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Study on Production of Bricks using Industrial Wastes

Suhas O S,
Assistant professors
Department of Civil Engineering
Mysore College of Engineering
Management
(Approved by AICTE, Affiliated to
VTU, Belgavi, Karnataka)

***Abstract*— Bricks, a crucial construction material with a history spanning 1000 years, are used in walls, pavements, and masonry structures. India commonly uses fired clay bricks. In this experiment, bricks are made using industrial wastes like fly ash, GGBS, and metakaolin, also known as aluminosilicate materials. To activate these materials, an alkali activator is required. Sodium-based alkaline solutions can provide good compressive strength, while combining sodium silicate and sodium hydroxide results in better strength. The ratio between binder to solution and sodium silicate to sodium hydroxide plays a significant role in strength development, workability, and setting time. New terracotta tile aggregates are created using leftover tiles from a nearby market. The bricks are tested for compressive strength and water absorption and compared to traditional burnt clay bricks to determine their marketability.**

***Keywords*—component; Bricks, Industrial Wastes, Fly Ash, GGBS, Metakaolin, Compressive Strength, Alkaline Solutions**

I. INTRODUCTION

Bricks have a long history dating back over 5,000 years, with the earliest known use of fired clay bricks originating in ancient Mesopotamia around 3500 BC. The technology of firing bricks in kilns was developed by the ancient Egyptians around 3000 BC, leading to more durable and standardized bricks. Bricks have been used in various civilizations for thousands of years, and their versatility, durability, and aesthetic appeal have made them a popular choice in construction.

There are various types of bricks available today; each designed to meet specific construction requirements. Common types include clay bricks, concrete bricks, fire bricks, and engineering bricks. Clay bricks are made from natural clay, shale, and other minerals, shaped into rectangular blocks and hardened through a firing process in a kiln. Concrete bricks, also known as concrete blocks or concrete masonry units (CMUs), are a common and versatile construction material used in a wide range of building project.

Fire bricks are specialized building blocks designed to withstand high temperatures and intense heat environments, providing thermal insulation and resistance to thermal shock. Engineering bricks are specialized construction bricks known for their strength, durability, and resistance to environmental factors. They are typically used in projects where strength and long-term stability are paramount, such as in the construction of load-bearing walls, bridges, tunnels, and other infrastructure

Bricks offer several advantages that contribute to their popularity in construction: durability, thermal insulation, aesthetic appeal, sustainability, and sound insulation. They are widely used in residential buildings, commercial and industrial buildings, infrastructure and landscaping projects.

Incorporating industrial wastes like GGBS, fly ash, metakaolin, rice husk ash, and silica fume into construction materials can encourage sustainable waste management practices, reduce the need for traditional raw materials like cement, and reduce the environmental impact associated with waste disposal. In this study, bricks are made using industrial wastes, such as GGBS, fly ash, metakaolin, rice husk ash, and silica fume, which can be activated using alkali activators such as sodium hydroxide, sodium silicate, potassium hydrogen, and calcium hydroxide. This alkaline solution increases the surface hydrolysis of aluminosilicate materials, resulting in better compressive strength and workability.

In addition to bricks, terracotta tile aggregate is also used to replace normal aggregate, as it is produced in the laboratory by breaking waste terracotta tile into small required-sized particles.

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II. MATERIALS

A. Fly ash

Fly ash is a fine, powdery residue from coal combustion in power plants, primarily composed of spherical glass particles and minor minerals. Its chemical composition can vary based on coal type and combustion method.

Table1: Properties of fly ash

Properties	Fly ash
Specific gravity	2.1
Colour	Greyish white
Surface moisture	Nil

B. Ground granulated blast-furnaceslag

Granulated Blast Furnace Slag (GGBS) is a hydraulic binder produced by cooling molten iron slag from a blast furnace. It is a supplementary cementitious material used in concrete production, partially replacing Portland cement. GGBS has specific physical properties, such as a characteristic fine particle size and high surface area, which allows effective integration and reactivity when mixed with cement. Its lower density and slower hydration rate contribute to continued strength development over time. The production process involves steam or water cooling molten iron slag.

Table2: Properties of GGBS

Properties	GGBS
Specific gravity	2.6
Colour	White
Surface moisture	Nil

C. Metakaolin

Kaolin clay, rich in aluminum and silicon, undergoes a physical and chemical transformation when calcined at temperatures between 600 to 800ºC. This results in the formation of metakaolin, a highly reactive pozzolanic substance. When blended with Portland cement, metakaolin forms a calcium silicate hydrate gel, contributing to the strength, durability, and chemical resistance of concrete.

Table3: Properties of Metakaolin

Properties	Metakaolin
Specific gravity	2.4
Colour	Off white
Physical form	Powder

D. Sodium hydroxide

Sodium hydroxide, a strong base, is a highly soluble in water compound. It forms an alkaline solution and is found in solid forms like flakes, pellets, or powder. In geopolymer concrete, it initiates the geopolymerization reaction by forming a three-dimensional polymer network when interacting with aluminosilicate materials.

E. Sodium silicate

Sodium silicate, a glassy, colorless, and viscous liquid, is essential in geopolymer concrete's alkaline activator solution. It provides soluble silica for geopolymerization, forming a geopolymer gel that holds aggregates together. The alkaline activator reacts with silica in fly ash or slag, resulting in a clear, odorless liquid with varying viscosity.

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F. Fine Aggregate

Fine aggregate, consisting of natural sand, crushed stone sand, and manufactured sand, is used in building materials like mortar and concrete. It fills voids between coarse aggregates, providing a solid matrix and contributing to the strength, cohesiveness, and workability of the mix. M-sand, used in this study, is artificially produced.

Table4: Properties of Fine Aggregate

Properties	**M-sand**
Specific gravity	2.67
Fineness modulus	3.4
Water absorption (%)	1.2
Bulking of sand (%)	4.0

G. Coarse aggregate

Coarse aggregate, a component of concrete mix, is larger than 4.75 millimeters and is used in crushed stone, gravel, and recycled concrete. Its surface texture can be smooth or rough, affecting bonding with cement paste and enhancing adhesion and binding strength.

Table5: Properties of Coarse Aggregate

Properties	**M-sand**
Specific gravity	2.6
Water absorption (%)	0.45
Bulking density (Kg/m^3)	1554.66

H. Terra cotta tile aggregates

This study uses waste broken terracotta tiles from a nearby market to create fine and coarse aggregates. The tiles are crushed using a hammer or roller, and preliminary tests are conducted to determine their characteristics. The aggregates are then sieved using a 10mm sieve, 4.75mm sieve, and a pan to obtain the required coarse aggregates. The fine aggregates are obtained using a 4.75mm sieve and a pan, and the final product includes both fine and coarse aggregates.

III. PRELIMINARY TESTS ON TERRA COTTA TILE AGGREGATE

Preliminary test which are conducted for terracotta tile aggregates are bulk density, specific gravity, water absorption and sieve analysis as per IS:2386 (part 3)-2002 and IS 383-2016.

A. Bulk density

The bulk density test for both fine and coarse aggregate sample are made as shown in figure 1 at the laboratory, and the results are shown in table 6.

Figure 1: Weighing of normal

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Table 6: Comparative bulk density

Sl. No	Parameters	Terra cotta tile Aggregates (Kg/m^3)	Normal aggregates (Kg/m^3)
1.	Passing through 10mm sieve	1082.66	1554.66
2.	Passing through 10mm sieve and retaining on 4.75mm sieve	999.33	1468.66
3.	Passing through 10mm sieve and retaining on 2.36mm sieve	969.33	1434

B. Specific gravity

Even the specific gravity test is conducted for both fine and coarse aggregates as shown in figure 2, which is required to calculate the amount of material required for mix. The results are tabulated in below table 7

Table 7: Comparative specific gravity

Sl. No		Coarse aggregate	Fine aggregate
1.	Terra cotta tile aggregate	1.9	1.8
2.	Normal aggregate	2.6	2.65

Figure 2: Specific gravity test

C. Water absorption

Water absorption test is conducted to know its water absorbing capacity of both fine and coarse aggregate. Water absorption is required to add required amount water to get good and workable mix. Figure 3 shows the conduction of water absorption test and the results are tabulated in table 8

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Table 8: Water absorption test results

Sl. No	Particulars	Coarse aggregate	Fine aggregate
1.	Terra cotta tile aggregate	12.6%	12.3%
2.	Normal aggregate	0.45%	1.2%

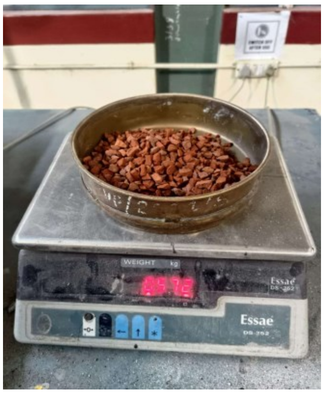

Figure 3: Water absorption test

D. Sieve analysis of fine aggregate

The tabulated sieve analysis value of terracotta fine aggregates is given below in table 9, and also graphical representation is shown in figure 4.

Table 9: Sieve analysis of terracotta fine aggregates

Sl. No	IS Sieve size	weight retained	%weight retained	Cumulative% Weight retained	%Passing
1	4.75	0.001	0.1	0.1	99.9
2	2.36	0.131	13.1	13.2	86.8
3	1.18	0.305	30.5	43.7	56.3
4	0.6	0.175	17.5	61.2	38.8
5	0.3	0.176	17.6	78.8	21.2
6	0.15	0.093	9.3	88.1	11.9
7	0.01	0.119	11.9	100	0

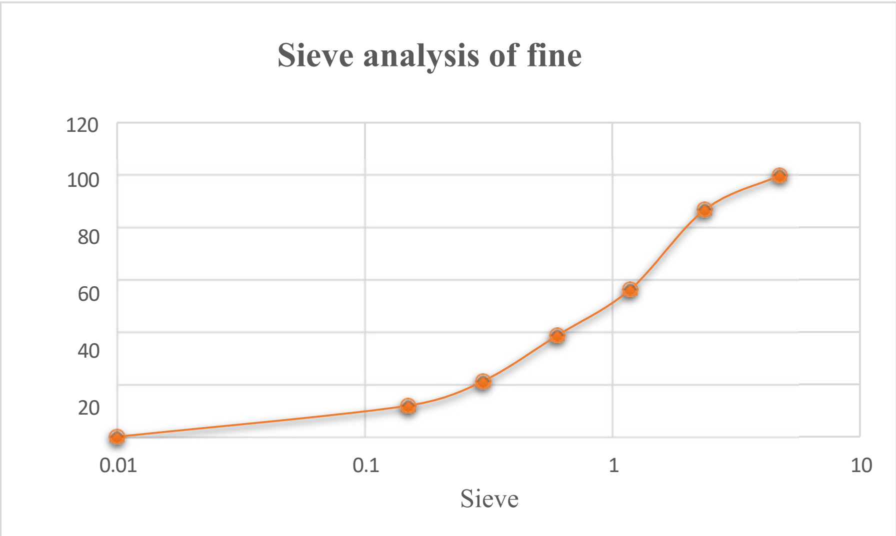

Figure 4: Sieve analysis of Fine aggregate

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E. Sieve analysis of coares aggregate

The tabulated sieve analysis value of terracotta coarse aggregates is as shown in table 10, and the graphical representation is shown in figure 5

Table 10: Sieve analysis of terracotta coarse aggregates

Sl. No	IS Sieve size	weight retained	%weight retained	Cumulative % weight retained	%Passing
1	10	0.01	0.33	0.33	99.67
2	6.3	2.22	74.00	74.33	25.67
3	4.75	0.668	22.27	96.60	3.40
4	0	0.104	3.47	100.00	0.00

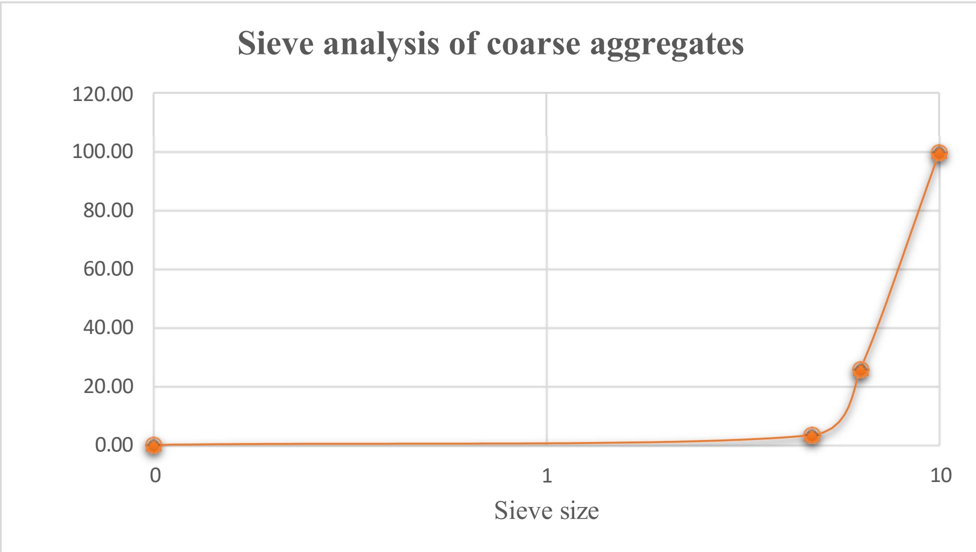

Figure 4: Sieve analysis of coarse aggregate

IV. METHODOLOGY

A. Wet process

Process that involved in wet process are given below, here the alkali to binder ratio is 0.5 and the fibre mould of volume 0.0201m3 is used

B. Preparation of solution

Solution is prepared by dissolving Sodium hydroxide crystals in water initially required amount of NaOH is weighed on weighing machine. Care should be taken while dealing with the Sodium hydroxide. Then the weighed NaOH is mixed with required amount of water which is taken in a bucket as shown in figure 5. When NaOH is mixed with water it gets heated to high temperature, since it gets heated up it cannot be used in that condition so it has to be cooled down hence it is kept for cooling and then it is used. The above prepared solution after when it gets cooled, it is mixed with Sodium silicate, even this is weighed according to calculation then it is mixed with NaOH solution to make the final alkali solution. This alkali solution is based on alkali to binder ratio which is taken during mix design calculation. Here the alkali to binder ratio which is maintained for the calculation is 0.5.

Figure 5: Preparation of solution

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C Weighing of materials

All the materials are weighed according to the calculation which is taken during the mix design. These weights are taken according the proportions which are considered during mix design calculation. The materials can be seen in figure 6.

Figure 6: Materials which are weighed according to calculation

D Assembling the mould.

The fiber mould of size 227mm*108mm*82mm is used to produce the bricks in this method. The typical picture of mould is shown in figure 7. Moulds are placed on wooden plank to support the upcoming mix. Then the oil is applied to all the surface of mould except the outer surface. The whole assembly is placed on vibrating table.

Figure 7: Wet mix mould

E Casting of bricks.

The weighed materials are then poured into the ready mixer which is present in the laboratory. Initially all solid parts like Fly ash, GGBS, Metakaolin, Fine aggregates and Coarse aggregates are taken and mixed until uniform dry mixture is obtained which can be seen in figure 8.a, then the prepared solution is poured and mixed until getting the uniform mix. The whole process of mixing should be done within short time of period since the GGBS has less setting time. After getting the uniform mix, this mix is placed into oiled mould using trowel until it is filled, after filling the mould with the mix vibration is given to compact or to fill the voids present within the poured mix, excess mix is removed if present then the above surface is made to a level as seen in figure 8.b

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Figure 8.a: Mixing of materials

Figure 8.b: Casting of bricks

F Demoulding.

After one day of casting the brick demoulding has done. Demoulding is done in normal procedure.

G Curing.

After demoulding of casted bricks from mould curing has to done. In this project water curing is does not required, ambient curing is done as shown in figure 9.

Figure 9: Samples kept for ambient curing

V. Tabulation of Wet mixe

Table 11 shows the quantity of materials required per brick. In TRAIL MIX the normal aggregates were used but in case of MIX 1 coarse aggregate is replaced terracotta tile coarse aggregates and in MIX 2 coarse aggregates used is normal but the fine aggregates used is terracotta tile fine aggregate. In case of MIX 3 both fine and coarse aggregates are replaced with terracotta tile fine and coarse aggregates. Here the Alkali solution / Binder ratio is kept constant i.e., 0.5. And the ratio of coarse aggregate: Fine aggregate: Binder is 1:1:2

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Table 11: Trail mixes of wet mix

Materials	TRAILMIX	MIX1	MIX2	MIX3
Coarse aggregate	1.04	-	0.95	-
Fine aggregate	1.04	0.96		-
Terra cotta tile coarse aggregate	-	0.96	-	0.97
Terra cotta tile fine aggregate	-	-	0.95	0.97
Fly ash	0.42	0.38	0.38	0.39
GGBS	1.04	0.96	0.95	0.97
Metakaolin	0.62	0.58	0.57	0.58
Sodium silicate	0.52	0.48	0.48	0.48
Sodium hydroxide	0.17	0.16	0.15	0.16
Water	0.35	0.32	0.32	0.33
Alkaline solution/Binder	0.5	0.5	0.5	0.5
Ratio	1:1:2	1:1:2	1:1:2	1:1:2

VI. TESTS WHICH ARE CONDUCTED FOR THE BRICKS

Compression test and water absorption tests were performed on the casted bricks under both the wet process and the dry process.

A Compression test.

A compression test is a common method used to determine the strength and durability of materials, including bricks. It involves applying a compressive load to a brick specimen until it fails or breaks. The test helps determine the maximum load the brick can withstand before it fractures. The compressive strength of bricks is measured in Mega Pascal's (MPa) and done according to IS 3495(Part-1):2002. After casing the bricks, this test should be performed on day 7, 14, and 28.

Figure 10: Set up of compression testing machine

B Procedure

Select a brick whose strength has to be determined and clean off any dirt or debris. Measure the dimensions of the brick using scale, note down the length, width, and height. Set up the compression testing machine as shown in figure 4.11 and ensure it is calibrated correctly. Place the brick on the testing device's lower compression plate, making that it is properly cantered and aligned. Apply a compressive load on the brick gradually using the compression testing apparatus. Increase the load at a steady rate until the brick fails or fractures. Note the maximum load applied. Note the size of the brick sample and the maximum load that was applied. Divide the greatest load applied on brick by the brick specimen's cross-sectional area to determine its compressive strength.
Compressive Strength = Maximum Load / (Length*Width)

C Water absorption test

The water absorption test on bricks is conducted as per IS 3495(Part-2):2002 to determine the amount of water the bricks can absorb. This test helps assess the quality and suitability of bricks for various applications such as construction.

D Procedure

Sample Preparation: Select representative samples of brick. Ensure that the samples are clean. Weigh each brick sample individually using a weighing scale and record the initial weight of each sample. Place the brick samples in a container filled with clean water, ensuring that the bricks are fully submerged. Allow the bricks to soak in water for a specified duration, which is typically 24 hours. After the soaking period, remove the bricks from the water and gently wipe off any excess water from the surface using a cloth or sponge. Do not allow the bricks to dry completely. Weigh each brick sample

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immediately after removing them from the water and record the final weight of each sample.
Calculation: Calculate the water absorption of each brick sample using the following formula:
Water absorption = [(Final weight - Initial weight) / Initial weight] * 100
The result is usually expressed as a percentage.

VII. RESULTS AND OBSERVATION

A. Compressive strength test

A basic test to measure a brick's capacity to sustain a compressive load or force is the compressive strength test. The test helps to assess the quality and durability of the bricks, especially in construction application. This test is done for both the mixes i.e., dry mix and also wet mix to know its load bearing capacity.

B. Compression test on wet mix bricks

Table 12 shows the compressive strength values of different mixes under wet condition. Here the trail mix where we used normal aggregates to cast the brick showed the higher value; also MIX 1 shows the similar strength in this mix we replaced normal coarse aggregate with produced terracotta tile coarse aggregate. Figure 11 displays the compressive strengths of various mixes when produced using a wet approach graphically.

Table 12: Compressive strength test results of wet mix

Trail mixes	7days (MPa)	14days (MPa)	28days (MPa)
TRAIL MIX	30.26	34.58	35.72
MIX1	31.91	32.73	33.97
MIX2	18.53	20.79	25.73
MIX3	10.70	21.41	25.11

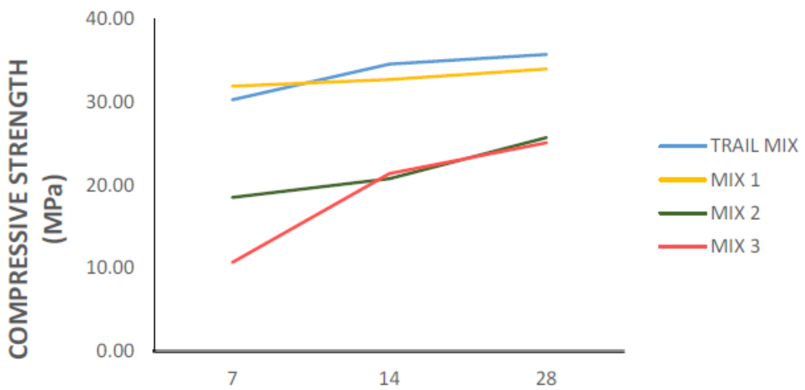

Figure 11: Compressive strength test results

C WATER ABSORPTION TEST

Water absorption is one of the major properties of brick. This test determines the amount of water absorbed over a time period by casted bricks. This property shows how porous the brick is and water resisting capacity of brick. The water absorption test typically involves soaking a brick sample in water and measuring the weight gain after a specified period. The percentage increase in weight is used to calculate the water absorption rate.

D Water absorption test on wet mix bricks

The water absorption test result of wet mix bricks is given in below table 13. MIX 1 shows the least absorption rate where we used normal aggregate and the other two shows higher absorption rate. Among the three MIX 3 shows the higher water absorption rate where we replaced both fine and coarse aggregate with terracotta tile fine and coarse aggregate. The graphical representation of water absorption is shown in figure 12.

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Table 13: Water absorption results of wet mix

MIXES	WATER ABSORPTION(%)
MIX1	11.30
MIX2	14.21
MIX3	20.53

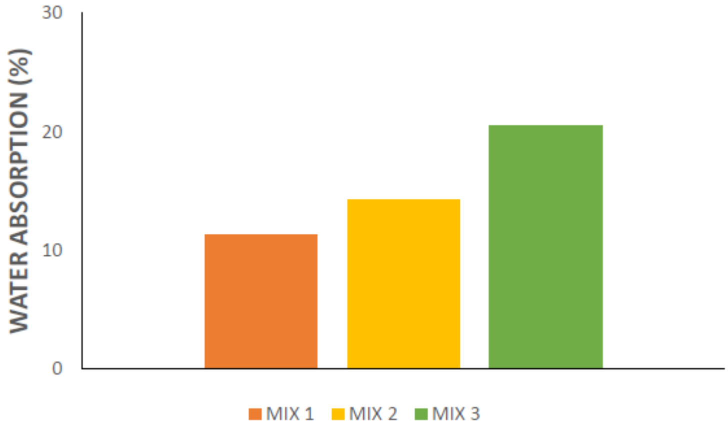

Figure 12: Graphical representation of water absorption

VIII. CONCLUSION

- The produced aggregates are characterization for basic properties which showed that aggregate can be used in the production of bricks.
- In this presented study, production of the bricks was done through wet process. From the experimental investigation and observation, the wet mix method of making bricks is easy
- In this study TRAIL MIX bricks produced using normal aggregates showed compression strength of 35.72 MPa. Whereas MIX 1 bricks are replaced with produced terracotta tile aggregates showed compression strength of 33.97MPa. It is observed that 5% of reduction in strength. Even MIX 2 and MIX 3 bricks showed good compressive strength i.e., 25.73MPa and 25.11Mpa respectively.
- The water absorption for MIX 1 and MIX2 bricks are 11.30% and 14.21 respectively which are less than 15% as per requirements of bricks. Whereas MIX 3 bricks showed high water absorption of 20.53% since the mix contains terracotta tile coarse and fine aggregates.
- Bricks made using the wet approach demonstrated three to four times more strength, one combination shown greater strength than a burnt clay brick. The water absorption values are nearly same when compared to burnt clay bricks. Burnt clay brick exhibited just 8.48MPa strength, which is 400% less when compared to manufactured bricks, whereas MIX 1 bricks showed a strength of 33.97MPa, MIX 2 bricks showed a strength of 25.73MPa, and MIX 3 bricks showed a strength of 25.11MPa.

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