مخلفات ورق المكتب

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جامعة الكوفة / كلية الهندسة / قسم هندسة المنشآت و الموارد المائية

الخلاصة

في هذا البحث، تم عرض تأثير استخدام مخلفات ورق المكتب كألياف (WOPF) على سلوك انكماش الجفاف في مونة السمنت. وقد استخدمت عينات من مونة السمنت بحجم (25 × 25 × 285) ملم، وجهاز قياس التغير بالطول (DIAL GAUGE) بدقة ± 0.002 ملم لدراسة انكماش الجفاف الحر لمونة السمنت طبقا للمواصفة ASTM C596 - 01. تم تقييم قابلية التشغيل لمونة السمنت المسلحة بـ WOPF باستخدام اختبار الانسياب. وأضيفWOPF لمونة السمنت بخمس نسب (0.2٪، 0.4٪، 0.6٪، 0.8٪، 1٪) من وزن السمنت وعلى فئتين: في الفئة الأولى وأضيف WOPF الى المونة بعد نقعه في الماء لمدة 24 ساعة. بينما في الفئة الثانية أضيف WOPF الى المونة بعد نقعه في زيت الطعام لمدة 48 ساعة. عدد الخلطات الكلي 10 خلطات بالإضافة إلى الخلطة المرجعية (الخلطة الحادية عشر) من دون WOPF. وأشارت نتائج الدراسة إلى أن الزيادة في نسبة WOPF يحد من قابلية التشغيل. في الفئة الأولى، عندما زادت نسبة WOPF إلى 0.4٪، بقيت نسبة الانسياب ضمن 110 ± 5٪ وعندما زادت نسبة WOPF إلى 0.6٪ وأكثر, نسبة الانسياب انخفضت بشكل واضح. بينما في الفئة الثانية، عندما اضيف WOPF، انخفضت نسبة الانسياب بشكل كبير في كل النسب. نسبة انكماش الجفاف زادت عندما أضيف WOPF للخلطات مقارنة مع الخلطة المرجعية لكل النسب المستخدمة في كلا الفئتين ما عدا النسبة الخامسة (أي 1 WOPF٪) والتي انخفضت فيها نسبة انكماش الجفاف في اعمار تجفيف 11 و 18 و 25 يوم للفئة الاولى وفي عمر 18 و 25 يوم للفئة الثانية. نسبة انكماش الجفاف للخلطات التي تحتوي نسبة متساوية من WOPF في كلا الفئتين لها نفس النزعة في التغاير مع الوقت. تتغاير نسبة الفقدان في الوزن لجميع الخلطات بشكل خطي تقريبا. فقدان الوزن في المئة من الفئة الأولى أكثر منه في فئة الثانية.

1. INTRODUCTION

The expression waste refers to the needless byproducts (materials) created during the production of a certain artifact or the artifact itself after a certain time duration. Waste has usually nothing to be given to the environment other than pollution. The reuse of waste materials is a waste reducing strategy which comprises regaining activities (Schroeder, 1994). Waste materials can be consumed directly or recycled to produce the same or a different product. Solid waste is most importance, as it is the greatest commonly occurring of all waste sort as it occurs from individual or local, industrial, and agricultural exercises (Okeyinka & Idowu, 2014).

The construction industry has been distinguished as one of the biggest consumer of non-renewable assets. Lately, there has been a resurgence of enthusiasm for conventional building materials (Akinwumi, 2014), particularly those produced using renewable or reused materials (Seyfang 2010). “Papercrete” is one of such materials appeal to public concern. Papercrete is a composite material including Portland cement, waste paper, water, and/or sand. It is similar to supplanting coarse-grained fraction and/or sand of Portland cement concrete with waste paper (Akinwumi et al., 2014). It has been considered to be an economical alternative building construction material (provides a suitable sound absorption and thermal insulation) to be a lightweight and fire-resistant items (Annesley, 2014; Fuller, 2014; Nepal & Aggarwal, 2014). Akinwumi et al. (2014) recommended that papercrete is an effectual and sustainable material for the construction of lightweight and fire-resistant hollow or solid blocks to be used to create partition walls of particularly high-rise buildings. Kareem (2014) mentioned that the adding of waste paper growths most of the mechanical strength considerably at 90 days of testing age. In spite of having a great deal of data about how to utilize papercrete as a development material, few examination works have been done to decide their structural suitability (Fuller et al., 2006 - cited by Akinwumi et al., 2014).

On the other hand, as concrete utilization turns out to be second after water, a more practical and financial new type of green admixtures may give positive effects on the construction building (Beddu et al., 2015). The influences of benefiting oil in concrete has been conducted using some types of oil, for example; engine oil, cooking oil, and waste paint. Beddu et al. (2015) stated that cooking oil can play as admixture for good properties of concrete using sustainable products. It increases workability, enhances mechanical properties, and reduces the interfacial transition zone and air voids size compared to reference mix. Kevern (2010) reported that soy bean oil as a curing agent enhances the durability of concrete pavements. He concluded that soybean oil considerably lessens moisture loss from fresh concrete and gives enormously improved deicer scaling resistance. Aravind and Animesh (2007) recommended that the applied of engine oil in highway construction needs well controlled oil collection method. The further research is imperative to yield the good quality and operation of concrete.

Concrete compressive strength is satisfactory and tensile strength is low (approximately ten percent of compressive strength). This weakness initiates problems, involving concrete shrinkage and cracking. Shrinkage of concrete depends on several elements entering: the ingredients, relative humidity and temperature of concrete, concrete age, size, and structure. To improve such weak tensile strength of concrete and construction materials similar to concrete, reinforced with fibers was developed (Batebi et al., 2013). Cement-based materials involving mortar and concrete are exposed to various types of volume changes in its service life. When mortar and concrete have been subjected to dry conditions, the material initiates to lose water and shrink. The lose free water from big cavities existing in paste microstructure might not lead to in shrinkage; though the lose adsorbed water and water held in small capillary pores produces a reduction in disjoining pressure, which is identified as the major cause of drying shrinkage (Mehta, 2006).

In the present study, an attempt has been made to reveal the influence of using waste office paper fibers in cement mortar on free drying shrinkage, and using oil cooking as an admixture to control the absorption and water evaporation of these fibers.

2. GENERAL PROPERTIES OF OFFICE PAPER

Paper is a thin material manufactured by squeezing together moist fibers of cellulose pulp derivative from wood, rags or grasses, and drying them into flexible layers. It is a useful material with various usages, involving writing, printing, packaging, cleaning, and a number of industrialized and construction processes. The chemical composition of paper relies on the type or grade of paper. Usually most grades of paper contain organic and inorganic material. Organic part comprising of cellulose, hemi-cellulose, lignin, and or numerous compound of lignin (Na-lignate, etc.) might be 70% to 100%. Inorganic part comprising of primarily filling and loading material as calcium carbonate, clay, titanium oxide, etc. might be 0% - 30% of paper (paperonweb [(1)]).

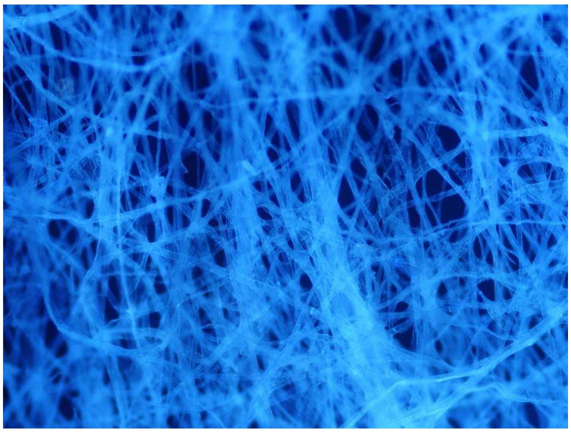

Plate 1. The microscopic structure of paper: The individual fibers in this sample are around 10 µm in diameter (Wikipedia).

The basis weight or grammage is an essential characteristics of paper. Paper basis weight is the weight per unit area. This could be stated as the weight in grams per square meter (GSM or g/m2), pounds per 1000 sq. ft, and it is about 80 g/m2 for office paper. Bulk is another important issue of paper. It is an expression used to specify volume or thickness in relation to weight. It is the mutual of density (weight per unit volume) and considered from caliper and basis weight. It is about 800 kg/m3 (grammage / thickness) for office paper. Thickness or Caliper of paper is quantified with a micrometer as the perpendicular expanse between two circular plane parallel faces under a pressure of 1 kg / cm2. Distinctions in caliper may alter several fundamental properties comprising strength, optical and roll quality. For office paper it is about 105-110 µm. Moisture in paper ranges from 2% - 12% depending on relative humidity, degree of refining, type of pulp, and chemical used. Most physical properties of paper altered as a result of variants in moisture content. Water influences plasticizing the cellulose fiber and relaxing and reduces the inter-fiber bonding. All strength properties are responsive to moisture – nearly 1% change in a sample's moisture content and varies the compression strength around 8%. Typical moisture values of office Paper are about 4%-4.5% (paperonweb (2)). Green stated that dimensional stability and its interpretation are important points, he considered that: 1. A chief measurement of dimensional stability is coefficient of moisture expansion (CME), in terms of % variation in dimension/% variation in moisture. 2. CME of paper relates with a measurement termed wet expansion. 3. An explanation of dimensional stability features of a sheet can be attained by wetting a paper, computing its wet expansion, then free drying the paper, and calculating the total shrinkage. Variance between total shrinkage and wet expansion is net shrinkage (a recovered shrinkage), also termed internal strain. 4. Total shrinkage is a degree of how much the sheet might shrink, if it was free dried, and is the summation of wet expansion and internal strain. 5. Internal strain is influential as it manifests itself when paper is subjected to high relative humidity (RH) and/or high temperature.

An essential side of dimensional stability is impact of fiber properties, and in what way they dry in paper. Fibers have drying shrinkage of 20 to 1 or further width to length, Fig. 1. While fibers dry in a sheet, they bond at a crossings. The shrinkage in fiber width of one contracts the length of another by crumpling or micro-compressing at the bond, Fig. 2. The amount of sheet shrinkage associated to fiber shrinkage.

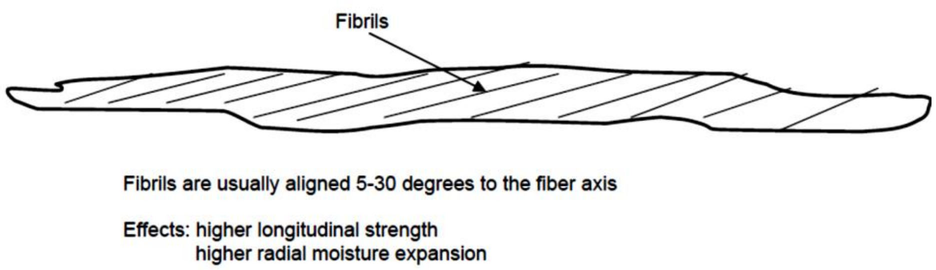

Fig. 1. Fiber diagram (Green).

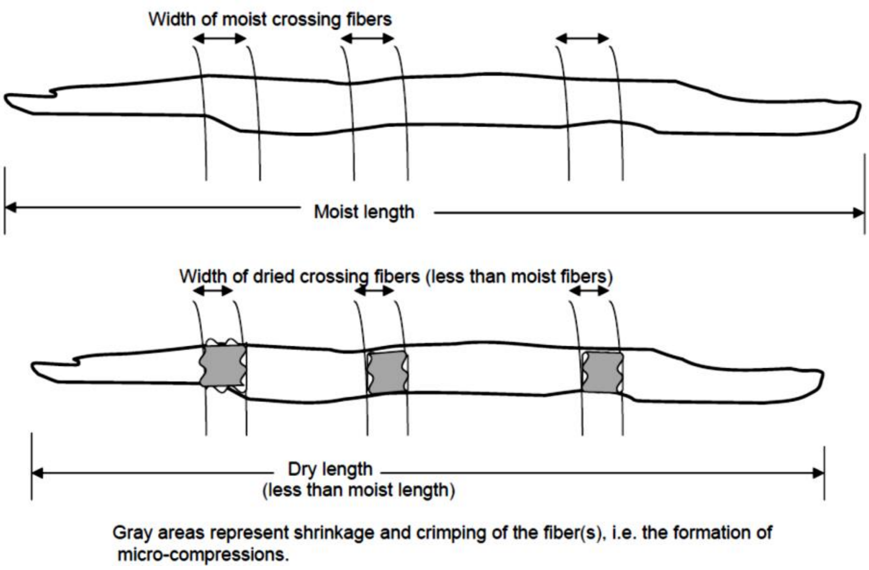

Fig. 2. Fiber shrinkage yielded by shrinkage at the crossings (Green).

Usually, coefficient of moisture expansions (CME) (% per moisture change) is 0.03%-0.06% (machine direction MD) and 0.07%-0.17% (cross direction CD). These amounts are valid in the 0-65% RH span. Fig. 3 shows relations (not to scale) when paper dimensions are available by free drying paper that has not been originally dried with restriction of shrinkage. Share of the internal strain constituent is a plastic strain (P) and non-recoverable. For a sheet dried with restriction, then rewet and dried, overall shrinkage is a bit less (about 1.5%) than if free dried from original wet state: To = H + I + P

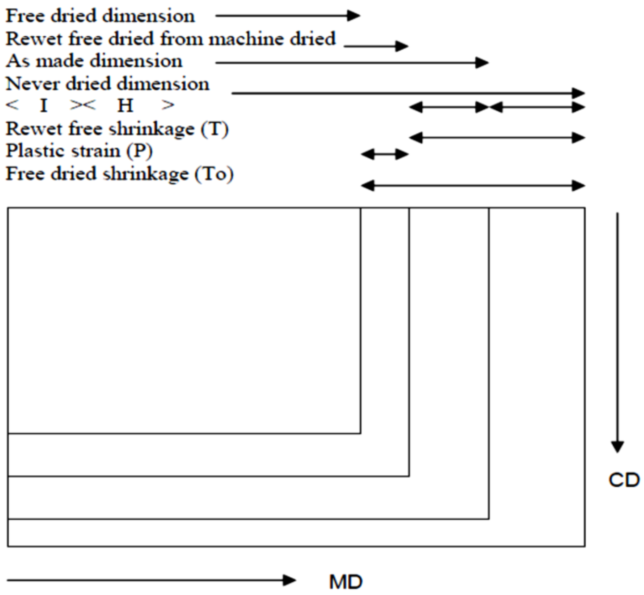

Fig. 3. Free dried paper dimensional diagram (Green).

Paper shrinks alters mechanical properties. Any decrease in drying shrinkage increases tensile stiffness index, breaking length, and decreases breaking strain, and CME (and vice versa). Figs. 4-7 show the relationship between numbers of paper properties of xerographic "bond" papers.

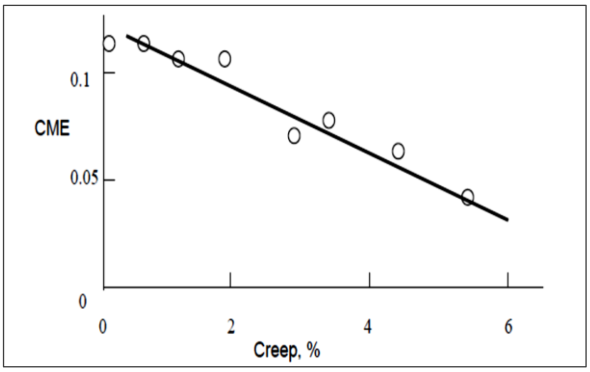

Fig. 4. CME versus creep (Green).

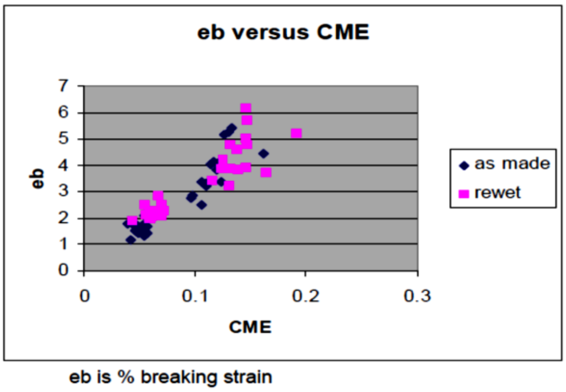

Fig. 5. Breaking strain versus CME (Green).

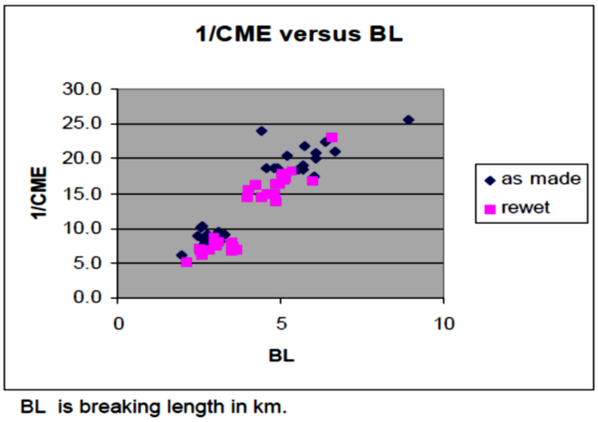

Fig. 6. CME versus breaking length (Green).

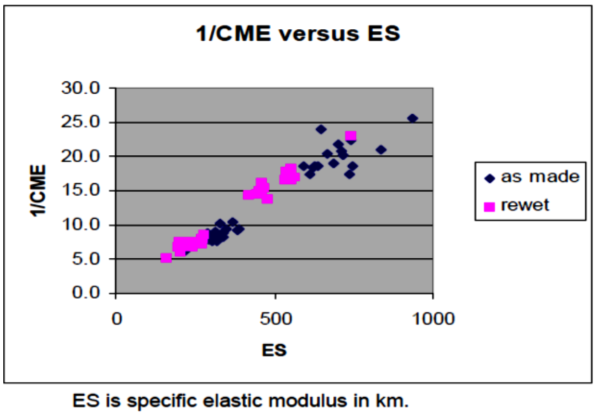

Fig. 7. CME versus elastic modulus (Green).

3. GENERAL PROPERTIES OF USED COOKING OIL

The chemical composition of used cooking oil is govern by the various usage by the user, but the major composition will be saturated fatty acid, triglyceride, diglyceride, and monoglycerid, and the saturated fatty acid refers to palmitic acid and stearic acid (Yanyong et al., 2012).

4. EXPERIMENTAL WORK

4.1. Materials

4.1.1. Cement

Ordinary Portland Cement (O.P.C.) (Type I) was used during this study. It is manufactured by New Kufa Cement Plant and met the Iraqi specifications (IQS No.5: 1984). Tables 1 and 2 display the chemical analysis and physical properties of the cement used in this study, respectively.

Table 1. Chemical Analysis of the Cement used throughout the Present Study

Oxide	**(%)**	**Limit of Iraqi specification** (IQS No.5: 1984)
CaO	63.50	…………
SiO_2	20.97	…………
Fe_2O_3	3.670	…………
Al_2O_3	5.500	…………
MgO	0.700	≤ 5.0
SO_3	2.500	≤ 2.8
Free lime	0.680	…………
L.O.I.	1.530	≤ 4.0
IR	-	≤ 1.5
Compound composition	**(%)**	**Limit of Iraqi specification** (IQS No.5: 1984)
C_3S	46.97	…………
C_2S	24.77	…………
C_3A	8.370	…………
C_4AF	11.15	…………
LSF	0.900	0.66-1.02

Table 2. Physical Properties of the Cement used throughout the Present Study

Physical properties	Test results	Limit of Iraqi specification (IQS No.5: 1984)
Fineness (Blaine method) cm^2/gm	3100	≥2300
Setting time (Vicat method)		
Initial hrs:min	1:25	≥0:45
Final hrs:min	4:22	≤10:00
Compressive strength		
3 days MPa.	18.6	≥15
7 days MPa.	29.0	≥23

4.1.2. Fine Aggregate

Al-Akhaidur natural sand was used in this study, passing sieve 2.36 mm (No. 8) according to the requirement in (ASTM C 157/C 157M – 08).

Table 3. Properties of the Sand used throughout the Present Study

Property	Test results	Limit of Iraqi specification (IQS No.45: 1984)
Fineness modulus	2.8	-
SO_3 %	0.4	≤ 0.5
Specific gravity	2.6	-
Absorption %	1.0	-

4.1.3. Waste Office Paper Fibers (WOPF)

Waste offices paper fibers collected from offices' paper shredder was used, the paper shreds have 50 x 2 x 0.1 mm dimensions, as shown in Plate 2.

Plate 2. Waste Office Paper Fiber (WOPF).

4.1.4. Cooking Oil

Cooking oil is collected from homes and restaurants, which is ejected as frying refuse.

Mix Design

WOPF added to cement mortar in five ratios (0.2%, 0.4%, 0.6%, 0.8%, and 1%) by weight of cement with two categories:

First / WOPF added after being soaked in water for 24 hours to reduce the absorption ratio. Second / WOPF added after being soaked in cooking oil for 48 hours to reduce the absorption ratio. The total mixes were 10 in addition to the reference mix (the 11th mix), which is made without WOPF (WOPF = 0).

The cement: sand ratio was chosen to be 1:1 because the results were obtained by (Yun et al., 2007) and (Aciu et al., 2014) which also adopted by (Akinwumi et al., 2014) showed that the sand-binder ratio of 1.0 has the best mechanical properties, with economy view. The mixes proportions are shown in Table 4.

Table 4. Mixes Proportions

	Category I : WOPF soaked in water for 24 hours		**Category II: WOPF soaked in cooking oil for 48 hours**
No.	**Cement : Sand : WOPF ratio**	**No.**	**Cement : Sand : WOPF ratio**
Mw1	1:1: (0.2%)	**Mo1**	1:l: (0.2%)
Mw2	1:l: (0.4%)	**Mo2**	1:l: (0.4%)
Mw3	1:l: (0.6%)	**Mo3**	1:l: (0.6%)
Mw4	1:l: (0.8%)	**Mo4**	1:l: (0.8%)
Mw5	1:l: (1%)	**Mo5**	1:l: (1%)
Mref. **(refrence mix)**	1:1:0		

4.2. Test Procedures

4.2.5. Workability Test

In order to assess the workability of cement mortar reinforced with WOPF, the percentage of the increase in average base diameter of the mortar mass, to the original base diameter, using flow table test method was conducted. This test was done according to (ASTM C 230/C 230M – 08) and (ASTM C 1437 – 07).

4.2.6. Drying Shrinkage Test

This test was done according to (ASTM C 596 – 01) and (ASTM C 157/C 157M – 08). Cement mortar specimens size was (25×25×285) mm, and a length measuring apparatus including a dial gauge capable of measuring the length accurately to ±0.002 mm (ASTM C 490 – 07). For the first category (WOPF socked in water), the specimens were removed from the molds after 24 hr ± 30 min and cured in lime-saturated water for 48 hr. For the second category (WOPF socked in oil) the specimens were removed from the molds after 48 hr ± 30 min to avoid destruction during removal from the molds and cured in lime-saturated water for 24 hr. At the age of 72 hr ± 30 min the specimens were removed from water and wiped with damp cloth, and immediately the length comparator reading for each specimen was obtained. Then the specimens were placed in an air storage for 25 days. A length comparator reading was obtained for each specimen after 4, 11, 18, and 25 days of air storage. Air storage and readings were taken in a room kept at a relative humidity of 50 ± 4 % while the specimens are at a temperature of 23 ± 2 °C (73 ± 3°F). Length change was calculated as follows:

$$\Delta Lx = \frac{CRD - initial\,CRD}{G} \quad (1)$$

Where: ΔLx = length change of specimen at any age, %,

CRD = difference between the comparator reading of the specimen and the reference bar at any age, and

G = the gage length [250 mm].

Plate 3. Apparatus and a specimen during test.

5. RESULTS AND DISSCUTIONS

5.1. Workability Test

Table 5 and Fig. 8 show the flow table test values for all mixes and indicate that the increase in WOPF ratio reduces the flow percent value and leads to worse workability. In category I, when WOPF ratio increased to 0.4%, the flow percent is still within 110±5%. When WOPF ratio increased to 0.6% and above, the flow percent obviously reduced. The reduction of flow percent was 35%, 44%, and 56% for 0.6%, 0.8%, and 1% WOPF ratio, respectively. In the second one (i.e. category II), when WOPF added, the flow percent dropped evidently. The reduction of flow percent was 45%, 60%, 65%, 70%, and 70% for 0.2%, 0.4%, 0.6%, 0.8%, and 1% WOPF ratio, respectively. The behavior of the two mixes categories was different; this may be due to WOPF in category II seems stiffer and – as mentioned earlier - most physical properties of paper altered as a result of variants in moisture content. Water influences plasticizing the cellulose fiber and relaxing and reducing the inter-fiber bonding. In general, the fibers tend to create a network; it can obstruct moisture and decrease bleeding in the wet statue and limit the mix outward radial movement distinctly on the flow table (Song, Pey-Shiuan and Tu, Chi-jen 2014).

Table 5. Flow Table Test Results

No.	Flow %	No.	Flow %
Mw1	110	Mo1	65
Mw2	105	Mo2	50
Mw3	75	Mo3	45
Mw4	66	Mo4	40
Mw5	45	Mo5	40
Mref. (refrence mix)	110		

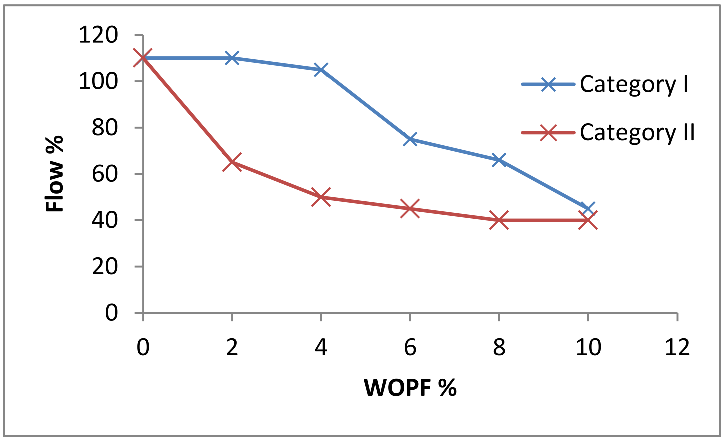

Fig. 8. Flow table test results.

5.2. Drying shrinkage test

Drying shrinkage increased when WOPF was added to cement mortar compared with reference mortar. This tendency is observed for all ratios added in both categories except the fifth ratio (i.e. Mw5 & Mo5 with 1%) in which the drying shrinkage decreased at age of drying 11, 18, and 25 days for Mw5 and at age of 18 and 25 days for Mo5, as it is evident from Table 6 and Figs. 9 and 10 where the variation of drying shrinkage percent with time for categories I & II is presented. The maximum drying shrinkage occurred in mixes with WOPF of 0.8% at all ages of observation in category I & II (i.e. Mw4 & Mo4 with 0.8% WOPF) except the age of 18 days in category II, at which the mix with WOPF of 0.6% (Mo3) had the maximum drying shrinkage. In Mw4 drying shrinkage percent was about 0.1932, 0.1226, 0.056, and 0.07 more than reference mix at age of 4, 11, 18, and 25, respectively. In Mo4, it was about 0.1488, 0.1572, and 0.0392 more than reference mix at age of 4, 11, and 25, respectively, and it was about 0.0624 more than reference mix for Mo3 at age of 18 days. On the other hand, the minimum drying shrinkage at age of 4 days occurred in mixes with WOPF of 1% (i.e. Mw5 & Mo5 with 1% WOPF), but it is more than reference mix. Drying shrinkage percent was about 0.024 for Mw5 and 0.0448 for Mo5 more than reference mix. At age of drying of 11 days the minimum drying shrinkage happened in Mw5, in category I, drying shrinkage percent was about 0.0116 less than reference mix. in category II, the minimum drying shrinkage at age of drying of 11 days happened in Mo2, but it more than reference mix. Drying shrinkage percent was about 0.0076 more than reference mix. At ages of drying of 18 and 25 days, the minimum drying shrinkage occurred in mixes with WOPF of 1% for the both categories (i.e. Mw5 & Mo5 with 1% WOPF). In Mw5, drying shrinkage percent was about 0.0292 and 0.1512 less than reference mix at ages of drying of 18 and 25 days, respectively. In Mo5, drying shrinkage percent was about 0.0708 and 0.1128 less than reference mix at ages of drying of 18 and 25 days, respectively.

From the above results, it is clear that there is compatibility between the result of present study and the results of mechanical properties of papercrete that are obtained by (Kareen, 2014). The ratio of (1%) has a lower drying shrinkage - as confirmed by the present study- and has more compressive strength than the low ratios, this may be clarified by the idea that with the amalgamation of fibers in the mixes at this intensity, the fibers block up the voids in concrete with a considerable bonding facility to the mix, therefore, the voids are diminished and the properties of concrete is improved (Kareen, 2014).

Figs. 11-15 show comparison between the behavior of category I and category II for each ratio of WOPF. It is obvious that an equal ratio of WOPF in the both categories had the same tendency with some disparity in the percent of the shrinkage due to variants in moisture content and evaporated quantity of water, as a result of the difference in moisten conditions (i.e. using water and cooking oil). In addition, as mentioned earlier, a chief measurement of dimensional stability of paper is coefficient of moisture expansion (CME), in terms of % variation in dimension/% variation in moisture.

Table 6. Drying Shrinkage and Loss of Weight Results.

No.	Shrinkage%				Loss of Weight %			
Drying Period:	4 Days	11 Days	18 Days	25 Days	4 Days	11 Days	18 Days	25 Days
Mref.	0.0288	0.0964	0.1444	0.1864	0.691904	2.201182	3.144817	4.151108
Mw1	0.1822	0.1378	0.1578	0.2172	1.473687	3.808690	5.64882	6.876202
Mw2	0.1652	0.1154	0.1938	0.2138	2.252016	4.504032	7.425592	9.251521
Mw3	0.1754	0.1584	0.1971	0.2284	1.215473	1.472764	4.041868	8.104667
Mw4	0.2220	0.2190	0.2004	0.2564	1.487629	1.811129	4.592253	8.602442
Mw5	0.0528	0.0848	0.1152	0.0352	1.268638	2.188237	5.009997	12.06002
Mo1	0.1798	0.1868	0.1808	0.1908	2.027223	3.041261	3.935612	4.710915
Mo2	0.1230	0.1040	0.1850	0.2000	0.977242	2.280174	3.257415	4.560093
Mo3	0.0994	0.1374	0.2068	0.2240	0.368553	1.597061	3.562977	5.161849
Mo4	0.1776	0.2536	0.1736	0.2256	0.507327	2.031398	4.058614	4.756712
Mo5	0.0736	0.1536	0.0736	0.0736	0.686813	2.197802	4.807692	5.769231

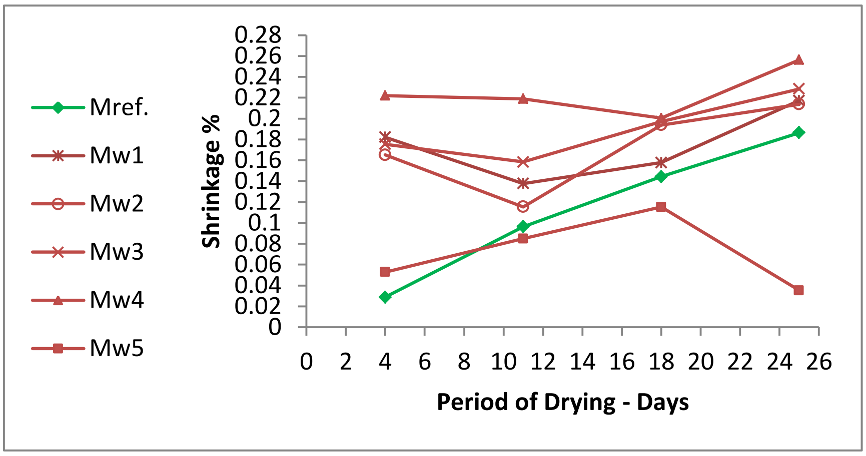

Fig. 9. Drying shrinkage percent development with time, category I.

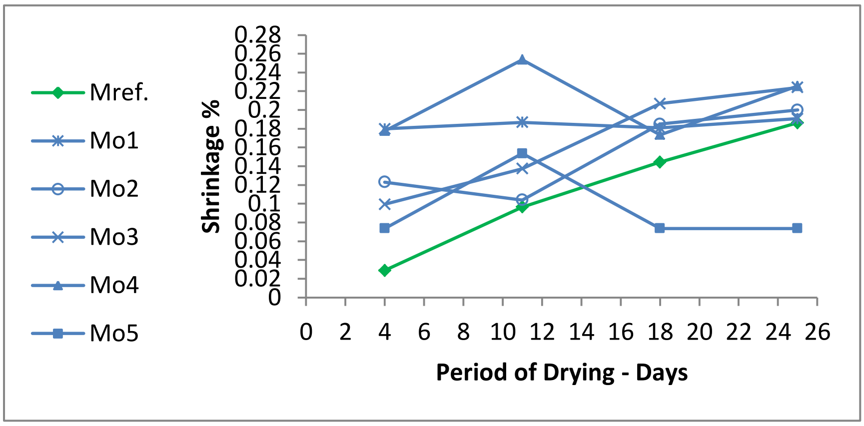

Fig. 10. Drying shrinkage percent development with time, category II.

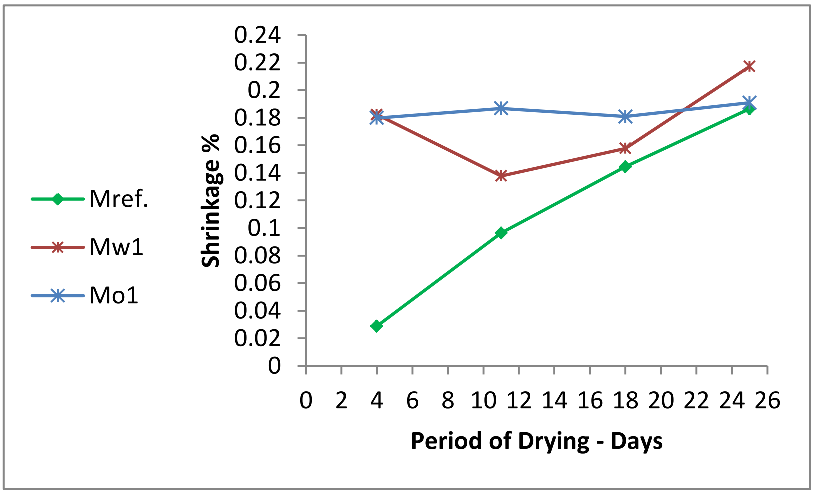

Fig. 11. Drying shrinkage percent development with time, WOPF ratio 0.2%.

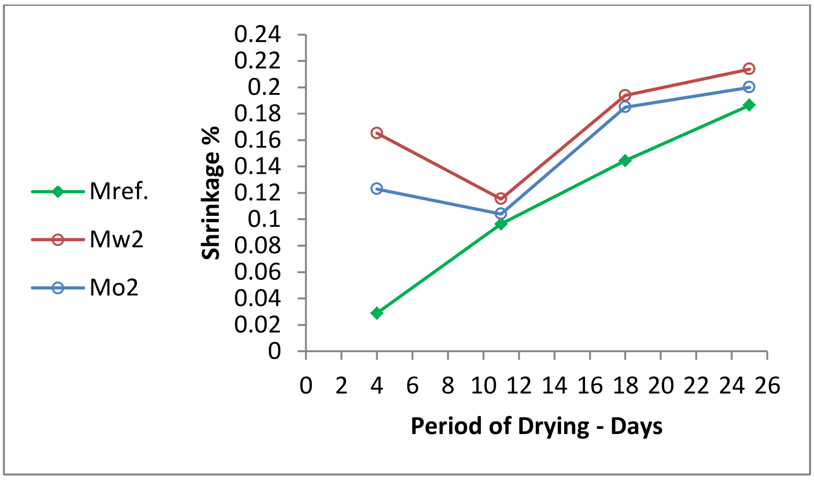

Fig. 12. Drying shrinkage percent development with time, WOPF ratio 0.4%.

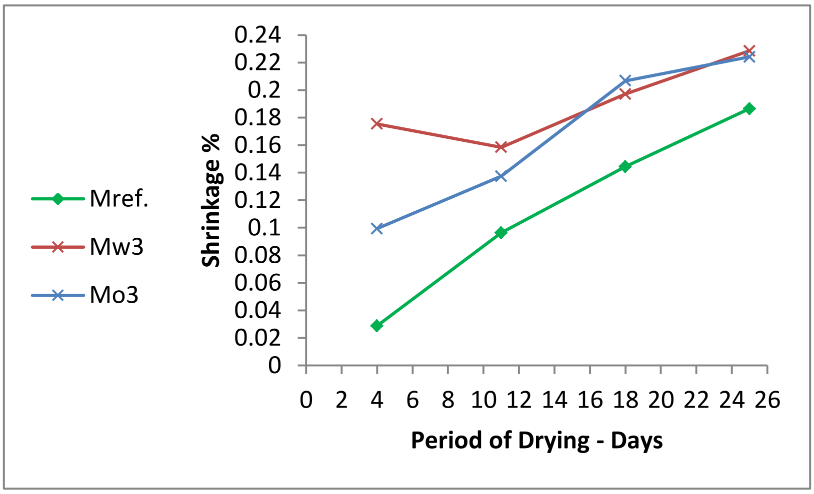

Fig. 13. Drying shrinkage percent development with time, WOPF ratio 0.6%.

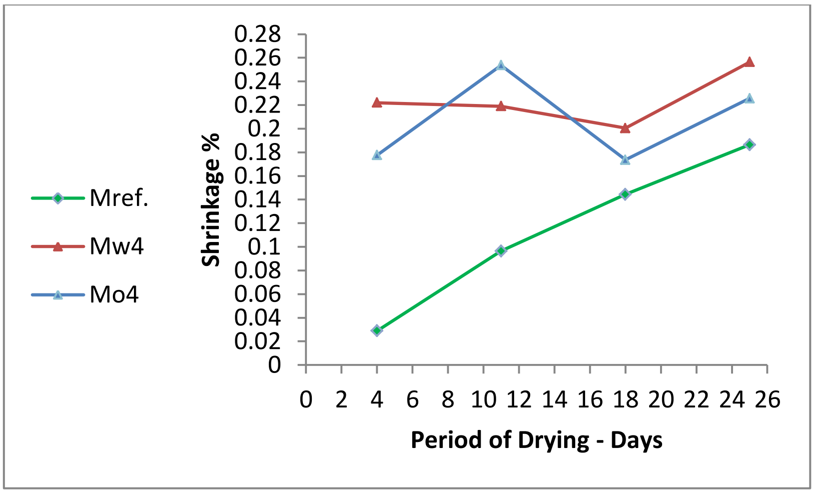

Fig. 14. Drying shrinkage percent development with time, WOPF ratio 0.8%.

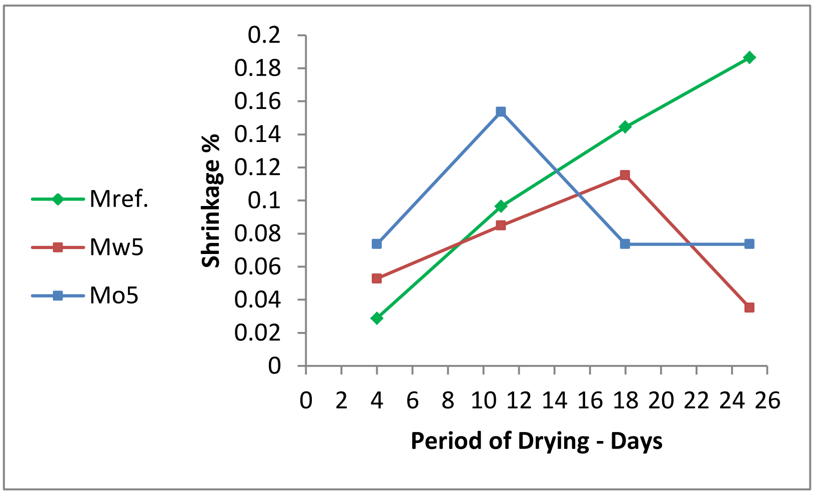

Fig. 15. Drying shrinkage percent development with time, WOPF ratio 1%.

On the other hand, Figs. 16 and 17 and Table 5 display that the loss of weight variation for all the mixes is approximately linear. The evaporated quantity of water is the function of the volume of paste (Bouhamou et al., 2013). It is clear that loss of weight percent of category I more than that of category II. As mentioned earlier, most physical properties of paper altered as a result of variants in moisture content and moisture influence plasticizing the cellulose fiber and relaxing and reducing the inter-fiber bonding. In Fig. 16, for category I, Mixes Mw1 and Mw2, approximately, behaved in same manner (i.e. mixes have the low percent of WOPF). The mix Mw2 had the maximum percent of loss of weight at ages of drying of 4, 11, and 18 days. The values of loss of weight percent were convergent for Mw3, Mw4, and Mw5 (i.e. mixes have the high ratio of WOPF) at ages of drying of 4, 11, and 18 days, and at age 25 days the mix Mw5 losing weight increased significantly more than all mixes and reached to 12.06002%. In addition, it is obvious that all mixes had loss of weight percent's more than reference mix at all ages of drying except Mw3, Mw4, and Mw5 at age of 11 days had values less than reference mix. In Fig.17, for category II, the mix Mo1 had loss of weight percent's more than reference mix at all ages of drying. The behavior of mix Mo2 comes near to reference mix. loss of weight percent for Mo2 was about 0.285337, 0.078991, and 0.112598 more than reference mix at age of drying of 4, 11, and 18, respectively, and it increased to 0.408985 at age of 25 days. The mixes Mo3, Mo4, and Mo5 (i.e. mixes have the high ratio of WOPF) had the same tendency and had values of loss of weight percent less than reference mix at age of drying of 4 and 11days and more than it at ages of 18 and 25 days.

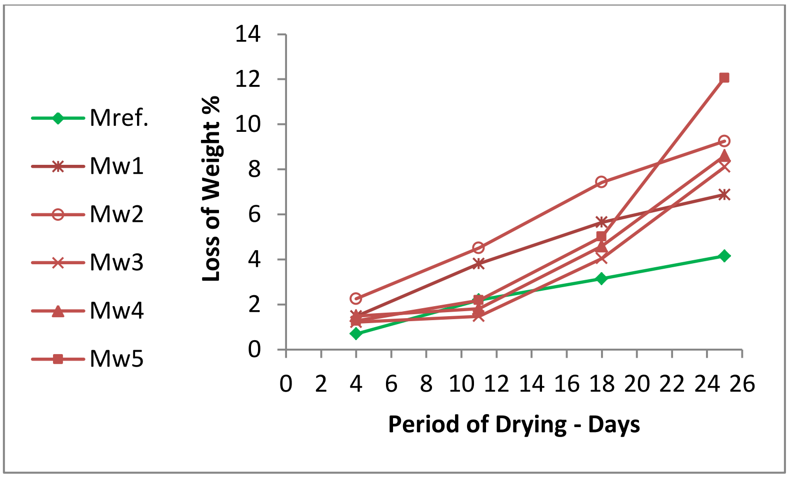

Fig. 16. Loss of weight percent change with time, category I.

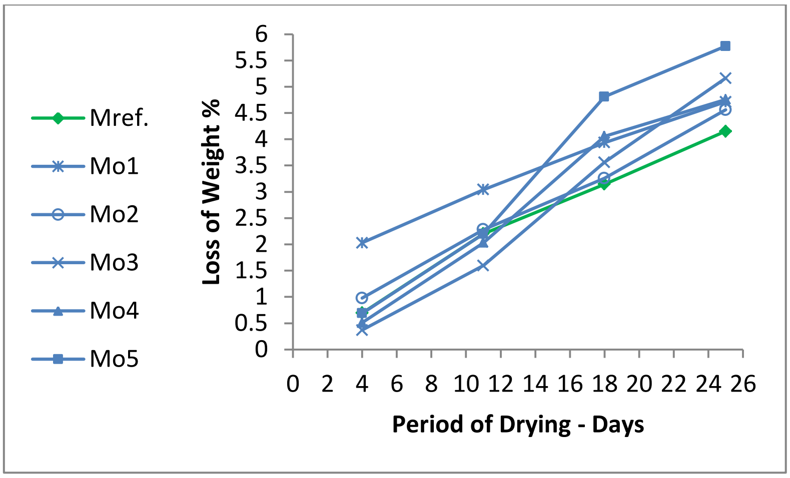

Fig. 17. Loss of weight percent change with time, category II.

Figs. 18-22 bring an additional proof of the effect of loss of weight percent on the drying shrinkage. These different evolution curves of drying shrinkage with respect to loss of weight show that mixes with WOPF of 0.2% and 0.4% in both categories behaved in same manner with a wider range of loss of weight in mixes of category I. While mixes with WOPF of 0.6%, 0.8%, and 1% had different propensity with sharply variants in mixes with WOPF of 0.8% and 1%, and this leads to the fact that with increasing WOPF ratio, absorption, and evaporation of water creates a very important volumetric strain.

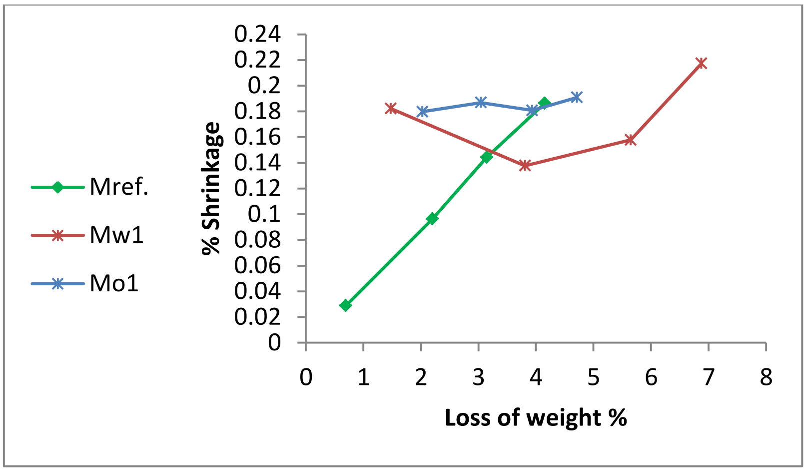

Fig. 18. Drying shrinkage percent versus with loss of weight percent, WOPF ratio 0.2%.

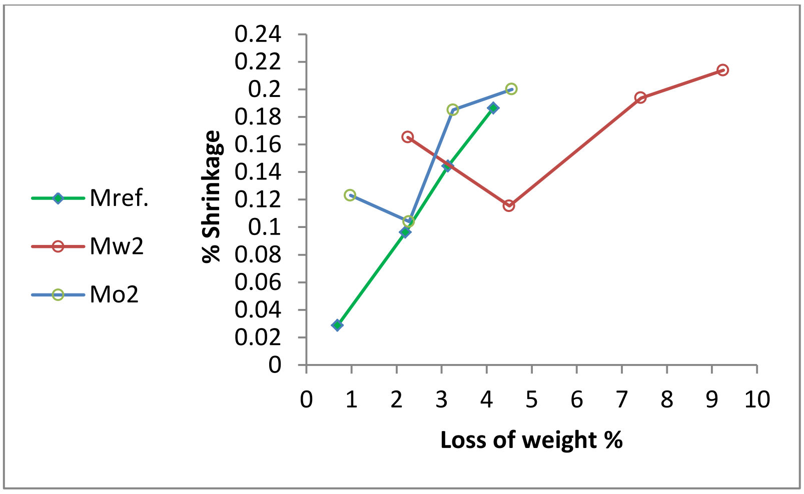

Fig. 19. Drying shrinkage percent versus with loss of weight percent, WOPF ratio 0.4%.

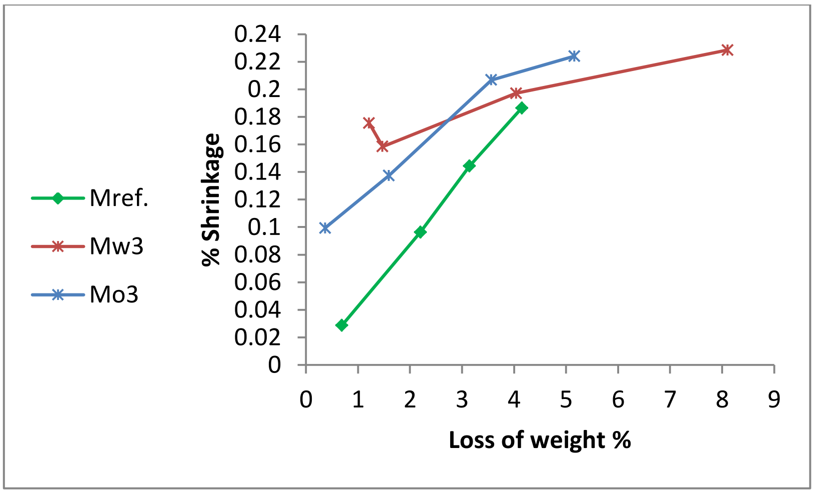

Fig. 20. Drying shrinkage percent versus with loss of weight percent, WOPF ratio 0.6%.

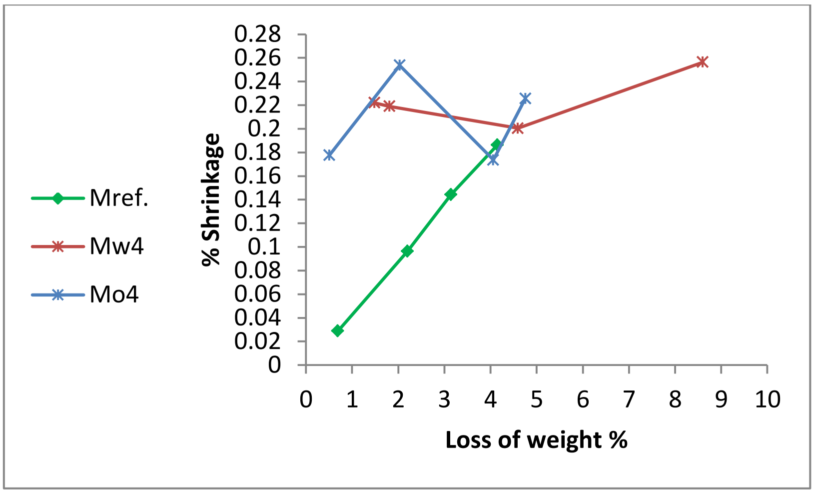

Fig. 21. Drying shrinkage percent versus with loss of weight percent, WOPF ratio 0.8%.

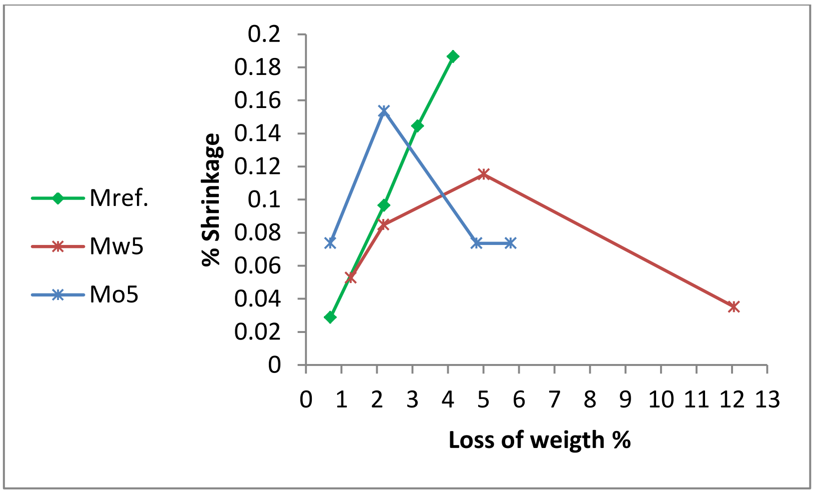

Fig. 22. Drying shrinkage percent versus with loss of weight percent, WOPF ratio 1%.

6. CONCLUSIONS

According to the above results, the main conclusions can be drawn as:

1. The increase in WOPF ratio leads to reducing in workability**.** In category I, when WOPF ratio increased to 0.4%, the flow percent is still within 110±5%. When WOPF ratio increased to 0.6% and above, the flow percent obviously reduced. While in category II, when WOPF added, the flow percent dropped evidently.
2. Drying shrinkage percent increased when WOPF was added to mixes compared with reference mix for all ratios used in both categories except the fifth ratio (i.e. Mw5 & Mo5 with 1%) in which the drying shrinkage decreased at age of drying 11, 18, and 25 days for Mw5 and at age of 18 and 25 days for Mo5.
3. The maximum drying shrinkage percent occurred in mixes with WOPF of 0.8% at all ages of drying in category I & II (i.e. Mw4 & Mo4) except the age of 18 days in category II, at which the mix with WOPF of 0.6% (Mo3) had the maximum drying shrinkage.

4. The minimum drying shrinkage percent at age of 4 days occurred in mixes with WOPF of 1% (i.e. Mw5 & Mo5 with 1% WOPF), and it is more than reference mix. At age of drying of 11 days the minimum drying shrinkage happened in Mw5, in category I, but it is less than reference mix. In category II, the minimum drying shrinkage happened in Mo2, and it more than reference mix. At ages of drying of 18 and 25 days, the minimum drying shrinkage occurred in mixes with WOPF of 1% for the both categories (i.e. Mw5 & Mo5 with 1% WOPF) and less than reference mix.
5. Drying shrinkage percent of mixes has an identical ratio of WOPF in the both categories had the same tendency in variation with time.
6. The loss of weight variation for all the mixes is approximately linear. The loss of weight percent of category I is more than that of category II.
7. Drying shrinkage percent of mixes with WOPF of 0.2% and 0.4% in both categories varied with loss of weight percent in same manner with a wider range of loss of weight in mixes of category I. While mixes with WOPF of 0.6%, 0.8% and 1% had different propensity with sharply variants in mixes with WOPF of 0.8% and 1%.

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