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The Use of Crushed Brick Waste for The Internal Curing In Cement Mortar

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ABSTRACT

Internal curing has become a modern technology holds promises for making a durable mortar and decreasing early-age cracking. Since mortar service life is a crucial factor of providing sustainable structures, internal curing can provide a distinct contribution to increase the sustainability of our nation's building. This study shows results of an experimental investigation of using crushed brick waste (CBW) in cement mortar mixtures prepared by substituting sand by some percentages (5, 10, 15, 20 and 25%) of (CBW). Three curing regimes were adopted in this study: water curing by immersing specimens in water for 28 days, partially water curing by immersing specimens in water for 3 days and left them in laboratory for 24 days and air curing in laboratory for 28 days without immersing samples in water to recognize an ideal methodology for determining whether a given (CBW) can be used for internal curing in cement mortar. Fresh density, hardened density, compressive strength, water absorption, and modulus of rupture were tested. Results indicated that fresh and hardened density, compressive strength and modulus of rupture were decreased with the addition of (CBW). However, they were higher for mortars cured in air conditions than those cured in water and partially water curing. Water absorption was increased with the increase of (CBW). It was demonstrated that air cured mortar give good results for mechanical properties as compared with water cured mortar, hence (CBW) can be used for internal curing in cement mortar especially in finishing works.

استخدام مخلفات الطابوق المحطم في الانضاج الداخلي في مونة السمنت

الخلاصة

ان العمر الخدمي لقد أصبح الانضاج الداخلي تكنولوجيا حديثة يحمل وعودا لانتاج مونة دائمة وتقليل التشققات في سن مبكرة. حيث للمونة هي العامل الحاسم في بناء المنشآت المستدامة. الإنضاج الداخلي يقدم مساهمة متميزة لزيادة استدامة بناء أمتنا. تبين هذه الدراسة نتائج فحص تجريبي لاستخدام الطابوق المحطم في خليط مونة السمنت عن طريق استبدال الرمل في بعض النسب (5، 10، 15، 20 25٪) من مخلفات الطابوق المحطم. تم اعتماد ثلاثة أنظمة انضاج في هذه الدراسة: الانضاج بالماء عن طريق غمر العينات في الماء لمدة 28 يوما، انضاج جزئي بالماء عن طريق غمر العينات في الماء لمدة 3 أيام، وتركهم في المختبر لمدة 24 يوما والانضاج بالهواء هو ترك العينات في المختبر لمدة 28 يوما دون غمر العينات في الماء للحصول على منهجية مثالية لتحديد امكانية استخدام الطابوق المحطم للانضاج الداخلي في مونة الأسمنت. تم اختبار الكثافة الطازجة ،الكثافة الصلبة، قوة الضغط، امتصاص الماء، ومعامل الكسر. أشارت النتائج إلى أن الكثافة الطازجة ، الصلبة، قوة الضغط ومعامل الكسر قد انخفضت مع إضافة الطابوق المحطم ، ومع ذلك سجلت النتائج قيم اعلى للمونة التي تم انضاجها في الهواء ممقارنة بالعينات التي تم انضاجها في الماء وجزئيا بالماء. امتصاص الماء قد ارتفع مع زيادة نسبة استبدال الطابوق المحطم بديل عن الرمل المضاف الى المونة .برهنت الدراسة ان المونة التي تم انضاجها في الهواء قد اعطت نتائج جيدة للخواص الميكانيكية بالمقارنة مع المونة التي تم انضاجها بالماء، وبالتالي يمكن استخدام الطابوق المحطم للانضاج الداخلي في مونة الأسمنت خاصة في اعمال النهاء .

الكلمات الرئيسة:

مخلفات الطابوق المحطم،الانضاج الداخلي،الانضاج بالماء،الانضاج الجزئي بالماء،الانضاج بالهواء،خواص المونة

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Introduction

The American Concrete Institute in 2010 characterized internal curing as providing water through a fresh cementitious mixture using reservoirs, pre-wetted lightweight aggregates, which is promptly release water as needed for hydration or to compensate moisture lost through evaporation or self-parching [1]. Internal curing has been incidentally incorporated into numerous lightweight concrete made the last century, recently this technology has been purposefully utilized into concrete mixtures at the proportioning stage, using various materials like pre-wetted lightweight aggregates, pre-wetted crushed returned concrete fines, superabsorbent polymers, and pre-wetted wood fibres as it was investigated by past studies [1].

The need for internal curing initiates directly from the chemical reaction during cement hydration process. As a mixture of cement and water reacts to produce crystalline and gel hydration products, the water included into the hydrated products mostly possess less space than water in its mass structure. Thus, the hydration and pozzolanic reactions are followed by a net chemical shrinkage as the products possess less space than the reactants [2]. As internal curing keeps on to proliferate in practice, examinations on this topic needs to find new material for exploration.

Crushed brick waste (CBW) is a constructional waste which has been clearly increased with the vast trail of urbanization and industrialization. recovered from wrecked brick work structures can be used in the production of new mortar mixes. On the other hand, up to 80% of volume of concrete is made of aggregate, which is usually extracted from virgin resources [3]. As natural aggregate suffers degradation in an expanding rate, the concrete industry is searching for other alternatives. Reusing CBW is one of the promising methods: it is not only economically viable and particularly in urban areas, but also focuses on an ecological cordial methodology [4]. Crushed bricks accumulated in building sites created a serious environmental pollution, hence, it is possible to be reduced by recycle it in mortar. This study gives significant knowledge to comprehension the potential advantages of utilizing (CBW) as sand substitution in cement mortar to develop the service life of mortar in extreme climatic conditions. Utilizing (CBW) as sand replacement for the internal curing in cement mortar has not yet been experienced, whereby, using crushed brick as an aggregate in mortar and concrete would have a positive effect on the economy also.

Material and Methods

Ordinary Portland cement (type 1) was used for casting all specimens throughout the study program. The cement complies with Iraqi specification (IQS No.5/1984) [5**]**. The physical properties for the used cement are listed in table 1. Graded natural sand with 3.02 finess modulus, specific gravity of sand is 2.6, 0.77% absorption, and bulk density of 1342 kg/m^3 was used. Demolish clay bricks were gotten from a domestic maker that salvages it off standards products and grounded roughly to sand fines, bulk density of crushed brick waste (CBW) is 1003 kg/m^3, finess modulus is 3.53 and specific gravity is 2.12. The gradations of sand and crushed brick is shown in Fig. (1). Basic information on the chemical composition of the constitutes used in this study is listed in Table 2. The aim of this paper is to evaluate the effect of crushed brick waste on the properties of cement mortar cured in three curing regimes. Sand, cement, water and (CBW) were mixed to prepare fresh mix in mortar mixer in different ratios. Mix design was (1:3) (cement: sand), crushed brick waste replaces (5, 10, 15, 20, 25) % by weight of sand. Mix code is given as X1present 5% replacement of sand, X2 is 10% replacement of sand, X3 is 15% replacement of sand, X4 is 20% replacement of sand and X5 is 25% (CBW) replace sand, (CB/S) represent the weight ratio between crushed brick and sand and it is shown in Table 3 along with mix design. Mix design was assessed based on laboratory trials. The mortar was put in mould to make 2 kinds of samples cubic (5×5) cm and prism (16×16×4) cm. Mortar was demoulded after 24 hours and separated into three groups cured in three curing environments in which immersed in water for 28 days, immerse in water for 3 days and then cured in air for 25 days and the third group was left to cure air in laboratory without immersing in water for 28 days to assess the probability of using crushed brick waste as an internal curing agent in cement mortar. Reference mortar was produced from (1:3) cement: natural sand and cured in water for 28 days to compare the results with the mortar produced in this study from crushed brick waste and cured in different conditions.

Table 1: Physical properties of cement

Property	**Result**	**Iraqi standards (I.Q.S)**
Finess by air permeability (blaine)	358 m^2/kg	≥230 m^2/kg
Initial setting time	120 min.	≥45 min.
Final setting time	240 min.	≤600 min.
Compressive strength (3D)	21.8 Mpa	≥15 Mpa
Compressive strength (7D)	30.5 Mpa	≥23 Mpa

Table 2: chemical composition of the constitutes

Material	**SiO_2**	**Al_2O_3**	**CaO**	**Fe_2O_3**	**MgO**	**Na_2O**	**K_2O**
Cement	20.58	5.38	64.61	2.14	2.08	0.26	0.46

Sand	80.78	10.52	3.21	1.75	0.77	1.37	1.23
Crushed brick	65.10	23.41	6.4	36.5	0.18	9.2	2.3

Table 3: Mix design

Mix code	(CB/S) %	C(kg/m^3)	S (kg/m^3)	CBW (kg/m^3)
X1	5	633	1804	94
X2	10	633	1767	152
X3	15	633	1614	285
X4	20	633	1519	379
X5	25	633	1425	474

Test Methods

Compressive Strength

Compressive strength is the capacity of a material to endure axially directed pushing forces. The compressive strength is tested at 7, 14, and 28days on (5×5) cm cubic specimens using a hydraulic universal digital compression testing machine (ELE-Digital Elect) of 2000 Kn capacity. The test was performed according to ASTM C67 – 07a, 2003 [6]. Three specimens were tested per each group from the three groups which were water, partially water and air cured mortar.

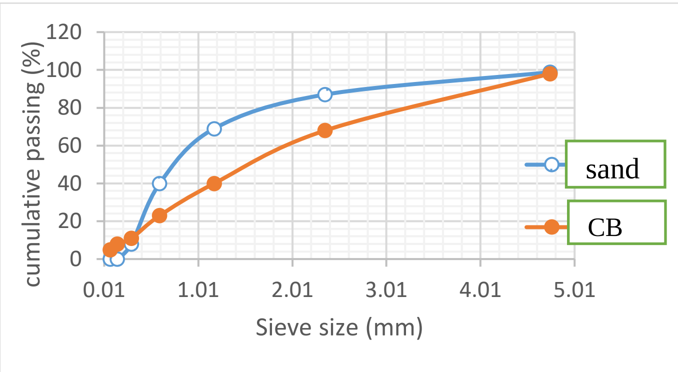

Figure 1: The gradations of sand and Crushed brick waste

Modulus of Rupture

The modulus of rupture test was done according to the ASTM C384-14, 2006 [7]. The methodology requires testing simply supported prism under two-point loading and with dimensions of (16×16×4) cm. Modulus of rupture was conducted at 28 days on three samples were rested for each group which were cured in different curing regimes.

Water Absorption

For the study of absorption three specimens per each curing condition was dried in oven at 105° C for 24hours and then immersed in water for 24 hours according to ASTM C1403-15, 2003 [8]. The water absorption was computed from the weight difference after immersing samples in water and dried them in oven using eq.1 below:

$$A=(m_w-m_d)/m_d \qquad (1)$$

Where A= water absorption (%).
m_w= wet mass (gm).
m_d= dry mass (gm).

Results and Discussion

Fresh Density and Hardened Density

Results for fresh density (F.D) and hardened density (H.D) for the samples cured in water curing (WC), partially water (PWC) and air curing (AC) are given in Table 4. Fresh density ranged in (1836-1666) kg/m^3. It is obvious to note that fresh density decreased with the increase of (CBW) as it is evidenced in Fig.(2) which indicate the relationship between fresh density and (CBW) content. It might be clarified as porosity is a measure of the void spaces in a material and the void substance of crushed-brick were few times higher than those of crushed stone aggregate, hence the addition of (CBW) to the mortar will increase the intruded pore volume which will be increased with the increase level of sand substitutions [4]. Furthermore, it was discovered that the density of recycled brick as aggregate is lower than the natural aggregate used concrete. When the percentage of crushed bricks substitution of natural aggregate increased the percentage of entrained air is also increases caused a density reduction in concrete as compared with concrete produced from natural aggregate [9]. Hardened density is ranged in (1740-1910) kg/m^3 for samples cured in air, (1985-2250) kg/m^3 for samples cured in water and (1835-1972) kg/m^3 for samples cured partially water. It is demonstrated that the hardened density for samples cured in water gave the higher magnitudes, while samples cured in air showed the least hardened density among the three groups of curing. It may be explained as the absorption of recycled crushed brick is estimated to have higher absorption capacity comparatively with natural aggregate. From the studies on water absorption of recycled bricks aggregates, it was demonstrated that recycled crushed brick becomes almost totally saturated with water after around 35 min of submersion in water. Submersion for a more than 24 hour produces an increase of about 2 % water absorption in which the weight will be increased [10].

Table 4: Results for fresh and hardened density for mortar.

Mix Code	F.D (kg/m^3)	H.D (kg/m^3)		
		AC	PWC	WC
X1	1836	1910	1972	2250
X2	1788	1855	1921	2183
X3	1770	1801	2003	2171
X4	1752	1780	1960	2078
X5	1666	1740	1835	1985

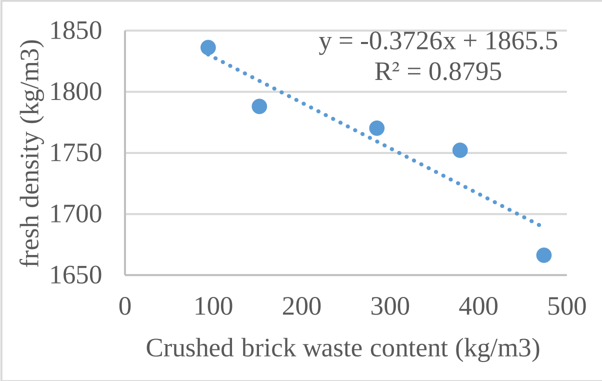

Figure 2: Relationship between fresh density and crushed brick waste content

Compressive Strength

Results for compressive strength at 7, 14 and 28 days for different curing conditions is shown in Table 5. Compressive strength for mortar cured in air ranged from (25.82-11.20) MPa, for mortar partially water cured is (21.14-9.12) MPa and for mortar cured in water is (19.33-8.16) MPa. Compressive strength for all mortars decreased comparatively with reference mortar which has 26.35 MPa at 28 days. Relationship between compressive strength for mortar cured in different curing conditions and (CBW) content is illustrated in Fig. (3). There have numerous endeavours to relate compressive quality with many parameters as porosity and pore structure of cementitous material. Close observations revealed a relation between compressive strength and pore volume when the pore volume increase the compressive strength decrease [9]. However, compressive strength for mortar cured in air conditions was significantly higher than those cured in water and partially water. Betkas concluded that crushed bricks particles keep the initially absorbed mixing water in its molecules and discharge it slowly by time. Therefore, drying shrinkage would be delayed due to the presence of internal moisture [11]. Therefore, further immersion more than 24 hours will result in higher water absorption and less compressive strength [12]. Therefore, compressive strength for mortar cured totally in water and partially in water showed less compressive strength than those cured in air.

Table 5: Results for compressive strength

Mix code	AC (MPa)			PWC (MPa)			WC (MPa)		
	7D	14D	28D	7D	14D	28D	7D	14D	28D
X1	20.12	22.36	25.82	16.01	18.2	21.14	15.12	17.21	19.33
X2	16.34	19.01	23.14	12.55	14.35	18.45	11.34	11.89	15.87
X3	11.33	14.77	16.56	8.44	11.62	13.17	7.23	10.02	11.34
X4	8.25	12.35	14.01	6.65	8.9	11.68	4.03	7.81	10.81
X5	4.50	8.01	11.2	3.13	6.11	9.12	2.4	5.23	8.16

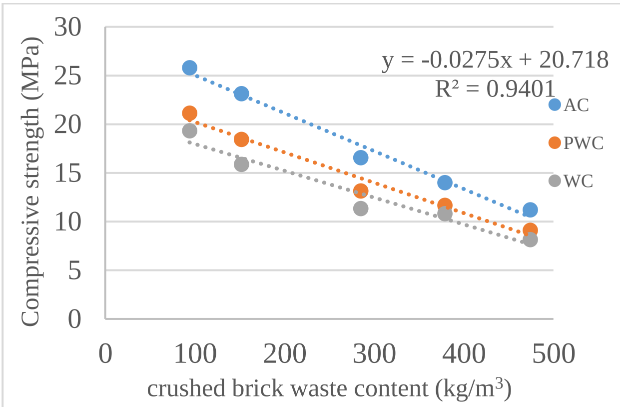

Figure 3: Relationship between compressive strength and crushed brick waste content

Modulus of Rupture and Water Absorption

Result for modulus of rupture of mortar and water absorption for mortar cured in different curing condition is shown in Table 6. Modulus of rupture ranged from (0.75-4.95) MPa for mortar cured in air, (0.10-3.60) MPa for mortar cured partially water and (0.07-2.8) MPa for mortar cured in water. Modulus of rupture was decreased as compared with reference mortar produced from natural sand which is 6.04 MPa. Reduction in modulus of rupture is clearly illustrated in Fig4. Past studies on concrete produced from Crushed bricks observed a decrease in modulus of rupture comparatively with the concrete made from natural sand [13]. However, mortar cured in air gave higher values for modulus of rupture as compared with mortar cured in water and partially in water. Previous researches found a homogenous relation between compressive strength and modulus of rupture, when the compressive strength increase the modulus of rupture is increased accordingly [14]. A uniform correlation between compressive strength and modulus of rupture was observed in this study and it is shown in Fig.(5). Water absorption ranged in (8.5-14.59) % for mortar cured in air, (7.1-13.34) % for mortar cured partially in water and (6.5-12.9) % for mortar cured in water. It was observed that water absorption was slightly increased with the increase of brick waste from 5% (CBW) replaced sand to 25% (CBW) replaced sand. (CBW) is a permeable material and has a water retention propensity higher than the common sand [13]. Water absorption decrease is clarified in Fig.(6). Water absorption for mortars cured in air were slightly higher than mortars cured in water and partially water curing.

Table 6: Results for modulus of rupture and water absorption

Mix code	MR (MPa)			WA (%)		
	AC	PWC	WC	AC	PWC	WC
X1	4.95	3.6	2.8	8.5	7.1	6.55
X2	3.41	2.45	1.85	10.54	9.24	8.78
X3	2.12	1.89	1.01	12.4	11.6	10.55
X4	1.89	0.73	0.55	14.16	12.85	11.97
X5	0.75	0.10	0.07	14.59	13.47	12.9

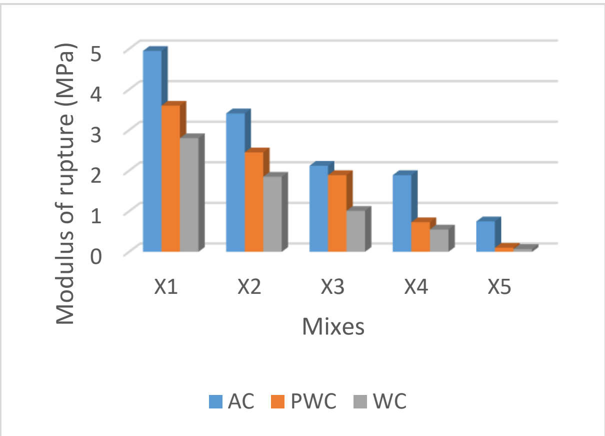

Figure 4: Modulus of rupture for mortar cured in different conditions

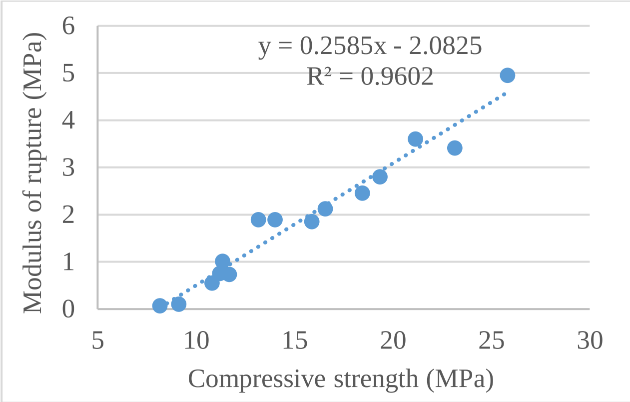

Figure 5: Relationship between compressive strength and modulus of rupture

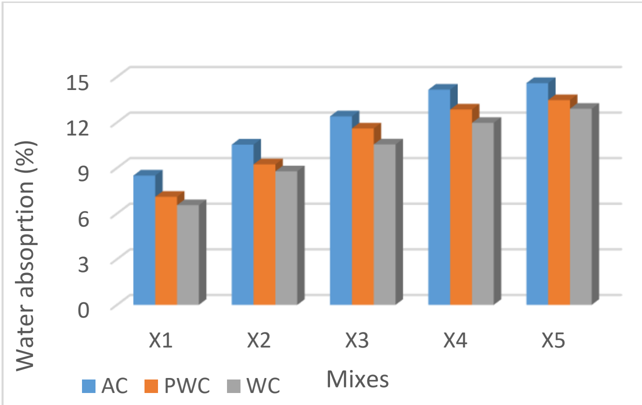

Figure 6: The water absorption for mortar cured in different condition

Conclusion

1. Fresh density and hardened density was significantly decreased with the increase in (CBW) substituted sand in mortar compared with reference mortar.
2. Compressive strength and modulus of rupture for the three groups cured in different conditions were decreased with increase of (CBW) replacement in mortar. However, mortar cured in air showed higher compressive strength and modulus of rupture than the mortar cured in water and the mortar cured partially in water.
3. Water absorption was increased with the increase in (CBW) replacement in mortar
4. It was concluded from this study that (CBW) could be used as internal curing agent due to the fact that when the water leaves the paste (CBW) keeps on hydrating bringing about a denser microstructure in the paste. This is comparable when supplying additional water to from outer curing.

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Nomenclature

AC	Air curing
CBW	Crushed brick waste
C	Cement
CB/S	The ratio between crushed brick and sand
F.D	Fresh density
H.D	Hardened density
PWC	Partially water curing
MR	Modulus of rupture
S	Sand
WC	Water curing
WA	Water absorption