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NON-FIRED BUILDING BLOCK USING INDUSTRIAL WASTES

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ABSTRACT

Demand for bricks is rising following the growth of the construction industry aimd infrastructure boom in Bangladesh. Bricks produced from traditional technique and agricultural clay contribute considerably to some of the worst air pollutions in the world. There is an urgent need to start using an environment-friendly alternative material/approach instead of conventional bricks to save the fertile topsoil and conserve a clean environment. This research, therefore, is aimed to explore different options to produce non-fired bricks. The study incorporated different types of industrial waste including Fly ash and Ladle Furnace Slag (LFS) as a partial replacement of CEM I and lime. Induction Furnace Slag (IFS) is used as a partial or full replacement of virgin fine aggregate (local sand) in non-fired building block manufacturing process at laboratory scale. The use of abundant solid waste from steel and power plants in brick production could be a potential solution for the management of these hazardous residues. The prepared building blocks without using any agricultural clay conforms to the minimum compressive strength requirement of 10.3 MPa as per ASTM C62 and BDS 208 while the maximum compressive strength was found to be 40.6 MPa. This highly promising performance pronounced the use of industrial waste materials in non-fired brick production to achieve a cleaner, environment friendly sustainable society as well as a potential waste management approach for hazardous industrial waste.

Keywords: *Industrial waste, Ladle Furnace Slag (LFS), Induction Furnace Slag (IFS), Waste management, Building block, Sustainability.*

1. INTRODUCTION

People have been using as an essential building construction material for thousands of years or its manifold superiorities over other earthen construction materials. The first clay brick was produced traced back to 10,000 BCE, found in Egypt which were hand-moulded and then sun-dried. The historic city Ur (modern Iraq) adopted clay bricks as the main construction materials around 4000 BCE. Archaeological evidence has been found of 5000 BCE on using fire to produce clay-based bricks for better performance. Since then, the brick industry has been developing using modern machinery, such as powerful excavation equipment, motors, tunnel kilns. 1500 billion units fired brick production was estimated in 2015 globally (CCAC, 2015). Despite the workability of conventional brick production, fired clay brick production consumes a considerable amount of virgin resource and energy. In the production of 1 tonne brick an estimated 706 kWh energy is required and 0.15 tonne carbon dioxide (CO_2) is being emitted (Carbon Trust, 2011). This considerable energy consumption and carbon footprint is barrier to achieve sustainable development.

Apart from that, the construction contributes to a loss of 1% of agricultural land annually Bangladesh. Approximately 80% of this loss is due to unplanned rural housing also over 17% to brick kilns. Excavation of per hectare of fertile topsoil could cause up to Tk. 3.1 million economic loss. The brick industries in this country are producing approximately 25 billion units every year by eliminating 100 million tonnes of topsoil considerably affecting agricultural production and achieving sustainable development. As a result, around 50 million people would face food shortage by 2050 when the country's population would reach 245 million (The Daily Star, 2018). An annual 80 million tonnes of CO_2 emission are estimated for this country of which ¼ is accounted from only 7,900 registered (constructed following proper design and environmental rules) conventional brick kilns. The number of unregistered conventional brick kilns is even higher than the registered ones. These kilns also consume 5 million tonnes of coal and 3 million tonnes of wood annually (Hossain, 2017). In Dhaka, 58% of air pollution is accounted for conventional brick kilns.

A survey by the Department of Environment (DoE) of Bangladesh during 2013-18 found brick kilns are the top air polluter in seven major cities of the country of which Narayangonj has the most polluted air followed by Dhaka. During production (dry) season November-April the air quality of these metropolises becomes extremely unhealthy by emitting lot of particles in the air. Another study in association with Norwegian Institute for Air Research (NILU), DoE conducted during 2013-16 in Dhaka and Chattogram city found 58% of the main air pollutants (Particulate Matter 2.5) originate from the conventional brick kilns. The country, therefore, is in urgent need of immediately start using an environment-friendly alternative instead of conventional bricks to save its fertile topsoil and conserve the environment. Turning to alternatives like compressed or thermal blocks incorporating waste residues is crucial in ensuring food security and thereby sustainable development.

Considering both environmental and economic issues, studies have been conducted to produce sustainable bricks as a way to minimize the large carbon footprint from this conventional clay brick producing industry. An alternative of conventional bricks could be cement based building blocks from Ordinary Portland Cement (OPC). However, the production of cement clinker is highly energy intensive; 1 kg clinker requires 1.5 kWh energy and releases about 1 kg of CO_2 to the atmosphere. In addition, the aggregates are obtained from quarrying and thus have the same issues as clay-based brick. Current global waste generation volumes are approximately 1.3 billion Metric tonnes per year and are expected to increase to 2.2 billion Metric tonnes by 2025. To reduce environmental pollution, decrease the amount of generated wastes and preserve virgin materials, thereby contributing to sustainability; researchers have made remarkable efforts to develop different bricks from various types of waste materials.

In near future, coal burning power plant will be the major source of power generation in Bangladesh. The current power generation of Barapukuria coal power plant is 525 MW and approximately

1,09,200 Metric tonnes fly ash is being generated every year (Tamim, Dhar & Hossain, 2013). The situation will be worsened once 3 others under construction coal burning power plant will come into full generation of 3840 MW. Considering a linear interpolation, the annual production of fly ash will rise to 865,000 MT per annum from 2024 onwards. For a densely populated country like Bangladesh; this volume of fly ash is an enormous amount to dispose of. Considering the chemical composition of Fly ash, incorporating it in non-fired eco-friendly brick can be a two-way solution for this problem.

Bangladesh has over 400 steel mills of different categories and sizes with annual production of over 4 million tons. Most of the Bangladesh steel industries use induction furnaces which produce approximately 3.2 million tons of steel every year along with along with 250 thousand tons of Induction Furnace Slag (IFS) (Rezaul et al., 2017). Approximately 60–80 kg of Ladle Furnace Slag (LFS) is recovered for each ton of steel to be refined. Some of this amount reintroduced in the production process, however, a considerable amount of LFS is dumped as landfill. Chemical composition of the powder like material indicates its potential as a supplementary cementitious material.

The supply chain e.g., waste-to-resources has been seriously considered in many industrial parks around the globe (Rashad, 2019). Conventional steel waste management by dumping or landfilling has a negative impact on the surrounding environment leading to pollution in addition to the cost needed to dispose of these. The incorporation of steel mills waste materials in brick production could be a potential solution for the management of these hazardous residues. Thus, strategically industries can take advantage of market opportunities and neutralize threats arising from environmental issues. The aim of this research is to explore different options to produce non-fired brick/building blocks from several industrial solid wastes including fly ash, LFS by full or partial replacement of cementitious media such as Portland based cement and lime powder. In addition, IFS is used to replace sand in the media.

2. MATERIALS AND METHODOLOGY

Characterization of the raw materials is described and then the performance of material composition in the pressurized building block preparation system was evaluated in terms of compressive strength. Industrial wastes- LFS and fly ash is used as supplementary binder in the production of building block. Another steel industry waste material IF is used as filler/fine aggregate. CEM I, building lime and local sands are other associated materials used in this research.

CEM I of strength class 52.5N with fineness 99.3% (#200 sieve) and building lime (passing through 1mm sieve) obtained from local sources. Fly ash is obtained from Barapukuria coal burning power plant in Bangladesh. A maximum of 73% fly ash (of total binder content) is used for building block preparation. LFS and IFS are collected from BSRM Steel Mills Ltd., Chittagong, Bangladesh. The LFS passing through 2mm sieve is used as binder. Induction furnace slag (IFS) of two different sizes (0-4 mm; F.M 2.33 and 4-8 mm; F.M 3.54) was collected from BSRM steel mills Ltd. It was used as a full or partial replacement of sand. A maximum of 60% IFS (both size same proportion) of total dry mix was used in the building block preparation. The local sand used for the study was prepared according to graded sand requirements ASTM C778-17.

2.1 Material Characterization

2.1.1 Particle size distribution (PSD)

Particle size distribution of binders' viz. CEM I, fly ash, LFS and building lime are obtained using a LASER particle size analyser. Approximately 1g of sample (fly ash/LFS) is dispersed in water using an ultrasonic attachment in the sample vessel of the equipment. In the case of CEM I and lime, these are dispersed in propanol (to prevent reaction). Commercial software is used to create particle size distributions from the degree of scattering of a collimated, monochromatic, dual laser beam (red and blue) passing through the mixture of sample and solvent. At least three measurements are carried out for each sample. Although repeated distributions are found to be similar for a given material, an average distribution result of these, created by the computer software, is reported. Figure 1 shows combined PSD of CEM I, fly ash, LFS, lime and IFS after 1-hour grinding. The mean size of CEM I (22.77 µm) and fly ash (20.1 µm) was found similar. However, the other two binders, building lime (49.37 µm) and LFS (59.2 µm) gave much higher mean particle size.

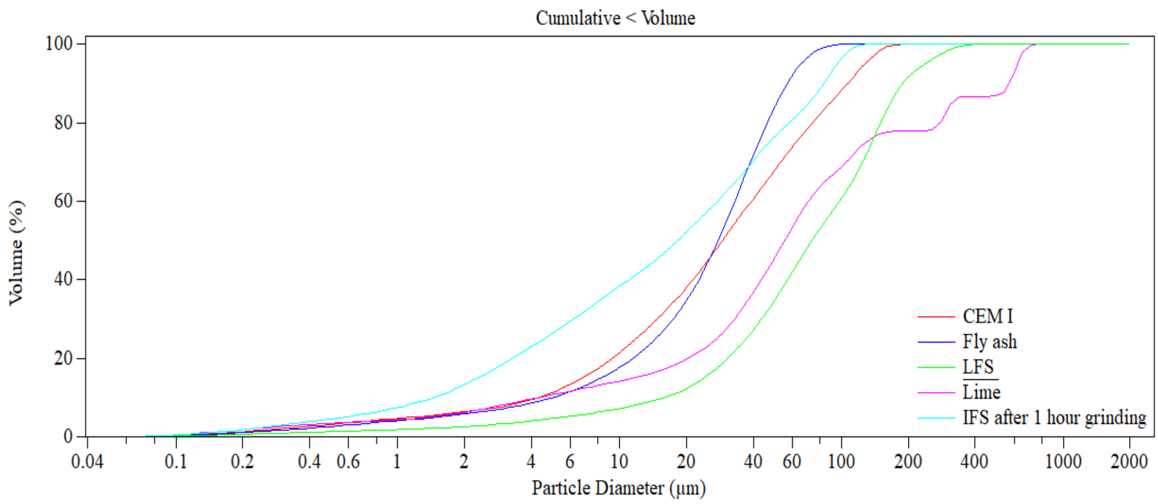

Figure 1: Particle Size Distribution of CEM I, Fly ash, LFS, Lime and IFS

2.1.2 Chemical compositions of materials used

The chemical compositions of fly ash, steel slags (IFS and LFS) and other binders are determined using X-ray Florescence (XRF) technique. All these works are conducted at Department of Pharmacy, Liverpool John Moore University, England. The chemical composition of fly ash satisfies the criteria of being Low calcium fly ash (Class F) according to ASTM C618. The chemical composition of LFS shown in Table 3.1 conforms to that found in literature elsewhere.

Table 2: Chemical composition of materials used in this study

Materials	**CaO %**	**SiO_2%**	**Al_2O_3 %**	**Fe_2O_3 %**	**MgO %**	**Na_2O %**	**K_2O %**	**TiO_2 %**	**MnO %**
IFS	4.92	46.80	6.58	16.35	3.22	1.50	0.33	1.05	7.52
FA	0.71	52.92	17.12	2.58	0.43	0.32	0.77	2.78	0.01
Lime	93.26	1.085	0.56	0.66	0.75	1.93	0.09	0.11	1.01
LFS	47.44	29.35	5.57	0.74	2.27	1.57	0.09	0.89	1.61
Cement	64.38	22.36	4.59	2.81	2.08	1.52	0.72	0.63	0.04

2.1.3 Morphology analysis by SEM

Figure 2 shows high magnification ESEM micrographs of the materials used in this study. SEM mode with an accelerating voltage of 15 kV in combination with a Links System Si(Li) X-ray detector is used. Selected samples are also analysed using the Energy-dispersive X-ray spectroscopy (EDX) mode at 20 kV voltage to identify the nature of crystalline deposits on their surfaces. Double sided adhesive carbon tape is secured to a 10mm diameter aluminium stub and the sample is sprinkled on it. Specimens are coated by Pd-Au alloy vapour to prevent charging during the test.

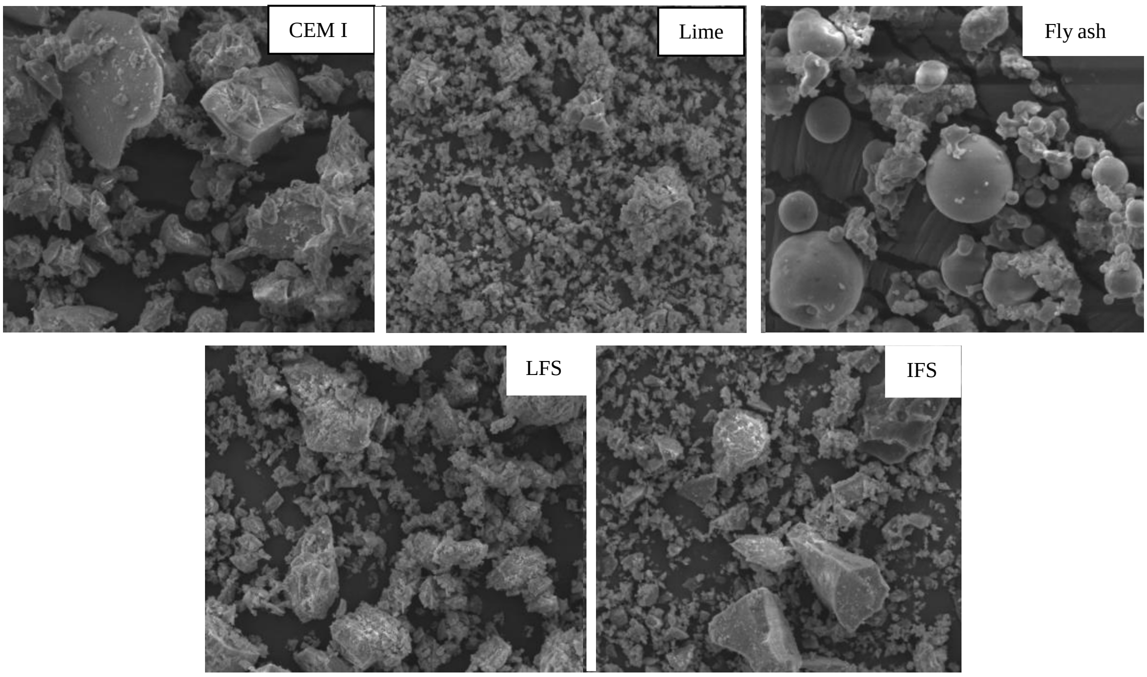

Figure 2: SEM images of materials used

2.2 Mix Details and Preparation of Building Blocks

2.2.1 Mixing Process

Mix details of the fly ash based and high-pressure building block are given in Tables 3 and 4 respectively. The required materials for building block preparation are first taken in an automatic pan mixer of 50 kg capacity. The mixer is kept rotating at a constant speed by a 1.5 kW motor. All the materials except water were mixed for 30 minutes. After that, water is added in such a way that no water comes out after squeezing by hand from the mix but moisture can be palpable in the hand. As pressure is applied to compact the building blocks lowest possible amount of water (maximum amount of water used is 15.7% of total dry mix) is added in the mixing stage. Excess amount of water could bleed out while applying pressure. After adding water, the mixing process is continued for another 30 minutes.

Table 3: Mix details of fly ash building blocks (kg/m^3)

Batch ID	Water	Binder			Fine Aggregate	
		Fly ash	Cement	Lime	Local sand	IFS
IF100C7.5LP7.5	248.0	651.0	122.1	122.1	---	732.4
IF67C7.5LP7.5	254.7	648.3	121.6	121.6	240.7	488.7
IF33C7.5LP7.5	254.7	648.3	121.6	121.6	488.7	240.7
IF00C7.5LP7.5	248.0	651.0	122.1	122.1	732.4	---
IF100C5LP10	234.4	656.4	82.1	164.1	---	738.5
IF100C10LP5	234.4	656.4	164.1	82.1	---	738.5

(IF100C7.5LP7.5 contains 100% IFS as fine aggregate; 7.5% cement and lime each and 40% fly ash of total dry mix was used as binder)

Table 4: Mix details of high-pressure building blocks (kg/m^3)

Batch ID	Water used	Binder		Fine Aggregate	
		LFS	Cement	Local sand	IFS
C10L05S25	159.6	111.4	222.7	556.9	1336.4

Batch ID	Water used	Binder		Fine Aggregate	
		LFS	Cement	Local sand	IFS
C10L10S20	163.1	222.4	222.4	444.8	1334.4
C10L15S15	163.1	333.6	222.4	333.6	1334.4
C7.5L7.5S25	149.2	167.8	167.8	559.5	1342.7

(C10L05S25 contains 10%, 5% and 25% of total dry mix are CEM I, lime powder and local sand respectively. Other 60% of total dry mix was IFS)

2.2.2 Casting and curing of the building block

A mould of surface dimension 9″×4″ (230mm×102mm) is used for building block casting. The finished height is around 75mm. Around 3.3 kg freshly mixed materials is required for each fly ash building block preparation. For high pressure building block approximately 4.2 kg mix was required. Fly ash blocks are greyish while high pressure block without Fly ash are brownish in colour. Figure 3 and 4 gives compaction machine with its application for building block preparation.

A constant bar pressure is applied by hydraulic jack 3 times, summing a total of 11 second (5s+3s+3s). In total 70 and 200 bar pressure are applied for fly ash and high-pressure building blocks. After casting, the blocks are taken from the mould instantly and kept at ambient temperature for 12 hours. Then those are kept under water for 7 days. At day 8 the samples are taken out of water and kept at room temperature for next 14 days. During this period, the blocks are immersed in water for 1 minute, at an interval of 8 hours. Then simple air curing was continued for the last 7 days prior to testing at total age of 28 days. Figure 5 shows the curing process of the building block samples.

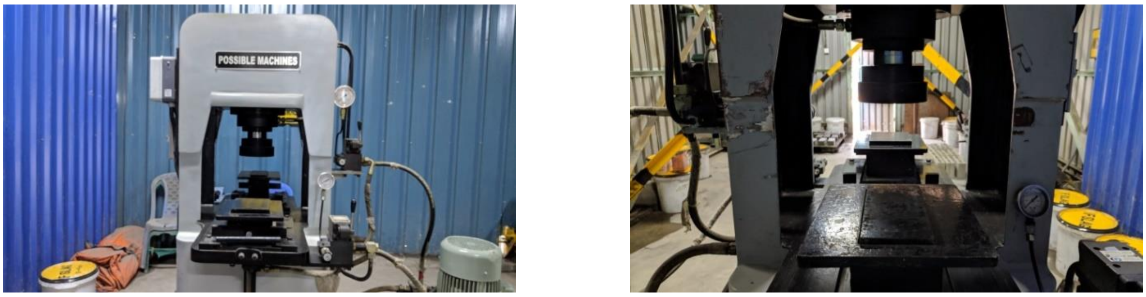

Figure 3: Building block casting machine

Figure 4: Pressure applying and casting

(a) Building blocks kept at ambient temperature | (b)Water curing of Building blocks | (c) Blocks after immersion in water for 1 minute

Figure 5: Curing process of building blocks

2.2.3 Water Absorption and Compressive Strength Test

The water absorption is calculated as the difference in weight after 7 days water curing from its weight prior to water curing and expressed in percentage. The compressive strength of a material is the uni-axial compressive stress reached when the material fails completely. For building blocks set of three blocks were tasted in each case and the average value of these three was reported as per ASTM C39-18.

(a) Compression test set up | (b) Fly ash block | (c) High pressure block

Figure 6: Compressive strength test and failure planes of building blocks

3. RESULTS AND DISCUSSIONS

3.1 fly ash-based building blocks

Fly ash incorporated building blocks are prepared using ternary combination of CEM I, fly ash and lime as binder with IFS and local sand as fine aggregate. Table 4.4 gives details of binder and fine aggregate combination and their corresponding compressive strength. IF00C7.5LP7.5 gives the maximum compressive strength of 18.5 MPa and 40.6 MPa at 7 and 28 days. The sample incorporated 100% IFS (45% of total mix content) as fine aggregate. The rest 55% of the mix includes 40% fly ash and 7.5% CEM I and lime each. With a gradual increase in CEM I content, 28 days compressive strengths are increased. For a fixed content of binder (fly ash, lime and cement) highest strength is obtained with local sand as fine aggregate.

Table 5: Compressive strength of fly ash-based blocks

SAMPLE	Materials, % of total dry mix						Compressive Strength (MPa)	
	Binder			Fine Aggregate		water		
	Cement	Fly Ash	Lime	IFS	Local sand		7 Days	28 Days
IF100C7.5LP7.5	7.5	40	7.5	45	---	15.2	11.8	19.1
IF67C7.5LP7.5	7.5	40	7.5	30	15	15.7	11.3	23.7
IF33C7.5LP7.5	7.5	40	7.5	15	30	15.7	14.1	26.6
IF00C7.5LP7.5	7.5	40	7.5	---	45	15.2	18.5	40.6
IF100C5LP10	5.0	40	10.0	100	0	14.3	9.2	14.4
IF100C10LP5	10.0	40	5.0	100	0	14.3	9.6	20.3

3.1.1 Effect of IFS and Lime in Fly ash Blocks

Figure 7 shows the variation of strength for 0%, 33%, 67% and 100% replacement of local sand by IFS. Approximately 40-50% strength is increased at 28 days from that obtained at 7 days. With the gradual increase in IFS content compressive strength decreased. For 28 days strength the decrease of strength (14 MPa) is high between 0 to 33% replacements of sand by IFS. After that, the strength decreases at a slower rate and with 100% IFS (as aggregate) give 47% strength of blocks with 100% sand (as aggregate). At 7 days the strength variation is relatively less. The lowest strength is obtained for building blocks with 67% IFS + 33% local sand as aggregate. Building blocks used 100% IFS gives strength of 11.8 MPa which still satisfies the minimum strength requirement by ASTM C62-17 (standard specification for building bricks). Therefore, even the compressive strength is found lower compared to the local sand, 100% IFS could be used as fine aggregate to produce building block to apply in the non-exposed weather condition such as interior partition walls.

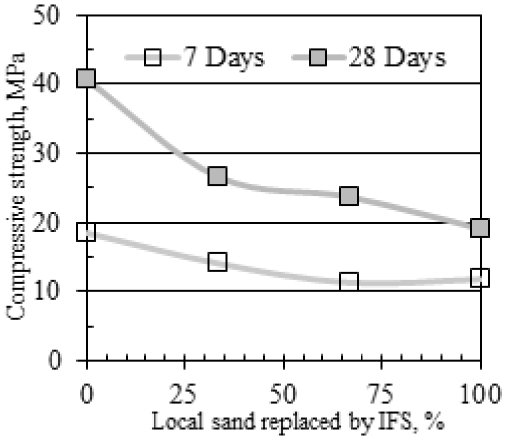

Figure 7: Compressive strength vs sand replaced by IFS (40% fly ash)

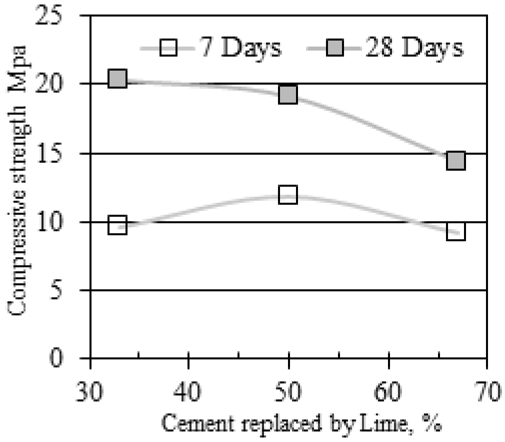

Figure 8: Compressive strength vs % cement replaced by lime (40% fly ash)

Considering 28 days compressive strength from Figure 8, it is evident that with the increase in CEM I replacement by lime compressive strength decreased. 28 days compressive strength reduces to 14.4 MPa from 20.3 MPa while cement replacement level increase from 33% to 67%. However, the reduction for 50% cement replacement is minor and therefore, it could be concluded that lime and fly ash combination could work similar to that of cement and fly ash.

3.2 High pressure Building Blocks

High pressure (200 bar) building blocks is prepared using 60% IFS with limited amount local sand (15-25%) and instead of lime and fly ash, LFS was used in a limited scale (5-15%). Table 6 shows mix combination and their compressive strength at 7 and 28 days. Sample C10L10S20 gives the highest 7- and 28-days strength than all other batches. 10% LFS is found optimum considering same number of IFS (60%) and Cement (10%) are used. C10L05S25 shows the lowest 28 days strength of 29.4 MPa. Nonetheless, the average strength of high-pressure building block is higher than the average strength of fly ash incorporated blocks indicating significant contribution of high pressure in obtaining compressive strength.

Table 6: Mix combination and compressive strength of high-pressure building block

SAMPLE	Mix combination, % dry mix				water content, %	water absorption %	Compressive Strength (MPa)	
	IFS	Cement	LFS	Local sand			7 Days	28 Days
C10LRF05S25	60.0	10.0	5.0	25.0	7.2	2.6	25.2	29.4
C10LRF10S20	60.0	10.0	10.0	20.0	7.3	3.2	27.2	38.0
C10LRF15S15	60.0	10.0	15.0	15.0	7.3	3.2	25.6	34.1
C7.5LRF7.5S25	60.0	7.5	7.5	25.0	6.7	3.0	23.1	31.1

3.2.1 Effect of LFS content on high pressure building block

As shown in Figure 9, 10% LFS content gives better compressive strength performance both in 7 and 28 days. 5% LFS content give lowest compressive strength in both for 7 and 28 days. The strength increment rate for 10% LFS content is the highest among all the samples. For this, the 28 days compressive strength is 10.8 MPa greater than that of 7 days compressive strength.

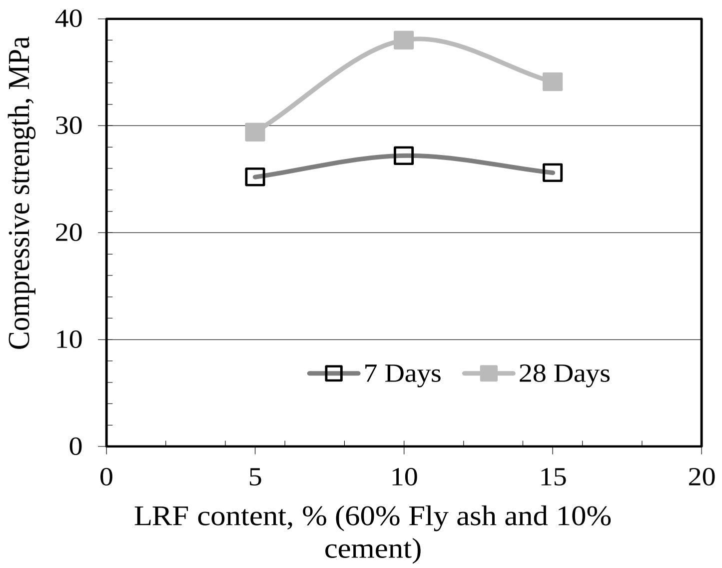

Figure 9: Compressive strength VS % LFS content

3.3 Excess water absorption and compressive strength of high-Pressure building block

The original total weight of the ingredients required to produce one building block is noted. After 7 days underwater curing the samples were surface dried and weighted. Figure 10 and 11 shows the water absorption rate (%) and compressive strength of fly ash incorporated building blocks and high-pressure building blocks. For fly ash blocks, the highest 7 days compressive strength (18.5 MPa) is obtained for IF00C7.5L7.5 batch which give lower water absorption (2.8%). Generally higher water absorption (above 3%) is obtained for the samples having low compressive strength (below 10MPa).

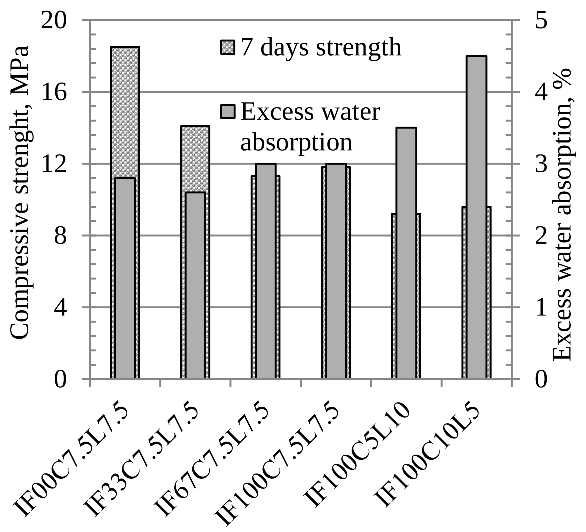

Figure 10: Water absorption (%) and compressive strength of fly ash based building block.

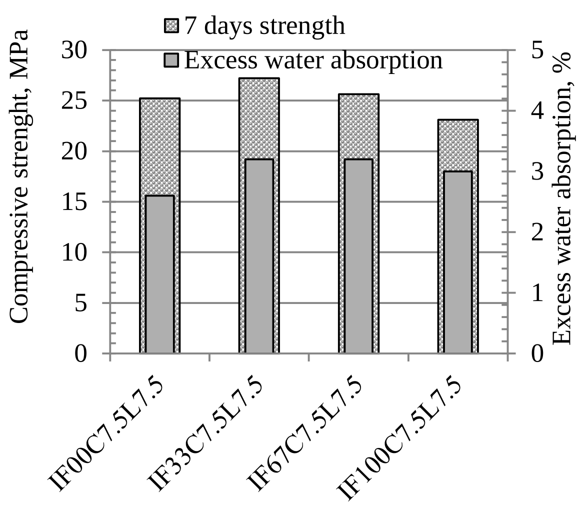

Figure 11: Water absorption (%) and compressive strength of high pressure building block.

The water absorption is small (≤3%) for highly pressurized building blocks however, no definite correlation was found between the 7 days excess water absorption and compressive strength. The highest compressive strength at 7 days was found to be 27.2 MPa for which excess water absorption is 3.2%. C10L05S25 sample give the lowest water absorption (2.6%) for which the strength is 25.2 MPa. Though it is not the lowest 7 days strength, its 28 days strength (29.4 MPa) is lowest of all. The water absorption rate for every sample of high-pressure system always gives lower value than that of fly ash-based building block. This is due to around 2000 psi higher pressure is applied to the high-pressure building block. In the mix, fly ash requires a higher level of water to make it workable.

4. CONCLUSIONS & RECOMMENDATIONS

The research aimed to assess the feasibility of non-fired brick/building block production using waste materials. In this regard, the compressive strength of fly ash-based blocks (70 bar pressure) increases with the replacement of IFS by local sand and maximum strength of 40.6 MPa was achieved. By applying a higher pressure (200 bar), the compaction level was improved and this increased the compressive strength of the building blocks. Overall the study with potential waste materials gave promising indication that with further modification, these materials could be used as an alternate of clay brick production. Researchers have a huge scope for further development to improve the quality of bricks. Durability tests such as chloride penetration/carbonation, water and gas permeability, dimensional performance/efflorescence, leaching of any heave metal/harmful constituents from the building blocks are required to carry out for its efficient use. For pressurized building blocks the effect of variable compaction pressures could be evaluated. Strength performance with other waste materials such as Rice Husk Ash, Ceramic waste could also be evaluated.

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