Fixation of Coal Fly Ash (CFA) in the Form of Construction Blocks with Variable Combinations of Lime and FGD Gypsum

[1]Ahmed Faraz, [1]Hongzhi Ma*, [2]Muhammad Imran, [2]Sun Hongjuan, [2]Zeng Li, [3]Shuang Wu, [3, 4]Xuguang Wang, [3]Junwei Bai and [3]Kai Shen

[1]*Department of Environmental Science and Engineering, University of Science and Technology, Beijing, Beijing Key Laboratory of Resource-oriented Treatment of Industrial Pollutants, Beijing 100083, China*

[2]*Institute of Mineral Material and Application, Sichuan Engineering Lab of Non-Metallic Mineral Powder Modification and High-value Utilization, School of Environmental Science and Engineering, Southwest University of Science and Technology, Mianyang Sichuan 621010, China*

[3]*Changzhi Shougang biomass energy limited company, No.9 Guxian East Street, Luzhou District, Changzhi City, Shanxi Province*, 046031.

Ahmedfarazkakar1@gmail.com; mahongzhi@ustb.edu.cn*

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Summary: Coal fly ash (CFA) is produced on very large scales in thermal energy plants. The recycling of coal fly ash (CFA) is essential decreasing its environmental impact. In this research, a FaL-G (coal fly ash (CFA), lime, and FGD gypsum) technology is used to reuse coal fly ash (CFA) in brick-type form. First, all of the small-grained FaL-G were dried in the oven at 60°C for 24 h. Three different combinations of coal fly ash (CFA), FGD gypsum, and lime were tested for block preparation. The blocks were treated with five conditions for hardening and drying, i.e., i. Sunlight, ii. Shade (room temperature), iii. Oven, iv. Presence of moisture, and v. Freezer (-16°C). After complete drying, the compressive strength and flexural strength tests were applied. Over all, the sunlight treated blocks showed strong compressive strength of 5.9 MPa and flexural strength of 7.19 MPa. The blocks made through FaL-G technology are very good raw materials for construction, i.e., partition walls and decoration, as these blocks have impressive texture and plain edges. It was the first time that the variable combinations of coal fly ash (CFA), gypsum, and lime were tested through different conditions and have achieved good strength. The literature showed that little work has been carried out through FaL-G, while additional materials have also been used. The main novelty of the current research work is development of an enhanced technique for preparing building materials, stabilizing coal fly ash (CFA), and reducing its environmental hazards.

Keywords: Coal fly ash (CFA), Hazardous Pollutant, FGD Gypsum, Compressive strength, Environmental Sustainability

Introduction

Nearly 180 billion tons of common burnt clay bricks are consumed worldwide annually. For that reason, the FaL-G blocks represent a really good alternative to use hazardous coal fly ash (CFA) to reduce the overall cost of the bricks [1]. The amount of cement or lime or lime plus gypsum required to achieve a certain strength depends on the amount of free lime available in the coal fly ash (CFA). Bricks with larger amounts of coal fly ash (CFA) could however, be considered for use in the construction of new buildings [2]. Unused coal fly ash (CFA) material poses a potential environmental hazard since it often contains trace levels of toxic elements, especially trace metals. coal fly ash (CFA) is a type of solid waste that gets discharged from coal-fired boilers. A splendid amount of water is beneficial for molding, and it is also vital for cementation [3]. As coal fly ash (CFA) is being accumulated as waste in giant quantities in thermal energy plants, its utilization as raw material is a key step [4]. The addition of coal fly ash (CFA) can enhance the quality of the bricks. Bricks with larger amounts of coal fly ash (CFA) can be considered for different purposes in the construction of new buildings [5]. Coal fly ash (CFA) has been used in many countries as an additive in clay bricks. Coal fly ash (CFA) blocks were found to be a better option for the replacement of burnt clay bricks to save natural resources and the environment [6,7]. The coal fly ash (CFA) bricks are lighter in weight and more suitable than frequent clay bricks. Due to its mineralogical and chemical composition, the use of coal fly ash (CFA) in fired products such as bricks, tiles, porcelains, and glass–ceramics is increasing [8]. The durability and overall performance are based totally on the performance of its components such as cement, class of coal fly ash (CFA), quarry dust, metakaolin, and water used in the blocks [9]. Coal fly ash (CFA) concrete has emerged as a valuable source, which

***To whom all correspondence should be addressed.**

accommodates large volumes of coal fly ash (CFA) into conventional Portland cement [10]. Coal fly ash (CFA) on its very own can be a splendid raw material for brick making [11]. The majority of the researchers use similar methods called FaL-G Technology; which is based on the usage of coal fly ash (CFA), cement/lime, and gypsum to manufacture coal fly ash (CFA) blocks through water application. Considering the aqueous reactivity between coal fly ash (CFA), lime, and gypsum gives great strength and flexibility to coal fly ash (CFA) blocks [12]. In recent years a higher level of FaL-G utilization has been noticed for different applications; such as lodging ventures, check dams, water tanks, and asphalts. The possibility of blocks with good strength is depending on (a) calcined phosphogypsum, coal fly ash (CFA) powder, and lime (b) calcined phosphogypsum, coal fly ash (CFA), lime, and application of various temperatures [13].

The objectives of this research were to study the optimal conditions to prepare good quality construction blocks with well-balanced strength and durability while reducing the accumulation of coal fly ash (CFA) as a pollutant in a perspective of environmental sustainability with low cost and effective applications.

Experimental

Sample processing

The 3 samples were taken from Datang Power Plant Inner Mongolia. The samples for coal fly ash (CFA), gypsum and lime were ground into powder form and dried at 60°C for 24 hours.

X-Ray Diffraction (XRD) and Scanning Electronic Microscope (SEM) analysis of samples

Samples of coal fly ash (CFA), FGD gypsum, and lime were analyzed through the XRD GENESIS 60s (the XRD patterns were obtained with an X'Pert Pro diffractometer with a Ni filter and Cu Kα radiation (λ = 0.154nm) generated at 40 kV and 40 mA. The scan rate was 2º (2θ) min-1 with a step size of 0.01º) and for SEM the ZEISS Ultra 55 made in Germany was used.

Ratio of coal fly ash (CFA), FGD gypsum and Lime

The FaL-G were mixed in three different fractions that are (a) 700g of coal fly ash (CFA), 150g of Lime and 150g of FGD gypsum were mixed with 435ml of tap water (b) 500g of FGD gypsum, 350g of coal fly ash (CFA), and 150g of Lime were mixed with 435ml of tap water (c) 450g of FGD gypsum, 450g of coal fly ash (CFA) and 100g of Lime were mixed with 435ml of tap water.

Standard Consistency Water Test of FaL-G

The amounts of water required were calculated through Standard Consistency Water Test while using the Vicat apparatus. The samples of 300g were taken from the mixed ratio of FaL-G and water was mixed slowly to make a paste. The samples were put in the Vicat apparatus mold for testing. At the beginning the initial reading was recorded by the free fall of the needle from above as the needle touched the bottom of the mold the reading was 1mm. The readings of samples were taken from time to time until the final reading was recorded i.e. there is no penetration of the needle in the samples the results are shown in **Table 1.**

Preparation of Block

Blocks of 3 different proportions were prepared in ratios of (a) 700g of coal fly ash (CFA), 150g of Lime, and 150g of FGD gypsum and mixed with 500ml of tap water (b) 500g of FGD gypsum, 350g of coal fly ash (CFA) and 150g of Lime and mixed with 435ml of tap water (c) 450g of FGD gypsum, 450g of coal fly ash (CFA) and 100g of Lime and mixed with 370ml of tap water in the bowl and stirred fully to hold. The mixture was poured into the mold and let standing for 15 minutes. Afterwards the mold plates were removed and blocks were kept in trays. The blocks were dried under sunlight, room temperature, oven (60°C), in the presence of moisture and freezed (-16°C).

Compressive Strength

For the compressive strength test, five conditions of treated blocks and bricks were analyzed through MTS Systems China; Model YAW4106. For each test N=3.

Flexural Strength Test

Flexural strength tests for five conditions treated blocks and bricks were analyzed through Shenzhen WANCE testing machine Co LTB China Model: ETM-305F-2. For each test N=3. The detection were carried out by three repeated experiments.

Results and Discussion

X-Ray diffraction (XRD) and Scanning Electronic Microscope (SEM) analysis of Samples

Crystal Phase XRD

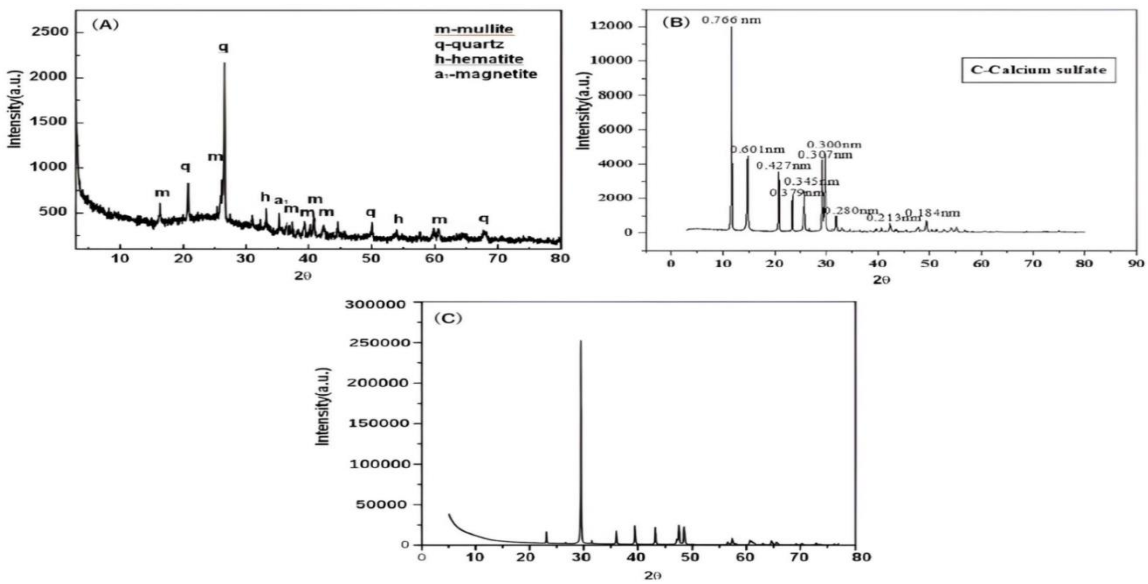

Fig. 1: XRD of (1A) FGD gypsum Crystal Phase, (1B) coal fly ash (CFA) Crystal Phase, (1C) Lime Crystal Phase.

The XRD of gypsum results show that the calcium sulfate dehydrates (DH) was the main mineral phase with some traces of anhydrite. The peak intensities for FGD gypsum are much smaller as shown in Fig **1A**. The XRD diagram of coal fly ash (CFA) presents 4 different minerals. Different peak intensities show the presence of mullite, magnetite, hematite, and quartz as highlighted in Fig **1B**. Lime peaks show the presence of calcite, silica, and muscovite Fig **1C**. The quantification of phases using the XRD-Riveted technique was applied to determine the composition of gypsum, coal fly ash (CFA) and Lime. Coal fly ash (CFA) is characterized by having phases of Hydrated silicate, aluminate, and calcium sulfoaluminate. The uniformity coefficient (Cu) and the coefficient of curvature (Cc) of FGD gypsum were 2.2 and 1.3, respectively [14,15].

Scanning Electron Microscope Analysis (SEM) Of coal fly ash (CFA) and FGD gypsum

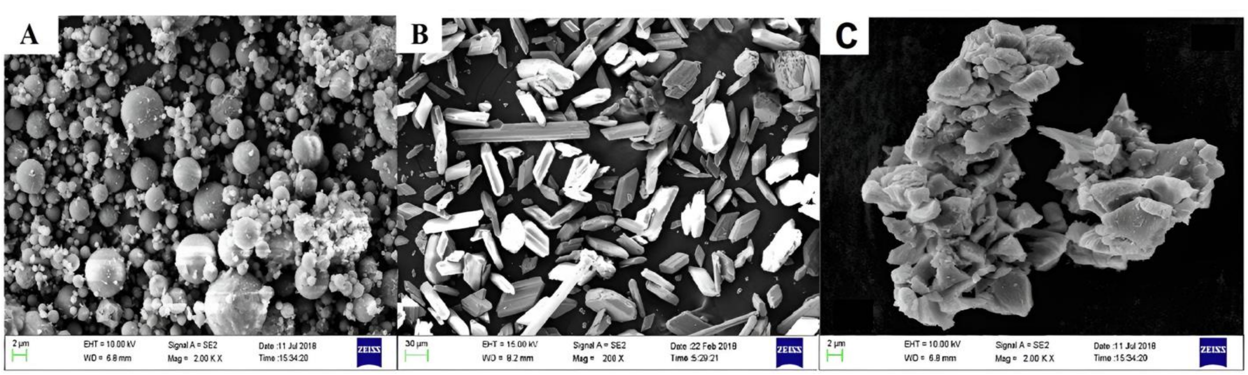

Fig. 2: SEM of (2A) coal fly ash (CFA) Mineral Phase, (2B) SEM spectra of FGD gypsum , (2C) Lime compact structure geometry.

Data that were obtained from the SEM images for coal fly ash (CFA). Fig 2A indicate the presence of particles of different sizes made of CaO, Al_2O_3, and SiO_2 of different mineral phases. The particles show a rounded shape over which some other minerals that are attached. Fig 2B shows that the SEM image of FGD gypsum reveals that water and calcium sulfate are having columnar bodies and a small number of irregular geometries. Fig 2C shows that lime has a compact structure having irregular structural geometry. The micro structures are mainly composed of coarse particles turbulently dispersed in the matrix. The occurrence of twinning structure, asymmetrical particle shapes, rounded fragments and their agglomerates are typical to gypsum crystals [15]. XRD analysis were performed to investigate the underlying mechanism by which FGD gypsum influences the cement hydration, which in turn affects the concrete internal environment and microstructure. FGD gypsum triggers the development of ettringite while decreasing the amount of monosulfate [16]. Effect of flue gas desulfurization gypsum addition on critical chloride content for rear corrosion in coal fly ash (CFA) concrete [17,18]. Addition of coal fly ash (CFA) with cement was found to increase the strength up to a certain coal fly ash (CFA) content and beyond that strength begins to drop. This reason of such behaviour was justified from the observation of SEM images of the prepared compressed stabilized earth blocks. The particle size of coal fly ash (CFA) varies within 0.009mm to 0.17mm and almost 70% of the particles are in the range of 0.015mm to 0.10mm size as previously observed [19].

Chemical composition of coal fly ash (CFA), FGD gypsum, and Lime.

Coal Fly Ash (CFA) is primarily composed of SiO_2 (47.92%) and Al_2O_3 (24.97%), with significant amounts of Fe_2O_3 (12.24%) and CaO (7.42%). FGD Gypsum has a high content of CaO (45.71%) and SO_3 (42.89%), with lower amounts of other oxides. Lime is dominated by CaO (62.25%) with notable quantities of SiO_2 (12.50%) and Al_2O_3 (12.50%), along with MgO (4.50%). Each material has a distinct chemical profile making them suitable for different applications in construction and industrial processes as shown in Table-2.

Standard Consistency Water Test of FaL-G

The time recorded for different 3 mixed ratios of coal fly ash (CFA), FGD gypsum, and lime were (A) 40 (B) 60, and (C) 70 minutes through standard consistency water test. The size of the Vicat apparatus needle for the initial reading was 1mm and for the final, reading was 7mm.

Compressive Strength Test

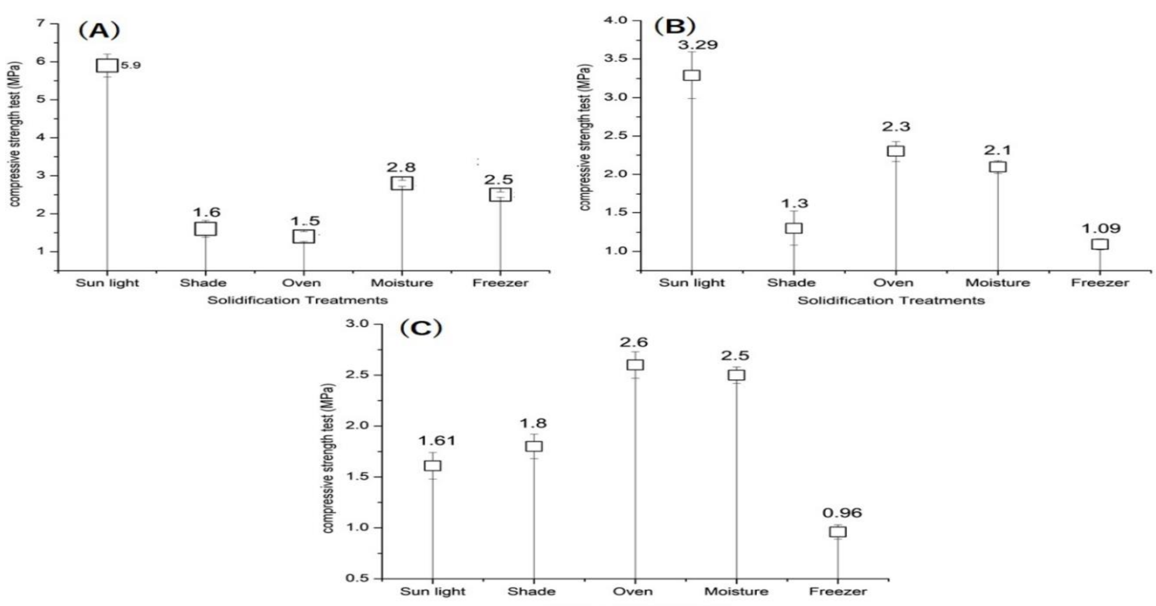

Fig. 3: (3A) FGD gypsum 700:150:150 (3B) coal fly ash (CFA) 700:150:150 (3C) coal fly ash (CFA) 450:450:100.

Table-1: Vicat Apparatus data for Standard Consistency Water Test of FaL-G.

Samples	Temperature(℃)	Time(min)	Water (g)	Reading (mm)			FaL-G (g)
				Initial (min)	Final (min)	mm	
1	60	40	150	7.0	40	7	300
2	60	60	135	6.4	50	7	300
3	60	70	118	9.0	70	7	300

Table-2: Chemical composition of coal fly ash (CFA), FGD gypsum and Lime.

	SiO_2	Al_2O_3	CaO	Fe_2O_3	K_2O	SO_3	MgO	TiO_2
Coal fly ash (CFA)	47.92	24.97	7.42	12.24	1.78	2.35	0.49	2.53
FGD gypsum	2.83	2.62	45.71	2.20	ND	42.89	2.53	ND
Lime	12.50	12.50	62.25	ND	ND	ND	4.50	ND

ND: not detected

For the compressive test, 12 blocks of each sample of FaL-G were taken and treated with different conditions (i. Sun light ii. Room temperature iii. Oven iv. Moisture, and v. freezer) Fig 3. Proportion of FGD gypsum 700g: coal fly ash (CFA) 150g: Lime 150g: 435ml of tap water has shown great strength of 5.9 MPa treated with sunlight as shown in Fig 3A. Followed by coal fly ash (CFA) 700g: FGD gypsum 150g: Lime 150g; 435ml of tap water with strength of 3.9 MPa shown in Fig 3B. Followed by coal fly ash (CFA) 450g: FGD gypsum 450g: Lime 100g; 435ml of tap water with strength of 2.6 MPa shown in Fig 3C. In the Oven drying when performed correctly can significantly enhance the compressive strength of blocks by reducing moisture content increasing density and ensuring uniform curing. This process is particularly beneficial for construction applications where high strength and durability are essential. The strength of blocks should be acceptable as the sunlight dryness is more effective then other drying conditions and also peaks showed that drying blocks directly to the exposure of sunlight are more stronger than the other conditions. The reason behind this is that drying the blocks in the natural sunlight condition improved block strength and strength bearing capacity more than the other conditions. It is acceptable for different specific applications in construction.

Flexural Strength Test.

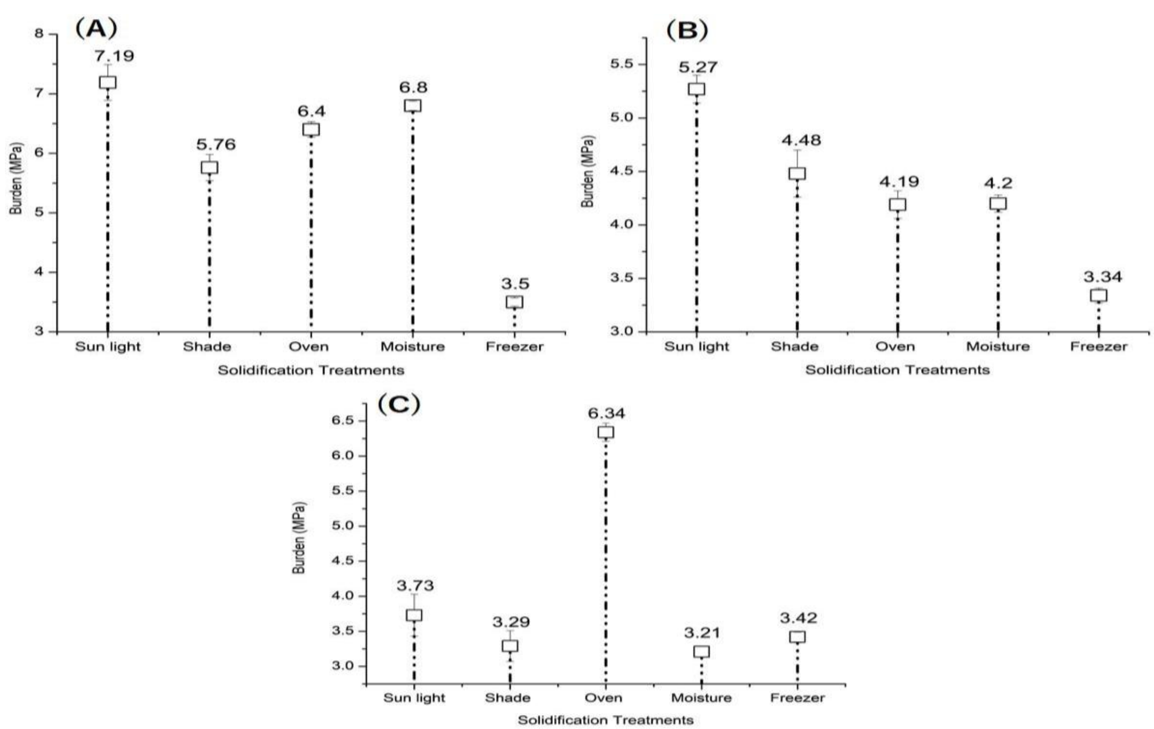

Fig. 4: (4A) FGD gypsum 700g:150g:150g (4B) coal fly ash (CFA) 700:150:150 (4C) coal fly ash (CFA) 450:450:100.

For the flexural test 12 blocks of each sample of FaL-G were taken; treated with different conditions (i. Sun light ii. Room temperature iii. Oven iv. Moisture and v. freezer). In the tests it was concluded that the burden strength of FGD gypsum 700g: coal fly ash (CFA) 150g: Lime 150g: 435ml water; treated with sunlight was much better i.e. 7.19 MPa followed by Fig 4A. Coal fly ash (CFA) 700g: FGD gypsum 150g: Lime 150g; 435ml of tap water; treated with sunlight was also better followed by Fig 4B. FGD gypsum 450g: coal fly ash (CFA) 450g: Lime 100g; 435ml of tap water; treated with heat (oven) is 6.34 MPa followed by Fig 4C.

The result obtained from the chemical and physical properties of the coal fly ash (CFA) particles is that; whenever heat is provided, it causes the mineral to become fluid and when it is about to cool then it makes different solid shapes of particles [20]. The FaL-G blocks need additional water other than alternative additional materials for the chemical reactions and solidifying process. These reactions are important because they will decrease the cost used for energy resources; as energy is used for heating the clay bricks [21]. The comparative analysis showed that when FaL-G was mixed with clay. The strength of FaL-G brick was 5 MPa and FaL-G+clay is 2 MPa. In our research, we have obtained load bearing of strength of 7.19 MPa, where as coal-ash-based concrete mixes keeping the quantities of cement, coarse aggregate, and super plasticizer constant [22]. The fine aggregate was entirely replaced by varying percentages of coal fly ash (CFA) and bottom ash mixture. Flexural strength of 4.2 $N.mm^2$ and compressive strength of 39.9 MPa were achieved. While in our research flexural strength of 7.19 MPa and 5.9 MPa for compressive test were obtained. The cement and other material mixed with FaL-G increases the overall cost of the blocks [23]. Soil, cement and coal fly ash (CFA) were mixed together for preparation of blocks [24]. Without coal fly ash (CFA) 9–10% cement is found to provide strength greater than 5 MPa, For 5-7% cement, the optimum coal fly ash (CFA) content is 15%; for 8-9% cement, coal fly ash (CFA) value is 20%. For 10% cement, strength is found to increase with increasing in coal fly ash (CFA) contents. Addition of 15% coal fly ash (CFA) with 6% cement; >15% coal fly ash (CFA) with 7% cement; >5% coal fly ash (CFA) for 8% cement is found effective to increase strength. Results showed that the FaL-G blocks need less water for curing in the constructed wall in comparison to clay bricks. The common parameters calculated by various researchers were water absorption and compressive strength. The common minimum value recommended for characteristic compressive strength for the clay bricks is more than 17.2 MPa. Whereas in our research the FaL-G maximum strength was more than 719.823 KN and 7.19 MPa in natural drying conditions which is a good strength to be achieved [25]. The increase in strength can be obtained by the addition of gypsum. Overall, the clay bricks have much higher strength than the FaL-G blocks but the FaL-G blocks with the aim of deposition of pollutants with the strength of 7.19 are acceptable to be used in such places which require less compressive and burden strength. The FaL-G blocks are also very useful in construction and decoration purposes because in our research it is evident that it has great bonding in natural condition i.e. 719.823 KN.

Conclusion

It is concluded that the FaL-G blocks are environment friendly and help in the proper recycling or reuse of coal fly ash (CFA). The compressive and flexural strength of Sunlight dry blocks gave the best results. It can be concluded that the natural FaL-G dry block is very beneficial having low cost, lighter in weight, non-porous and having strong binding capacity as coal fly ash (CFA) with 720 KN strength is acceptable for the deposition of pollutants such as coal fly ash (CFA) in the form of building blocks where large strength is not needed.

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