American Journal of Materials Engineering and Technology, 2013, Vol. 1, No. 3, 35-40
Available online at http://pubs.sciepub.com/materials/1/3/2

DOI:10.12691/materials-1-3-2

Experimental Studies on Fly Ash-Sand-Lime Bricks with Gypsum Addition

Tahmina Banu, Md. Muktadir Billah, Fahmida Gulshan, ASW Kurny*

Department of Materials and Metallurgical Engineering, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh
*Corresponding author: aswkurny@mme.buet.ac.bd

Received August 14, 2013; Revised August 26, 2013; Accepted August 28, 2013

Abstract Coal fly ash, a burnt residue of pulverized coal, is hazardous and its disposal is a problem. In Bangladesh, the annual generation of this waste is approximately 0.6 million tons. On a global basis, less than 20 percent of coal fly ash (CFA) is used in the concrete related applications while the remainder is disposed of in landfills leading to various environmental problems such as polluting soils and groundwater. In this study, production of light weight structural bricks using fly ash, generated at Barapukuria Thermal Power Plant, as the major ingredient has been investigated. Optimum mix of fly ash, sand, hydrated lime and gypsum has been identified and the brick forming pressure was also optimized. 55% fly ash, 30% sand and 15% hydrated lime with 14% gypsum was found to be the optimum mix. The compressive strength, microstructure, shrinkage property, unit volume weight, Initial rate of absorption, absorption capacity, apparent porosity, open pore and impervious pore of the fly ash–sand–lime-gypsum bricks produced with optimized composition under various brick forming pressures were determined. Efflorescence and radio activity of the bricks formed under optimized conditions were also investigated. Later on effect of various curing process and variation of curing period were studied. The results of this study suggested that it was possible to produce good quality light weight non-fired structural bricks from coal fly ash generated at Barapukuria Thermal Power Plant.

Keywords: *coal fly ash, structural bricks, sand, gypsum, microstructure, properties*

Cite This Article: Tahmina Banu, Md. Muktadir Billah, Fahmida Gulshan, and ASW Kurny, "Experimental Studies on Fly Ash-Sand-Lime Bricks with Gypsum Addition." *American Journal of Materials Engineering and Technology* 1, no. 3 (2013): 35-40. doi: 10.12691/materials-1-3-2.

1. Introduction

Pulverized fuel ash commonly known as fly ash is a useful by-product from thermal power stations using pulverized coal as fuel. The high temperature of burning coal turns the clay minerals present in the coal powder into fused fine particles mainly comprising aluminium silicate. Fly ash produced thus possesses both ceramic and pozzolanic properties. Fly ash is a hazardous waste. The problem with fly ash lies in the fact that not only does its disposal require large quantities of land, water, and energy, its fine particles, if not managed well, by virtue of their weightlessness, can become airborne. When not properly disposed, fly ash is known to pollute air and water, and causes respiratory problems when inhaled.

Globally around 20% fly ash is used in concrete related applications. Mainly $CaO–SiO_2–H_2O$ and $CaO–Al_2O_3–SiO_2–H_2O$ phases contribute to hardening [1,2]. Fly ash is also utilized in many different areas like paints, plastics and in agriculture [3,4,5,6,7]. In Bangladesh about 0.6 million tons fly ash is produced annually and its production is likely to increase significantly because the future power plants in Bangladesh are likely to be coal fired. Use of fly-ash is, on the other hand, yet to be popular. A small quantity of imported fly-ash is reported to be used in the manufacture of cement in Bangladesh. A viable option for the bulk utilization of fly-ash could be in the production of structural bricks containing fly ash as a major ingredient. The manufacture of conventional clay bricks involves the consumption of large amounts of clay. This depletes topsoil and causes degradation of agricultural land. If fly ash bricks containing no clay can be manufactured then this would not only help preserve the topsoil but also reduce environmental problem by caused by dumped fly ash.

In this study an attempt has been made to produce light weight bricks for structural applications using fly-ash generated at the Barapukuria Thermal Power Plant.

2. Materials and Methods

Fly ash, sand and hydrated lime mixtures with gypsum as a binder were used to make bricks. Process variables like the composition of the mix, pressure, curing conditions, etc were optimized. Finally the properties of the bricks produced under the optimum conditions were determined.

Fly ash used in this study was collected from Barapukuria Thermal Power Plant. The other ingredients hydrated lime, sand and gypsum were collected from the local market. The major ingredients in fly-ash are presented in Table 1.

Table 1. Chemical composition of Barapukuria Power plant fly-ash

Compound	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
Mass fraction, %	48.20	41.24	3.37	3.31	0.20

Brick specimens were produced under the conditions given in Table 2. At least five bricks were made for each specimen type. Before making a brick, each ingredient of the raw materials was dried in a muffle furnace at 110℃ for 24 hour. Required amount of each ingredient was weighed, 14% moisture was added and the components were mixed thoroughly. To ensure uniform size of the bricks a known weight of mixture was used each time to fill the mould cavity. Dimension of the mould cavity opening was 6 X 3.5 cm. A hydraulic press was used to apply pressure for a period of 15 Sec (Figure 1). The bricks (Figure 2) were then ejected and finally cured. Curing was done in air, using water spray, by putting the bricks under wet cloth and by keeping the bricks immersed in water. Bricks formed under various pressures were also cured for different periods in optimum curing condition.

Figure 1. Hydraulic press

Figure 2. Fly ash-sand-lime-gypsum bricks

Table 2. Test parameters

Bricks code	Sand wt %	Fly ash wt %	Lime wt %	Gypsum wt %	Forming Pressure (psi)	Curing process	Other parameters
T1	10	80	10	2	1000	In air*	14% moisture added Pressure applied for 15 sec Number of bricks for each type is at least 5
T2	20	70	10	2	1000	In air*	
T3	30	60	10	2	1000	In air*	
T4	40	50	10	2	1000	In air*	
T5	30	65	5	2	1000	In air*	
T6	30	62.5	7.5	2	1000	In air*	
T7	30	60	10	2	1000	In air*	
T8	30	57.5	12.5	2	1000	In air*	
T9	30	55	15	2	1000	In air*	
T10	30	55	15	2	1000	In air*	
T11	30	55	15	6	1000	In air*	
T12	30	55	15	10	1000	In air*	
T13	30	55	15	14	1000	In air*	
T14	30	55	15	14	1000	In air*	
T15	30	55	15	14	2000	In air*	
T16	30	55	15	14	3000	In air*	
T17	30	55	15	14	3000	In air*	
T18	30	55	15	14	3000	Under water spray*	
T19	30	55	15	14	3000	Under wet cloth*	
T20	30	55	15	14	3000	Under water*	
T21	30	55	15	14	1000	In air**	
T22	30	55	15	14	1000	In air and then water***	
T23	30	55	15	14	2000	In air**	
T24	30	55	15	14	2000	In air and then water***	
T25	30	55	15	14	3000	In air**	
T26	30	55	15	14	3000	In air and then water***	

*Curing period 7 days, **Curing period 5 weeks
***Cured 7 days in air and then 4 weeks in water

2.1. Test Methods

2.1.1. Compressive Strength

Compressive strength was determined by applying load on the specimen using a Universal Testing Machine. Load was applied on an area measuring 6mm X 3.5 mm [The size of one face of the entire brick].

2.1.2. Microstructure

The samples were observed under an optical microscope (OM) and micrographs were recorded with a digital camera (OPTIKA Microscope B-600 MET) to investigate porosity. No preparation of the samples was done.

2.1.3. Shrinkage Property

Dimensions of the bricks were measured immediately after making the bricks and also after curing to determine the shrinkage of the bricks.

2.1.4. Unit Volume Weight

After 7 days of curing period bricks were dried at 110℃ for 24 hr and then allowed to cool to room temperature. Dry weight D (gm) was then measured. Following that the bricks were immersed for 24 hr in water at room temperature and suspended weight S (gm) was measured. The bricks were then removed, the surface water was wiped off with a damp cloth and the saturated weight W (gm) was measured within 5 min after removing the bricks from the water bath. Unit volume weight B, $gm/cm^3 = D/V$, where volume V, $cm^3 = (W - S)$ was calculated.

2.1.5. Initial Rate of Absorption (IRA)

After measuring dry weight D (gm) as mentioned earlier, the bed surface of the brick (the face measuring 6mm X 3.5 mm) was caused to absorb water for 1 min. Water was wiped out completely from the surface of the brick within 10 s of removal from contact with the water and weight D' (gm) was determined within 2 minutes. Initial rate of absorption IRA, % = D' – D was then calculated [ASTM Designation C 67 – 00].

2.1.6. Absorption Capacity

ASTM Designation C 67 – 00 was followed to measure the absorption capacity A, % = [(W – D)/D].

2.1.7. Apparent Porosity, Open Pore and Impervious Pore

ASTM Designation C 67 – 00 was followed to determine apparent porosity P, % = [(W - D)/ V], Open pore volume, cm^3 = W – D and impervious pore volume, cm^3 = D – S.

2.1.8. Efflorescence Test

This test was carried out according to ASTM C67-08. For this test, one brick was vertically placed in water with one end immersed and another brick stored in ambient condition. After 7 days both bricks were dried in oven at 110℃ for 24 hours. Then both bricks were observed from 10 ft distance under not less than 50 fc with normal vision. If any difference is observed because of presence of any salt deposit then the rating is reported as 'effloresced'. If no difference is noted, the rating is reported as 'not effloresced'.

2.1.9. Radioactivity test

Radio activity of the mixture of optimum composition was examined from Health Physics Division of Bangladesh Atomic Energy Commission.

2.1.10. Variation of Curing Process and Time

Effects of four different curing processes i.e. in still air, with water spray twice a day, keeping the specimen under wet cloth and keeping the specimen immersed under water for seven days were examined. Finally the effect of long duration curing was studied. For optimum composition and different compaction pressure one set of bricks were cured in air for five weeks. Another set was cured in air for one week and then for four weeks under water. Then their compressive strengths were compared. Difference in compressive strength was investigated with Fourier transform infrared spectroscopy (FTIR).

3. Results and Discussions

3.1. The Effect of Sand on Compressive Strength

The specimens T1 – T4 (Table 2) were prepared to determine the effect of amount of sand on compressive strength. The compressive strength could be increased from 113.46 kg/cm^2 to 165.57 kg/cm^2 by increasing the amount of sand from 10 to 40% (Figure 3). The maximum strength was found for 40% sand – 50% fly ash – 10% lime bricks with 2% gypsum. As bulk utilization of fly ash was the major goal of this investigation, the optimum amount of sand was taken to be 30% that gave a compressive strength of 155.20 kg/cm^2**.** The improvement in mechanical strength with increasing sand content has been attributed to a greater extent by the increased amount of free SiO_2 which reacts more easily with lime than fly ash [8].

3.2. The Determination of the Optimum Lime and Fly Ash Content

Compressive strength test results conducted on specimens T5 – T9 showed that maximum strength could be obtained with 15% lime and 55% fly ash (Figure 4). Compressive strength found for this composition was 181.75 kg/cm^2.

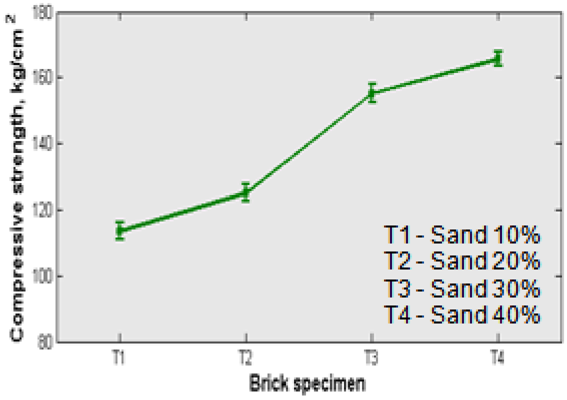

Figure 3. Effect of sand addition on compressive strength

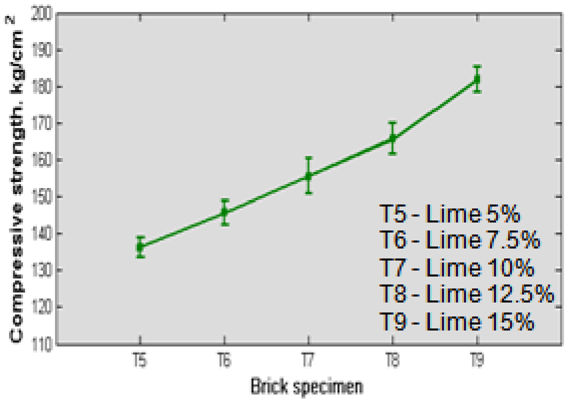

Figure 4. Effect of lime addition on compressive strength

3.3. Optimum Amount of Gypsum Addition

The variation in compressive strengths of specimens T10 - T13 containing varying amounts of gypsum is shown in Figure 5. It can be seen that the compressive strength increased from 181.75 kg/cm^2 for 2 percent gypsum to 287.78 kg/cm^2 for an optimum gypsum content of 14%.

3.4. Effect of Brick forming Pressure on the Compressive Strength

Compressive strength tests on specimens T14 - T16 showed that compressive strength increased with increasing brick forming pressure (Figure 6). Specimen T16 showed maximum compressive strength of 417.96 kg/ cm^2 for a brick forming pressure of 3000 psi.

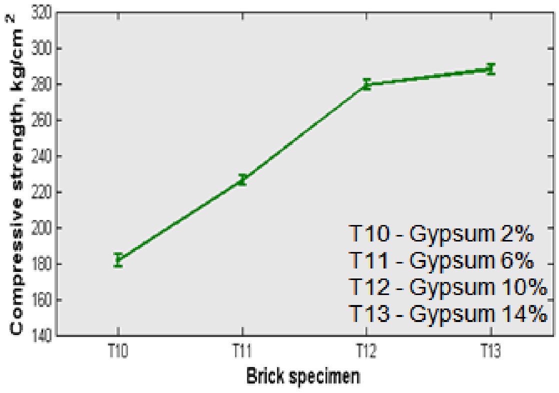

Figure 5. Effect of gypsum addition on compressive strength

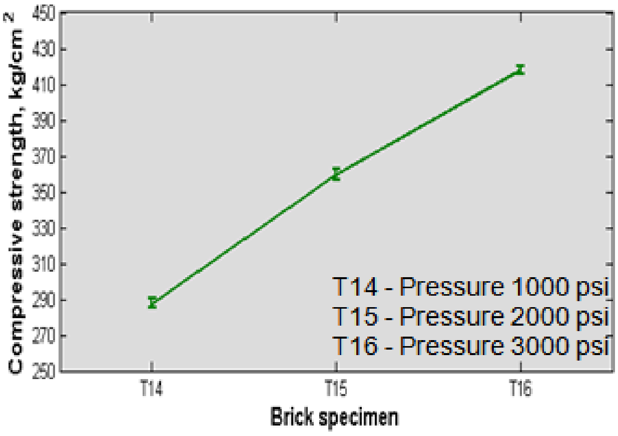

Figure 6. Effect of brick forming pressure on compressive strength

3.5. Microstructure

Specimens T14, T15 and T16 are the specimens with optimum composition and different brick forming pressures. Microstructure and other properties besides compressive strength of these specimens were investigated to optimize brick forming pressure. Figure 7 shows that both individual pore size and total porosity decreased with increasing brick forming pressure. This is to be expected.

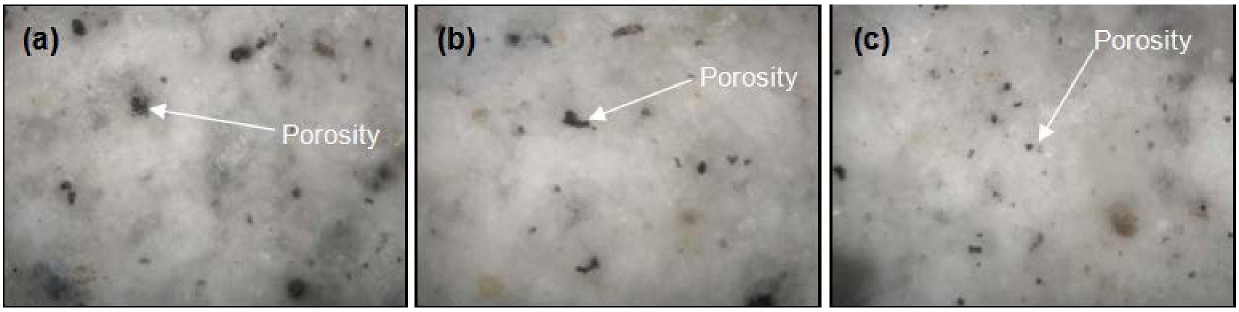

Figure 7. Microstructure of bricks formed with pressure (a) 1000 psi (b) 2000 psi (c) 3000 psi [All magnification 500X]

3.6. Shrinkage property

No noticeable shrinkage occurred as was measured for specimens T14, T15 and T16.

3.7. Unit Volume Weight

With increasing brick forming pressure unit volume weight of the bricks increased (Figure 8). But above 2000 psi the change in density was insignificant. Maximum density of 1.81 gm /cc was found for bricks formed under 3000 psi pressure which is much lower than the density of fired clay based bricks density.

3.8. Initial Rate of Absorption (IRA)

Initial rate of absorption of bricks made under 1000 psi pressure exceeded 30 gm and so according to ASTM C 67 – 00 these bricks should be wetted before laying (Figure 9). With increasing brick forming pressure IRA decreased below 30 gm. Lowest IRA of 14.84 gm was found for a pressure of 3000 psi. So these bricks are not needed to be wetted before laying.

3.9. Absorption Capacity

As shown in Figure 9 absorption capacity was 14.63% for brick forming pressure 1000 psi. With increasing pressure this value dropped down to 11.58% for a pressure of 3000 psi. Above 2000 psi pressure change in absorption capacity was not significant.

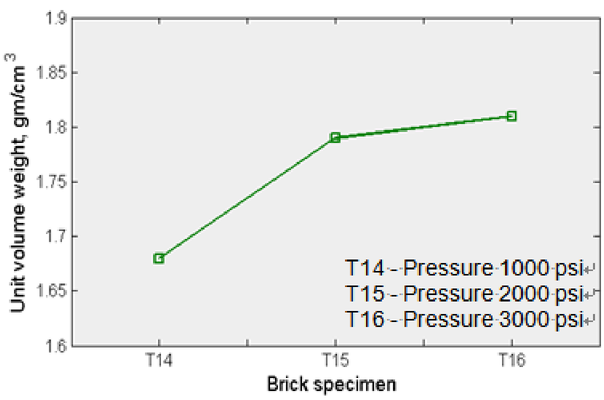

Figure 8. Effect of brick forming pressure on unit volume weight

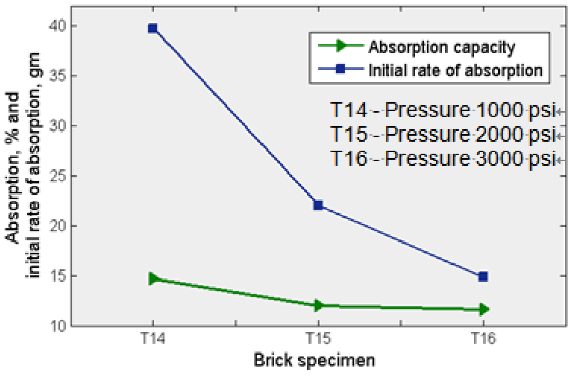

Figure 9. Effect of brick forming pressure on absorption capacity and IRA

3.10. Apparent Porosity, Open Pore and Impervious Pore

Effect of brick forming pressure on apparent porosity, open pore and close pore volume is shown in Figure 10. Apparent porosity decreased with increasing pressure. Above 2000 psi the change was insignificant. Open pore volume also followed the same trend. Whatever, impervious pore volume was not affected by brick forming pressure. This result indicted that more densification at same pressure is possible if close pore can be decreased by means of particle size control.

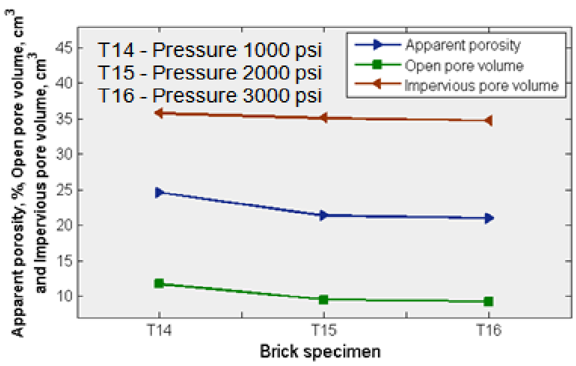

Figure 10. Effect of brick forming pressure on apparent porosity, open pore and impervious pore volume

3.11. Efflorescence

Bricks of optimum composition were found to be 'not effloresced'. As seen in Figure 11 no salt was found on the tested brick surface.

Figure 11. Efflorescence test of bricks of optimum composition

3.12. Radioactivity

Radioactivity of Cesium-137 was below the detection limit of the machine i.e. below 1.54 Bq/kg. So these bricks are not threatening as radioactivity source.

3.13. Effect of Curing Process

Specimen T17 was cured in still air. Specimens T18, T19 and T20 were cured with water spray twice a day, keeping the specimen under wet cloth and keeping the specimen immersed under water respectively. Maximum compressive strength of 442.96 kg/cm^2 was found for specimen T18 (Figure 12).

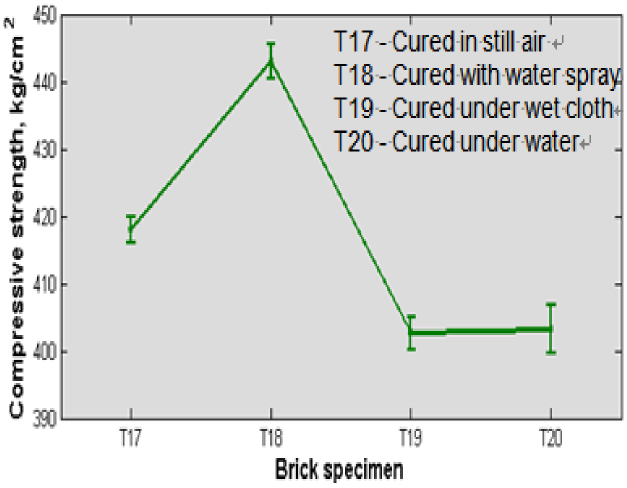

Figure 12. Effect of curing process on compressive strength

3.14. Effect of Curing Period

One set of bricks was cured for seven days in air; one set for five weeks in air and another set for first four weeks in water followed by one week in air. Maximum strength of 877.36 kg/cm^2 was found for bricks formed under 3000 psi pressure and cured in water for four weeks followed by one week in air. FTIR analysis has shown (Figure 14) that when bricks were cured in water for four weeks followed by one week in air instead of five weeks in air, stronger inter-molecular OH-O bond became dominant over the weaker intra-molecular OH bond.

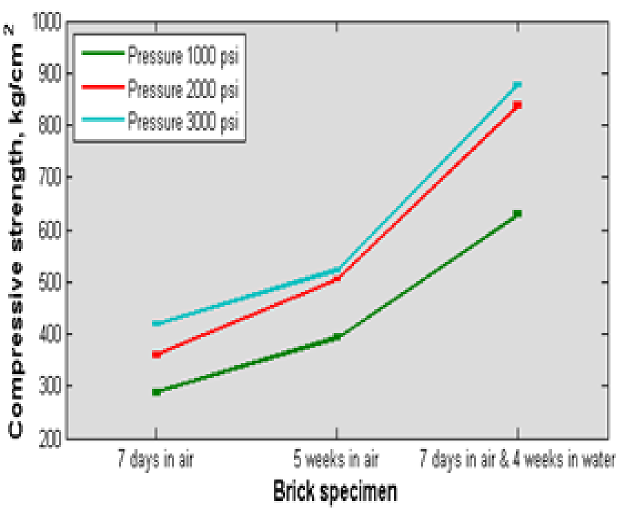

Figure 13. Effect of curing process on compressive strength

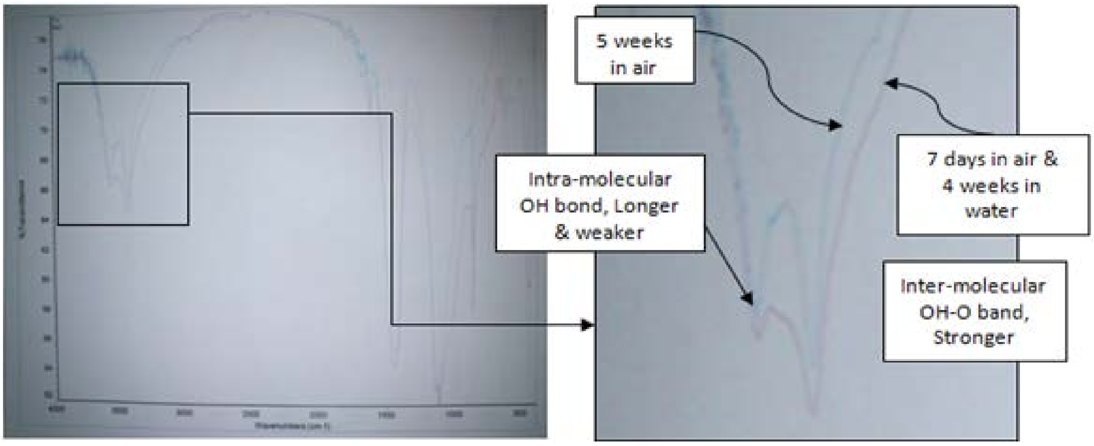

Figure 14. FTIR analysis of bricks cured under different curing condition

4. Conclusions

The following main conclusions can be drawn from this study:

- The optimum composition of fly ash-sand-lime-gypsum unfired bricks was fly-ash 55 percent, sand 30 percent, lime 15 percent and gypsum 14 percent and optimum brick forming pressure was 3000 psi.
- Increased brick forming pressure showed an increase in compressive strength and unit volume weight and a decrease in IRA, absorption capacity, apparent capacity and open pore volume. Impervious pore volume was found to be virtually independent of the brick forming pressure.
- For optimum composition and pressure bricks exhibited following properties:
  1 No shrinkage.
  2 Unit volume weight: 1.81 gm/ cm^3.
  3 Initial rate of absorption (IRA): 14.84 gm. So these bricks need not be wetted before laying.
  4 Absorption capacity: 11.58%.
  5 Apparent porosity: 20.99%.
  6 Open pore volume: 9.23 cm^3.
  7 Impervious pore volume: 34.74 cm^3.
  8 For optimum composition and pressure bricks cured under spray water twice a day exhibited maximum compressive strength of 442.96 gm/ cm^2.

Finally for bricks formed under 3000 psi exhibited maximum strength of 877.36 kg/cm^2 when cured in water for four weeks followed by one week in air and strength was determined by the extent of inter-molecular OH-O bond.

Even though further studies will be required before a final comment is made, the fly ash–sand–lime-gypsum bricks produced in this study seem to be suitable for use as construction material. The production of this type of bricks (if viable technically and commercially) will certainly contribute to the recycling of the fly ash and hence minimize the negative impact on the environment.

References

[1] Goni, S. Guerrero, A. Luxan, M.P. and Macias, A. 2003. Activation of the fly ash pozzolonic reaction by hydrothermal conditions, *Cem Concr Res*, Vol. 33, pp.1399-405.

[2] Klimesch, D.S. and Ray, A. 1998. Effect of quartz particle size on hydro garnet formation during autoclaving at 180 ℃ in the CaO–Al_2O_3 –SiO_2 –H_2O system, *Cem Concr Res*, Vol. 28, pp. 1309-16.

[3] Baykal and Doven, A.G. 2000. Utilization of fly ash by pelletization process; theory, application areas and research results, *Resour Conserv Recy*, Vol. 30, pp. 59-77.

[4] Iyer, R.S. and Scott, J.A. 2001. Power station fly ash-a review of value-added utilization outside of the construction industry resources, *Conserv Recy*, Vol. 31, pp. 217-28.

[5] Pimraksa, K. Wilhelm, M. Kochberger, M. and Wruss, W. 2001. A new approach to the production of bricks made of 100% fly ash, *International ash utilization symposium*, Available from: http://www.flyash.info/agenda.html.

[6] Poon, C.S. Kou, S.C. and Lam, L. 2002. Use of recycled aggregates in molded concrete bricks and blocks, *Constr Build Mater*, Vol. pp. 281-9.

[7] Toktay, M. C. and Etin, B. 1991. Mechanical strength and water absorption properties of autoclaved fly ash-lime bricks, TMMOB, *Chamber of Civil Engineers' Publication*, Vol. 1, pp. 385-394.

[8] Cicek, T. and Tanrıverdi, M. 2007. Lime based steam autoclaved fly ash bricks, *Construction and Building Materials*, Vol. 21, pp. 1295-1300.