INVESTIGATION OF DRYING SHRINKAGE AND COMPRESSIVE STRENGTH OF CEMENT MORTAR WITH PARTIAL REPLACEMENT OF CEMENT BY EGG SHELL POWDER AND MILLED GLASS

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ABSTRACT

One of environmental pollution and global warming sources is cement industrials. In line to diminish the effects of cement industrial activities on environment, wastes are used in cement mortar as a partial replacement of cement weight throughout the present study. These wastes comprise poultry egg shell which is wealthy in calcium and glass of bottles of juices and soft drink which has high content of silica. Both types of wastes were grinded carefully and passed sieve No. 200 (75μm opening size) to produce egg shell powder (ESP) and milled glass (MG). Cement was substituted by (5%, 7.5%, and 10% ESP), and (10% MG). These ratios of replacement was evaluated individually and in groups by compressive strength test at age of 28 days and drying shrinkage test at ages of 4, 11, 18, 25, and 60 days of drying. Results of tests indicated that compressive strength and drying shrinkage have the same trend when the replacement ratios of ESP used individually in mortar mixes. The higher results were recorded with ratios of 5% and 7.5%. While, compressive strength increased when 10% of MG was used as a partial replacement of cement, and drying shrinkage decreased at ages 11, 18, and 25 days of drying. The combination of MG and ESP in one mix, decrease compressive strength in all percent of addition. However the gathering of MG to 5% of ESP, and MG to 7.5% of ESP decrease drying shrinkage at all age of testing when compared it with the reference mix.

Keywords: egg shell powder (ESP), milled glass (MG), cement mortar, compressive strength, and drying shrinkage.

تحقيق في انكماش الجفاف ومقاومة الانضغاط لمونة السمنت باستبدال جزئي للسمنت بقشور البيض والزجاج المطحون

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الخلاصة

واحدة من مصادر تلوث البيئة والاحتباس الحراري هي صناعات السمنت. في اتجاه تقليل تأثير العمليات الصناعية للسمنت على البيئة، تم استخدام المخلفات في مونة السمنت كاستبدال جزئي من السمنت خلال الدراسة الحالية. هذه المخلفات شملت قشور بيض الدجاج الغني بالكالسيوم وزجاج قناني العصائر والمشروبات الغازية الذي يملك محتوى عالي من السليكا. كلا النوعين من

المخلفات تم طحنهما بعناية ومرر من منخل رقم ٢٠٠ (مقاس الفتحة ٧٥ ميكرون) لإنتاج مسحوق قشور البيض (ESP) والزجاج المطحون (MG). تم استبدال السمنت بـ (٥%، ٧.٥%، و ١٠% من مسحوق قشور البيض)، و(١٠% من مسحوق الزجاج). هذه النسب من الاستبدال تم تقيمها بصورة منفرة وعلى شكل مجاميع بواسطة فحص مقاومة الانضغاط في عمر ٢٨ يوم وفحص انكماش الجفاف في اعمار ٤، ١١، ١٨، ٢٥، و٦٠يوم من التجفيف. نتائج الفحوصات اشارت الى مقاومة الانضغاط وانكماش الجفاف يملكان نفس النزعة عند استعمال نسب الاستبدال من ESP بصورة منفردة في خلطات المونة. اعلى النتائج سجلت عند نسب ٥% و٧.٥%. بينما مقاومة الانضغاط ازدادت عند استعمال ١٠% من MG كنسبة استبدال من السمنت، وانكماش الجفاف قل في اعمار ١١، ١٨، و٢٥ يوم من التجفيف. الجمع بين ESP و MG في خلطة واحدة، يقلل من مقاومة الانضغاط في جميع النسب المضافة. ولكن الجمع بين ٥% من ESP و MG و ٧.٥% من ESP و MG يقلل من انكماش الجفاف في كل اعمار الفحص عند مقارنته مع الخلطة المرجعية.

1. INTRODUCTION

In all over the world, concrete is actually commonly employed for the creating of the most of constructions. Concrete is well-known as backbone of the infrastructure progress. Now, concentration of the engineering community is converting to sustainable construction. Studies demonstrate that it is feasible to employ recycled materials to substitute a number of the conventional mix constituents in concrete and generate a new sustainable building material (Raji and Samuel 2015). Constructions industry is in need of an appropriate and efficient waste outcome that would significantly reduce the consumption of cements and eventually decreases the building cost. Moreover, agriculture and manufacturing waste byproducts such as; fly ash, rice, egg shells, quarry dust, glass, etc. are forming ecological and health anxiety problems and there is essentially demand to recycle these waste (Dhanalakshmi et.al. 2015). Consequently, in the current investigation egg shell powder and milled glass are used in cement mortar as a partial replacement of cement.

Poultry Egg shell are wealthy in calcium ($CaCO_3$) and with chemical composition analogous limestone. ASTM C150, in 2004, permitted combination of up to a 5 % bulk portion of limestone in ordinary Portland cement. Employment of up to 5 % limestone does not influence performance of Portland cement, and high limestone ratio can be applied in concrete at low w/c ratios. The replacement of limestone powder in cement effects on concrete reduction cost and energy, and minimizing emissions of carbon dioxide. However, use limestone as a natural material source, might cause challenges associated with sustainable and environmental changes. Besides, production of lime includes energy intensive treatment and exhausts water. Hence, detecting similar material as a waste and consuming the identical in concrete construction might be a prudent suggestion. Utilization of egg shell waste as an alternative of natural lime in cement could has advantages such as keeping natural lime and consuming waste materials (Yerramala 2014). **Table (1)** shows the compositions of egg shell powder as confirmed by an Iraqi study at university of technology, Baghdad by (Nasif 2015). Mtallib and Rabiu 2009 used egg shell ash as an admixture in concrete. They detected that egg shell ash accelerate the setting of cement. Sathanantham et. al. 2014 studied concrete properties by replacing sand partially by egg shell powder and rice husk ash. The maximum strength was discovered at 20% for compressive, spliting tensile and flexural strength. Raji and Samuel 2015 investigated utilization of egg shell powder in light weight concrete, and replace conventional fine aggregate at 100% substitute level. They recommended that egg shell could be used in making light weight concrete. Qureshi et.al. 2015 exploited egg shell powder and rice husk ash as a partial replacement of cement. They identified that compressive and tensile strength enhanced with rising the percentage of egg shell powder and rice husk ash at 7 and 28 days curing.

On the other hand, Millions tons of glass are embedded in the planet annually. Concrete construction could be a good consumer of millions tons of waste glass each year both as aggregate or supplementary cementitious material (Kara et.al.2014). However, alkali-silica reaction (ASR) which lead to drop in concrete strength and durability, limits the consumption of waste glass as a fine aggregate replacement in concrete (Byars 2004). Accordingly, several efforts focused on investigating the practicability of milling glass and forming glass powder to recycled it to substitute cement in concrete. This is due to glass powder comprised high content of silica that could act pozzolanically and produce C-S-H gel, and improving concrete strength and durability (Linga et.al. 2013). (Kara et.al. 2014) substituted cement with waste glass powder at ratios 20% or 30% per weight. It was revealed that the waste glass powder adding is valid in sight of drying shrinkage by whole deformation up to 2.5 % at age of 592 days. Shayan and Xu 2004 stated that waste glass can be recycled as aggregate and pozzolan in concrete that might substitute traditional pozzolanic materials like; silica fume and fly ash.

2. AIM OF THE STUDY

The aim of this work is to evaluate the employing of egg shell powder and milled glass when these waste materials added individually and collectively to cement mortar as a partial replacement of cement weight and assess the compatibility between these two types of waste and the Iraqi cement, in terms of drying shrinkage and compressive strength, in order to shrink ecological pollution and natural reserves depletion.

3. EXPERIMENTAL PROGRAM

3.1 Materials

3.1.1 Cement

Ordinary Portland cement (O.P.C.) (Type I) was used to prepare the specimens during the experimental program. and manufactured by New Kufa Cement Plant and conformed to the Iraqi specification (IQS No.5 : 1984). **Tables (2)** and **(3)**, demonstrate the chemical analysis and physical properties of the cement, respectively.

3.1.2 Fine aggregate

Natural sand was used, passing sieve 2.36 mm (No. 8) concurring to the condition in (ASTM C 157/C 157M – 08).

3.1.3 Egg shell powder (ESP)

Ejected egg shells as a solid waste, from local restaurants, was collected. Egg shells washed by tap water, dried in air for three days, crushed, grinded by domestic mixer, and passed sieve 75 µm (No. 20). **Plate (1)** shows the egg shell powder.

3.1.4 Milled glass (MG)

Waste of glass bottles of juices and soft drink was collected, cleaned with tap water, dried in air, hand crushed and grinding, and passed sieve 75 µm (No. 20). **Plate (2)** shows milled glass.

3.1.5 Water

Tap water was used throughout this study for preparing and curing the specimens.

3.2 Mix design

Eight mixes of cement mortar have been prepared with cement : sand ratio equivalence to 1:1. Water : cement ratio was 0.45. ESP was added to cement mortar mixes in three ratios (5%, 7.5%, 10%) as a partial replacement of cement weight. MG was added in one ratio (10%) as a partial replacement of cement weight. Then combined these two types of waste materials together in cement mortar in three mixes. **Table (4)** detailed the mixes proportion of cement mortar.

3.3. Tests

3.3.1.Workability test

Flow table test method was performed to evaluate the workability of cement mortar for all mixes, the proportion of the enlargement in average base diameter of the mortar form to the prime base diameter was determined. This test was performed in accordance to (ASTM C 230/C 230M – 08) and (ASTM C 1437 – 07).

3.3.2. Compressive strength test

Iraqi Reference Instructional Guide 198: 1990 was adopted to accomplish the compressive strength test. (70.7×70.7×70.7) mm cubes were used, after the cubes were removed from the water curing tank, the excess water on their surfaces was dried, and the cubes were set aside for few minutes in a laboratory to attain saturated specimens with dry surfaces. The cube was positioned on opposed sides, as cast. The load was operated without shock and grew regularly with a grade of 0.34 MPa/sec. The average of three cubes was measured to be the compressive strength.

3.3.3. Drying shrinkage test

Drying shrinkage test was carried out according to (ASTM C 596 – 01) and (ASTM C 157/C 157M – 08). (25×25×285) mm cement mortar prisms were prepared and an apparatus with a dial gauge efficient of determining the length precisely to ±0.002 mm was used (ASTM C 490 – 07). Test specimens and the apparatus was shown in **Plates (3)** and **(4)**, respectively. The prisms molds were opened after 24 ± 0.5 hr. and the specimens were cured in lime-saturated water for 48 h. At the age of 72 h ± 30 min, the length comparator reading was recorded for each specimen after removed the specimens from water and wiped them with clean cloth. Air storage was adopt for 60 days. A length comparator reading was recorded at 4, 11, 18, 25, and 60 days of air storage. Air storage and readings were obtained in a room with a relative humidity of 50 ± 4 % and a temperature of 23 ± 2 °C (73 ± 3°F). length change was obtained from the following equation:

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

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].

4. RESULTS AND DISSCUTIONS

4.1. Workability

Generally, the flow percent dose not affected with low replacement ratio of waste and it is decreased with the increase in waste ratio as illustrated in **Table (5)** and **Figure (1)**. The flow percentages are within 100±5% when waste ratio increased to 10%. While it deceased with waste ratios up to 10% (i.e. when ESP and MG gathered in one mix). The decrease in flow percent is about 6.4% for mix with ESP5%+ MG10%, and 9.1% for mix with ESP7.5%+ MG10%, and mix with ESP10%+ MG10%.

4. 2. Compressive strength

The attained results are donated in **Table (6)** and **Figure (2)**, which comprise compressive strengths at age of 28 days of all mixes corresponding to the type and quantity of the waste additions. Evidently, the advantageous influence of ESP on compressive strength particularly for low replacement ratio. The ratios of 5% and 7.5% increase the hydration of cement and provide strengths greater than those of ordinary cement. The increases in compressive strength are about 9.7% and 8.2% for mixes of ESP ratios of 5% and 7.5%, respectively compared with reference mix. From literature, it was stated that the activities of ESP in concrete or mortar can be paralleled with limestone substituted concrete (Yerramala 2014). Limestone creates reaction with the alumina in cement pastes to procedure a calcium mono-carboaluminate hydrate phase and impacts on strength modification (Guemmadi et. al. 2008). To some extent, higher strength in ESP of 5% replacement of cement, might be occasioned by chemical reaction between ESP and cement paste like in limestone concrete. At greater limestone substitute the size of pore growths and as a result the strength drops (Guemmadi et. al. 2009). Likewise performances are done in current study, the increase in ESP replacement ratio to 10% decreased the compressive strength of mortar about 23% in comparison with reference mix. Besides, it is clear from **Table (6)** and **Figure (2)** that the mortar with MG ratio of 10%, has compressive strength more than reference mix about 16.4%. As mentioned earlier, This is due to glass powder comprised high content of silica that could act pozzolanically and produce C‑S‑H gel and improving concrete strength and durability (Linga et.al. 2013). On the other hand, the incorporation of ESP and MG wastes in same mixes lead to reduction in compressive strength as shown in **Figures (2)** and **(3)**. The reduction rate of strength increase with the increase of wastes ratio, and it is about 14.4%, 21.7% and 25.6% for mix with ESP5%+ MG10%, mix with ESP7.5%+ MG10%, and mix with ESP10%+ MG10% less than reference mix respectively. This might be related to the reduction in cement content in these mixes with ratio ranged about 15%-20%. The utilization of this replacement proportion can be acceptable for economic or environmental matters.

4.3. Drying shrinkage

The drying shrinkage characterizes the distortion of the mortar specimens in the existence of water replacement with the exterior surroundings. These quantities signify the grouping between the dehydration and the carbonation which indicates the porosity of the microstructure and its capability to sustenance drying (Itim et. al. 2011). **Table (7)** depicts the variants in drying shrinkage for all mixes. In mixes involve one type of waste (i.e. CESP5%, CESP7.5%, CESP10%, and CMG10%), drying shrinkage initiates with rate higher than reference mix at age of 4 days of drying, as display in **Figure (4)**. Drying shrinkage percent was about 0.0552, 0.0712, 0.0112, and 0.0312 more than reference mix for CESP5%, CESP7.5%, CESP10%, and CMG10%, respectively. Drying shrinkage continues in increase more than reference mix at ages of 11 & 18 days of drying, in mixes with low ratios of waste (i.e. CESP5%, and CESP7.5%). The higher percent of drying shrinkage occurs in CESP5% and it is about 0.0676 more than reference mix. While it decreases in mixes with high ratios of waste (i.e. CESP10%, and CMG10%), the maximum reduction happens in CESP10% and it is about 0.0964 and 0.0844 less than reference mix at age of 11 & 18 days of drying, respectively. At age of 25 days of drying, drying shrinkage is lower than reference mix in all mixes except CESP7.5%. However, it increased in all mix except CESP10% at age of 60 days of drying, in comparison with reference mix. The greatest drop occurs in CESP10% and it is about 0.1804 and 0.0404 less than reference mix at age of 25 & 60 days of drying. In general, the mixes CESP5%, CESP10%, and CMG10% have the same propensity, with higher values of drying shrinkage in mix CESP5%. While the mix CESP7.5% trends in the same way of reference mix, but with values of drying shrinkage greater than reference mix especially at age of 60 days of drying. The mix CESP10% has the lowest percent of drying shrinkage in all ages of testing, that means MG performs drying shrinkage more than ESP; i.e. CMG10% give values of drying shrinkage more than the mix CESP10%.

Figure (5) shows the drying shrinkage in all mixes with both type of waste (i.e. CESP5%+ MG10%, CESP7.5%+ MG10%, and CESP10%+ MG10%) at all ages of testing in comparison with reference mix. At age of 4 days of drying, the minimum percent of drying shrinkage take place in mix CESP5%+ MG10%, and it is about 0.0288 lower than reference mix. While the maximum percent of drying shrinkage occurs in mix CESP7.5%+ MG10%. It is about 0.0512 more than reference mix. The behavior of mixes CESP5%+ MG10%, and CESP7.5%+ MG10% converge together at ages of drying 11, 18, 25, and 60 days and it is less than reference mix by about 0.0672 and 0.0964, 0.1072 and 0.904, 0.1172 and 0.1464, and 0.912 and0.0804 at ages of drying 11, 18, 25, and 60 days, respectively. While the drying shrinkage of the mix CESP10%+ MG10% more than that of mixes CESP5%+ MG10%, and CESP7.5%+ MG10% at ages of drying 11, 18, 25, and 60 days. However, it is more than reference mix at ages of drying 11, and 60 days, and less than reference mix at ages of drying 18, and 25 days.

The comparison among mixes with individual and merged ratios of waste of each case of addition is represented in **Figures (6)** to **(8)**. From these figures it can be seen that the mixes with low percent's of waste (CESP5%+ MG10%, and CESP7.5%+ MG10%) have clear improvement in drying shrinkage. While the mix with high percent's of waste CESP10%+ MG10% has drying shrinkage more than the mixes with separated same percent's of waste (i.e. CESP10% and CMG10%) at all age of testing except at age of 18 days of drying, where it less than CMG10%.

Another comparison is demonstrated in **Figures (9)** and **(10)** which reveal the results of the drying shrinkage in accordance to the replacement rate of waste at all ages of testing. It is apparent from **Figure (9)** that the using of ESP with 5% replacement ratio in cement mortar growths drying shrinkage at all ages of testing excepting at 25 days of drying. While the using of ESP with 7.5% replacement ratio, increases drying shrinkage at all ages of testing more than reference mix (i.e. ESP=0), but it is lower than case of using 5%ESP replacement ratio except at 25 days of drying, at which the adversely behaver was recorded. Also, the increase in ESP replacement ratio to 10% minimize the drying shrinkage to the lowest values at all age of testing.

On the other hand, as exhibit in **Figure (10)**, the merge of MG to 5% of ESP in one mix, reduces drying shrinkage at all age of testing. However, the combine of MG to 7.5% of ESP decrease drying shrinkage at all age of testing when compared it with the reference mix, and only at ages of 11, and 25 days of drying when compared it with the case of merge of MG to 5% of ESP. Besides, the employing of MG with 10% of ESP in one mix, causes progress in drying shrinkage at all age of testing compared it with the cases of using MG to 7.5% of ESP and MG to 5% of ESP excepting at

age of 4 days of drying, at which drying shrinkage decreased lower than that of case of MG to 7.5% of ESP. While it decreased only at age of 18 and 25 days in comparison with the reference mix.
From the above discussion, the compatibility between drying shrinkage and compressive strength results can be detected. When ESP was added to mixes with low percent (5% and 7.5%) the drying shrinkage and compressive strength increased, this might be attributed to ESP with high fineness can be included in the hydration of the cement paste and that leads to the mortar paste be involved fewer porous thus regulating the desiccation. The same tendency was recorded when MG added alone to mortar mix (i.e. the drying shrinkage and compressive strength increased). While when higher percent of waste was present in mix (i.e. ESP10%+ MG10%) both drying shrinkage and compressive strength decreased, this might be related to increasing in the porosity of the microstructure. Conversely, there is a decreasing in drying shrinkage and compressive strength when the total percent of waste ranged between 10% to 17.5% (i.e. ESP10%, ESP5%+ MG10%, and ESP7.5%+ MG10%), this depend on characteristic of microstructure and internal pores adaptation which control evaporation of water.

5.CONCLUSIONS

The main conclusions from the current study can be summarized as:

1. Results confirm that the using of ESP as an alternative of natural limestone in cement can be suitable.

2. The workability dose not affected with low replacement ratio of waste and it is decreased with the increase in waste ratio

3. Using of ESP as a partial replacement of cement within ratios of 5% and 7.5%, increases the compressive strength. While a reduction in compressive strength was recorded when ESP used with replacement ratio of 10%. In addition, the same behavior was observed in drying shrinkage test results.

4. Compressive strength increased when 10% of MG was used as a partial replacement of cement, and drying shrinkage decreased at ages 11, 18, and 25 days of drying.

5. The incorporation of MG and ESP in one mix, decrease compressive strength in all percent of addition. The employment of this replacement proportion can be satisfactory for economic or environmental topics.

6. The gathering of MG to 5% of ESP, and MG to 7.5% of ESP decrease drying shrinkage at all age of testing when compared it with the reference mix. When the employing of MG with 10% of ESP in one mix, decreased drying shrinkage only at age of 18 and 25 days in comparison with the reference mix.

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Table (1): Compositions of egg shell powder analyzed by X-ray (Nasif 2015).

Compositions	Concentration %
Al_2O_3	0.001
SiO_2	0.002
S	0.001
Cl	0.008
CaO	99.82
Cr_2O_3	0.003
MnO	0.001
CuO	0.001
LOI	0.163

Table (2): Chemical analysis of the cement used in the experimental program.

Oxide	(%)	Limit of Iraqi specification (IQS No.5 : 1984)
CaO	62.98	…………
SiO_2	21.07	…………
Fe_2O_3	3.59	…………
Al_2O_3	5.39	…………
MgO	0.71	≤ 5.0
SO_3	2.52	≤ 2.8
Free lime	0.67	…………
L.O.I.	1.54	≤ 4.0
IR	-	≤ 1.5
Compound composition	**(%)**	**Limit of Iraqi specification**

		(IQS No.5 : 1984)
C_3S	46.82	…………
C_2S	23.57	…………
C_3A	8.47	…………
C_4AF	11.25	…………
LSF	0.95	0.66-1.02

Table (3): Physical properties of the cement used during the experimental program.

Physical properties	Test results	Limit of Iraqi specification *(IQS No.5 : 1984)*
Fineness (Blain method) cm^2/gm	3150	≥2300
Setting time (Vicat method) **Initial hrs:min** **Final hrs:min**	 1:27 4:32	 ≥0:45 ≤10:00
Compressive strength **3 days MPa.** **7 days MPa.**	 19.6 28.5	 ≥15 ≥23

Table (4): Information of the mixes proportion of cement mortar.

No.	Cement%	Sand%	w/c	ESP%	MG%
$C_{ref.}$	100	100	0.45	0	0
CESP5%	95	100	0.45	5	0
CESP7.5%	92.5	100	0.45	7.5	0
CESP10%	90	100	0.45	10	0
CMG10%	90	100	0.45	0	10
CESP5%+ MG10%	85	100	0.45	5	10
CESP7.5%+MG10%	82.5	100	0.45	7.5	10
CESP10%+MG10%	80	100	0.45	10	10

Table (5): Flow table test results of cement mortars.

No.	Flow %
$C_{ref.}$	110
CESP5%	110
CESP7.5%	105
CESP10%	105
CMG10%	105
CESP5%+ MG10%	103
CESP7.5%+MG10%	100
CESP10%+MG10%	100

Table (6): Compressive strength at age 28 days of all cement mortars.

No.	Compressive strength at age 28 days (MPa.)
$C_{ref.}$	37.816
CESP5%	41.49
CESP7.5%	40.91
CESP10%	29.153
CMG10%	44.01
CESP5%+ MG10%	32.337
CESP7.5%+MG10%	29.602
CESP10%+MG10%	28.143

Table (7): Drying shrinkage values.

No.	Shrinkage%					
	Drying Period:	4 Days	11 Days	18 Days	25 Days	60 Days
$C_{ref.}$		0.0288	0.0964	0.1444	0.1864	0.1004
CESP5%		0.0840	0.1640	0.2500	0.1400	0.2800
CESP7.5%		0.1000	0.1400	0.1880	0.2120	0.2200
CESP10%		0.0400	0.0000	0.0600	0.0060	0.0600
CMG10%		0.0600	0.0720	0.1300	0.0800	0.1400
CESP5%+ MG10%		0.0000	0.0292	0.0372	0.0692	0.0092
CESP7.5%+MG10%		0.0800	0.0000	0.0540	0.0400	0.0200
CESP10%+MG10%		0.0612	0.1532	0.0932	0.1332	0.1932

Plate (1): Egg shell powder.

Plate (2): Milled glass.

Plate (3): Drying shrinkage specimens.

Plate (4): Drying shrinkage apparatus.

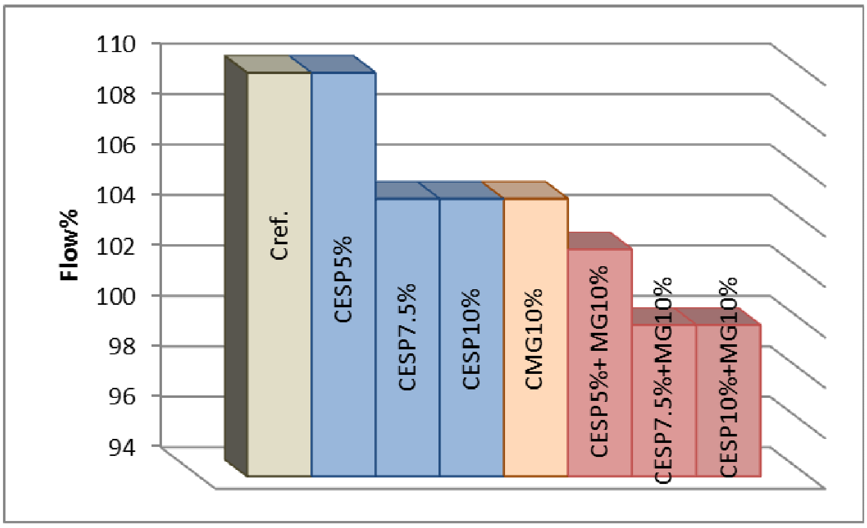

Figure (1): Flow table test results of cement mortars.

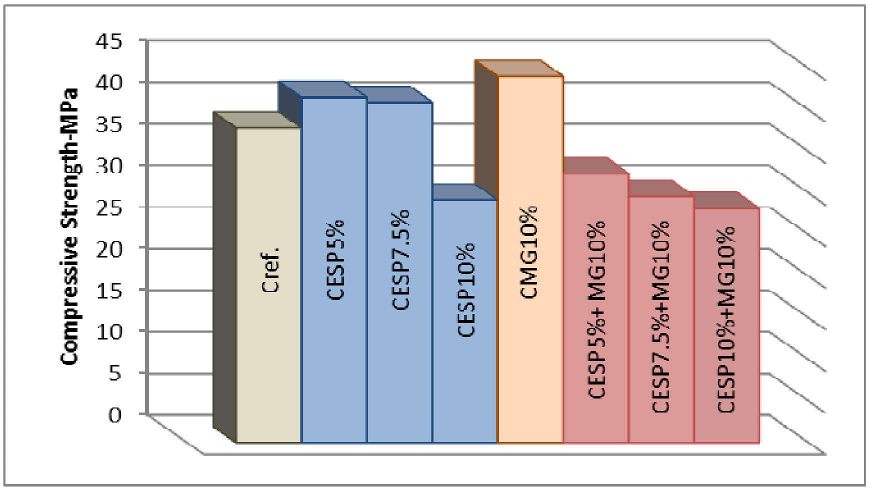

Figure (2): Compressive strengths at age of 28 days of cement mortars.

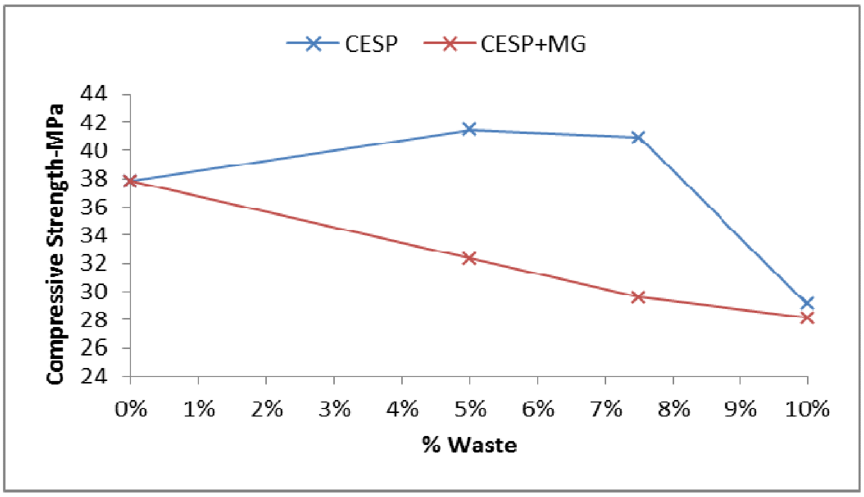

Figure (3): Compressive strengths comparison for mixes with ESP only and with ESP+MG.

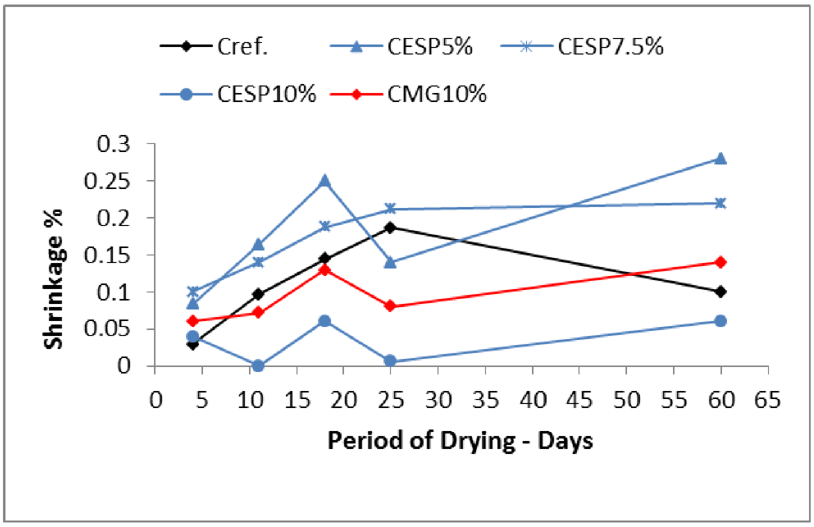

Figure (4): Drying shrinkage percent progress with time for mixes involve one type of waste.

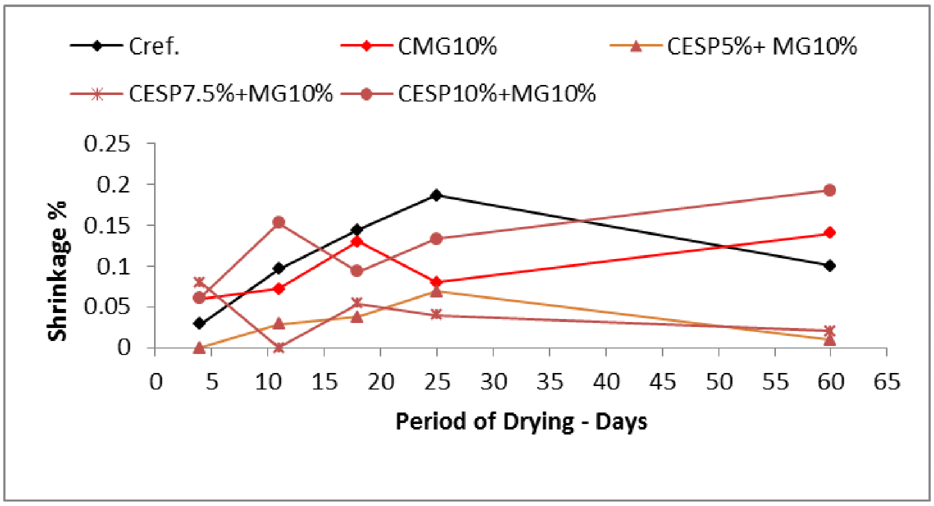

Figure (5): Drying shrinkage percent progress with time for mixes involve both type of waste.

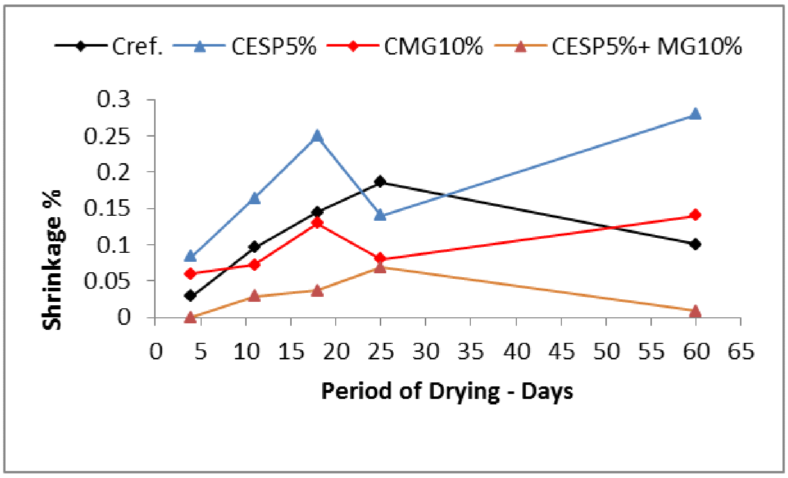

Figure (6): Comparison of drying shrinkage percent progress with time among mixes with individual and merged ratios of waste (ESP=5%, MG=10%).

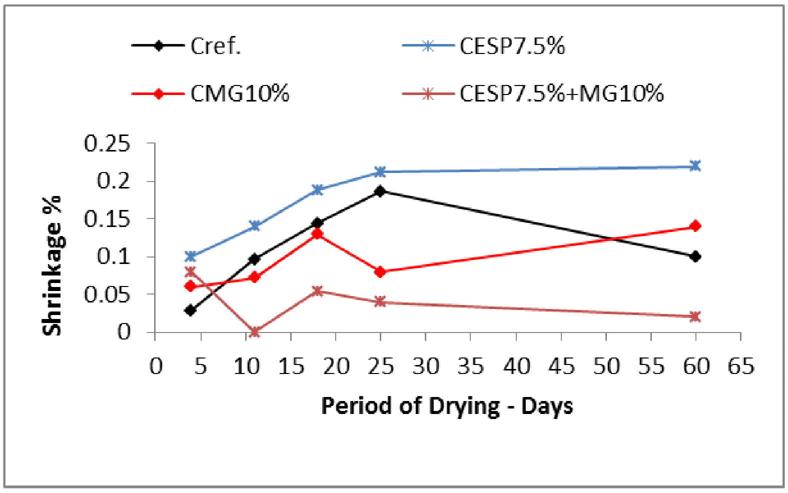

Figure (7): Comparison of drying shrinkage percent progress with time among mixes with individual and merged ratios of waste (ESP=7.5%, MG=10%).

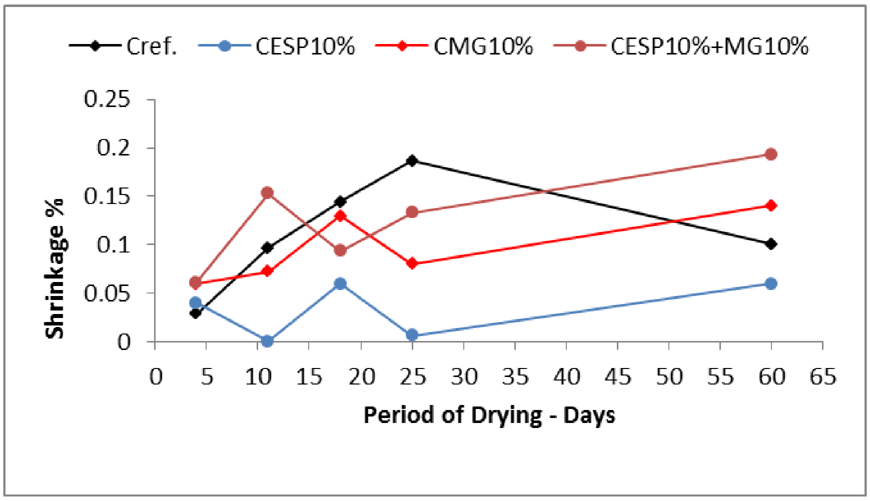

Figure (8): Comparison of drying shrinkage percent progress with time among mixes with individual and merged ratios of waste (ESP=10%, MG=10%).

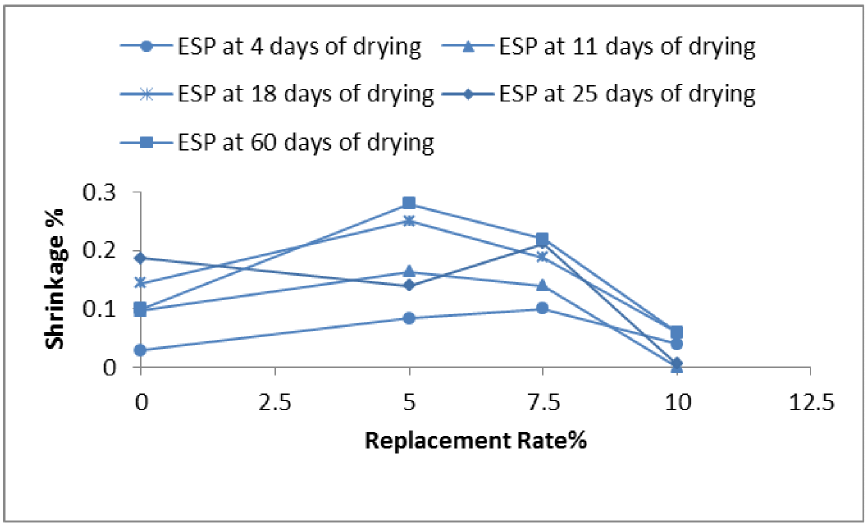

Figure (9): Drying shrinkage percent development with ESP replacement rate.

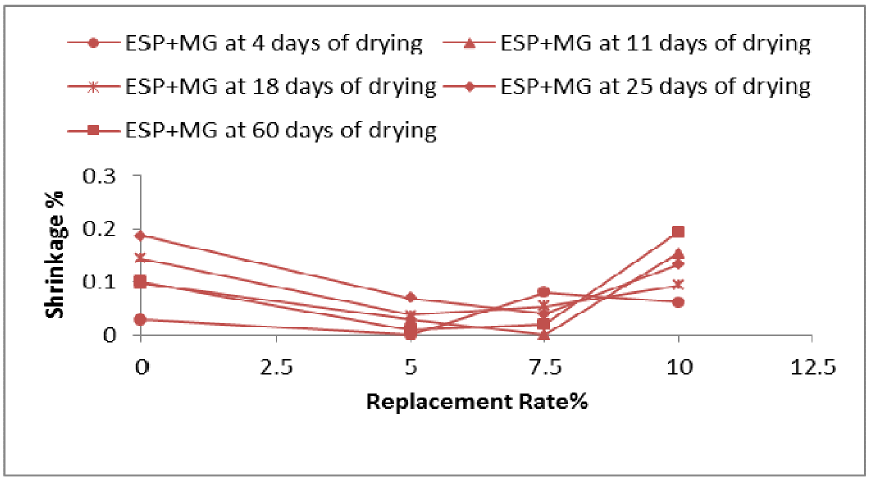

Figure (10): Drying shrinkage percent development with ESP+MG replacement rate.