Analysis of Ground Clay Brick as Supplementary Cementitious Material

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Abstract: Present work evaluates performance of binder composed with partial replacement of ordinary Portland cement (OPC) using ground clay bricks (GCB) used in building construction. The replacement level of OPC with GCB is kept as 5%, 15% and 35%. The results demonstrate that addition of GCB do not produce any detrimental effect on performance of the binder in terms of normal consistency (NC), setting time and soundness. The compressive strength of the binder is reducing with increasing replacement of OPC with GCB at all ages. The reduction in 28-D compressive strength is not very significant upto 15% cement replacement level, but is significant at 35% cement replacement level compared to OPC and fly ash based binders. Gain of strength from 28 to 56 days for all the GCB based binders is higher than that of OPC and fly ash based binders indicating good pozzolanic activity of GCB. Based on the results of the study we can conclude that ground clay bricks can be used as supplementary cementitious material.

Keywords: Ground clay brick powder, binder, paste, mortar, compressive strength.

INTRODUCTION

Concrete is everywhere. It is the second most consumed material after water and it shapes our built environment. Concrete is extremely durable and can last for hundreds of years in many applications. Popularity of concrete as construction material is on three counts, i) excellent mouldability, ii) adequate (compressive) strength, and iii) amenable to the utilization of local materials as ingredients. Another reason for its popularity is that it can be manufactured at site maintaining requisite quality without much elaborate production process. It is estimated that roughly 25 billion tonnes of concrete is manufactured globally each year. This means over 3.8 tonnes per person in the world each year. According to the concrete recycling report of World Business Council for Sustainable Development (WBSCD), China and India are now producing and using over 50% of the world's concrete, their waste generation will also be significant as development continues [1].

The main source of carbon emissions in concrete is in cement production. The majority of the cementitious binder used in concrete is based on Portland cement clinker which is an energy-intensive process. As per WBSCD's Cement Sustainability Initiative (CSI) progress report 2005, one ton of cement production is responsible for one ton of CO_2 emission: half of the CO_2 is from the chemical process of clinker production, 40% from burning fuel, and the remaining 10% is split between electricity use and transportation. According to the recent data of the WBSCD, globally, cement industry produces 5% of global man-made CO_2 [2].

Annual global cement production as of 2012 is over 3.6 billion tons, and is expected to be increased soon to over 4 billion tons per year, nevertheless, the cement industry is confronting with the continuous increase in cost for energy supplies, the obligations to reduce CO_2 emission and the need of appropriate supply of raw materials both in quality and quantity. Cement cannot be recycled. The cement content in concrete cannot be viably separated and reused or recycled into new cement and thus carbon reductions cannot be achieved by recycling concrete [1].

Materials containing calcium, aluminates, and amorphous phases of silica, in addition to other phases, can react within the environment of hydrating cement to provide a product which shares some of the properties of Portland cement through a secondary reaction known as the pozzolanic reaction. The use of supplementary cementitious materials (SCMs) to offset a portion of the cement powder in concrete is a promising method for reducing the environmental impact of the industry. If an alternative material can be substituted for at least a portion of the cement powder that does not contribute additional green house gasses to the atmosphere, conserves natural resources, and does not negatively affect the properties of the resulting concrete, then the environmental impact of the industry can be reduced [3, 4]. As an added incentive, researchers and manufacturers of cement and concrete have explored ways to not only offset the use of cement powder, but to improve the properties of the resulting concrete, reduce the cost of the materials, and further reduce environmental damage by utilizing streams of waste material as SCMs [5].

Several industrial by-products have been used successfully as SCMs, including silica fume (SF), ground granulated blast furnace slag (GGBFS), and fly ash (FA). These materials are used to create blends of cement which can improve concrete durability, early and long term strength, workability, and economy [6, 7].

The present work aims at examining the possibility of using ground clay bricks as a supplementary cementitious material. The scope of work will include studying the performance binders composed with partial replacement of ordinary Portland cement (OPC) with ground clay bricks in terms of consistency, setting time, soundness and compressive strength. The results of the investigation will give the performance of the binders made using waste clay bricks powder as partial replacement of ordinary Portland cement as a cementitious material. The findings of this investigation may instigate further research on effect of these materials on the hydration of the cementitious system, concrete microstructure and long term performance of concrete towards better understanding of these materials as supplementary cementitious material.

LITERATURE REVIEW

This section reviews the research and literature that focuses on the different aspects like workability, and strength of paste/mortar/concrete made using clay brick powder as partial replacement of OPC. A considerable amount of effort has been undertaken by the research community for an intimate understanding of using these materials as SCM. The evidence of usage of cementitious material in Egypt, Greek and Italy is understood well before Christian era [8].

According to Campbell and Pryce in Reference [9], the earliest fired bricks discovered so far dates back to 5000–4500 BC in Mesopotamia. Despite the advanced technology used in nowadays clay brick manufacturing, the significant amounts of products are still discarded because they do not confirm the standards. Sinton C W writes in their book that some clay minerals possess pozzolanic property when thermally treated: upon heating interlayer water is removed, crystal structure is destroyed, and a new material with pozzolanic property is formed [10]. Pozzolans have been known to construction industry since the ancient Greeks. The volcanic ash from Santorin Island in Aegean Sea was used in lime mortars to build durable structures [11]. Baronia and Binda report that the successors of the Greeks, the Romans, refined the practice and discovered new pozzolana sources one of which is brick powder. When the natural pozzolanic material was not available the Romans used powdered brick to mix with lime to obtain a strong, durable binding material [12].

The results of the study done by the authors on cementitious pastes where cement was replaced by ground clay bricks (GCB) up to 25% showed that the effect on normal consistency and time of setting was insignificant; the temperature rise during hydration was reduced; and the calcium hydroxide production was decreased. The mechanical properties of concrete have values low at early age but higher or comparable at later ages and the resistance to chloride penetration was improved. These results suggested a pozzolanic activity provided by finely ground brick [13].

Calcined kaolin, or metakaolin, has been successfully used in mass concrete applications in Brazil since 1965. The production cost was one third of the Portland cement and it suppressed the potential alkali-aggregate reaction in several dams built with reactive aggregate [14]. The most kaolin-rich and the mostly poorly crystallized clay show the best pozzolanic activity [15]. Kaolin is an essential ingredient of clay brick manufacturing due to its sintering behaviour [16]. Therefore, kaolin-rich clay brick may show pozzolanic activity in finely divided form and has potential to be used as supplementary cementitious material. Wild et al. achieved to produce pozzolan by heat treatment of Oxford clay used in brick production [17] In their study with eight different clay bricks from Britain, Denmark, Lithuania, and Poland, authors carried out chemical test for pozzolanicity and compression test for strength development of mortar mixtures containing up to 30% ground brick as cement replacement; and concluded that all the ground brick types used in the study exhibit pozzolanicity [18].

In Reference [19] found that ground brick improves the resistance of mortar to aggressive environments. O'Farrell et al. showed the resistance of mortar mixtures to sulfate attack is increased when ground brick is added to mixture; similarly, negative effects of seawater on the mortar mixtures were mitigated [20]. The study done by Bektas et al. on the cementitious pastes showed that the ground brick slightly increased the water demand for normal consistency, delayed the time of setting, reduced the temperature rise during hydration, and decreased the $Ca(OH)_2$ content. The tests on concrete showed that the mechanical properties (compressive, flexural and splitting tensile strengths and modulus of elasticity) of concrete containing ground brick were well comparable to those of the concrete without ground brick. Furthermore, the GCB increased the resistance of concrete to chloride ion penetration [21].

In a comprehensive research project, Copernicus Research Project—CIPA-CT94-0211-1998, on the use of waste clay brick and tile material as partial cement replacement, ground brick is found to decrease early age strength but at later ages strength values of ground brick concrete reach or exceed that of control mixture [22]. A recent study by Toledo Filho RD et al. on mortars containing up 40% of waste clay ground brick demonstrated that the compressive strength is not negatively affected up to 20% replacement and resistances to chloride ion penetration and sulfate attack are increased [23]. Lin and Chiou have found that the effect of replacing 10–50% of cement with waste brick increased the initial and final setting times. The compressive strength of waste brick cement pastes developed slowly in the early ages, and increased at the later ages [24].

Rocha et al. have studied the influence of stone cutting waste and ground waste clay bricks, in isolation and in combination, on hydration and packing density of cement paste. Here the authors have found that in a paste composing of Portland cement and ground clay brick, a small acceleration of hydration reactions was also observed at early ages. The reduction in the amount of Calcium Hydroxide and the increase in the amount of combined water indicated that the ground clay bricks had pozzolanic activity. However, the packing density of the paste composing of Portland cement and ground clay brick was lower than that of the Portland cement paste and a decrease of compressive strength occurred [25].

EXPERIMENTAL PROGRAMME

As part of the project ground waste clay bricks will be analysed for their suitability as a supplementary cementitious material. Samples of the clay bricks will be collected from local construction site and ground to powder having cement equivalent fineness. The performance of this powder will be tested using binders composed of partial replacement of 53 grade OPC. This clay brick powder will be subjected to chemical analysis and particle size distribution (PSD). Total six binder compositions will be used for the project. 53 grade Ordinary Portland cement complying with IS 12269-2013 [26] will be one binder. The other five binder compositions will be with 5%, 15% and 35 % replacement of OPC with waste brick powder (GCB), and with 15%, 35% replacement of OPC with fly ash.

The binders will be designated as follow;

1) 100-OPC = 100% OPC
2) 5-GCB = 95% OPC + 5 % GCB
3) 15-GCB = 85% OPC + 15 % GCB
4) 35-GCB = 65% OPC + 35 % GCB
5) 15-FA = 85% OPC + 15 % FA
6) 35-FA = 65% OPC + 35 % FA

RESULTS AND DISCUSSION

Ingredient Analysis

Figure 1 shows the images of clay bricks and brick powder after grinding in laboratory ball mill.

Fig 1 Waste Bricks and Brick Powder

The chemical properties and specific gravity of OPC, FA and GCB are given in Table 1. The particle size distribution of OPC, FA and GCB are given in Table 2.

Table 1 – Chemical Properties and Specific Gravity of OPC, FA and GCB

Parameter	GCB	FA	OPC
SiO_2(%)	45.72	55.94	23.91
Al_2O_3	21.39	32.17	5.01
Fe_2O_3 (%)	18.41	4.89	3.70
CaO(%)	2.45	1.38	62.15
MgO(%)	3.09	0.73	0.68
Na_2O(%)	0.76	0.18	0.25
K_2O (%)	0.82	1.66	0.51
SO_3 (%)	0.07	0.23	1.80
Cl (%)	-	-	-
TiO_2 (%)	2.70	1.47	0.41
LOI (%)	3.78	0.58	3.88
IR (%)	-	92.93	1.08
Sp. Gr.	2.7	2.2	3.15

The analysis of PSD of OPC, FA and GCB indicates that the fly ash is very fine with mean particle diameter of almost 1/10th of that of OPC. With such a fine PSD the fly ash is likely to exhibit high reactivity. GCB is the coarsest of all the three materials with mean particle diameter of 70.43 micron.

Table 2 – Particle Size Distribution of OPC, FA and GCB

Material	Particle Size Distribution (μ)			
	D_{10}	D_{50}	D_{90}	Mean Diameter
GCB	2.71	41.17	178.22	70.43
FA	0.27	1.70	4.68	2.13
OPC	6.85	23.94	54.16	27.72

Consistency, Setting Time and Soundness Test

All the six binders are subjected to the standard consistency (NC), initial setting time (IST), final setting time (FST), soundness test, both Le-Chatelier and Autoclave expansions as per IS 4031 (Parts – 4, 5 and 3) respectively [27, 28, 29].

The NC, IST, FST, Le-Chatelier and Autoclave expansions of the 6 different cement pastes made using varying replacement with GCB are given in Table 3. The results show that the NC of the paste increases with the increasing replacement of cement with GCB. This indicates that the addition of GCB reduces the plasticity of the paste. This means that the desired plasticity/rheology can be achieved with higher water content while using GCB as cement replacement material compared with 100% OPC.

The IST has slightly increased from 165 minutes to 175minutes with 5% GCB replacement compared 100% OPC. Whereas, the IST has shown reducing trend with increasing addition of GCB i.e. reduction of 10 minutes and 35 minutes for 15 and 35% replacement by GCB respectively compared to 100% OPC. The FST has slightly increased from 230 minutes to 255minutes with 5% GCB replacement compared 100% OPC. Whereas, the FST has shown reducing trend with increasing addition of GCB i.e. reduction of 15 minutes and 45 minutes for 15 and 35% replacement by GCB respectively compared to 100% OPC. Although, both the IST and FST are reducing with the increasing replacement level of GCB, it is well within the requirement of the code i.e. minimum 30minute for IST and maximum 600minutes for FST respectively [26].

The Le-Chatelier expansion has increased to 1mm compared to 0.5mm with the 100% OPC paste. The Autoclave expansion has rather reduced to 0.03% for the paste with 5% GCB compared to the control mix with 100% OPC; whereas it has rather reduced to 0.04% for the paste with 15% and 35% GCB replacement as compared to the control mix with 100% OPC. Although, both the Le-Chatelier and Autoclave expansions are showing varying trends with addition of GCB both the expansions are well within the requirements of the code i.e. maximum 10mm for Le-Chatelier expansions and 0.8% for Autoclave expansions respectively [26].

Results of the above tests indicate that the GCB do not show any harmful effect on paste performance when used as partial replacement of OPC hence can be used as a cement replacement material.

Table 3 – NC, IST, FST and Soundness of Paste with Different Binders

Binder Designation	NC (%)	Setting Time (minutes)		Soundness	
		IST	FST	Le-Chatelier (mm)	Autoclave (%)
100-OPC	31	165	230	0.5	0.08
5-GCB	32	175	255	1	0.03
15-GCB	33	155	215	1	0.04
15-FA	31.33	175	240	0.4	0.07
35-GCB	35.33	130	185	1	0.04
35-FA	32.66	185	270	0.6	0.1

Compressive Strength Test

For the Compressive Strength Test, total six mortar compositions will be formed one each for the six binders as designated above. All the six mortars will be tested for cube compressive strength following the guidelines of IS 4031(Part-6) [30]. The mix composition of the mortar will be kept as 1 part of the binder with 3 parts of standard Ennore sand used for cement testing. The standard Ennore sand is composed of 3 particle sizes is equal proportions namely: smaller than 2mm – greater than 1mm; smaller than 1mm – greater than 0.5mm and smaller than 0.5mm – greater than 0.09mm. The size of the mortar cube will be 70.7*70.7*70.7 mm. The mortar cubes will be tested for compressive strength at 1, 7, 28 and 56 days. The compressive strength of the mortar made with OPC and varying replacement level of OPC with GCB from 5, 15 and 35% are given in Figure 2. The results of the compressive strength test indicates that the compressive strength of the binder is reducing with the increasing addition of GCB as cement replacement material compared to 100% OPC, 15% FA and 35% FA binder .

The 1-day compressive strength of the 100% OPC as binder is 18.4MPa. Although 1 day compressive strength of the binder made with 5% replacement of OPC with GCB is 4% more than that of 100% OPC binder; at 15 and 35% replacement of OPC with GCB it has reduced by 15 and 50% respectively as compared to that of 100% OPC binder. The 28 days compressive strength of the 100% OPC binder is 60.9MPa. The 28 days compressive strength of the binder composed with 5, 15 and 35% replacement of OPC using GCB is reduced by 10, 17 and 36% respectively than that of 100% OPC binder.

However, the gain of strength from 28-days to 56-days is 14% for 100% OPC binder whereas that for binder composed with 5%, 15% and 35% cement replacement of OPC with GCB is 18%, 17% and 24% respectively. This indicates enhanced hydraulic activity at later age when using GCB as a cement replacement material in increasing replacement level of OPC as compared to 100% OPC.

For comparison purpose two more mortar mixes were produced with same mix composition but with replacement of OPC by high grade fly ash at 15 and 35 percent replacement level. The 1-day strength of binder with 15% replacement of OPC by fly ash exhibited almost same strength compared to that with GCB. But, the 1-day strength of binders with 35% replacement of OPC by fly ash exhibited 11% higher strength compared to that of the binder with 35% GCB. However, at 28 days, the compressive strength of binder with 15% fly ash is 14% higher than that of the binder with 15% GCB; whereas the compressive strength of binder with 35% fly ash is 19% higher that than with 35% GCB. The higher 28 days strength of fly ash mixes is possibly due to high reactivity of fly ash with very finer particle size compared to that of GCB. But, the gain of strength from 28 to 56 days of the binders with GCB is 2% more than that of binders with FA at 15 CRL and is same as that of FA based binder at 35% CRL, indicating better pozzolanic activity of the GCB compared to fly ash at 15% as well as 35% CRL.

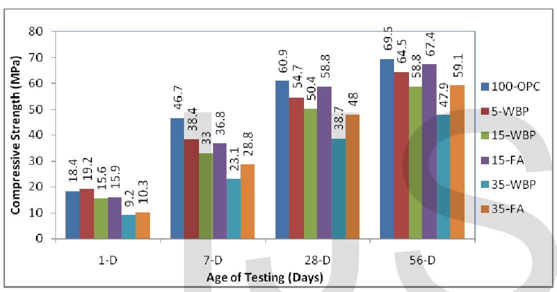

Fig 2 Compressive Strength of Different Binders at various Ages

CONCLUSION

Based on the results of the above experimental work we can conclude as follows;

1) Addition of clay brick powder, as a SCM, up to 35%, do not produce any detrimental effect on the performance of the binder in terms of consistency, setting times and soundness.
2) Although compressive strength of the binder is reducing with the increasing cement replacement levels of OPC with brick powder at all ages compared to 100% OPC, 15% and 35% fly ash based binder, the higher recovery of compressive strength from 28 days to 56 days for binders with clay brick powder indicates enhanced pozzolanic activity of the clay brick powder.
3) The particle size distribution of clay brick powder, OPC and FA shows that the brick powder used for this study is very coarser than that of OPC and FA.
4) Based on the above we can conclude that ground clay brick is exhibiting comparable pozzolanic behaviour and can be used as supplementary cementitious material up to 35% cement replacement level.
5) Further research is needed to evaluate the performance of ground clay brick in concrete in terms of plastic properties, strength and durability performance as well as microstructural analysis of concrete made using ground clay brick as SCM. Also, a further research can be undertaken towards understanding the hydration of the binders with ground clay brick.

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