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Properties Improvement of Cast Stone Produced Using Recycled Glass Waste and Lightweight Aggregates

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Abstract

Cast stone (CS) is a form of pre-cast concrete widely, used in architectural applications for decorating and building face in place of natural stone due its superior features. The present study was an attempt in using of local lightweight aggregate materials (LWAM) as an alternative to percentage of coarse aggregate, and glass wastes as alternatives to percentages of fine aggregate in cast stone normal mixtures with white cement and plasticizer admixture. The CS products were cured after 24 hrs using of two different processes: water curing (at 23 C° for 3 days) and steam curing (at 60 C° for 14 hrs). Then the products were characterized by tests of compressive strength, design, absorption, flexure strength and liner drying shrinkage. The addition of alternative materials was done by trial mixes (M0-M3) through 3 groups (A, B, and C) according to standards. Group A: design of reference mixtures of CS with compressive strength of 46.3 MPa and the absorption of 6.19%, Group B: design of mixtures containing 50% LWA were 16% lighter than those of Group A with compressive strength of 43.6 MPa and 11% improvement in the absorption, Group C: design of mixtures containing (50 and 75%) glass waste with compressive strength of (47.5-44.3 MPa) and the absorption of (5.3-4.7%), respectively. The modified steam curing process (curing after 24 hrs casting) done in this study could prove its effectiveness in the achievement of the required compressive strength in comparison with the normal process (direct curing after casting) due to the effect of such new process in providing the more uniform distribution of the cement gel with good physical properties. Results from the flexural strength test could prove the achievement of the required levels (6.9 – 6.3 at 50 – 75% glass waste addition) recorded in the standard.

Keywords: Cast stone, Glass waste, Lightweight aggregate, Water and steam curing, Compressive strength and absorption.

الخلاصة

حجر الصب أو الحجر الصناعي هو نوع من انواع الخرسانه مسبقه الصب الواسعه الاستخدام في التطبيقات المعماريه لغرض الديكور و تغليف واجهات المباني بدل الحجر الطبيعي نظراً لمواصفاته المتميزه. الدراسه الحاليه هي محاوله في استخدام مواد محليه مثل الركام خفيف الوزن كبديل عن نسبه من الركام الخشن، و مخلفات الزجاج كبديل عن نسبه من الركام الناعم في خلطات حجر الصب التقليديه مع الاسمنت البيض و الملدنات. حجر الصب المنتج من الخلطه المرجعية تم معالجته بعد ٢٤ ساعه من الصب باستخدام طريقتين مختلفتين:

المعالجه بالماء (عند ٢٣مº لثلاثه ايام) و المعالجه بالبخار (عند ٦٠مº لمده ١٤ ساعه). تم توصيف منتجات حجر الصب باختبارات مقاومه الانضغاط، الكثافه، الامتصاصيه، مقاومه الانحناء، و التقلص الجاف الخطي. تمت اضافه المواد البديله بنظام الخلطات التجريبيه (M3–M0) باستخدام ٣ مجاميع (A،B و C) تبعاً للمعايير. مجموعه A: تصميم الخلطه المرجعيه لحجر الصب مع مقاومه انضغاط ٤٦.٣ مغا باسكال و امتصاصيه ٦.١٩%، مجموعه B: تصميم خلطات تحتوي على ٥٠% من الركام الخفيف الوزن وكان أخف وزنا بنسبة ١٦٪ من حجر المجموعة A مع مقاومة انضغاط ٤٣.٦ ميجا باسكال وتحسن ١١٪ في الامتصاص، مجموعه C: تصميم خلطات تحتوي ٥٠% و ٧٥% مخلفات الزجاج مع مقاومه انضغاط (٤٧.٥–٤٤.٣ مغا باسكال) و امتصاصيه (٥.٣–٤.٧%)، على التوالي. إن عملية المعالجة بالبخار المعدلة (المعالجة بعد الصب ٢٤ ساعة) التي أجريت في هذه الدراسة قد اثبتت فعاليتها في تحقيق مقاومة الانضغاط المطلوبة بالمقارنة مع العملية العادية (المعالجة المباشرة بعد الصب) نتيجة لتأثير هذه العملية في توفير توزيع أكثر انتظام لعجينه الاسمنت مع الخصائص الفيزيائية جيدة. اثبتت نتائج اختبار قوة الانحناء تحقيق المستويات المطلوبة (٦.٩ – ٦.٣ عند ٥٠ – ٧٥٪ من إضافة النفايات الزجاجية) المسجلة في المعايير المعتمده.

الكلمات المفتاحية:– الحجر الصناعي ، مخلفات الزجاج ، الركام خفيف الوزن ، المعالجه بالماء والبخار ، مقاومة الانضغاط ، الامتصاصيه.

1. Introduction

Cast stone(CS) is a masonry product manufactured from white and/or gray cement, sands and crushed stone or natural gravels to simulate the natural cut stone in providing architectural trim, ornamentation or function features to construction and the other structures (Matthen, 2006). Wide application has been going-on the cast stone as a form of precast concrete in architectural applications in decoration and facing building in place of natural stone. The dense finishing of cast stone makes it look like natural, dimensional, cut building stone with more resistance to weather and dirt (Cast Stone Institute, 2014).

Recently more investigations and innovative efforts have been going on reusing the waste materials by economically and environmentally sustainable methods in building materials such as bricks, tiles and concrete blocks for saving of energy and natural resources and may for improving some properties. Utilization the waste materials as replacement of some raw materials helps in reducing the cost of cement, concrete and masonry products manufacturing and may improve the mechanical, durability and microstructure properties of concrete and mortar, which are difficult to achieve by the use of only Portland cement (Siddique and Rafat, 2007) . Glass is not disintegration and therefore causes problem for solid wastes throwing. So, the utilize of glass waste in building materials can be valuable solution for glass waste to the environmental problem (Safiuddin *et.al.*,2010). The porous medium as a lightweight aggregate is a versatile material and important; it is used in concrete mixtures to make lightweight aggregate concrete (LWAC). LWAC has many wide range of applications(Chandra and Berntsson , 2002), and it has good advantages such as lightness, thermal insulation, sound insolation, fire resistance, non- decomposability, limited water absorption, and average density (320 Kg/m³)[Fadox Company].

Meyer *et.al.,* 2001 study demonstrated the possibility of using waste glass as aggregate for concrete. Four groups were produced, Group 1 raw materials used only. In group 2 used glasses with size 600 µm alternatively 10% of fine aggregate. In group 3 used finely ground glass powder with size 37 µm alternatively 10% of the cement. And group 4 contained both, 10% glass aggregate and replacement 10% cement by glass powder. This research showed the different steps that must take place for recycling to the glass, separated from the other materials, cleaned and crushed to get the appropriate size to meet the required need applications (Meyer *et.al.*, 2001).

Ammash *et.al.,* 2009 studied the possibility of utilition glass waste of size up to 0.5cm with percentages of 10, 20, 30 and 40% as sand in mortar and concrete. The results have indicated that increasing percentage sand replacement leads to reduce the compressive strength of concrete and mortar. At 20% replacement, that compressive strength of concrete and mortar is about (95% and 92%) from the reference strengths, respectively. Also, with increasing the waste glass content was the expansion of mortar specimens increasing in the mix, and the expansion is slightly higher at 20% sand replacement(Ammash *et.al.,* 2009) .

K. Harmon discussed the unique physical properties of rotary kiln expanded slate lightweight aggregate for manufacturing high strength and high performance lightweight concrete. The elastic modulus, compressive strength, specific creep, splitting tensile strength, and other characteristics of lightweight concrete are safely affected by the structural characteristics of the lightweight aggregate utilized. Concrete manufacture, transport, placing and pumping are also influenced. Rotary kiln processing and raw materials are discussed. Data from laboratory studies and academic is offered as well as data from present projects such as the Hibernia Offshore Oil Platform Gravity Base and the Raftsundet Bridge in Norway and (Harmon, 2007).

In the present study cast stone is manufactured from White Portland cement, fine and coarse aggregates, chemical admixtures (SP2000) and water with utilization the glass waste as replacement of fine aggregate and lightweight aggregate as replacement of coarse aggregate to manufacture the cast stone and possibilities to improve the physical and mechanical properties.

2. Experimental Part

2.1 The materials

Table (1) shows the local raw materials used in this study, as the main components of cast stone were cement, sand (fine aggregate), coarse aggregate, water and admixture of high super plasticizer, also glass waste and lightweight aggregate.

2.2 Preparation of Alternative Materials

Glass have a many of properties that make it likely aggregate for a variety of concrete products. Glass waste was crushed by hand hammer to appropriate size specified in the standard (less than 4.75 mm) as shown in fig.(1), and table (2) after sieving. The lightweight aggregate additives from the local markets were used in the process of manufacturing cast stone with its granular size specified according to ASTM (C330/C330M−14**)** for lightweight aggregate, so the required preparations for the additive were the washing and drying only as shown in fig(2).

2.3 Mix Design

Table (3) shows the mixture design according to "Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete" (ACI 211.1-91). Table (4) shows the quantity calculation in the mix design.

2.4 Testing Procedures

Workability (slump test) was tested for fresh cast stone concrete according to ASTM (C143/C143M. The compressive strength of (50 mm cubes) was tested at the ages of 7 and 28 days, according to ASTM (C1194) for samples cured by immersion and tested at age 7 days for samples cured by steam. Fig(3)shows the procedure for steam curing process, and fig(4) shows home-made chamber for the steam curing process. Density, absorption and avoid were tested for hardened cast stone according to ASTM (C642). The flexure strength of (100x100x400mm) was tested at age 28 days, according to ASTM (C293). Liner drying shrinkage was measured using a length comparator device as shown in fig.(5) according to ASTM C426. Three prisms having the dimension of (40×40×285 mm) were cast for each mix and kept in water. The drying shrinkage was measured at ages of initial reading, 3, 5, 7 and 9 days.

3. Results and Discussion

3.1 slump test

Table (5) shows the results of a slump test for fresh cast stone, it can observe from this table that the workability is according to the mixture specification. Glass sand improves the flow properties of fresh concrete so that higher strengths can be reached without the utilized of super plasticizers (Meyer *et.al.,* 2001).

3.2 Compressive Strength

From table (6) it can be observed that the addition of glass waste (mixes M1 and M2 samples) could provide a little improvement in the compressive strength of Cast Stone despite the value recorded for the mix M5 samples (44.3 MPa). The more expected improvement in the compressive strength due to the presence of C3S in the mixture components is affected by the lower adhesive strength between the smooth glass surface and the cement pastes. Furthermore, the C3S component in the cement pastes is characterized with high compressive strength (Neville, 2000).The mix M3 samples could exhibit a compressive strength little lower than that of the specified value of cast stone (45 MPa). This behaviour can be attributed to the decreasing in density of light weight concrete, which led to more voids in the concrete structure. It is clear that the existence of these voids decreases the strength of lightweight concrete compared with normal concrete(Shiv and Ghansham, 2007).

The steam cured samples at 7 days showed compressive results much better than those of the water cured samples at 7 days as shown in table (7). Such improvement in the steam curing results can be attributed to the accelerated hydration process which led to the quick formation of Calcium Silicate Hydrate (C-S-H) crystals. Also, the steam curing accelerating the formation of gel and colloid, and the C-S-H diffusion (Shiv and Ghansham, 2007).

3.3 Density, Absorption and Avoid

From comparison table (8) with table (6) can be observed that the compressive strength decreased with absorption increasing due to porosity increasing. The samples M1 and M2 could record the highest compressive strength (44.3-47.5 MPa) at the absorption of (4.7-5.3%) among the other samples due to the low absorbency and non-porous structure of the glass surface and it has zero water absorption (Siddique and Rafat, 2007). The sample M3 compressive strength (43.6 MPa) at absorption of (5.5%) because low absorbency (closed cells and with densely sintered firm external skin), and lightness of the lightweight aggregate[Fadox Company].

3.4 Flexure Strength

Flexure strength results are affected by the same variables and factors mentioned in discussion of compressive strength results. Flexure strength increased with compressive strength increasing as shown in table (9).

3.5 Liner Drying Shrinkage

It can be noticed that the M2 samples provided the highest shrinkage (0.207 mm). M3 samples could show the lowest shrinkage (0.163 mm) because it's have closed cells and with densely sintered firm external skin as shown in table (10).

Conclusion

The success of the present study of cast stone production by using local materials such as white cement, sand, coarse aggregate, water and SP2000 plasticizer admixture according to ASTM-1364 with compressive strength of 46.3 MPa and absorption of 6.19%. The success of the present study of cast stone production by using of the same local materials mentioned above and substitution of sand with curses glass waste materials(less than 4.75 mm). The success claimed in point 2 above included the production of cast stone containing (50-75%) glass with compressive strength of (47.5-44.3 MPa) and the absorption of (5.3-4.7%), respectively, due to the low absorption and non-porous structure of the glass surfaces. The possibility of using the steam curing process done in this study (24 hrs after casting) at 7 days for 14 hrs in the achievement of the required compressive strength (37.3 – 36.2 MPa for 50%-75% glass waste addition). The addition of 50% light weight aggregates (10mm) as coarse aggregates resulted in cast stone 16% lighter than the normal type with compressive strength of 43.6 MPa, and 11% improvement in the absorption. Results from flexural strength test could prove the achievement of the required levels (6.9 – 6.3 at 50 – 75% glass waste addition) recorded in the standard.

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Table (1) Datasheet of Mock-up Test

Materials	Type	Origin
Cement	Iraq specification No.5/1984	Iraqi Markets
Sand	Zone 2/ Iraqi Specification No. 45 of 1984	Iraqi Markets (Al-Ekhaider region)
Coarse aggregate	(5-20mm)/ Iraqi Specification No. 45 of 1984	Iraqi Markets
Sp2000	F /ASTM C494	Iraqi Markets
Glass	-	Waste
Lightweight aggregate	(4-10mm)	Iraqi Markets

Table (2) Sieving results of glass crushed as fine aggregates.

Sieve opening size	**Total percentage of materials passing**	**Specification IQS 45/1984 Standard Regimes**			
	Sample	**Zone 1**	**Zone 2**	**Zone 3**	**Zone4**
10 mm	100	100	100	100	100
4.75 mm	94	90-100	90-100	90-100	95-100
2.36 mm	83	60-95	75-100	85-100	95-100
1.18 mm	75	30-70	55-90	75-100	90-100
600 µm	58	15-34	35-59	60-79	80-100
300 µm	25	5-20	8-30	12-40	15-50
150 µm	5	0-10	0-10	0-10	0-15

Table (3) The mixtures design

Mix Code	**Main Components**
M0 (reference mixture)	Raw materials only
M1	50% sand and 50% glass waste
M2	25% sand and 75% glass waste
M3	50% coarse aggregate and 50% lightweight agregate

Table (4) The quantities of mix design

Concrete mixture	**Cement (Kg/m^3)**	**Water (Kg/m^3**	**Fine aggregate (Kg/m^3)**	**Coarse aggregate (Kg/m^3)**	**W/C ratio**	**Glass Waste (Kg/m^3)**	**Lightweight aggregate (Kg/m^3)**	**Glass Waste (Kg/m^3)**	**SP2000 1.5% of cement**	**Bulk density for fresh concrete (Kg/m^3)**
M0	425	180	620	1240	0.40	-	-	-	6.4	2455
M1	425	180	310	1240	0.40	310	-	310	6.4	2455
M2	425	180	155	1240	0.40	465	-	465	6.4	2455
M3	425	180	620	620	0.40	-	155	-	6.4	1990

Table (5) The slump of fresh cast stone mixtures

Mixtures	M0	M1	M2	M3
The slump mm	120	127	129	121

Table (6) The compressive strength of samples mixtures

Mixtures		M0	M1	M2	M3
Compressive Strength MPa	**At 7 days**	22.6	26.2	25.8	29.8
	At 28 days	46.2	47.5	44.3	43.6

Table (7) The comparison of compressive strength for samples cured by immersion and steam

Mixtures		M0	M1	M2	M3
Compressive Strength MPa at 7 days	**Immersion curing**	22.6	26.2	25.8	29.8
	Steam curing	36.4	37.3	36.2	35

Table(8) Results of density, absorption and avoids for all mixtures after 28 day

Concrete mixture	Bulk density dry (Kg/m³)	Apparent density (Kg/m³)	Absorption %	Avoids %
M0	2206	2638	6.19	16.3
M1	2222	2599	5.3	14.5
M2	2267	2609	4.7	13.1
M3	1868	2128	5.5	12.2

Table (9) Results of flexure strength for all mixes samples

Flexure strength MPa	Concrete mixture			
	M0	**M1**	**M2**	**M3**
	7.1	6.9	6.3	5.2

Table (10) Results of liner drying shrinkage for M0-M3 mixes samples.

Samples No.	Initial reading	2 days	5 days	7 days	9 days	Liner shrinkage
M0	0.009	0.023	0.102	0.153	0.195	0.186
M1	0.006	0.019	0.110	0.162	0.203	0.197
M2	0.005	0.024	0.114	0.168	0.212	0.207
M3	0.004	0.014	0.092	0.138	0.167	0.163

Figure (1) The glass waste crushed

Figure (2) The lightweight aggregate

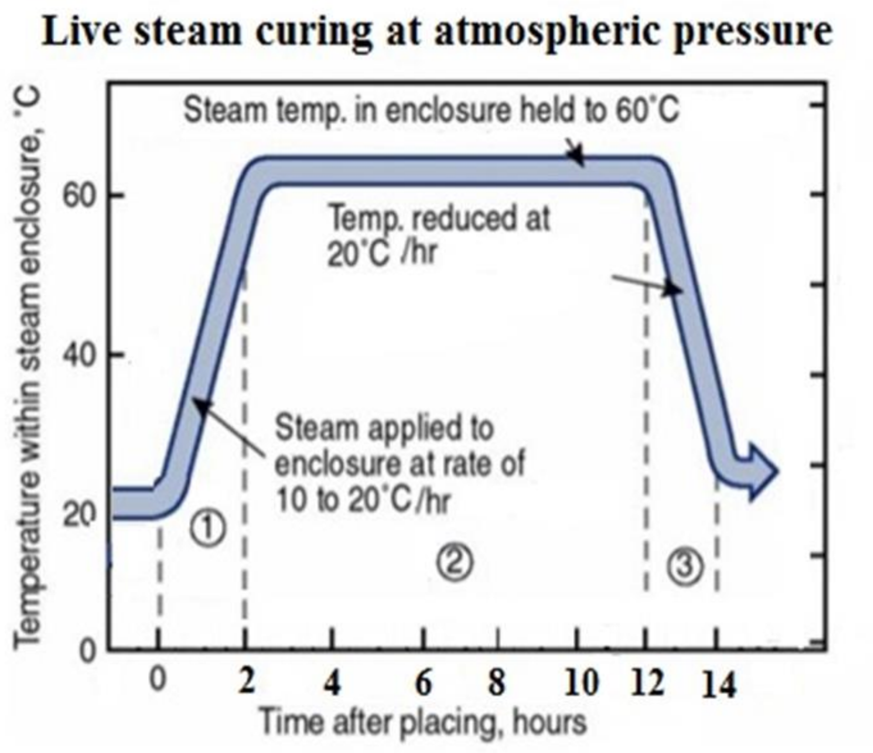

Figure (3) Steps of curing by steam

Figure (4) steam curing chamber

Figure (5) Length comparator device