Effect of Compaction on the Properties of Eco-Friendly Building Block using Industrial By-Products.

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Concrete Projects Competition 2021

EXECUTIVE SUMMARY

Brick industry emits large pollutants e.g., particulate, SO_2, CO and CO_2 which has a significant impact on human health and the environment, therefore, the Government of Bangladesh has banned the use of clay bricks for government construction work after 2024. On the other hand, the steel manufacturing company and coal-based power industry produce a lot of by-products that are valueless for them but require the cost to manage. The industries dump these by-products as waste materials in the secluded area causing adverse effects on the environment. Therefore, the main aim of this research is to use those by-products in the production of construction materials and thereby saving the environment. The study used induction furnace slag (IFS) as partial replacement of fine aggregate (local sand) and fly ash as a filler material. Combinations of CEM I and lime are used as a binding material. Different compacting effort (viz. 10.3 MPa and 20.7 MPa) are used during casting. The result shows the sensitiveness of operating pressure on the achieved strength. The produced bricks conform to the BDS strength requirement (17.2 MPa) of traditional clay burnt first class bricks. The amount (thereby cost) of the binding materials could be reduced by up to 50% by improving strength through increasing operating pressure from 10.3 MPa to 20.7 MPa. Other essential properties such as water absorption, efflorescence, hardness, and microstructure tests also gave promising results. Therefore, building block produced using these industrial by-products could lead to the sustainable development of this country.

Keywords: Brick, fly ash, induction furnace slag, compaction effort, local sand, industrial by-product.

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CHAPTER 1

INTRODUCTION

1.1 General

An enormous number of brick kiln was established in Bangladesh to provide adequate housing to meet the alarming increase in population. These are not maintaining any standard guidelines. The relevant authority has been struggling to guide these uncontrolled kilns to follow regulations. Consequently, the uncontrolled emission of different toxic gases from these kilns has led to the deterioration of the ecosystem with unpredictable long-term effects. Therefore, the Government of Bangladesh (GoB) has banned clay bricks for government construction work after 2024. The construction industry has never been fully sustainable and, therefore, requires a great effort to conserve virgin material for future generations. To achieve sustainability in the construction sector, the GoB gave impetus for an alternative way to produce bricks, especially by using waste materials. It creates value for the waste products and saves the environment from pollutions (Sarker *et al.*, 2020).

1.2 Research Significance

The traditional red brick (clay formed and burnt) is one of the prime materials responsible for making the construction industry unsustainable in Bangladesh. This requires the upper fertile top clayey soil (150-600 mm) from the agricultural field. The production of 25 billion bricks per year consumes 100 million tons of virgin agricultural clay (Daily Star Correspondent, 2018). If such damage continues, national food security might face enormous strife to satisfy the demand for food of the next generation. The brick kiln owners have long been consuming the hills in Khagrachari remote areas, especially in winter, to produce bricks. This hill cutting triggers the land sliding by heavy rainfall during the winter season. The Brick Manufacturing and Brick Kilns Establishment (control) act 2013 prohibit soil collected from agricultural land or hills as a raw material in brick manufacturing (Bangladesh National Parliament, 2013). This agricultural land and the environment are in threat from the clay burning process (Bangladesh National Parliament, 2013). The brick manufacturing and brick kilns Establishment control act prohibit wood as fuel in brick kilns. Manufacturers can only use standard coal as fuel; however, this also releases large amounts of CO_2 into the atmosphere. The latest 2018 Department of Environment (DoE) data reported 7,707 brick kilns in Bangladesh, including 366, 1529, 356, 2295, 873, and 1176 in Barisal, Chattogram, Sylhet, Dhaka, Khulna, and Rajshahi division, respectively (Alam, 2019). In 2015 DoE reported 1,957 brick kilns (total 6895) did not have proper permission to run. Those enormous illegal number of brick kilns was responsible for half of the air pollution of Dhaka city in 2017-18 fiscal years (Alam, 2019). According to the World Health Organization (WHO), Dhaka became the second-worst city in air pollution behind Delhi and Cairo in 2018 (Grififiths, 2019). The United Nations (UN) health entity estimated 37,000 deaths per year in Bangladesh due to air pollution. Unfortunately, the average age of the victims is 38 years (Alam, 2019). According to a report of WHO, around 7 million die from exposure to fine particles in polluted air every year. Ninety percent of the deaths were in low- and middle-income countries, mainly in Asia and Africa. It caused stroke, heart disease, lung cancer, chronic obstructive, pulmonary disease, and respiratory infections. In Bangladesh, the hospital treats about 100 outdoor patients every day and most of them come with respiratory problems. GoB has already taken the initiative to shut down all harmful brick kilns by 2024 (Sarker *et al.*, 2020). Fly ash is a by-product produced from coal combustion (both bituminous and lignite) (Islam *et al.*, 2011). The only coal-based power plant in Barapukuria, Bangladesh, generates 525 MW of power with approximately 1,09,200 Metric tons of fly ash as a by-product every year (Tamim, Dhar and Hossain, 2013). The Government is planning to open 13 coal power plants in the upcoming years. Among these Matarbari power plant (1200 MW), Payra thermal power plant (1320 MW), Rampal power plant (1320 MW) is going to be opened before 2024 (BPDB, 2020). According to the data available, ash produced is approximately 10% by mass of the coal burnt (BCMCL, 2020). Out of this ash, 80% is estimated to be fly ash, and the rest is bottom ash. Once the ongoing construction of coal-based power plants are completed, fly ash production is projected to 865,000 MT per annum from 2024 onwards (Sarker *et al.*, 2020). This will create enormous storage, disposal, and management crisis for the producers. It is generally insoluble in water, but the insignificant amount of heavy metal present in fly ash may come from leeching. Due to the presence of alumino-silicate compounds, fly ash is capable of carrying a pozzolanic reaction with free lime (McCarthy *et al.*, 2012). Induction Furnace Slag (IFS) is a by-product of the steel purification and making process. This material is slightly poured with high hardness (Sarker *et al.*, 2020).

There is a various alternative of traditional *Clay burnt brick* available in the market. Concrete brick, Sand Lime Brick, Fly Ash brick are some of the examples of it. But every category has its demerits. Concrete block is not an economical solution. Also, it can be susceptible to water seepage over time, absorb much water and increase the structure's load. Lime Sand brick is not suitable for laying the foundation. It also has low resistance to water and fire for a longer period.

The abrasion resistance of these bricks is also significantly less. The mechanical strength of Fly ash brick is low. Unit weight of this type of brick is also higher than the as usual and incompatible in cold weather. That is why tis research aims to find out a solution to get optimum efficiency of workability considering the experience with the addition of some new techniques.

1.3 Research Goals

The main aim of this research is to produce more economical and eco-friendly building blocks than conventional clay brick. The below are the research's objectives:

1. To recycle the industrial waste materials.
2. To see how mechanical compaction affects the properties of building blocks.
3. To see how the curing state affected the properties of mechanically compacted building blocks.

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CHAPTER 2

LITERATURE REVIEW

2.1 General

This modern world is now running behind sustainable development. Sustainable growth aims to address today's needs by not jeopardizing tomorrow's (Shah, 2008). This means that we cannot use the whole of the available wealth and must instead leave as much as possible for future generations. And as usual traditional red bricks (clay formed) are the main barrier to this sustainable development in Bangladesh. The production of these conventional clay formed bricks require the upper layer (6 inch – 24 inch) soil of the agricultural field. UN finds out that about 690 acres of agricultural land every day is turning into the non-agricultural ground over the country. And those traditional clay burnt bricks are the main culprit of these problems. If such devastation continues, National food security will face considerable strife to satisfy the demand for food for the next generation. Not only this agricultural land but also the environment is in a threat for the clay burning process. According to DoE, the vast number of brick kilns established here is the main culprit of the air pollution in Dhaka. Researchers are working to find out an alternative solution to these traditional clays formed bricks to overcome these problems. This chapter discusses the materials and techniques of an alternative block.

2.2 Brick kilns and environment

On the other hand, Bangladesh (a developing country) has lost 1% of its farmland and nearly 17% of its due to brick kilns. According to one study, the world produces 25 billion pieces of traditional bricks per year, causing about 100 million tons of surface soil to be destroyed. This fertile topsoil provides the nutrients for agriculture. Depending on the field area, it will take not less than 15 years to restore this fertile soil surface after it has been destroyed. The loss of the surface layer has additional consequences. Since its owners sold their topsoil, the amount of land next to the kilns fell. It will not be possible for them to keep irrigation water on their field then. For producing 1.2 million bricks, they take almost 7 acres of land, while a kiln makes between 1.5 and 3.0 million bricks each year. Brick kiln owners have been consuming the hills in Bangladesh (Khagrachari) remote area for a long time, particularly in the winter, to manufacture bricks. Heavy rainfall triggered landslides because of the hill cutting. The Brick Manufacturing and Brick Kilns (Control) Act of 2013 bans further uses of soil obtained from farmland or hills as a raw material in brick production. The table illustrated below shows the major impact of brick kilns on agricultural production.

Table 2. 1- Impacts of brick kilns on food production (Saha and Hosain, 2016)

Impacts on local crops or fruits	**Soil horizon**		
	Topsoil (%)	**Subsoil (%)**	**Deep soil (%)**
Paddy	91.67	2.77	5.56
Maize	84.44	1.67	13.89
Kharif crops	31.11	25	43.89
Rabi crops	90	7.22	2.78
vegetables	92.22	1.67	6.11
orchard	97.22	1.11	1.67
Coconut	79.44	3.33	17.23
Impacts on plantation			
Declining fruit size	91.67	7.22	1.11
Leaf burning	37.78	17.78	44.44
Decaying fruit and quality	68.33	7.78	23.89
Diminishing fruit quality	97.22	0	2.78
Less delicious	30.56	20	60.56
Getting low price	91.11	2.22	6.67
Reduced cultivability			
Necessary to use fertilizer and insecticide	81.11	10.56	8.33
Leaf disease	34.44	27.78	37.78
Diminishing soil fertility	85.56	6.67	8.89
Changes in crops colors	51.11	13.89	35.0
Decreased crop production	92.78	3.33	3.89
Leaf burning	59.44	10.0	30.56
Dying crops seedlings	43.33	25.0	31.67
Delayed growth of crops	37.78	27.22	35.0
Reduced crops prices	55	11.67	33.33

Every year, about 70 lakh people die due to small particles in contaminated air, as per the World Health Organization survey. And 90% of those who died were from low and middle-income countries, mainly in Asia and Africa. Stroke, coronary disease, chronic obstructive pulmonary disease, lung cancer, and respiratory diseases are all caused by it. Every day, over 100 outdoor patients are treated at the hospital in Bangladesh, most of which have respiratory issues. Bangladesh Government has also taken steps to close all hazardous brick kilns by 2025.

2.2.1 Impacts of brick kilns on peri-urban Bangladesh

Most brick kilns in Bangladesh are located within or close to residential areas. Despite their high emissions and energy-intensive characteristics, Fixed Chimney Kilns (FCK) continue to be common in Bangladesh. Improved zigzag kilns (ZK), Hybrid Hoffmann kilns (HHK), and vertical shaft brick kilns, on the other hand, produce somewhat less pollution than FCKs, but kiln owners are unwilling to build these types of kilns. In Bangladesh, most of the kiln consume trees as their fuel. Almost 75% of brick kilns in this country is based on wood as their fuel source (Saha and Hosain, 2016). The whole scenario of brick kilns is shown in Table 2.3.

Table 2. 2- General information on brick kilns in Bangladesh (Saha and Hosain, 2016)

Location	**Percent (%)**
Cultivable land	78
Residential area	72
Reserved forest	8
Adjacent to academic institution	13
Municipal area	38.89
Fallow land	6
Marshy land	11.11
Types	**Percent (%)**
TDK	19.95
FCK	41.67
ZK	29.44
HHK	7.77
VSBK	1.67
Fuel types	**Percent (%)**
Wood	75.56
Oil	4.44
Coal	40
Natural gas	13.33
Required fuel for per 1 lakh bricks	**Percent (%)**
12-14 tonnes	1.11
14-16 tonnes	4.44
16-18 tonnes	8.33
18-20 tonnes	33.89
20-22 tonnes	48.89
More than 22 tonnes	3.33
Surrounding area	**Percent (%)**
Agricultural land	66.67
Wetland	22.22
Orchard	17.78
Residential area	91.11
Educational institution	12.78
River and pond	19.44
Marketplace	31.11
Playground	5.56

Non-Agricultural land	3.89
Soil for brick making	**Percent (%)**
Loam	80.56
Clay	66.67
Silt/Alluvium	16.67
Soil for agricultural production	**Percent (%)**
Loam	100
Clay	36.11
Silt/Alluminium	24.44

2.3 Technology of alternative brick

Using cement as a binder for making non-fired brick could be an option to reduce pollution from the brick industry. However, high cement content could indirectly lead to the same environmental damage as cement production also leads to higher emissions (Surul *et al.*, 2019). In addition, an ordinary cement-based block requires a higher curing period, increasing the cost of production due to space and time requirement (Gupta, 2021). In addition to participating in reaction with a binding material, generally, water is required in concrete to wet the surface of the aggregate to make a plastic mixture of the various ingredients that provide workability of concrete. Adding more water than that required for hydration to the mix leaves behind pores that cause the high-water absorption of concrete when get matured. The water molecule at the microscopic level becomes availed by the hydration reaction are generally evaporates with time. Hyper-pressing is a technology to produce chemically bonded building blocks without heat application. This technology compacts the ingredients with extremely high pressure. Therefore, high pressure can reduce the water demand significantly (minimum requirement for hydration). Low water/cement ratio is expected to provide higher strength, durability, and less permeability. Thus, hyper-pressing ensures the mix economical. This research, therefore, studied the effect of compaction pressure on the strength and other properties (water absorption, efflorescence, hardness, and microstructure) of building blocks. Induction Furnace Slag (IFS) was used as replacement of fine aggregate (local sand) and locally available fly ash was used as a filler material. Combinations of CEM I and lime is used as a binding material. The aim is to improve properties of building block alternative to clay burnt brick using industrial byproducts and compaction pressure keeping the cement content as low as possible.

2.3.1 Hyperpressing

This is a method of manufacturing chemically bonded bricks that do not require heat or autoclaving. This technology compacts the material using extremely high pressure and binding compounds. Increased pressure allows a low water-cement ratio. As water is needed in concrete to wet the surface of the aggregate to develop adhesive quality and make plastic mixture of the various ingredients to impart workability to concrete. High pressure ensures the workability of the concrete, and water requires for the hydration of the binding material is very low. Thus hyperpressing ensures the low-water cement ratio and makes the mix more economical. Because a low water-cement ratio gives higher strength, durability and less permeability (Mehdizadeh *et al.*, 2021). In simple the mechanism involves, more water added to the mix, then water molecule at a microscopic level will be get availed by the hydration reaction leaving behind pores that cause the high-water absorption of concrete when get matured

2.3.2 Advantages of Hyperpressing

- There is no need for thermal production (drying, burning, or processing by steam), so energy consumption is minimal.
- It allows to use various kinds of industrial waste and creates a value for them producing high-quality construction material.
- Initial investment and maintenance of equipment cost is exceptionally low.
- *Zero waste technology* during the manufacturing process, there is no chance of producing any waste. All raw ingredients are turned into blocks, and any waste generated during the process of manufacturing can easily be recycled.
- Ensures exceptional consistency that meets or exceeds the most stringent national and international requirements.

2.3.3 Impact of W/C ratio on the properties of compressive strength

The W/C ratio is the most significant aspect that affects the compressive strength properties of cement-based products (Levy, 2012). For the hydration of cement, a very negligible amount of water (less than 0.18) is needed. Workability, on the other hand, necessitates a large volume of water. Without a high W/C ratio, proper compaction cannot be achieved by hand. The strength of the cement concrete product decreases as the W/C ratio rises, and so the durability of the concrete is illustrated in Figure 2.3. Required compressive strength can be acquired through a low W/C ratio by using a superplasticizer or compacting mechanically.

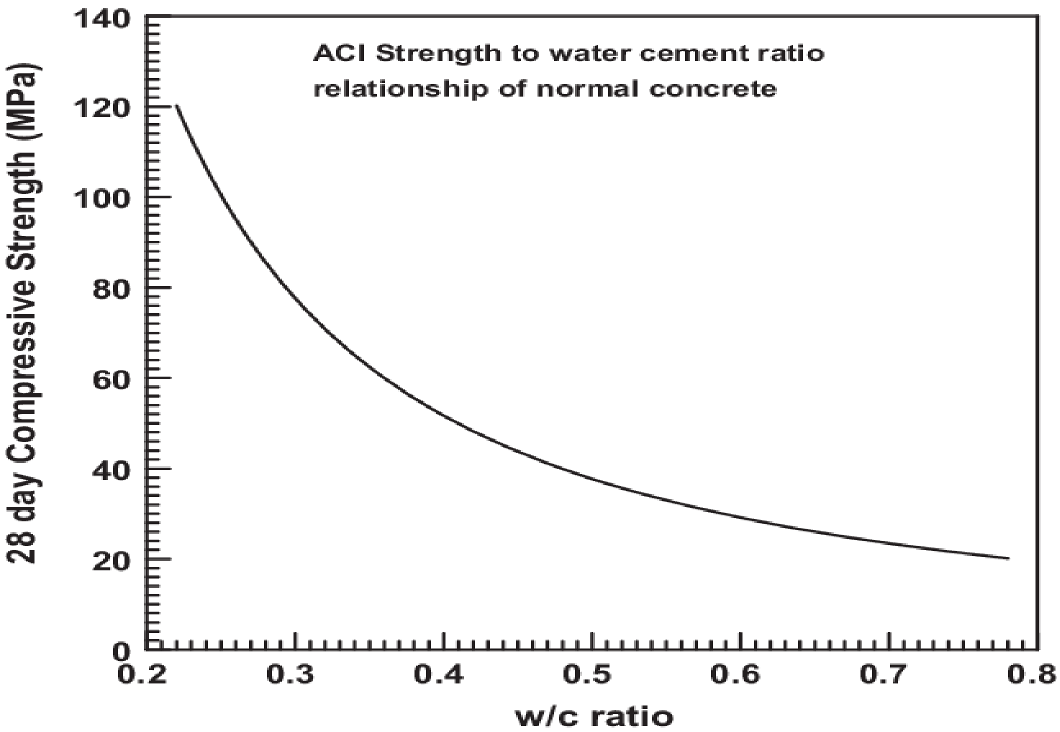


Figure 2. 1: Effect of W/C ratio on the compressive strength of brick (Levy, 2012)

2.3.4 Optimum mixing sequence for hydrated lime fly ash brick

(Gupta et al., 2021) investigated to determine the effect of different mixing sequences at different moisture contents on the properties of hydrated lime fly ash (HLF) bricks and, as a result, to determine the most successful method for producing HLF bricks within the given parameters. Two different mixing sequences were used, as well as five different moisture content levels. The first mixing protocol ensures the binders blended thoroughly and get them to a wet state before applying the stone materials to the mixture. On the other hand, mixing sequence II was planned to ensure the homogeneous mixing of solid particles and the addition of moisture after the stone dust had been mixed. According to (Gupta et al.,2020), the mixing sequence and moisture content have a significant impact on the mechanical properties of HLF bricks. Findings showed that mixing design II have better efficiency than mixing design I.

2.4 Materials of alternative brick

This research aims to use binding materials as low as possible to keep them economical. As the coarse aggregate and fine aggregate will be compacted using high pressure, we may hope that (5-10)% of binding materials of the total mixer will provide the favourable result. Different combination of CEM I and lime have been used not exceeding 10% of the total volume in this experiment. On the other hand, aggregate works as an inert filler. It usually makes up 60-80% of the overall mix volume and 70-85% of its weight. Not only the thermal and elastic properties but also the dimensional consistency of concrete are all specified by the aggregate (Tamim, Dhar and Hossain, 2013). It is primarily divided into two different types: coarse and fine. In this experiment, Induction furnace slag (IFS) has been used as a coarse aggregate, and sand is used as a fine aggregate. Size and shape of the aggregate are also important because it provides the exact interlocking between them. IFS has been used of 10 mm downsize, and FM value of sand is 1.16. Fly ash is used as filler material, and the volume of it is the same for all the batches, i.e. 40% of the total mix.

2.4.1 Induction furnace slag

Bangladesh consumes over forty lakh tons of steel per year, which is achieved by 400 steel mills(IDLCSL, 2020). Almost all of them, except one, use an induction furnace to melt scraps rather than a typical electric arc furnace. Induction furnaces manufacture about 3.2 million tons of steel in Bangladesh. A significant volume of slag is formed due to this melting process, which is known as Induction Furnace slag (IFS). To produce 3.2 million tons of steel, almost 24 thousand tons of (IFS) is produced as a by-product. Steel slag is described by the American Society for Testing and Materials (ASTM) as a nonmetallic substance made up primarily of calcium silicates and ferrites mixed with fused oxides of iron, calcium, manganese, aluminium, and magnesium produced in plain oxygen, electric arc, or open-hearth furnaces at the same time with steel. In Bangladesh, there is no official available data on the overall annual output of IFS. However, for the production per ton of steel in an induction furnace, 15 to 11 kg of IFS is produced. Therefore, annual estimation of IFS output in Bangladesh is approximately six lakh tons based on this. There is also little long-term recycling option is needed for these by-products other than ground filling. However, as land available to fill becomes scarce for the next generation, the choice of landfilling is decreasing drastically. So, disposal of this massive amount of by-product is a cause of headache for the steel company. So, any viable solution of this by-product will benefit the construction site and alleviate the disposal problem of the steel company.

2.4.2 Induction furnace and production of slag as by product

Over the past fifty years, coreless induction furnaces are being used in the steel industry. It has become one of the most common methods of melting and retaining ferrous materials. It is a kind of electric melting furnace that melts metal with the current. Induction melting works on the principle that the primary coil with a high voltage and low current source produces a low voltage high current in the metal (secondary coil). This high eddy current, combined with the metal's resistance, generates a lot of heat, causing the metal to melt. Almost 396 KWh of electric power is needed to raise one ton of iron to 1500° C, (Hilmawan, 2011). It reflects the significance of electricity in the steel industry. In the furnace, several losses take place. The major losses are,

- Radiation loss from furnace top.
- Conduction losses from the refractory lining.
- Heat losses from the coil during cooling.
- Heat carried by the removed slag.

The volume of slag produced from the steel industry depends on the type of raw materials they use. More production of slag will consume more electricity. Energy loss is 10 KWh per ton of each 1% slag produced at 1500° C. Therefore, selecting the raw material is a crucial decision for the steel maker. The primary raw materials for steel making in induction furnace are,

- Steel scrap
- Iron scrap or pig iron
- Sponge iron
- Carburized
- Additives

When the electric power supply is switched on, a high voltage is induced in the material, which causes strong eddy currents. Due to the strong eddy currents and the resistance of the metal a high heat is produced which causes the metal to be melted. The defects bind with CaO to form a liquid slag that floats on top of the molten iron. After the denser iron has been discharged from a tap hole at the furnace bottom, the slag is removed. Thus, it is a continuous process(Nadeem and Pofale, 2012).

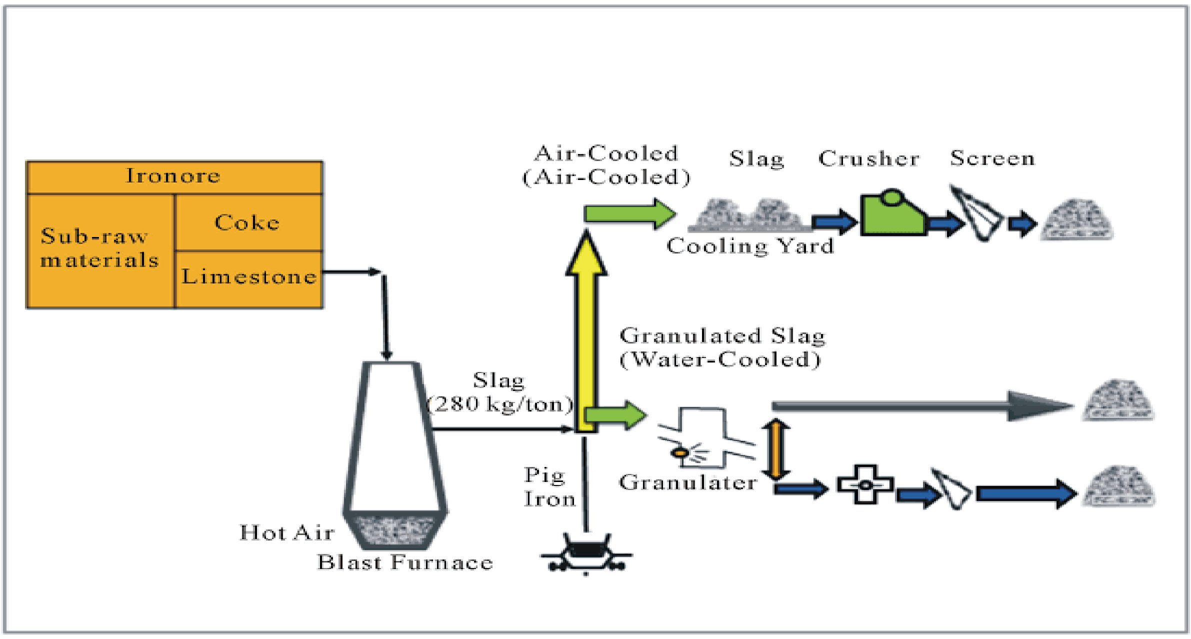


Figure 2. 2: Production of slag as by-product

2.4.3 Fly ash

Fly ash is a natural by-product of coal-based industry and is formed when burning the coal (both bituminous and lignite) (Marinković and Dragaš, 2018). Every year, massive quantities of fly ash produced by thermal power plants and coal ash-based factories create disposal, storage, and management challenge. It is a fine-grained substance made up of glassy, spherical particles. Fly ash chemical composition depends based on where it comes from and what it's used for. Mainly it consists of oxides of different elements such as SiO_2, Al_2O_2, CaO, Fe_2O_3, SO_3 etc. It is insoluble in water. A little amount of heavy metal is also found in it. For the presence of this, it is also assumed that fly ash may come from the leaching of heavy materials. In Bangladesh, till now, six potential coalfields have been identified. Out of which, only Barapukuria is in production. It has a coal reserve of nearly 390 million tonnes. The yearly output of about 1 million ton. In 2017-18 it was 923276.08 ton. The coal power plant in Barapukuria receives 65% of the total. It has a capacity of 525 MW (BCMCL, 2020). Bangladesh Government is planning to open 13 coal power plant in the upcoming years. Of which Matarbari power plant (1200 MW), Payra thermal power plant (1320 MW), Rampal power plant (1320 MW) is going to be opened before 2024. About 9000 tonnes of coal is required daily for a 1000 MW power plant. In 2024 Bangladesh is going to produce up to 4365 MW of electricity.

For this, it will require almost (4365*9) = 3 9285 tonnes of coal daily.

That means annual consumption of coal will be (39285*365) = 14339025 tonnes of coal.

This massive amount of coal will be supplied by the middle-east and from African countries. According to existing data, ash emitted accounts for around 10% of the coal burned by mass.

So, the production of ash from this coal will be (14339025*0.10) = 1433902.5 tonnes.

About 80% of this ash is believed to be fly ash, with the remainder being bottom ash (BCMCL, 2020). Then, total fly ash production will be up to (1433902.5 * .8) = 1147122 tonnes before 2024.

2.4.4 Production procedure of Fly ash

Fly ash is a fine-grained, powdery particulate substance formed primarily by pulverised coal combustion in a coal-fired boiler. Then these powdery combustion byproducts are taken away in the flue gas and are typically gathered via electrostatic precipitators, baghouses, or mechanical collection systems like cyclones.

In the electric utility industry, there can be three major kinds of coal-fired boiler furnaces. Dry-bottom boilers, wet-bottom boilers, and cyclone furnaces are the main three types of boilers. The dry-bottom furnace seems to be the most preferred of these. As pulverized coal is burned in dry ash, dry bottom boiler, approximately 80% of the ash is released as fly ash, which is entrained in the flue gas. However, if pulverized coal is burned in a wet bottom furnace, about half of the ash escapes the fly ash and becomes entrained in the flue gas. 70-80% of the ash in a cyclone furnace is stored as boiler slag, although about 20-30% of the ash exits the furnace fly ash generation in a dry bottom coal-fired utility boiler as dry ash in the flue gas. Figure 2.3 shows a flow diagram of fly ash production.

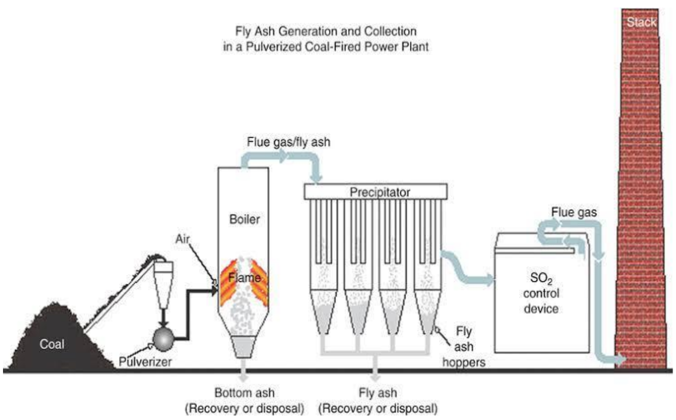


Figure 2. 3: Production of fly ash in a dry-bottom utility boiler

CHAPTER 3

RESEARCH METHODOLOGY

3.1 General

This study deals with five different materials to produce building block. This chapter includes the properties of the material used and the procedure of making blocks in details. In this research, the compaction effect was used to reduce the water-cement ratio as this is related to strength. In this process, blocks can be made of much better control which results in better strength than the ordinary one. Again, air and natural water curing were ensured by keeping the blocks in water for a certain period in a day for seven days and 28 days.

3.2 Materials used

3.2.1 Fly ash

Fly ash is a residual of coal combustion that is crushed or powdered. Because of its pozzolanic and cementitious qualities, this waste material is commonly used in concrete. The ASTM: C 618 standard specifies how fly ash can be used in concrete. There are two categories of fly ash: class C and class F, with class C coming from the combustion of lignite or sub-bituminous coal and class F coming from bituminous coal combustion. Class C may have cementitious properties, while class F has pozzolanic properties. This study used class F fly ash, with the volume of fly ash remaining constant through all mixing variations. Scientifically, it is proved that the pozzolanic characteristics protect the concrete material from sulphate attack. In contrast, the main chemical attack in concrete comes from sulphate attack. The element C_3A in cement is susceptible to sulphate attack. Table 3.1 lists the chemical properties of the class F fly ash used in this analysis.

Table 3. 1- Chemical properties of fly ash (Saha, 2018)

Parameter	Percentage	Parameter	Percentage
SiO_2	76.34	CaO	0.6
Al_2O_3	14.72	Na_2O	0.19
Fe_2O_3	3.69	K_2O	0.96
MgO	0.54	P_2O_5	0.1
SO_3	0.11	TiO_2	0.61

Figure 3. 1: Fly ash used in the study

3.2.2 Induction furnace slag (IFS)

The slag from induction furnaces is a waste product from the steel industry. IFS was used as a partial substitute for fine aggregate in this analysis. Local sand has been consecutively replaced by IFS, which helps to give the volume to the specimen and provides a sustainable solution to the industrial waste. The physical properties of IFS are shown in Table 3.2. IFS has been used as a size of having 8 mm down. The IFS collected to conduct the study has FM value of 4.828. Sieve analysis conducted on the collected IFS is given in the following table 3.3.

Table 3. 2- Physical properties of IFS

Property	Test value
Water absorption	Nil
Specific Gravity	2.78

Table 3. 3- Sieve analysis of IFS

Sieve size (mm)	wt. retained (gm)	Cumulative wt. retained (gm)	% Cumulative wt. retained (gm)	% passing wt. (gm)
19	0	0	0	100
9.5	3	3	0.6	99.4
4.75	161	164	32.8	67.2
2.36	226	390	78	22
1.18	53	443	88.6	11.4
0.6	21	464	92.8	7.2
0.3	8	472	94.4	5.6
0.15	9	481	96.2	3.8
pan	18	499	99.8	0.2

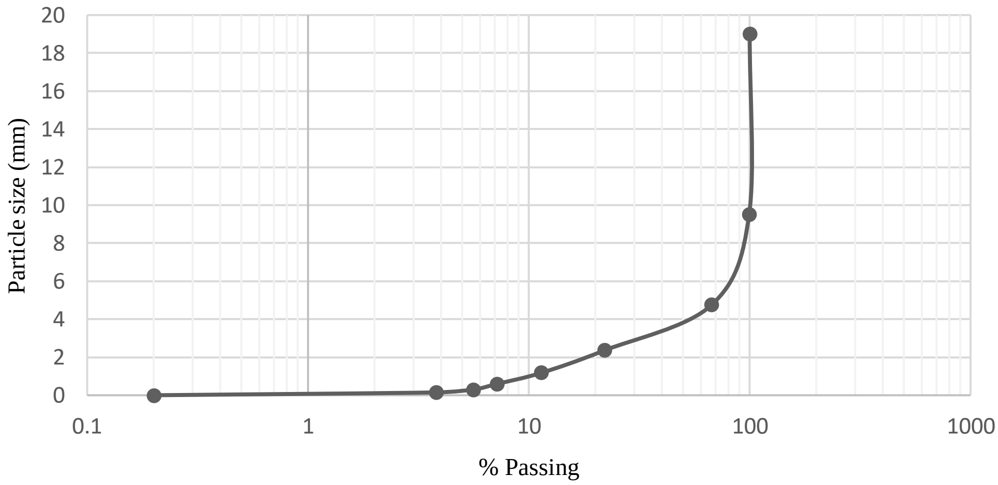


Figure 3. 2: GSD of IFS

Figure 3. 3: IFS used in this study.

3.2.3 Sand

Sand is a granular aggregate made up of small rock and mineral crystals that have been finely separated. It comes in a variety of compositions, but its grain size is what distinguishes it. In this study sand has been used as fine aggregate along with IFS. It is an inert substance that plays a significant part in the mix design of the building blocks, even though it is inert. Using sand as fine aggregate helps the blocks prevent excessive shrinkage and provides volume to the blocks that make them economical. Again it protects the structure from the adverse atmosphere.

Local sand has been used in this study and the sand has fineness modulus of 1.16. Sieve analysis for the grading of the sand is given in the table below.

Table 3. 4- Sieve analysis of sand

Sieve size (mm)	wt. of Sand retained	Cumulative wt. retained	% Cumulative wt. retained	% passing = 100 - cumulative % retained
4.75	1	1	0.5	99.5
2.36	1	2	1	99
1.18	1	3	1.5	98.5
0.6	2	5	2.5	97.5
0.3	45	50	25	75
0.15	121	171	85.5	14.5
pan	28	199	99.5	0.5

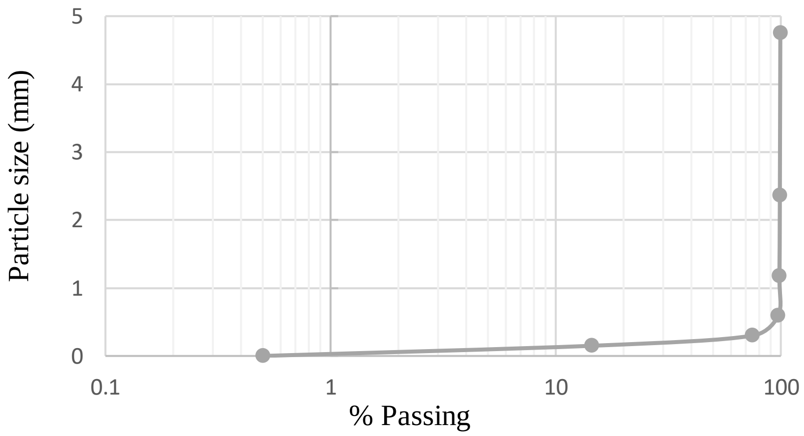


Figure 3. 4: GSD of sand

3.2.4 Cement

Cement is made by grinding materials, combining them closely in specific proportions based on their purity and composition, and then burning them in a kiln at temperatures ranging from 1300°C to 1500°C, where the material sinters and partially fuses to form nodular-shaped clinker. Then, with the addition of around 3 to 5% gypsum, the clinker is cooled and ground to a fine powder. Portland cement is the result of this process.

Table 3. 5- Chemical composition of cement (Gambhir, 2013)

Oxide composition, %		Compound	
CaO	6.3	Tricalcium Silicate (C_3S)	54.1
SiO_2	20	Dicalcium Silicate (C_2S)	16.6
Al_2O_3	6	Tricacium Aluminate (C_3A)	10.8
Fe_2O_3	3	Tetracalcium Aluminoferrite (C_4AF)	9.1
MgO	1.5		
SO_2	2.0		
K_2O	1.0		
Na_2O	1.0		

Lime, silica, alumina, and iron oxide are the most common raw materials used in cement production. At high temperatures in the kiln, these oxides interact to form a more complex compound. Table 3.5 shows the approximate oxide concentration as well as four compounds that are commonly considered main compounds.

The study deals with a very nominal amount of cement. Again, for higher strength and durability water-cement ratio should be kept lower. The water in the mix percentage is just there to keep the cement hydrated. When anhydrous cement compounds are combined with water, they react to form hydrated compounds with exceptionally low solubility.

Hydration of C_3S : $(3\ CaO.SiO_2) + 6H_2O \rightarrow 3\ CaO.2\ SiO_2.3\ H_2O + 3\ Ca(OH)_2$

(Calcium Silicate Hydrates)

Hydration of C_2S : $2\ (2\ CaO.SiO_2) + 4H_2O \rightarrow 3\ CaO.2\ SiO_2.3\ H_2O + Ca(OH)_2$

The produced Calcium Silicate Hydrates is responsible for gaining strength, and Calcium hydroxide is an undesirable product. Besides, due to the hydration of C_3A and C_4AF, the form CaO-Al2O3-H2O and CaO-Fe2O3-H2O formed respectively, which does not contribute anything to the strength.

Figure 3. 5: Cement used in this study

3.2.5 Lime

Lime is impure calcium oxide (CaO) and obtained by calcination (heating of shells, corals, limestones, and other substance composed of almost pure or impure calcium carbonate). Study shows that use of lime along with cement have a high level of flexural bond strength. Again, autogenous healing is another advantage of using lime. This is the hairline crack repairing mechanism. When a crack develops, hydrated lime reacts with atmospheric carbon dioxide, thus producing limestone, which helps seal the cracks and fill voids. In addition, lime helps keep low air content, provide high plasticity, and have finer particles contribute an excellent extent to the bond.

Figure 3. 6: Lime used in the study

3.2.6 Water

Water is an essential component since it plays a role in the chemical reaction that occurs as cement mixes with it. Since water quality influences strength, it is essential to investigate the quality and purity of water. Therefore, the water used in any concrete work should be of drinking quality. In this study, tap water available in the laboratory has been used, which was fresh enough to look at and has no odour.

3.3 Mixing of materials and preparation of blocks

Fly ash, induction furnace slag, sand, lime, and cement were used to make the mixture. The sample of Induction furnace slag, lime, and fly ash collected from the BSRM industry and the whole experiment was conducted at the paving lab of BSRM. Sand and Cement were collected from the local market. Mixing of the material was completed following the undermentioned mixing proportion discussed in section 4.1. Materials were mixed thoroughly for 25 minutes using the mixture machine at 22 rev/minute. Then water was added gradually as required until the surface of the mixture is wet. As usually, it varies from 10%-12% of the full weight. The wetted mixture has been thoroughly mixed again for 10 minutes using the mixture machine. A total of 154 blocks was made, of which 84 were tested for compressive strength. The rest of them were for other testing operation. A compaction effort of 10.3 MPa was used to cast half of the bricks while the rest of them experienced 20.7 MPa. Approximate weight of 3.5 kg mixture was used to fill up the mould to maintain a constant volume during casting. Pressure applied on the brick for three-round. Each of them lasted for 3 seconds. Then the blocks were moulded and kept in the air for 24 hours. And at last, underwater curing procedure was followed to finalize the block for testing.

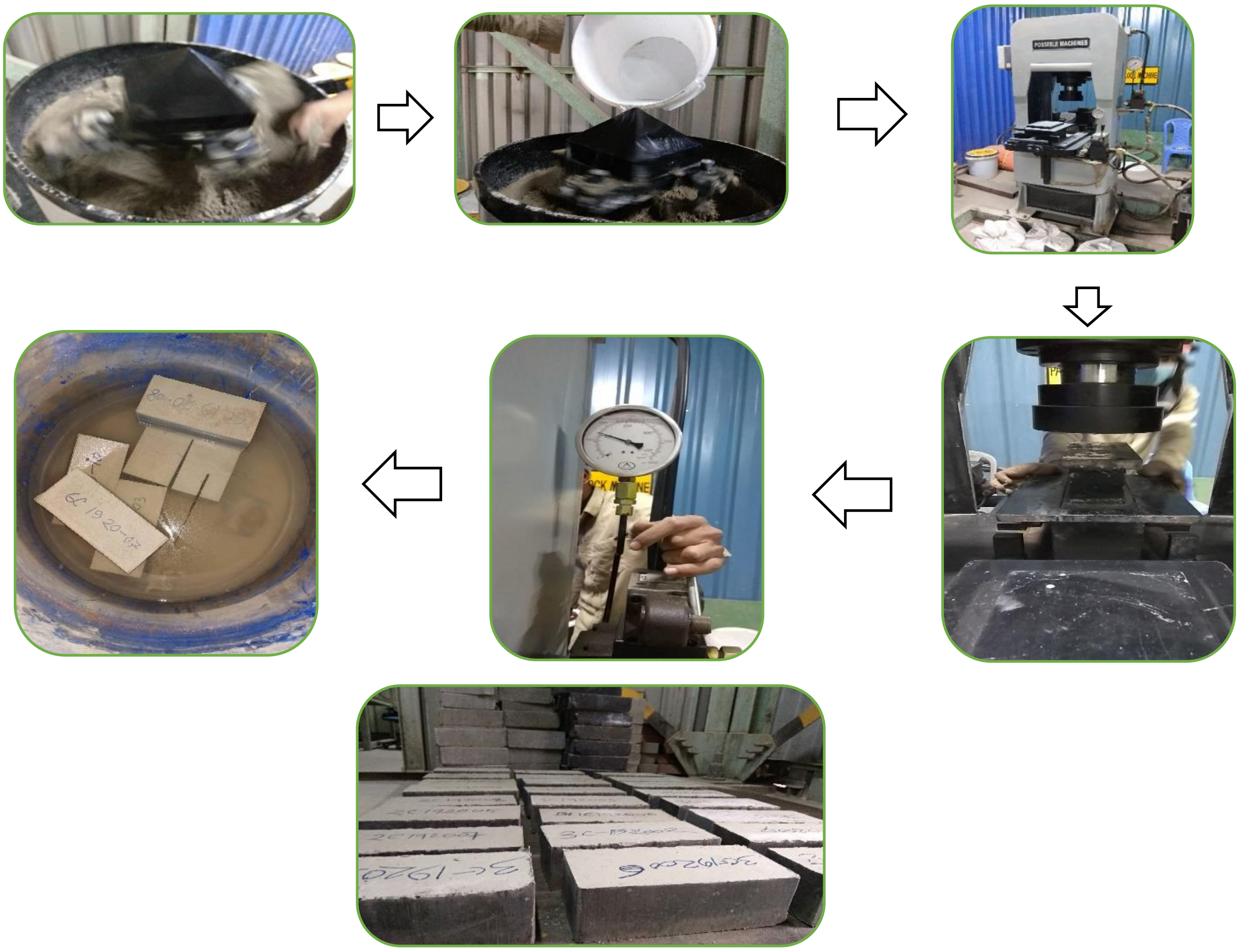


Figure 3. 7: Overall scenario of specimen preparation

Table 3. 6- Mix proportion of the building blocks (by weight %)

Batch Name	Ingredients, mass % of the total mix					
	Fly Ash	**Sand**	**IFS**	**Lime**	**Cement**	**Water**
I45L5C10	40	0	45	5	10	10.5
I45L7.5C7.5	40	0	45	7.5	7.5	10.3
I45L10C5	40	0	45	10	5	11
I30L7.5C7.5	40	15	30	7.5	7.5	10.7
I15L7.5C7.5	40	30	15	7.5	7.5	10.5
I0L7.5C7.5	40	45	0	7.5	7.5	10.3
I35L5C5	40	15	35	5	5	10.1

3.3.1 Flowchart for specimen preparation

An overall scenario for preparing the specimen is represented by the following flow chart.

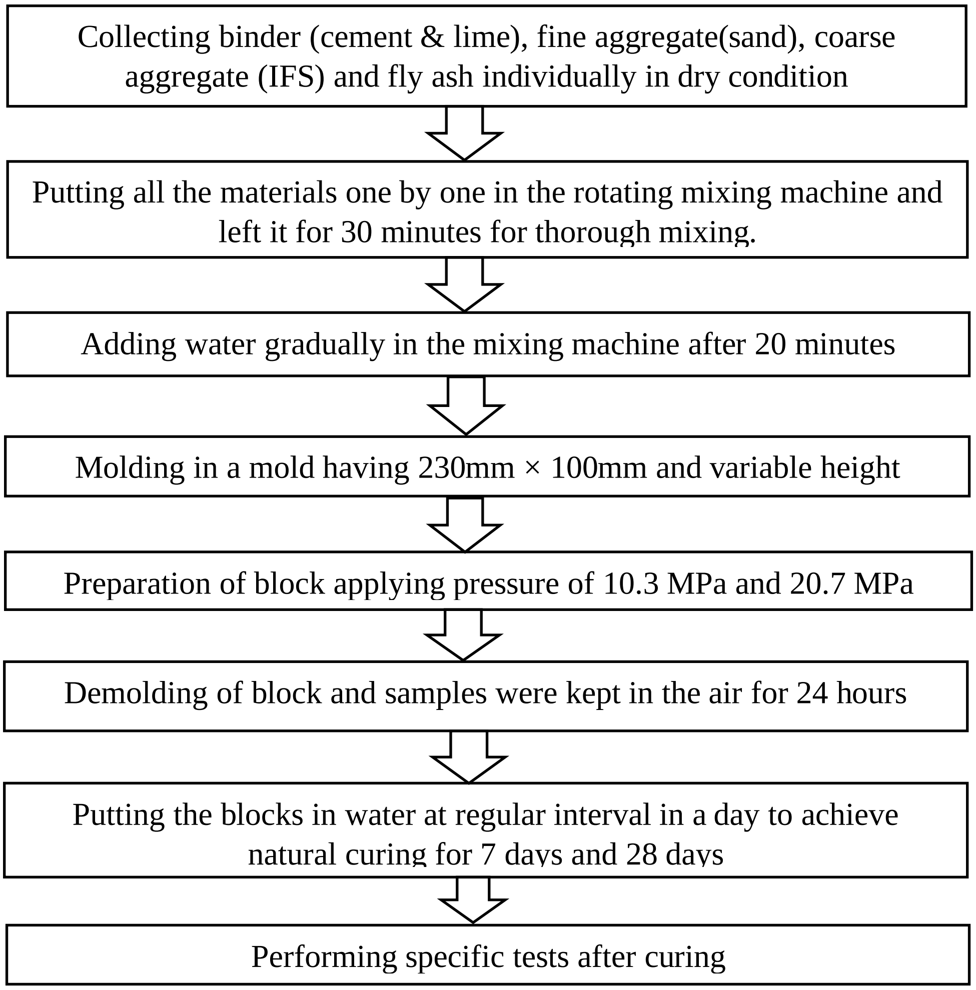


Figure 3. 8: Flowchart of specimen preparation

CHAPTER 4

EXPERIMENTAL PROGRAM

4.1 General

This study deals with a total number of seven batches to substantiate the suitability of different percentage of waste materials in building block production. In this study, cement and lime were consecutively replaced IFS consecutively replaced each other and sand to find the best suitable combination of materials. To check the usability of the blocks for practical purposes, it is needed to perform some tests, e.g., compressive strength, efflorescence, water absorption and microstructure test.

4.2 Mix design and properties

A mix design was made to find out the best economical combination of respective materials without compromising strength and other structural properties.

This study involves producing building blocks having two distinct pressure of 10.3 MPa and 20.7 MPa. The dimension of the block is 230mm × 100mm × variable height (nearly about 75 mm). The produced number of blocks for each batch is calculated below.

Table 4. 1- Number of blocks for individual investigation

Performed test	Applied pressure (MPa)	Curing period (days)	No. of blocks
Compressive strength test	10.3	7	3
		28	3
	20.7	7	3
		28	3
Water absorption, efflorescence, hardness and microstructure test	10.3	28	5
	20.7	28	5

Number of block for each batch = 22

Total number of brick for all the batches = 154

Block size = 230mm × 100mm × 75mm

Volume of each block = $(230 \times 100 \times 75) \div 1000^3 = 1.725 \times 10^{-3}$ m^3

A total of 80 kg material for each batch is taken, considering each block as 3.5 kg

A distinct calculation of all the materials required for each batching is given below:

4.2.1 Batch 1 (I45L5C10):

Mix proportion: Fly ash : Sand : IFS : Lime : Cement = 40 : 0 : 45 : 5 : 10

Required amount of fly ash = 80 × 40/100 = 32 kg

Required amount of Sand = 80 × 0/100 = 0 kg

Required amount of IFS = 80 × 45/100 = 36 kg

Required amount of Lime = 80 × 5/100 = 4 kg

Required amount of Cement = 80 × 10/100 = 8 kg

Water used to make the mix into a sticky condition = 9.4 kg = 10.5% of the total mix

4.2.2 Batch 2 (I45L7.5C7.5):

Mix proportion: Fly ash : Sand : IFS : Lime : Cement = 40 : 0 : 45 : 7.5 : 7.5

Required amount of fly ash = 80 × 40/100 = 32 kg

Required amount of Sand = 80 × 0/100 = 0 kg

Required amount of IFS = 80 × 45/100 = 36 kg

Required amount of Lime = 80 × 7.5/100 = 6 kg

Required amount of Cement = 80 × 7.5/100 = 6 kg

Water used to make the mix into a sticky condition = 9.2 kg = 10.3% of the total mix

4.2.3 Batch 3 (I45L10C5):

Mix proportion: Fly ash : Sand : IFS : Lime : Cement = 40 : 0 : 45 : 10 : 5

Required amount of fly ash = 80 × 40/100 = 32 kg

Required amount of Sand = 80 × 0/100 = 0 kg

Required amount of IFS = 80 × 45/100 = 36 kg

Required amount of Lime = 80 × 10/100 = 8 kg

Required amount of Cement = 80 × 5/100 = 4 kg

Water used to make the mix into a sticky condition = 9.88 kg = 11% of the total mix

4.2.4 Batch 4 (I30L7.5C7.5):

Mix proportion: Fly ash : Sand : IFS : Lime : Cement = 40 : 15 : 30 : 7.5 : 7.5

Required amount of fly ash = 80 × 40/100 = 32 kg

Required amount of Sand = 80 × 15/100 = 12 kg

Required amount of IFS = 80 × 30/100 = 24 kg

Required amount of Lime = 80 × 7.5/100 = 6 kg

Required amount of Cement = 80 × 7.5/100 = 6 kg

Water used to make the mix into a sticky condition = 9.6 kg = 10.7% of the total mix

4.2.5 Batch 5 (I15L7.5C7.5):

Mix proportion: Fly ash : Sand : IFS : Lime : Cement = 40 : 30 : 15 : 7.5 : 7.5

Required amount of fly ash = 80 × 40/100 = 32 kg

Required amount of Sand = 80 × 30/100 = 24 kg

Required amount of IFS = 80 × 15/100 = 12 kg

Required amount of Lime = 80 × 7.5/100 = 6 kg

Required amount of Cement = 80 × 7.5/100 = 6 kg

Water used to make the mix into a sticky condition = 9.4 kg = 10.5% of the total mix

4.2.6 Batch 6 (I0L7.5C7.5):

Mix proportion: Fly ash : Sand : IFS : Lime : Cement = 40 : 45 : 0 : 7.5 : 7.5

Required amount of fly ash = 80 × 40/100 = 32 kg

Required amount of Sand = 80 × 45/100 = 36 kg

Required amount of IFS = 80 × 0/100 = 0 kg

Required amount of Lime = 80 × 7.5/100 = 6 kg

Required amount of Cement = 80 × 7.5/100 = 6 kg

Water used to make the mix into a sticky condition = 9.2 kg = 10.3% of the total mix

4.2.7 Batch 7 (I35L5C5):

Mix proportion: Fly ash : Sand : IFS : Lime : Cement = 40 : 15 : 35 : 5 : 5

Required amount of fly ash = 80 × 40/100 = 32 kg

Required amount of Sand = 80 × 15/100 = 12 kg

Required amount of IFS = 80 × 35/100 = 28 kg

Required amount of Lime = 80 × 5/100 = 4 kg

Required amount of Cement = 80 × 5/100 = 4 kg

Water used to make the mix into a sticky condition = 9 kg = 10.1% of the total mix

Table 4. 2- Total amount of material for the study

Material	The total amount required for all the blocks
Fly ash	224 kg
Sand	84 kg
IFS	172 kg
Lime	40 kg
Cement	40 kg

4.3 Investigation program

4.3.1 Compressive strength

One of the most significant characteristics of a building block is its compressive strength. Blocks, in general, have properties that allow them to withstand compression and are used in situations where tension or shear strength is less critical. The capacity of a material to withstand the direct pressure of steadily applied compression force until failure is known as compressive strength. The test was done by following BDS 208. Compressive strength of each specimen as follows:

$$C = W / A \quad \text{(eqn-1)}$$

Where,

C = Compressive strength of the specimen (MPa)

W = Maximum load indicated by testing machine (N)

A = Average of the gross areas of the upper and lower bearing surface (mm^2)

The observed load calibrated as the following equation, which was attached to the testing machine.

Calibrated load (kN) = 0.5428 × Observed load (kN) + 16.552

Figure 4. 1: Compressive strength test

4.3.2 Efflorescence test

The test to determine whether there are harmful salts (like sulphates of sodium and potassium) is present in the specimen. The presence of salts in the block directly exposed to the air may absorb moisture from the atmosphere, leading the structure to severe disfigurement. The test was done according to BDS 208. Five blocks were taken, and each block placed on end in a shallow flat bottom non-absorbent dish keeping a minimum clearance of 5 cm between two consecutive blocks. Water poured to a depth of 2.54 cm so that it surrounds each block by a 2.54 cm layer. After a few days, when the water had been absorbed, and the blocks appear to be dried similar quantity of water again poured and allowed for further drying and then efflorescence measured. The result classified as nil, slight, moderate, severe, and heavy.

Figure 4. 2: Efflorescence test

4.3.3 Water absorption test

The test determines the total moisture absorbed by the specimen as a percentage of its total dry weight. It is desirable to get the rate of water absorption more negligible in value. Five blocks were taken to conduct the test, and the test followed the BDS 208. Calculation of the absorption of each specimen as follows:

$$\text{Absorption, \%} = (W_s - W_d) / W_d \times 100$$

Where,

W_d = Oven dry weight of the specimen

W_s = Saturated weight of the specimen after submerged into water.

4.3.4 Microstructure test

It is observing the broken blocks whether it has any severe cracks inside it or having any undesirable pores inside it.

Figure 4. 3: Microstructure test

4.3.5 Hardness test

It is a test that measures the resistance of blocks against scratch. A good quality block should resist scratches against sharp things and fingernail. If there is no significant scratch impression, it can be termed an as hard block.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 General

The primary goal of this research was to determine the effect of compaction effort on the compressive strength properties of sample blocks, evaluate the impact of IFS on compressive strength properties, and determine the best mix combination between the binding materials of lime and cement. The result and discussion part are categorized into two sections: the compressive strength test and the workability test of the block. The outcomes of the experiment work are shown in a tabular and graphical form. It has been observed that the compaction effort and the presence of IFS have a positive impact on the properties of the compressive strength of the blocks. This study consists of seven batches, and each set experienced two different pressure of 10.3 MPa and 20.7 MPa. The sample bricks are tested for compressive strength, efflorescence, hardness and structural microstructure test. And all of these test results showed the positive effect to use it for practical purposes. Each of the different test results with different combinations is defined in various ways and plotted as per the specifications.

5.2 Compressive strength test

Tabular representation

Table A1 to Table A14 in Appendix represents weight, height, observed load and, actual load and compressive strength of individual bricks on the perspective of their brick id and compacting effort they have experienced. The length and width of each of the brick is same (230 mm x 100 mm).

5.2.1 Compressive strength

The major part of this experiment was concerned with the crushing strength of the building block samples. Generally, the crushing strength of hyper-press building block is a function of w/c ratio, compaction pressure, cement type, aggregate type, test procedure, specimen shape, size, age, and curing. Figure 5.1 shows the effect of compaction pressure on the compressive strength test results. By increasing the compaction pressure from 10.3 MPa to 20.7 MPa significant improvements (37-55%) in compressive strength were noted. Especially the effect on the lower compressive strength batches was improved one half of its basic strength at 10.3

MPa compaction pressure. Therefore, keeping other parameters the same, just improving the compaction pressure can significantly improve the situation and requires almost no additional material but a small amount of electric energy (Danso, 2016). All building blocks prepared with higher compaction pressure met the strength (17.2 MPa) conforming criteria specified by BDS 208 (BSTI, 2009). With 10.3 MPa compaction pressure, the last two batches with comparatively less amount of IFS did not achieve the requirement of first-class brick specified by BDS. In addition, I35L5C5 is composed of a 10% binder which is less than 5% from other mixtures. With the improved compaction pressure this mixture also achieved the minimum strength requirements specified by BDS.

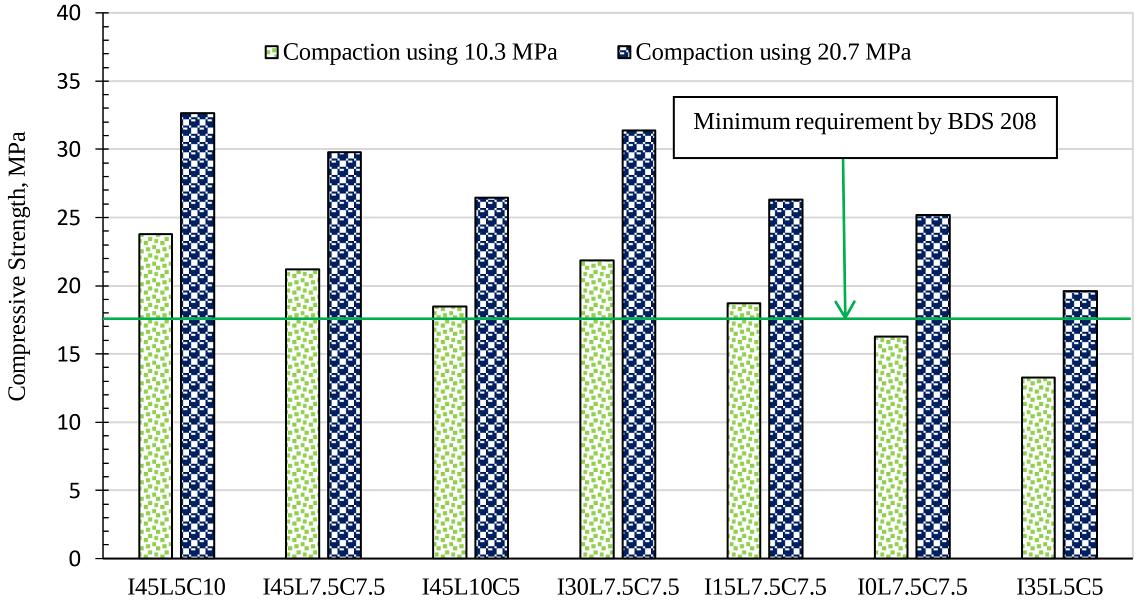


Figure 5. 1: 28 days Compressive strength of building blocks

5.3 Water absorption

Water absorption is an important criterion of the building block to be considered for its intended use. Empirically water absorption of building block is a function of the type of aggregates, void, testing procedure, time, and weather. The water absorption by weight should not exceed 10%, 15%, and 20% for bricks of S, A, and B grade grades classified according to BDS 208, respectively (BSTI, 2009). The water absorption test of results of building blocks compacted with 20.7 MPa at 28 days is given in Figure 5.2. The improvement of microstructural integrity and density using high pressure is reflected in the absorption of water. All the test result complied with BDS 208 and was well below the maximum range of 10-20%.

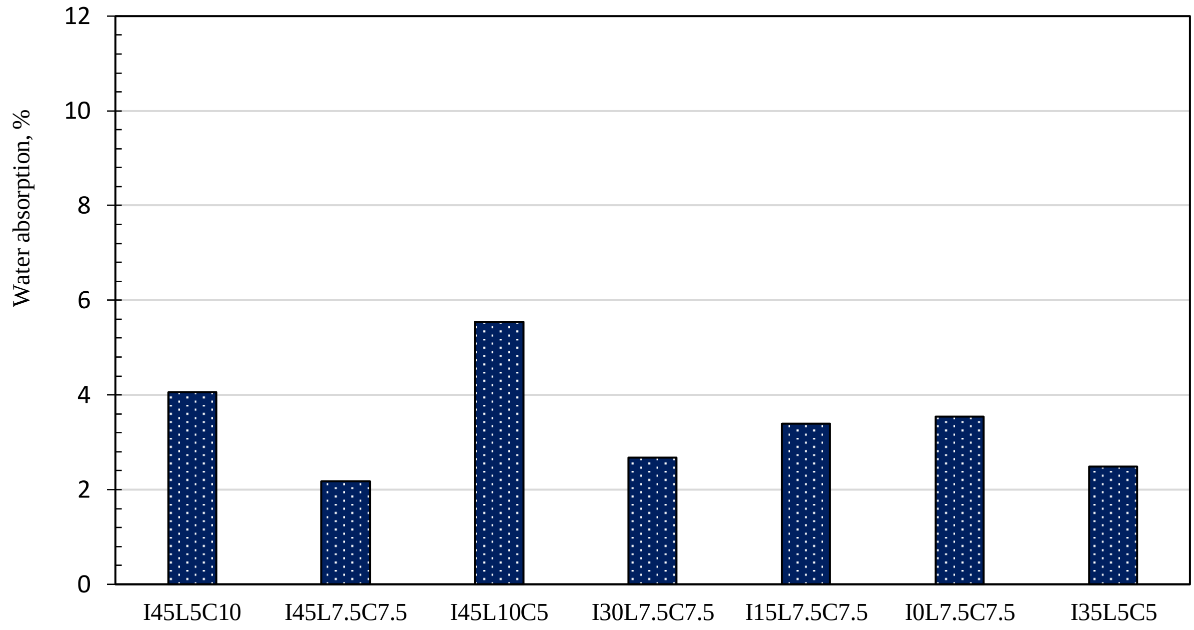


Figure 5. 2 : Water absorption of building blocks (20.7 MPa compaction pressure)

5.4 Efflorescence, Hardness, and Microstructure

Efflorescence, hardness, and microstructure were also examined to ensure the building block's long-term performance. The efflorescence test result indicates the presence of any soluble salt in the building block. This test is conducted according to the BDS 208 (BSTI, 2009). On the other hand, hardness is an indication of the surface resistance of the block. The microstructure of the building blocks was observed after crushing strength to evaluate the relative amount of void in the structural part of the building block. Table 5.15 gives a summary of the test results and observations. In general, the clay burnt bricks produced in the south zone of Bangladesh suffers from efflorescence. The made building blocks were found free from this adverse effect. The surface hardness was found sufficient to withstand. The dense microstructure indicates the overall improved property of the building block through higher compaction pressure.

Table 5. 1- Efflorescence, hardness, and microstructure test results of the building blocks

Name of the Test	Result
Efflorescence	Nil
Hardness	No impression
Structural microstructure	Homogeneous and Compact

5.5 Effect of compacting effort

One of the main objectives of this research was to evaluate the effect of compaction pressure on the properties of building blocks. It helps to interlock the inert materials (sand, IFS, and fly ash) properly and allows a negligible amount of water absorption, leaving less pour and enhancing the block durability. High compaction pressure also allows less W/C ratio in the mix as there is no need for any extra water to lubricate the mix. The Study shows that Compacting pressure has a significant effect on the properties of building blocks. The cost of this binding material could be reduced by up to 50% by improving strength through increasing compacting pressure from 10.3 MPa to 20.7 MPa.

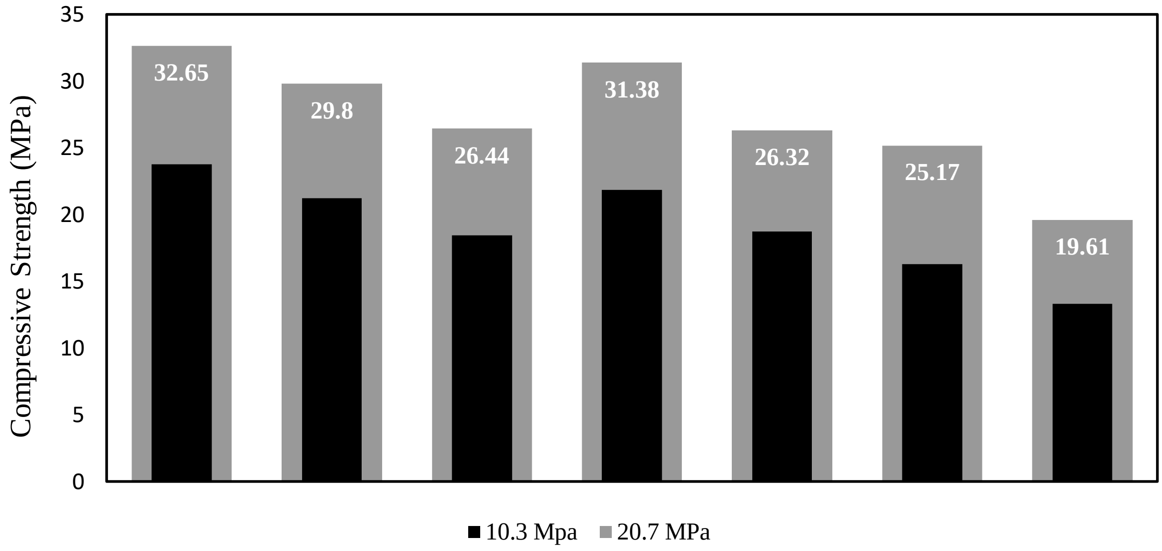
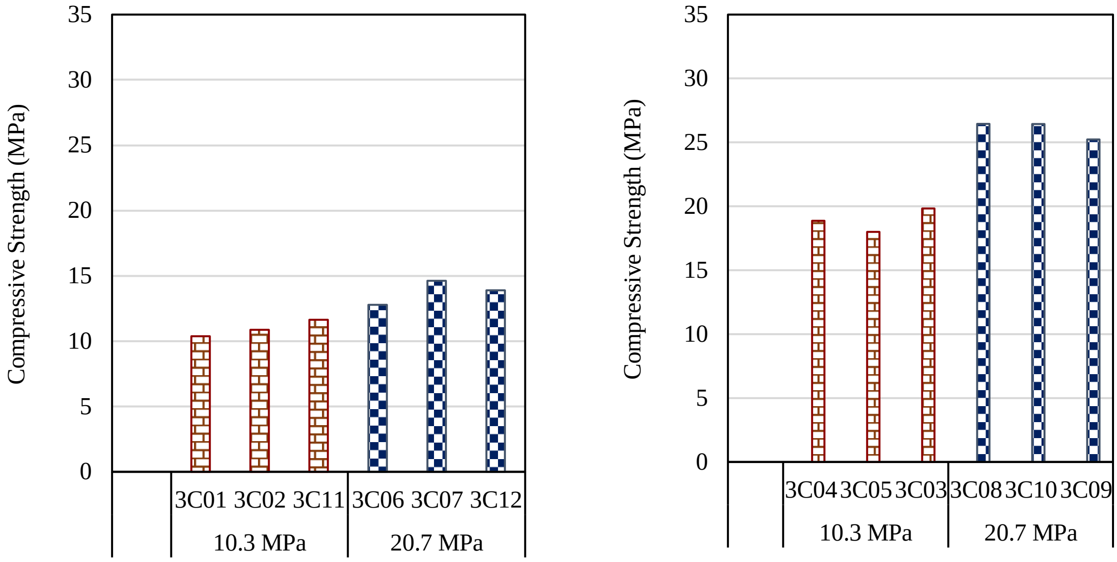


Figure 5. 3: Strength variation for different compacting effort (10.3 MPa and 20.7 MPa)

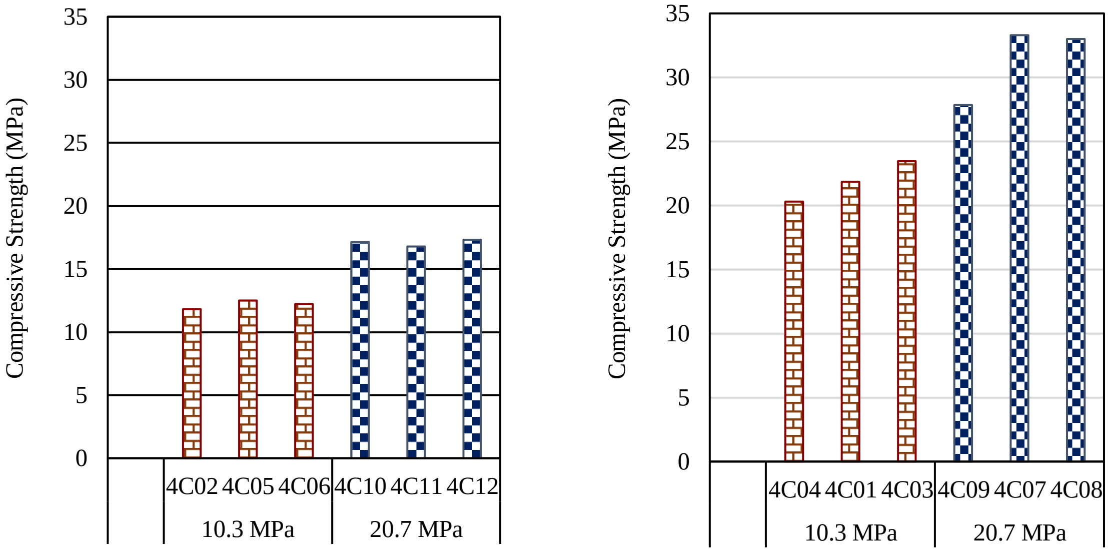
This bar graph illustrates how the strength of block has varied depending on the one parameter of compacting effort. This graph also indicates that the amount of cement also influences the strength that develops by hyper pressing. For example, the variance of strength for batch I45L5C10 is almost 10 MPa, whereas I45L7.5C7.5 and I45L10C5 show only 8 MPa and 6 MPa of strength variation, upgrading compacting effort from 10.3 MPa to 20.7 MPa. That means a higher variance of compressive strength for the higher content of cement.

5.6 Effect of IFS content

Steel slag is a nonmetallic substance made up primarily of calcium silicates and ferrites mixed with fused oxides of iron, aluminum, manganese, calcium, and magnesium that are formed simultaneously with steel in basic oxygen, electric arc, or open-hearth furnaces, according to the American Society for Testing and Materials. This nonmetallic product makes a good bonding with fine aggregate and filler. The rough surface creates a better interlocking with sand. Sand also fills the internal void of IFS. Therefore, to achieve optimum property, a certain amount of sand is required.



(a)



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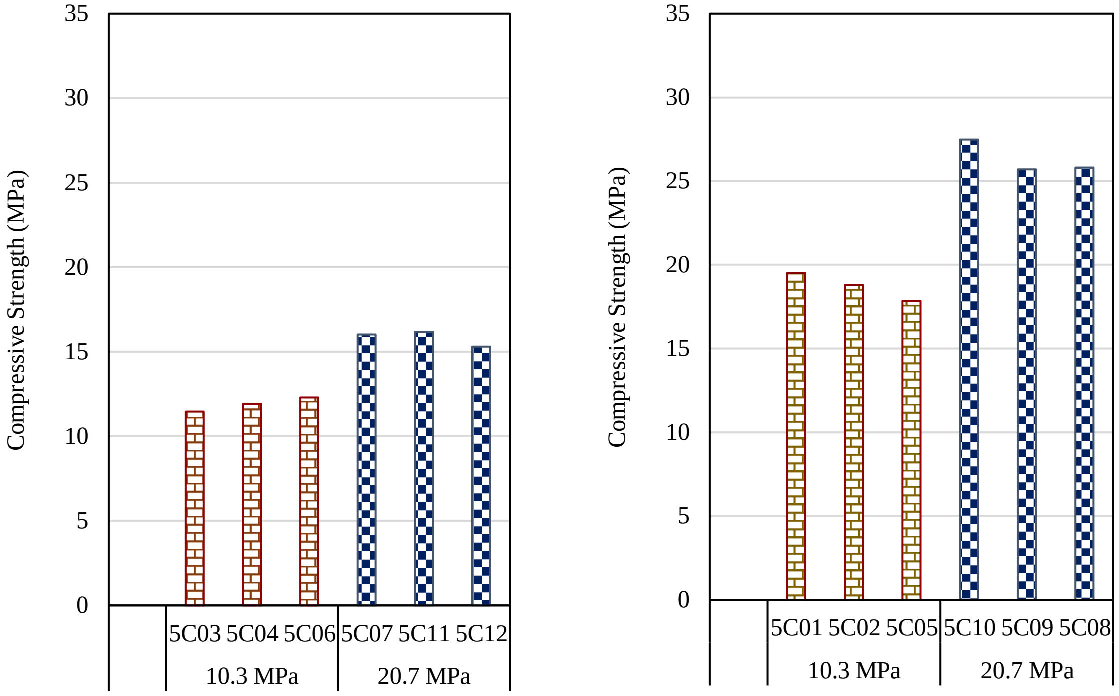

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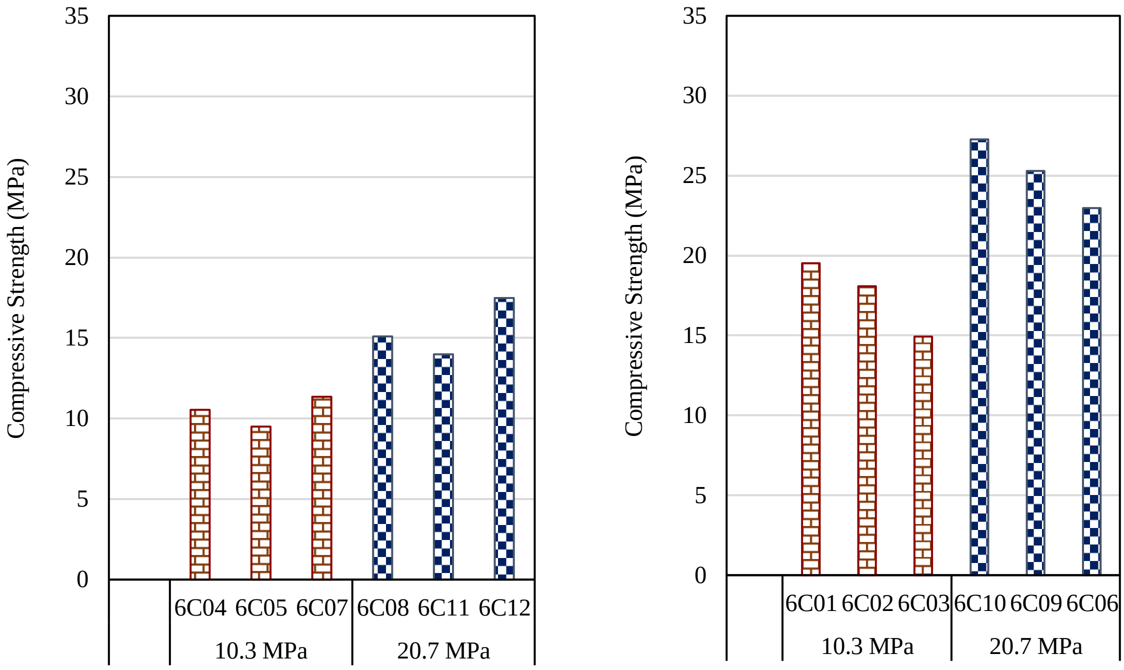


(d)

Figure 5. 4: Strength variation with different combination of aggregate (IFS and sand) (7 days compressive strength is in left, 28 days compressive strength is in the right) (a) 45% IFS with absence of sand (b) combination of 30% IFS with15% sand (c) combination of 15% IFS and 30% sand (d) absence of IFS with 45% sand.

In this study, sand is consecutively replaced by IFS. As shown in Figure 5. 5, introducing IFS in the place of sand increased the strength for both 10.3 and 20.7 MPa compaction pressures. However, the absence of sand gave lower strength of building blocks. This might be due to poor interlocking. This result is supported by the water absorption test results shown in Figure 5.2. With 15% sand and 30%, IFS content the water absorption was found to be less than 3% by weight. It is, therefore, recommended to use optimum quantity (15% of the total mix by weight) of sand for the best strength results.

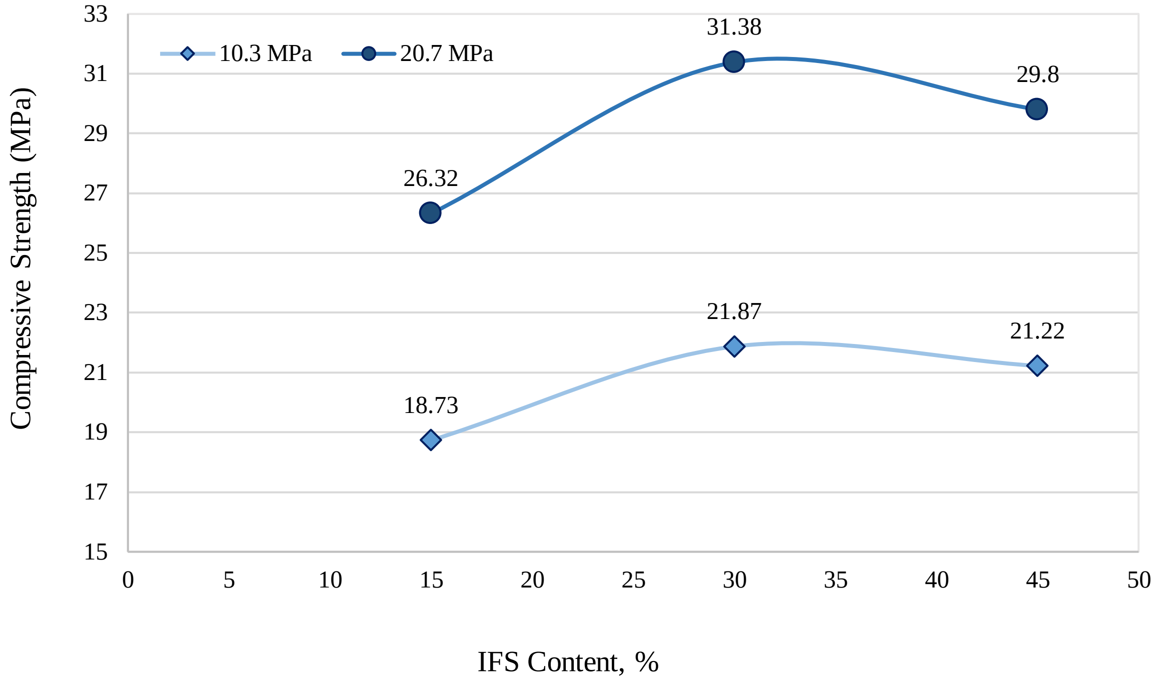
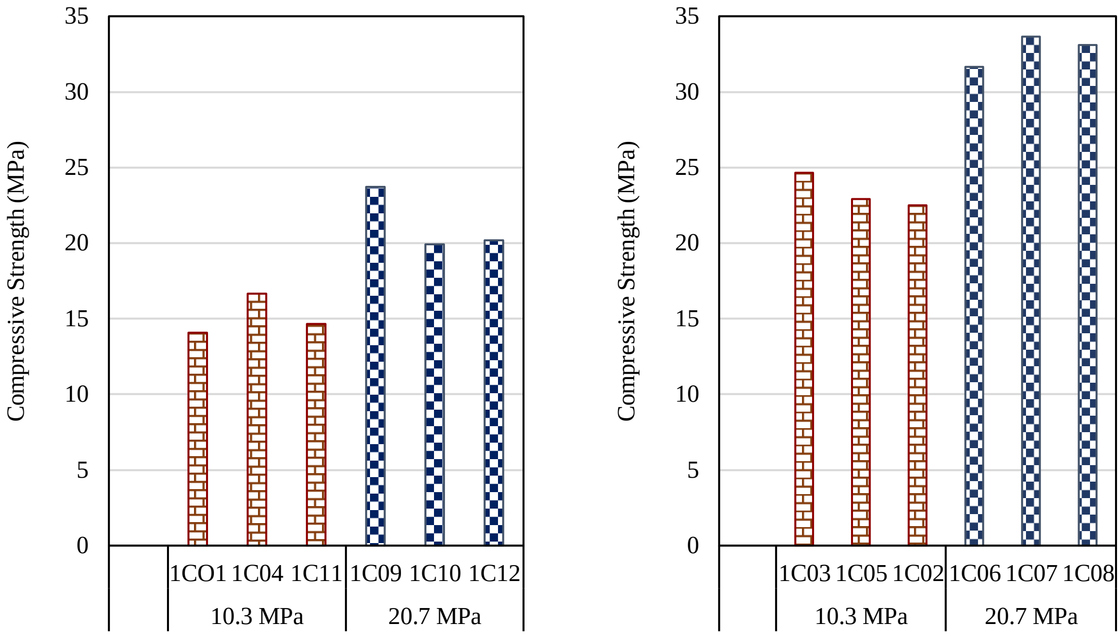


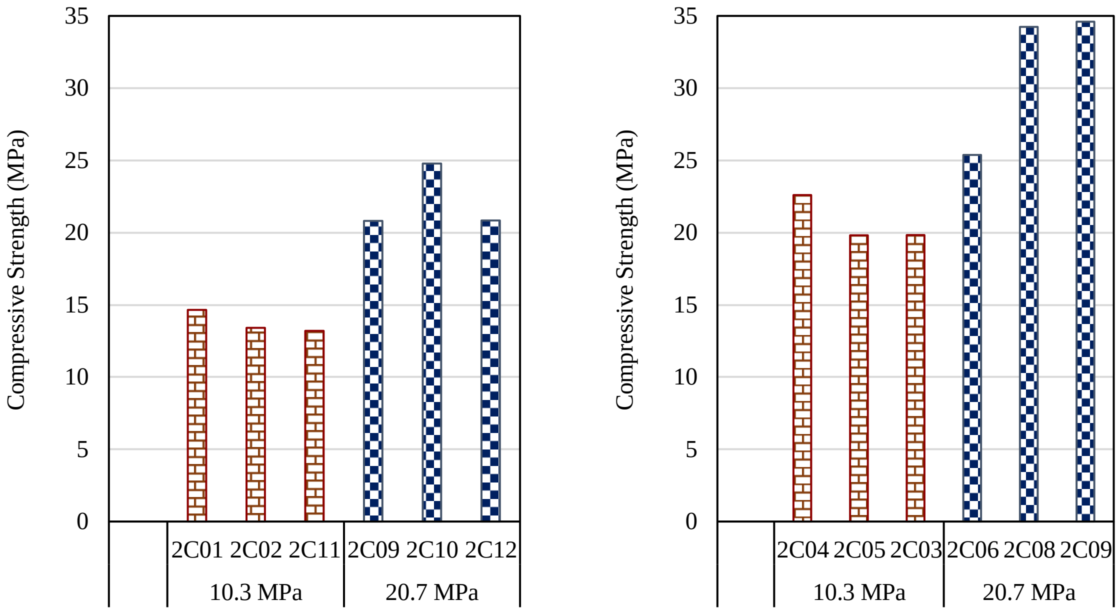
Figure 5. 5: Effect of IFS content on the compressive strength of building block

5.7 Effect of cement content

In this study, Ordinary Portland cement (OPC) and lime are used as binding materials. OPC cement gains strength earlier than the Portland composite cement (PCC) though PCC provides a better result with time (Uddin *et al.*, 2013). As a large amount of fly ash is used as filler materials and OPC does not contain any fly ash by itself, it is chosen instead of PCC. But cement industry and the production procedure of cement have a negative impact on the environment (Ali *et al.*, 2016). Therefore, this study aimed to use cement as a binding material as low as possible. Compaction effort provides an excellent option to cut the amount of cement in the mixer, and lime can also be another option. But the excess amount of lime also negatively impacts the strength of block by affecting strength.



(a)



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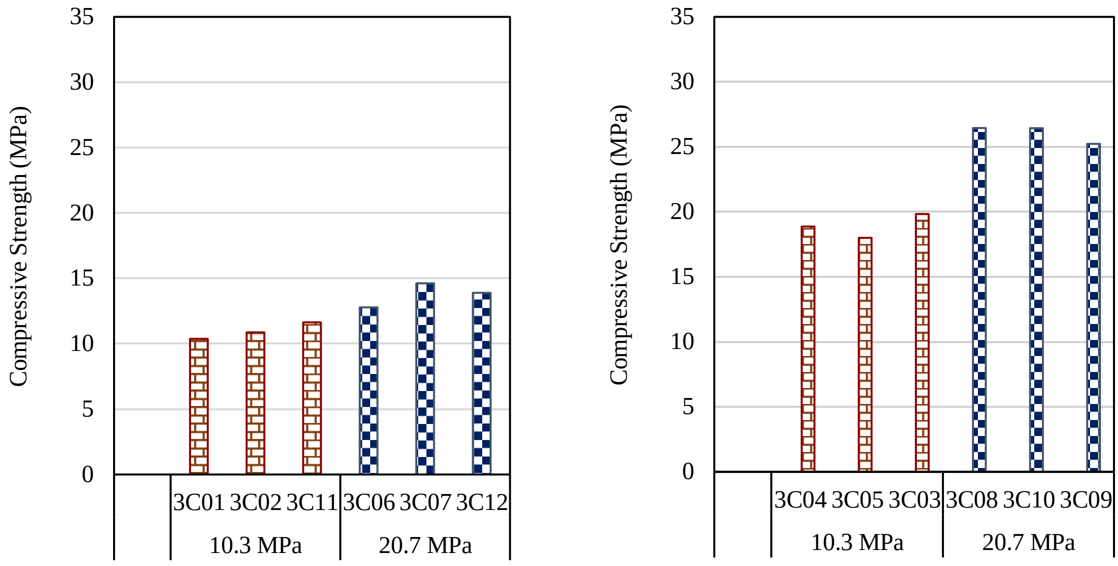

(c)

Figure 5. 6: strength variation with different combination of binding materials (Cement and Lime) (7 days compressive strength is in left, 28 days compressive strength is in the right) (a) combination of 10% cement with 5% lime (b) combination of 7.5% cement with 7.5% lime (c) combination of 5% cement and 10% lime

The result shows that the percentages of the presence of cement have a high impact on the strength of block. The strength of block increases consistently with the rate of cement content. As the main target of this research was to use cement as low as possible, 7.5% of cement with the combination of 7.5% lime could be the best option.

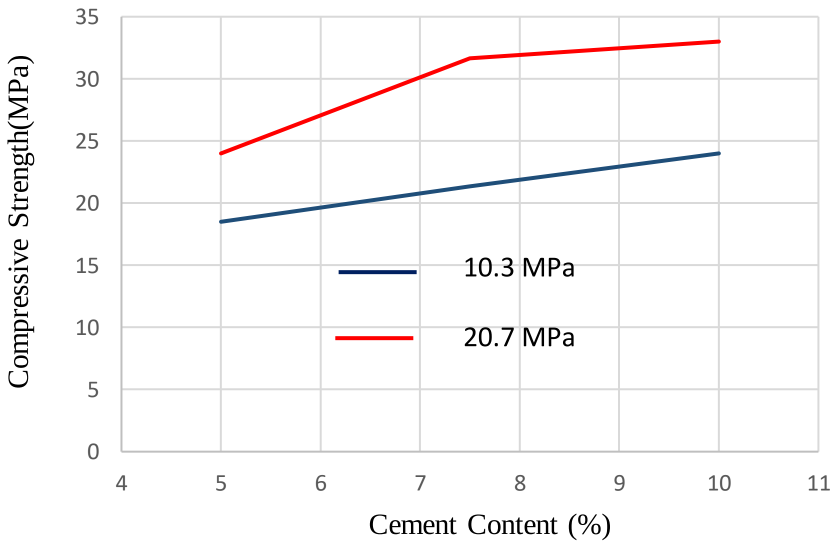

Figure 5. 7: Effect of cement content on the compressive strength of building block

5.8 Cost Analysis

This study aimed to use the maximum possible amount of IFS in the place of sand to maximize the use of this by-product. This will impact the sustainable use of the material and the cost-effectiveness of the finally produced building block. Figure 5.8 gives a cost analysis of the individual materials/process to make 100 building blocks. These totals 7.9 USD including marketing of the product. The Public Works Department (PWD) rate schedule for first-class brick is 10.26 USD/100 clay burnt bricks.

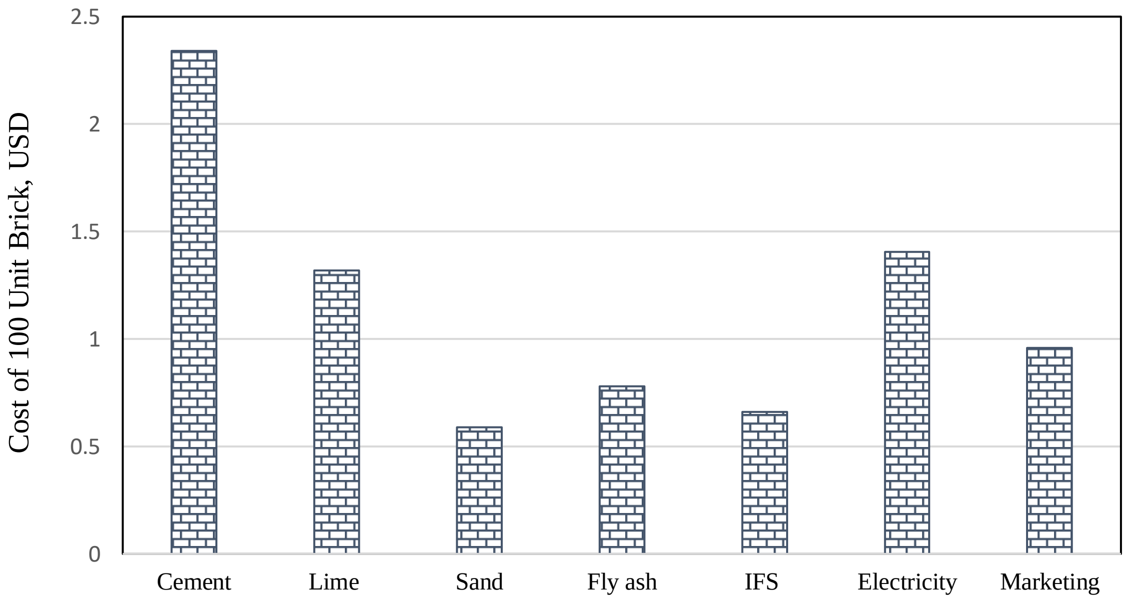

Figure 5. 8: Cost analysis of building blocks

For proper interlocking of the materials, compaction is mandatory. Water assists to lubricate the material for appropriate compaction; however, it increases the w/c ratio. Increasing w/c affects the building block strength adversely. Therefore, it would be necessary to increase the amount of binding material to ensure the quality of the building block. This is expected to result in cost ineffectiveness. Strength improvement (thereby cost) with compaction pressure of the binding materials could be reduced by up to 50%. The electricity cost to improve the compaction pressure from 10.3 MPa to 20.7 MPa is much less than the cost of saved binding materials. The high pressure also ensures better microstructural property and low water absorption of the block. The above analysis indicates the cost-effectiveness of the building block produced by the hyper-pressing technique with waste materials. Moreover, the produced material gives better property than that specified by BDS and PWD rate schedule. The technique will therefore be considered as a cost-effective and sustainable method for building block production.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1 General

This study consists of seven different batches in which the amount of fly ash is constant in all of those batches, which is 40%. IFS is consecutively replaced by sand, and binding material lime is consecutively replaced by cement. A very negligible amount of water is used for hydration purposes, which is not higher than 10%-12% of the total mix.

The result shows that the compacting effort has a significant effect on the properties of compressive strength of the block. Almost 50% cost of the binding materials can be reduced just by increasing pressure from 10.3 MPa to 20.7 MPa. It is also suggested to use at least 10% sand with IFS for better interlocking.

We also have faced some limitations at the time of performing this study. Using a good grade of sand could make this study more reliable. There was also some limitation in the laboratory setup. Testing machines were not available in time for some cases.

Except these limitations, it was a well-equipped study, and the findings have great potentiality in the field of brick production.

6.2 Specific Conclusion

This study aimed to produce a building block of standard size and shape used in Bangladesh using industrial by-products and hyper-pressing technology. The experimental investigation gives the following conclusion:

a. Replacement of sand by IFS increases the properties of the building block. However, a minimum amount of sand is required to produce better interlocking between ingredients. With 35% IFS combining with 10% sand and hyper-pressing with 20.7 MPa pressure provides the optimum result.

b. Replacing cement with lime reduces the strength of the building block. However, to produce a cost-effective building block up to 7.5% lime could be permitted in the mixture.

c. An increase in compacting pressure improves strength. However, this will also increase the cost of the electric bill. Overall, 20.7 MPa compacting pressure will balance between the cost of binding material and electricity bill to optimize the overall cost of building block production.

d. Cost analysis indicates that the produced building block is cost-efficient than the usual clay burnt brick.

6.3 Recommendation for further study

Produced sample bricks are cost-effective and eco-friendly, and it has an immense potentiality especially in the brick producing sector, still, it has some limitations. The main challenge for the production purposes in the practical field of this sample is curing. A large amount of area and lots of potable water is required for the curing process. Another limitation of this sample brick is its weight, which is slightly higher than the usual clay burnt brick. So, an enormous scope is available for the researcher to work in this field. Some of this can be summarized as follows,

i. Rice husk can be tried as a partial replacement of fly ash as a filler material to reduce the weight of the sample brick.
ii. A geopolymer based binder can be used instead of cement to enhance the potentiality of these sample bricks by making them more eco-friendly.
iii. For practical purposes of this brick, there must be a joint on the block surface for better interlocking. The effect joint on the surface of the block on compressive strength is required to check.
iv. As the water absorption rate of this sample brick is relatively lower and the surface of this brick is sufficiently smooth, negligible or no plastering is required, making it flexible for practical purposes. A further study is required for the proof of this statement.
v. Different colour of pigment can be used in the mixer to enhance the wall's aesthetic quality and cut up the cost of the painting. A further study is required to check the effect of using pigment on the properties of compressive strength.
vi. A further study is required to assess the durability and long-term effect of this type of brick using it for practical purposes.

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Appendix

Table A1- Weight height and strength of individual brick of Batch 1 after seven days curing

BATCH 1						
Compacting Effort	Brick Id	Weight (gm)	Height (mm)	Observed Load (kN)	Actual Load (kN)	Strength (MPa)
10.3 MPa	1CO1	3465	75	578	330.29	14.08
	1C04	3489	75	689.55	390.84	16.66
	1C11	3490	76	603	343.86	14.66
20.7 MPa	1C09	3505	76	994.7	556.48	23.72
	1C10	3517	76	830.45	467.32	19.92
	1C12	3525	75	842	473.59	20.19

Table A2- Weight height and strength of individual brick of Batch 1 after 28 days curing

Compacting Effort	Brick Id	Weight (gm)	Height (mm)	Observed Load (kN)	Actual Load (kN)	Strength (MPa)
10.3 MPa	1C03	3217	77	1030.71	567	24.653
	1C05	3461	76	940.49	527.04	22.914
	1C02	3325	76	938	526	22.5
20.7 MPa	1C06	3397	74	1310.8	728.05	31.654
	1C07	3271	77	1395.53	774	33.653
	1C08	3342	76	1385	766	33.1

Table A3- Weight height and strength of individual brick of Batch 2 after seven days curing

BATCH 2						
Compacting Effort	Brick Id	Weight (gm)	Height (mm)	Observed Load (kN)	Actual Load (kN)	Strength (MPa)
10.3 MPa	2C01	3663	76	602.7	343.70	14.65
	2C02	3637	75	549	314.55	13.41
	2C11	3630	75	548	314.00	13.20
20.7 MPa	2C09	3504	75	868.92	488.20	20.81
	2C10	3506	75	1040.51	581.34	24.78
	2C12	3525	76	870.2	488.90	20.84

Table A4- Weight height and strength of individual brick of Batch 2 after 28 days curing

Compacting Effort	Brick Id	Weight (gm)	Height (mm)	Observed Load (kN)	Actual Load (kN)	Strength (MPa)
10.3 MPa	2C04	3229	82	928.33	520.44	22.60
	2C05	3504	82	809.07	455.71	19.81
	2C03	3453	81	810	456	19.83
20.7 MPa	2C06	3066	76	1044.83	583.68	25.38
	2C08	3452	75	1420.24	787.45	34.24
	2C09	3350	75	1425	790	34.60

Table A5- Weight height and strength of individual brick of Batch 3 after 7 days curing

BATCH 3						
Compacting Effort	Brick Id	Weight (gm)	Height (mm)	Observed Load (kN)	Actual Load (kN)	Strength (MPa)
10.3 MPa	3C01	3511	77	418	243.44	10.38
	3C02	3543	77	439.35	255.03	10.87
	3C11	3563	77	472.54	273.05	11.64
20.7 MPa	3C06	3560	77	522	299.89	12.78
	3C07	3531	77	601.56	343.08	14.62
	3C12	3530	76	570	325.95	13.89

Table A6- Weight height and strength of individual brick of Batch 3 after 28 days curing

Compacting Effort	Brick Id	Weight (gm)	Height (mm)	Observed Load (kN)	Actual Load (kN)	Strength (MPa)
10.3 MPa	3C04	3468	80	769.26	434.1	18.87
	3C05	3465	79	726.7	411	18.00
	3C03	3453	80	810	456	19.83
20.7 MPa	3C08	3391	75	1090.34	608.38	26.45
	3C10	3417	76	1089.75	608	26.44
	3C09	3389	76	1060	591.92	25.23

Table A7: Weight height and strength of individual brick of Batch 4 after 7 days curing

BATCH 4						
Compacting Effort	Brick Id	Weight (gm)	Height (mm)	Observed Load (kN)	Actual Load (kN)	Strength (MPa)
10.3 MPa	4C02	3458	78	480	277.10	11.81
	4C05	3410	77	510	293.38	12.51
	4C06	3563	79	498	286.87	12.23
20.7 MPa	4C10	3612	78	710	401.94	17.13
	4C11	3423	77	695	393.80	16.79
	4C12	3528	76	718	406.28	17.32

Table A8- Weight height and strength of individual brick of Batch 4 after 28 days curing

Compacting Effort	Brick Id	Weight (gm)	Height (mm)	Observed Load (kN)	Actual Load (kN)	Strength (MPa)
10.3 MPa	4C04	3556	79	829.86	467	20.30
	4C01	3255	79	895.18	502.45	21.85
	4C03	3219	76	963.33	539.61	23.46
20.7 MPa	4C09	3219	79	1149.38	640.43	27.85
	4C07	3229	75	1380.43	765.84	33.30
	4C08	3273	76	1367.88	759	33.00

Table A9- Weight height and strength of individual brick of Batch 5 after 7 days curing

BATCH 5						
Compacting Effort	Brick Id	Weight (gm)	Height (mm)	Observed Load (kN)	Actual Load (kN)	Strength (MPa)
10.3 MPa	5C03	3265	77	465	268.95	11.46
	5C04	3335	78	485	279.81	11.93
	5C06	3428	76	501	288.49	12.30
20.7 MPa	5C07	3512	75	662	375.89	16.02
	5C11	3218	78	669	379.69	16.18
	5C12	3369	77	631	359.06	15.31

Table A10- Weight height and strength of individual brick of Batch 5 after 28 days curing

Compacting Effort	Brick Id	Weight (gm)	Height (mm)	Observed Load (kN)	Actual Load (kN)	Strength (MPa)
10.3 MPa	5C01	3445	78	796.72	449	19.52
	5C02	3443	79	766.31	432.5	18.8
	5C05	3413	76	725.91	410.57	17.85
20.7 MPa	5C10	3162	75	1133.88	630	27.48
	5C09	3320	74	1058.37	591	25.7
	5C08	3319	74	1063.07	593.6	25.81

Table A11- Weight height and strength of individual brick of Batch 6 after 7 days curing

BATCH 6						
Compacting Effort	Brick Id	Weight (gm)	Height (mm)	Observed Load (kN)	Actual Load (kN)	Strength (MPa)
10.3 MPa	6C04	3528	79	425	247.24	10.54
	6C05	3469	80	380	222.82	9.50
	6C07	3601	80	460	266.24	11.35
20.7 MPa	6C08	3589	76	622	354.17	15.10
	6C11	3489	75	574	328.12	13.99
	6C12	3530	75	725	410.08	17.48

Table A12- Weight height and strength of individual brick of Batch 2 after 28 days curing

Compacting Effort	Brick Id	Weight (gm)	Height (mm)	Observed Load (kN)	Actual Load (kN)	Strength (MPa)
10.3 MPa	6C01	3578	80	640.2	364	19.52
	6C02	3615	80	735.72	415.9	18.08
	6C03	3605	81	602.14	343.39	14.93
20.7 MPa	6C10	3307	74	1125.05	627.22	27.27
	6C09	3202	74	1041.3	581.67	25.294
	6C06	3528	73	942.64	528.21	22.97

Table A13- Weight height and strength of individual brick of Batch 7 after 7 days curing

BATCH 7						
Compacting Effort	Brick Id	Weight (gm)	Height (mm)	Observed Load (kN)	Actual Load (kN)	Strength (MPa)
10.3 MPa	7C04	3477	77	292.05	175.08	7.61
	7C05	3481	77	287.93	172.84	7.52
	7C06	3485	77	289	174	7.56
20.7 MPa	7C07	3428	75	486.23	280.48	12.19
	7C09	3501	80	397.57	232.35	10.10
	7C12	3451	76	403	235.3	10.40

Table A14- Weight height and strength of individual brick of Batch 2 after 28 days curing

Compacting Effort	Brick Id	Weight (gm)	Height (mm)	Observed Load (kN)	Actual Load (kN)	Strength (MPa)
10.3 MPa	7C01	3491	78	608	346.59	15.06
	7C02	3492	77	457.54	264.9	11.52
	7C03	3485	77	502	301	13.3
20.7 MPa	7C08	3446	75	814.9	485.88	19.95
	7C10	3475	75	786.12	443.26	19.27
	7C11	3451	75	790	445.364	19.3