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Potential Use of Crushed Ghanaian Limestone in Paste and Mortar Formulated for Masonry

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ABSTRACT

Crushed Ghanaian limestone (L) powder was analysed for its physical, chemical and microstructural properties for the formulation of mortar for masonry. Ordinary Portland Cement (OPC) was replaced by 10- 40% limestone powder for paste and mortar formulation. Mechanical properties that included compressive strength, water demand and setting times (initial and final) were analysed. The mechanical properties were determined in accordance with ASTM standards. The test results indicated that crushed limestone powder contained about 88.7% CaO in calcite form. A 10-30 % and 35-40% limestone content in conjunction with OPC was suitable to produce ASTM type M and S mortars respectively. Formulated OPC - L paste showed a high water demand and a delayed final setting time than the plain OPC paste.

INTRODUCTION

In recent decades, research into cementitious materials as replacement materials for Portland cement has received enormous attention in many developed countries such as USA, Europe and some parts of Asia and still continues to attract interest for further interest. This is due to the technical, economical and ecological importance of these materials [Malhotra and Mehta 1996]. Technically, the inclusion of cementitious materials in ordinary Portland cement has been reported to improve both early and late hydration of ordinary Portland cement, enhance the workability, durability and compressive strength development of mortar and concrete. The ecological advantages are the reduction of CO_2 and NO_x gas emission per ton of cement manufactured and the conservation of fossil fuels and mineral resources [Bonavetti et al. 2003]. From the economical view point, ordinary Portland cement is known to be more expensive as its production is highly energy intensive. On the other hand, cementitious material processing requires little or no direct energy-related costs, hence cheaper than Portland cement. This therefore illustrates that a significant replacement of Portland cement by cementitious material is a cost-effective means to produce mortar or concrete [Bouzoubaa and Fournier 2009]. The most common cementitious materials which have been used as partial replacement of cement are latent hydraulic component like blast-furnace slag, pozzolanic components such as fly ash, rice husk ash, condensed silica fume and calcined clay or filler components such as limestone and other waste agricultural ashes [Hernandez et al. 1998; Singh et al. 2000]. It has been stated that, generally blended cements behave quite similar to that of ordinary Portland cement since they harden when mixed with water and form the same hydration products [Diwivedi et al. 2006].

In most developing countries such as Ghana, many builders and engineers have dearth knowledge over the benefits and use of cementitious materials as partial replacement of Portland cement. Meanwhile, the price of a bag of Portland cement weighing 50 kg has risen astronomically in recent years. For instance, the price of a bag of Portland cement which was GH¢8.00 in 2007 is now GH¢14.00 in 2009. This represents about 62.5% of price increase in a period of three (3) years. It has also been realized in previous data from the Ministry of Trade and industry that in every four years, the price of Portland cement always doubles [Anon. 2007]. From this simple analysis, it can be predicted that by 2012, cement price per 50 kg bag will be about GH¢26.00. The need to explore suitable alternative materials that can replace a significant portion of OPC could be a means to salvage the economy and reduce the high costs that confront the construction industry and housing delivery in Ghana and other developing countries.

Limestone, which has been reported by some authors like Guemmadi et al. [2008], Tsivillis et al. [2002], Benachour et al [2008] and Ingram and Daugherty [1991] as a suitable material and can be used to replace part of Portland cement exists in large proven reserves in Ghana. Kesse [1985] has estimated the total limestone deposit in the country to be over 230 million tonnes. In this study, limestone deposit from Orterkpolu located at the Eastern region of Ghana was analyzed and used to produce paste and mortar. The aim of the study was to examine the potential use of limestone powder to replace part of Portland cement for masonry works.

MATERIALS AND METHODS

Materials

Ordinary Portland cement (CEM I 42.5N) produced by Ghana Cement Works (Ghacem) that conformed to EN 197-1 and labeled OPC was used. Crushed limestone powder (L) used was obtained from Orterkpolu in the Eastern Region of Ghana. Table 1 gives the physical, mineralogical and chemical properties of OPC and L. The Blaine values of OPC and L were 338m^2/kg and 420m^2/kg indicating that the limestone powder contains more fines than OPC. The specific gravity of OPC was 3.14, higher than that of limestone with a value of 2.56. The mean particle size of OPC and L were 4µm and 32µm respectively. The mineralogical composition of the OPC shows that it contains 59.6% C_3S, 12.6% C_2S, 7.86% C_3A and 9.49% C_4AF. The X- ray fluorescence (XRF) was used to determine the chemical properties of the limestone powder. The major chemical component in the limestone was calcium oxide (CaO) being 49.47%. This could mean that, limestone powder contains 88.7% $CaCO_3$ in pure calcite form when deduced from the stoichoimetric equation, $CaCO_3 \rightarrow CaO + CO_2$. By the European standards EN 197, the minimum $CaCO_3$ requirement is 75%. The sand used was natural silica sand. Tap water was used for the mixing of the paste and mortar. The microstructure of limestone powder (L) is shown in Figure 1.

Table1. Physical and chemical properties of OPC and L

Property	OPC	L
Physical		
Blaine fineness(m^2/kg)	338	420
mean particle size(µm)	4	32
specific gravity	3.14	2.56
Mineralogical		

C_3S	59.6	-
C_2S	12.6	-
C_3A	7.86	-
C_4AF	9.49	-
Chemical		
SiO_2	19.7	17.65
Al_2O_3	5	3.45
Fe_2O_3	3.16	1.56
CaO	63.03	49.57
MgO	1.75	2.11
K_2O	0.16	0.78
Na_2O	0.2	0.3
SO_3	2.8	0.3
LOI	2.58	23.43

OPC: ordinary Portland cement, L: limestone

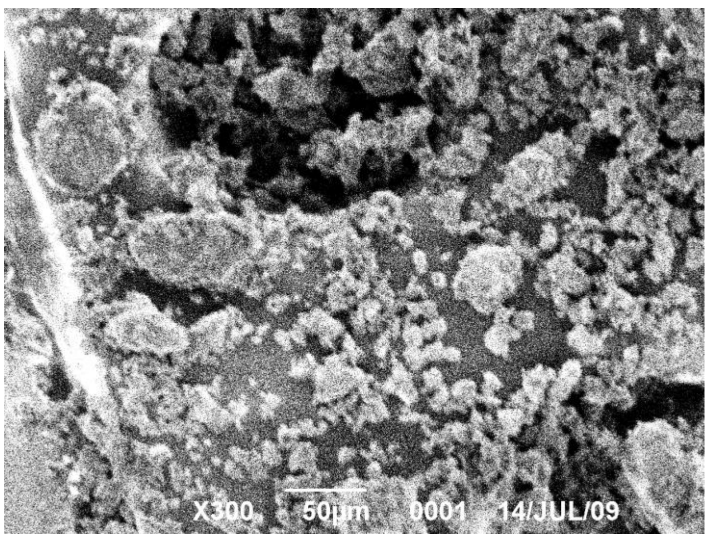

Fig. 1. Microstructure of limestone powder (SEM)

METHODS

Ordinary Portland cement (OPC) was partially replaced by limestone (L) powder at 10%, 20%, 25%, 30%, 35% and 40% to prepare both pastes and mortars. Water demand and setting time was determined on the OPC and L mixture paste using the Vicat apparatus whilst compressive strength test was determined on the mortars. The OPC and L mortar mix was prepared using a binder-to-sand ratio of 1:3 whilst maintaining the water-to-binder ratio at 0.4. The prepared mortar mixes were filled in a 75mm metallic cube moulds and arranged on an electric vibrator which was turned on for 2 minutes to ensure good compaction of the mortar. After casting, the mortar specimens were covered with a wet cloth in order to control water evaporation from the mortar during the hydration process for 24 hrs. After the 24 hrs the moulds containing the mortar were demoulded and then transferred into the curing tank containing the tap water for curing. The compressive strength was determined on an average of 3 mortar specimens after curing in the tap water for 28 days which was in accordance with the EN 197-1 standards.

RESULTS AND DISCUSSIONS

Water demand and setting times

Table 2 shows the water demand and setting times (initial and final) of ordinary Portland cement (OPC) and powdered limestone (L) mixture paste. It can be seen from the table that the inclusion of limestone powder from 10% to 40% demanded more water, estimated between 3.6% and 7% more than the control paste (C). The water demand for the paste labeled L10, L20, L25 and L30 were steady at a value of 0.29. Beyond L30, that is at L35, water demand increased to 0.3 which was the highest. It remained at this highest point of 0.3 up to L40. Helal [2002] obtained similar results and attributed the high water demand of limestone incorporated paste as due to its water absorption capability. The fact that L35 and L40 indicated the highest water demand shows that the blended cement paste contained finer particles of limestone within the cement paste and therefore increased the surface area [Rao Appa 2003].

The initial setting time as given in Table 2 shows that the blended cement paste containing between 10 and 40% limestone content were higher, estimated between 27.7% and 69.8% more than the control cement paste (C). The trend of the initial setting time at L10, L20, L25, L30 and L35 was similar. The trend was however seen to decrease from L35 to L40 as compared to the pure cement paste. The delayed in the initial setting time between L10 and L40 as compared to the pure cement paste could be attributed to the decrease in the stiffening agent, Portland cement, which has the potential of causing a faster setting. L40 showed a fall in the initial setting time and this could be attributed to the fact that at that higher dosage, cement compounds reactivity could be enhanced.

The final setting time as shown in Table 2 was reduced at L10, L20, L25, L35 and L35, and computed to be between 12.6% and 25.5% less than the control paste (C). Similar final setting time results were obtained by Helal [2002]. He explained that the decrease in the final setting time was due to the formation of increased amounts of calcium carboaluminates hydrates which have a high rate of formation at early age of the hydration process. L40 had its final setting occurring at 232 minutes almost the same as the plain cement paste at 231 minutes. At this dosage of limestone content (40%), it could mean that there was a dilution of the cement paste that resulted in a delay of the final setting time.

Table 2. Mix proportion, Water demand and Setting times of OPC and L paste.

Mix	Mix Proportion		Water demand	Setting time(mins)	
	OPC	L		Initial	Final
C	100	0	0.28	83	231
L10	90	10	0.29	141	174
L20	80	20	0.29	134	172
L25	75	25	0.29	140	202
L30	70	30	0.29	138	183
L35	65	35	0.3	136	192
L40	60	40	0.3	107	232

OPC= ordinary Portland cement, C= control, L= limestone

Compressive strength

Figure 2 shows the mortar strength results of a mixture of ordinary Portland cement (OPC) and limestone (L) mortar at 28 days. The compressive strength of plain mortar (C), L10, L20 and L25 were 26.0MPa, 20.4MPa and 23.2MPa respectively, higher than 20.0MPa required for a type M mortar. L30 and L35 had values of 19.2MPa and 17.8MPa respectively which were higher than the minimum strength required to produce a type S mortar of 14.8MPa. L40 had a strength value which was below type S mortar strength requirement. The results suggest that 10% and 25% of limestone contents (L) in cement mortar are more appropriate for a type M mortar whilst those from 30% to 35% are suitable for a type S mortar. Limestone content of 40% in masonry mortar is not suitable for either type M or S mortar.

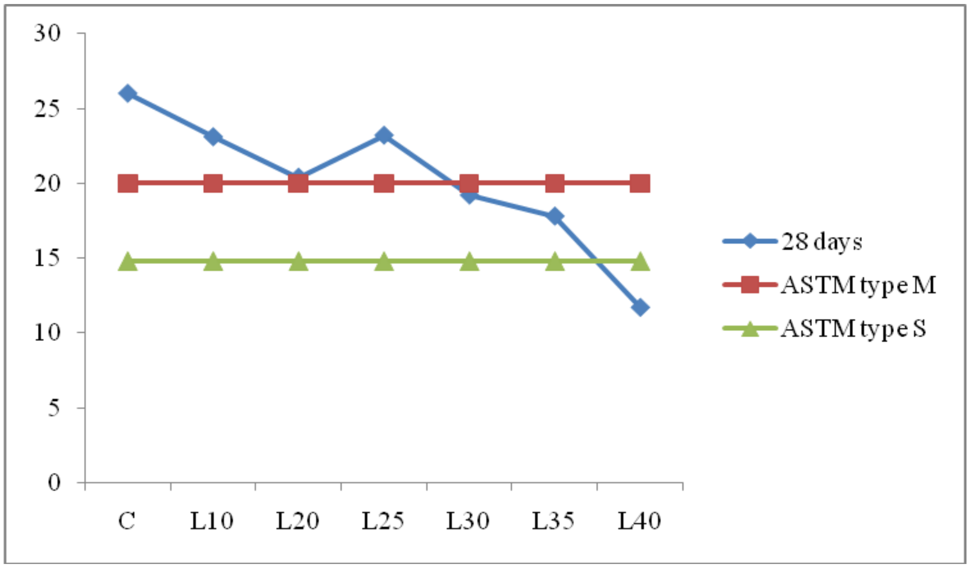

Fig. 2. 28-days Compressive strength of OPC-L masonry mortar blend compared to ASTM standards

Table 3. General recommendation on masonry mortar type selection by ASTM C91

Masonry mortar type	Location	Building segment	28days compressive Strength (MPa)
Type M	Exterior above grade Interior	load bearing walls load/non load bearing walls	20
Type S	Exterior at or below grade	foundation walls, retaining walls manholes, sewers, pavements, patio, parapet walls	14.5

CONCLUSIONS

The following conclusions are made from the study:

1. From the chemical composition, it is deduced that the limestone powder contains 88.7% of $CaCO_3$ in pure calcite form. By European standards, EN 197-1, the minimum $CaCO_3$ requirement is 75%.

2. Partial substitution of OPC by limestone powder between 10% and 40% demands more water than the unblended OPC paste.

3. Ordinary portland cement paste containing between 10% and 30% has the same value for water demand, however between 35% and 40% of limestone content, the water demand is high.

4. The formulated paste containing from 10% to 40% replacement of OPC by limestone shows retarded initial setting times as compared with OPC paste, however the final setting is shorter than OPC paste.

5. The 28-day compressive strength of mortars containing 10% and 25% limestone content is higher than type M mortar strength and therefore best for it, whereas from 30% to 35% content is higher than type S mortar strength and can therefore be used apprropriately to produce mortars of that class.

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