

*Full Length Research Paper*

# Utilization of demolished concrete, grog, hydrated lime and cement kiln dust in building materials

H. M. Khater

Housing and Building National Research Centre (HBNRC), 87 El-Tahreer St., Dokki, Giza, P. O. Box 1770, Cairo, Egypt.  
E-mail: [Hkhater4@yahoo.com](mailto:Hkhater4@yahoo.com). Tel: 0020237618125-0020111686524.

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It is desirable to completely recycle concrete waste in order to protect natural resources and reduce environment pollution. In this paper, the studied reference mix composed of demolished waste concrete/grog/hydrated lime in the ratio of (40/50/10, wt. %), while other mixes has cement kiln dust as a partial replacement of hydrated lime in the ratio from zero up to complete replacement. Both grog and burned cement kiln dust were obtained from firing clay materials as well as by-pass cement kiln dust at 850°C for 1 h with a heating rate of 5°C/min. Results of this study possess a method for recycling of demolished wastes in brick making as fine materials not in the traditional method that used it as aggregate. Waste concrete, grog, hydrated lime and by-pass cement dust can be used instead of the cement constituent of mortar and hydrated building brick making.

**Key words:** Demolished concrete, cement kiln dust, grog.

## INTRODUCTION

Recycling of concrete wastes in construction has been investigated extensively in the past decades due to environment pollution and exhaustion of natural resources. In some countries, many technologies for recycling concrete wastes have been developed and some recycling specifications have been established as well (Khater, 2006; Poon et al., 2002; Shui et al., 2008). In the process of the practical reutilization to recycle waste concrete requires further breaking and crushing of demolished concrete. Generally, two typical grades of crushed concrete aggregates can be produced and classified by size gradation. One is coarse recycled concrete aggregates (CRCA), part of which can be used in new concrete or road base materials. Other is fine recycled concrete aggregates (FRCA) or recycled mortar from crushed concrete waste whose sizes are smaller than 5 mm; recycling, evaluation and application of both parts are discussed in different researches (Works Bureau of Hong Kong, 2002; Ryu, 2002; Khatib, 2005; Nagataki et al., 2004; Park, 2003; Poon et al., 2006). On the other hand, the cement dust contains a mixture of kiln

raw feed as well as calcined materials with some concentrated volatile alkali salts, recycled back into the cement kiln as raw feed. It also reduces the need for limestone and other raw materials, that saves natural resources and helps conserve energy. Another principal use of CKD is for various types of commercial applications in building brick making along with latter demolition wastes (IEEE-IAS, 2008; Maslehuddin, 2008; Siddique, 2006; Sreekrishnavilasam et al., 2006). This paper possesses an experimental research for successful construction and demolition waste recycling and utilization operations and the reduction of wastes produced from demolition works, increase of wastes recycling and utilization, as well as harmless disposal of the remaining wastes.

Many researches have been carried out in the field of recycling and utilization of construction and demolition wastes in building works (Assal, 2002; Assal et al., 2003, 2004; Demir and Orhan, 2003). The aim of this work is to evaluate the use of waste concrete, cement kiln dust as a by product from cement manufacture, grog as well as

hydrated lime for the production of building materials.

## EXPERIMENTAL TECHNIQUES

### Raw materials

Materials used in this investigation are coarse aggregate included destructive concrete without reinforcement steel, grog, hydrated lime, and by pass cement dust. 6th October City, Giza governorate, while the grog was brought from Kom-Oshem clay, Fayoum Governorate and the hydrated lime was taken from a lime production plant at Cairo, Egypt. By-pass cement dust was obtained from National Cement Company, Helwan, Cairo, Egypt. The mineralogical composition as revealed from x-ray diffraction (XRD) and differential scanning calorimeter (DSC) and chemical composition as indicated from Table 1, illustrate that the waste concrete (WC) composes mainly of quartz ( $\text{SiO}_2$ ), in addition to lesser amounts of portlandite [ $\text{Ca}(\text{OH})_2$ ], calcite ( $\text{CaCO}_3$ ), CSH (I) and tobermorite-like phase (tobermorite gel,  $\text{C}_3\text{S}_2\text{H}_{3-4}$ ). The grog (which is fired clay at  $850^\circ\text{C}$  for 1 h with a heating rate of  $5^\circ\text{C}/\text{min}$ ) composes mainly of quartz, in addition to lesser amounts of hematite ( $\text{Fe}_2\text{O}_3$ ). Hydrated lime composes mainly of portlandite and a very lesser extent of calcite. Cement dust consists primarily of calcium carbonate and silicon dioxide which is similar to the cement, but the amount of alkalis, chloride and sulphate is considerably higher in the dust, as it composed of CaO as a major component and  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{Fe}_2\text{O}_3$  as well as  $\text{SO}_3$  as minor component, where the sulphate source may be from the included gypsum anhydrite.

### Preparation and treatment

Representative batch of coarse aggregate included demolished waste concrete crushed to 1 mm, and ground in a steel ball mill to  $90\ \mu\text{m}$ . Grog as well as burned dust are prepared by firing the clay and cement dust samples separately, at  $850^\circ\text{C}$  for 1 h with a heating rate of  $5^\circ\text{C}/\text{min}$ , left to cool in the furnace up to room temperature, then ground to  $90\ \mu\text{m}$ . Burning of cement dust was done in order to get ride of the volatile alkalis salts. Hydrated lime was dried at  $80^\circ\text{C}$  for 24 h then ground to  $90\ \mu\text{m}$ . Studied reference mix composed of WC/grog/hydrated lime (40/50/10, wt. %) where the amount of hydrated lime added was replaced by calcined CKD with 20, 40, 60 and 80% up to full replacement of hydrated lime by dust as indicated in Table 2. The dry mixes were mixed well with suitable water of workability, hand moulded in one inch cubic steel moulds, and then left in air for 24 h, demoulded, water cured for 3, 7 and 28 days, and then dried at  $80^\circ\text{C}$  for 24 h.

### Methods of investigation

Chemical analysis was carried out using wave length dispersive X-ray fluorescence Axios PW 4400-XRF Spectrometer (Panalytical, Netherlands, 2009), and accompanied by the standerless software program for unknown analysis measurements. The x-ray diffraction (XRD) analysis was carried out using a Philips PW3050/60 diffractometer. The data were identified according to the XRD software (pdf-2: database on CD-Release 2005). The differential scanning calorimeter (DSC) was followed using DSC-50 differential scanning calorimeter (Schimadzu Co-Kyoto, Japan) for the investigation of the phase composition of the formed hydrates. The data were compared with DTA standard data (Ramachandran,

1969). Some physico-mechanical properties, for example bulk density, water absorption, and compressive strength were determined according to the Egyptian Standards (Egyptian Standards, 1972).

## RESULTS AND DISCUSSION

### Phase composition

X-ray diffraction (XRD) patterns of the mixes with variable calcined CKD content on the expense of hydrated lime are shown in Figure 1. The figure shows that, portlandite decreases on water curing up to 28 days, as a result of its consumption in the reaction with amorphous reactive silica forming CSH binder phases. Calcite increases on water curing due to the partial carbonation of the formed CSH phases and portlandite while it slightly decreases with the increase of CKD as a result of the decrease of CSH phases and portlandite contents. A remarked larnite ( $\beta\text{-C}_2\text{S}$ ) peak observed at earlier hydration ages that decreases with curing time as a result of its transformation to tobermorite gel. A noticeable peak of ettringite resulted from the addition of excess BD (burned cement dust) is appeared, which results in an expansion in the matrix composition. Quartz is almost unchanged on water curing as well as with the addition of burned cement kiln dust. The differential scanning calorimeter (DSC) patterns (Figure 2) indicate an endothermic peak below  $100^\circ\text{C}$  for free water, the endothermic peaks between  $162$  to  $199^\circ\text{C}$  for CSH(I) and tobermorite gel, an endothermic peak at  $396^\circ\text{C}$  also for CSH(I), endothermic peak at about  $490^\circ\text{C}$  for dehydroxylation of  $\text{Ca}(\text{OH})_2$ , and endothermic peak at about  $586^\circ\text{C}$  for ( $\alpha \rightarrow \beta$ ) quartz conversion. From the DSC patterns, the endothermic peaks of CSH(I) and tobermorite gel increase with curing time as the increased formation and accumulation of CSH binder phases, also the extra endothermic peak of CSH(I) after 28 days of curing at  $396^\circ\text{C}$  emphasize the growth of binder phases with hydration age. Portlandite content nearly vanishes with time as a result of its incorporation in the formation of CSH phases.

With the increase of burned dust, the endothermic peak of the CSH(I) and tobermorite gel displaced to the lower temperature range indicating their lower stability and weak hydraulic character in addition to their ill-crystallinity.

### Physico-mechanical properties

#### Compressive strength

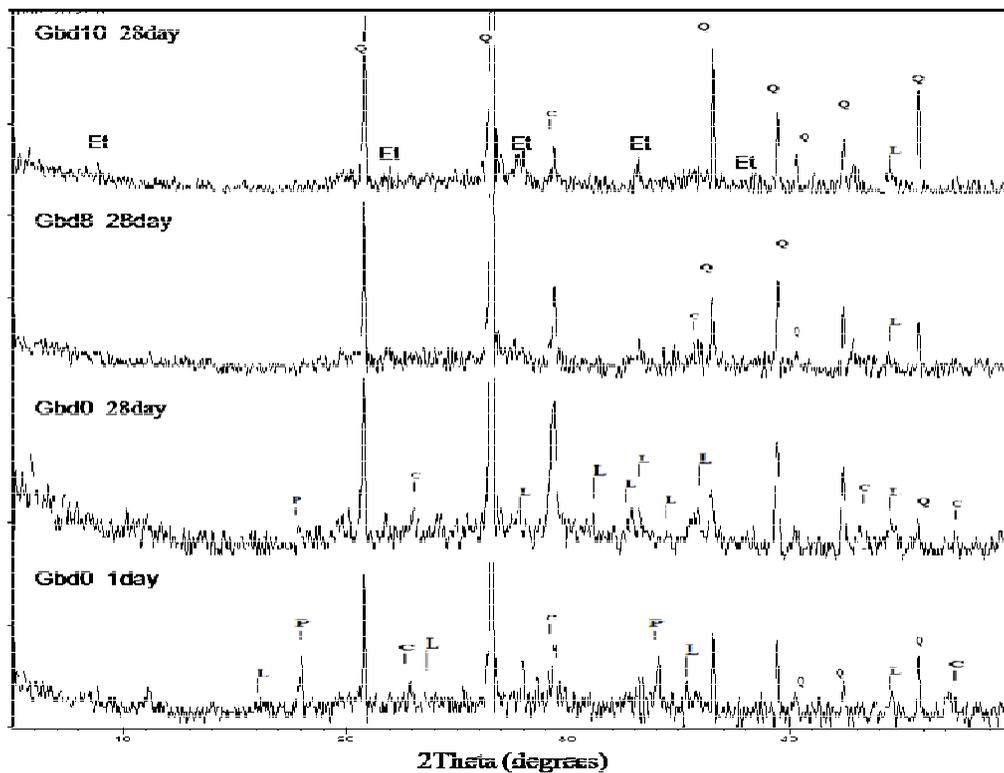
The results of compressive strength of mixes with variable amounts of BD (burned dust) that water cured up to 28 days are shown in Table 3 and represented in

**Table 1.** Chemical composition of the starting materials (Mass, %).

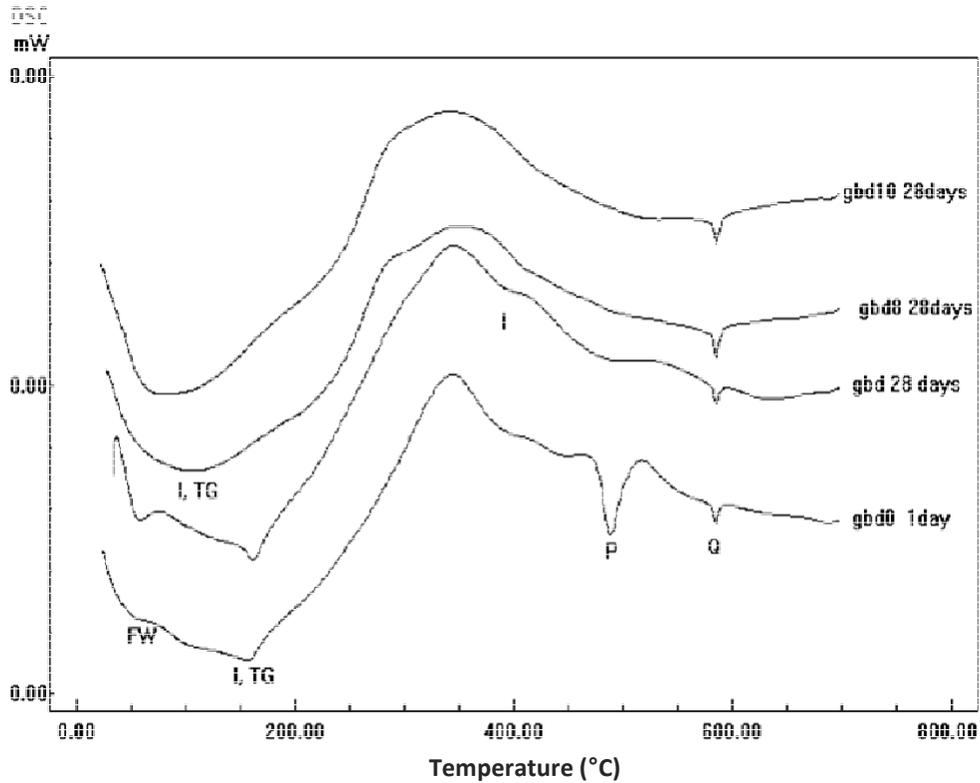
Oxide	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	Na <sub>2</sub> O	K <sub>2</sub> O	SO <sub>3</sub>	TiO <sub>2</sub>	P <sub>2</sub> O <sub>5</sub>	L.O.I.	Total
Demolished waste concrete	79.11	2.3	1.04	5.14	0.38	0.27	0.17	0.02	nill	nill	11.52	99.96
Grog	55.18	21.89	11.33	1.12	2.89	1.52	1.28	0.5	1.45	0.12	2.26	99.74
Hydrated Lime	1.62	0.4	0.2	70.9	0.23	16	0.03	1.05	0.1	0.09	25.14	99.84
CKD	9.3	4.24	2.89	51.3	1.14	3.84	2.18	3.56	0.34	0.12	20.68	99.59

**Table 2.** Composition of the mixes used in this study (Mass, %).

Mixes	Demolished waste concrete	Grog	Hydrated Lime	BD
GBDO	40	50	10	-
GBD2	40	50	8	2
GBD4	40	50	6	4
GBD6	40	50	4	6
GBD8	40	50	2	8
GBD10	40	50	0	10



**Figure 1.** XRD patterns of 1 and 28 days water curing control mixes and various burned cement kiln dust contents water cured at 28 days. (C: calcite, L: larnite, Q: quartz, ET: ettringite, P: portlandite).



**Figure 2.** DSC patterns of 1 and 28 days water curing mixes and various burned cement kiln dust contents water cured at 28 days. (FW = free water, P = portlandite, Q = quartz, I = CSH(I), TG = tobermorite gel).

**Table 3.** Compressive strength of various burned cement dust mix specimens at different hydration ages.

Curing time (Days)	Compressive strength (kg/cm <sup>2</sup> )					
	GBD0	GBD2	GBD4	GBD6	GBD8	GBD10
1	45.21	43.50	34.43	32.10	27.63	19.10
3	116.95	94.50	88.50	75.40	31.10	24.83
7	144.20	109.30	94.60	83.00	53.80	49.70
28	161.90	113.20	99.20	87.80	83.60	80.00

Figure 3. The results show that, the compressive strength decreases with the addition of burned dust on the expense of hydrated lime. Burned dust is considered as impure lime, contains other constituents than lime such as gypsum as revealed from SO<sub>3</sub> inclusion as well as alkalis. The partial or full replacement of portlandite with this dust decreases the amount of hydrated lime needed for the reaction with silica to form CSH binder phases,

therefore the strength decreases up to full replacement. The results also shows that the compressive strength increases with water curing period due to the formation and accumulation of CSH binder phases (Assal, 2002).

The XRD emphasize compressive strength results where the larnite as well as portlandite decrease with curing time due to larnite hydration and the reaction of portlandite with SiO<sub>2</sub> forming CSH phases leading to the

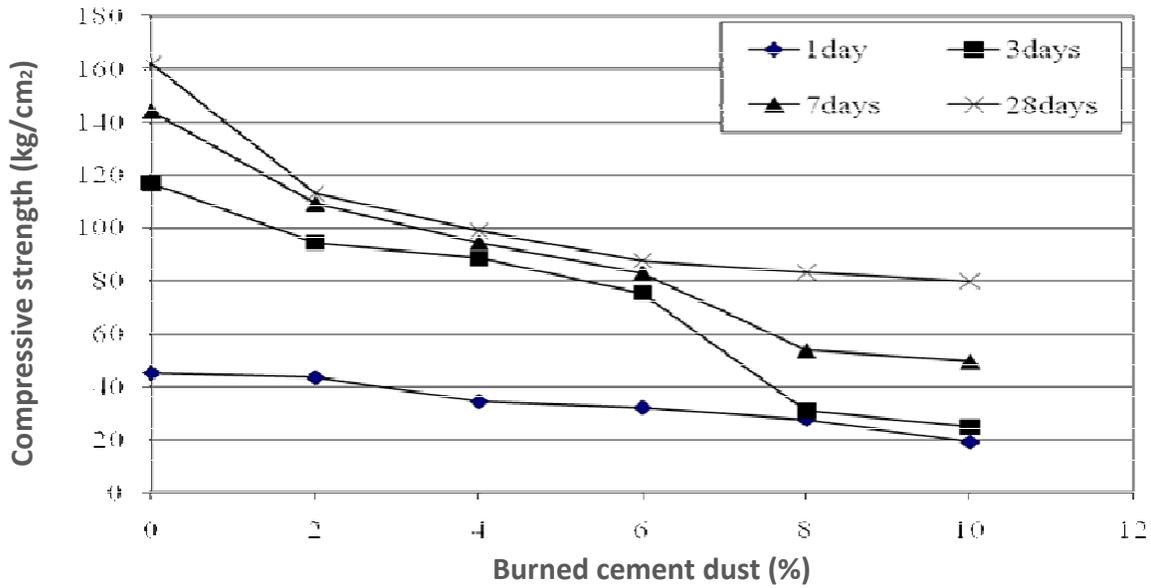


Figure 3. Compressive strength of various burned cement dust mix specimens at different hydration ages.

Table 4. Bulk density and water absorption of various burned cement dust contents hydrated for various curing ages.

Curing time (Days)	Bulk density (gm/cm <sup>3</sup> )						Water absorption (%)					
	GBD0	GBD2	GBD4	GBD6	GBD8	GBD10	GBD0	GBD2	GBD4	GBD6	GBD8	GBD10
1	1.391	1.388	1.396	1.407	1.399	1.378	23.62	26.99	24.80	25.70	26.01	26.81
3	1.536	1.470	1.476	1.488	1.481	1.462	13.13	15.18	13.82	15.39	15.94	16.73
7	1.450	1.429	1.435	1.443	1.436	1.423	23.20	25.73	24.27	25.06	25.31	26.55
28	1.481	1.439	1.470	1.477	1.474	1.452	20.60	22.45	21.70	22.50	22.82	23.06

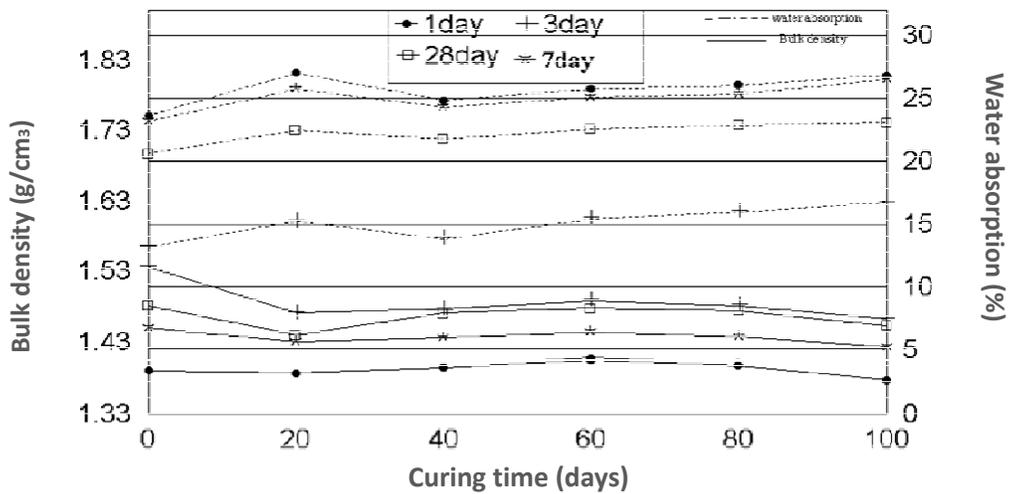


Figure 4. Bulk density and water absorption of various mix specimens hydrated for different hydration ages.

strength increase, while the ettringite appearance at higher burned dust contents up to full replacement leading to an expansion and decrease in strength.

On the other hand, DSC emphasizes also the same results as XRD where a remarked increase in the CSH(I) and tobermorite gel with curing age that accompanied by a decrease of portlandite content which results in an enhancement in the strength behaviour.

### **Bulk density and water absorption**

The bulk density and water absorption of the water cured specimens mixes are shown in Table 4 and represented in Figure 4. The results show that the bulk density increases in all mixes up to 3 days as the binder phase formed is CSH(II) that has higher Ca/Si ratio, then decreases up to 7 days due to phase transformation to CSH(I) which has low Ca/Si ratio and so a little tendency for carbonation that reflected on strength increases and increases again up to 28 days as a result of accumulation of CSH(I). Also, bulk density has the same trend as that of compressive strength with respect of burned dust content, that is, bulk density decreases with the increase of dust content up to full replacement due to the same reasons discussed earlier. The results also show that, water absorption has the reverse trend of bulk density, due to the same reasons that is previously discussed. The reasons lead to a decrease in bulk density and compressive strength, lead at the same time to an increase in water absorption and vice versa.

### **CONCLUSIONS**

- 1) Compressive strength of all the studied mixes increases with hydration age and decreases with burned dust giving more than 20 kg/cm<sup>2</sup> enough for safe handling, after one day of hydration except for mix that has full replacement by dust.
- 2) After one day of water curing, all mixes give compressive strength exceeds that required for the concrete bricks used in the non-load bearing walls (25 kg/cm<sup>2</sup>), according to the Egyptian Standard Specifications 1292 (1992), except the specimens of the mix of 100 wt. % burned cement dust replacement that reaches the last mentioned value after 3 days. Beyond 3 days mixes having up to 60 wt. % BD give a compressive strength higher than that required for the concrete bricks used in the load bearing walls (70 kg/cm<sup>2</sup>).
- 3) According to the same Egyptian standard specifications, the specimens of all mixes at all water curing periods have a moderate bulk density (1.40 to 2.00 g/cm<sup>3</sup>).
- 4) The results of this study show that the mix of waste

concrete, grog, hydrated lime and burned cement dust can be used instead of the cement constituent in mortars, and in concrete brick-making.

5) In spite of the decrease of compressive strength values (main property of building materials) with the replacement of hydrated lime by burned dust, yet these values reach the compressive strength required for the brick used for the load bearing walls (70 kg/cm<sup>2</sup>) after 1, 3 or 28 days of hydration in addition to the benefit of saving a raw material (hydrated lime) that used in many industries using an environmental pollutant waste dust instead.

6) Generally, it could be said that direct replacement (mixing) of burned cement dust with demolished wastes is more effective than the recycling of dust with cement raw materials, which forms unfavoured clinker phase during the firing in cement kilns that attributed to the effect of high dust alkalinity on the nature of clinker phases.

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