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# Energy efficient production of clay bricks using industrial waste

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## Abstract

Clay brick manufacturing is a sector which involves a lot of firing processes requiring higher temperature. To maintain this temperature, large amount of fuel in the form of wood, coal, biomass etc. need to be burnt in the kiln causing serious issues of air pollution. Also, with the increase in the number of industries coming up, large amount of un-disposable waste gets accumulated. If suitable remedies are not adopted for its safe disposal, it may pollute the water bodies through runoff. This project is an effort to reduce the brick firing temperature in the kiln to about 600 °C thereby reducing the cost of production and making the whole process environmental friendly. This work will put forward a suitable alternative for the safe disposal of industrial debris like quarry dust and glass powder by incorporating them as a partial substitute for river sand which is one of the costly constituent of clay brick and thereby further reducing the cost of production. Experimental results showed higher compressive strength of 21.31 N/ $mm^2$ when the brick was casted with mix proportion of Cement: Sand: Red earth: Glass Powder: Quarry Dust = 4:1:1:1.5:2.5. The strength measured at temperature 600 °C met the requirements of the National Standards.

Keyword: Civil engineering

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# 1. Introduction

Brick firing is an energy intensive process consuming around 24 million tons/year of coal and is a potential source of air pollution [1]. Even in the world of modern technology, between one-half and two-thirds of the world's population, in both traditional societies as well as developed countries, still live or work in buildings made with clay, often baked into brick, as an essential part of its load-bearing structure and this sector also proves to be the livelihood of large number of unskilled labour. As per estimates the temperature required in the kiln is around 1400 °C which requires burning lump sum quantity of fuel causing emission of highly polluted gases such as carbon monoxide (CO), carbon dioxide (CO2), ammonia (NH3) and in some cases chlorine and fluorine which are unsafe [2, 3]. Because of huge quantities of toxic emissions, brick kilns cause serious health issues. Even though, the impact of pollution caused locally by small isolated brick kilns is not significant, large kilns near towns and cities are an important cause of concern.

In developing countries like India open dumpsites are common scenes, due to the lack of skilled manpower and low budget for waste disposal. These wastes can be potential hazards to the environment and human health unless properly stored, transported, disposed of or managed [4]. Even though the disposal of hazardous wastes and effluents are regulated, solid wastes are often disposed of indiscriminately into environment posing health risks. In this view, management of such wastes, their disposal in environment friendly and economically viable way is very important and this paper put forward suggestions to cope up with this risk. Quarrying of lateritic stone produces 15−20% of soil wastes which poses a problem of disposal [5]. Similarly waste glass generated from glass industry is industrial debris whose disposal needs to be taken care of. Out of the total glass produced in India only 45% is recycled which shows that there is a need for proper procurement and management of waste glass [6].

Through this work, we are putting forward an efficient alternative for safe disposal of industrial by products such as quarry dust and glass powder by incorporating them partially in clay bricks by replacing river sand which is a costly constituent and whose availability is scarce. Our goal is to seek out innovative production of energy efficient brick, environmentally friendly in the manufacturing process and for the end use of clay brick products. We are on the quest to seek clay bricks that provide exceptional energy efficiency, durability, recyclability, and low maintenance with minimal impact on the environment from which they originate.

## 1.1. Experiment procedures

Firstly, the major constituents such as sand, clay, red earth, glass powder and quarry dust required for the casting of samples are collected and sieve analysis is conducted. The constituents are then taken according to trial proportions and mixed properly in dry


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state followed by adding required quantity of water to get a proper consistency. Table moulding is adopted for casting the samples where first the mix prepared is filled into the mould and extruded out after proper finishing of the surface. The samples so prepared are properly dried in 3 different stages, initially, they are dried under the shade for duration of 3 days, then they are exposed to direct sunlight for a duration of 5 days and finally burned in the muffle furnace for 3 more days. The fired brick samples are then tested for compressive strength and water absorption to identify the quality and designation of these bricks so as to identify their suitability for use in different type of works.

## 2. Materials and method

### 2.1. Materials

The various materials used in the production of clay bricks in this work are clay, sand, red earth, quarry dust and glass powder as shown in Fig. 1. A brief description of these materials is as follows:

Clay (C): These are finely-grained natural rock or soil material that combines one or more clay minerals with possible traces of quartz, metallic oxides and organic matters. They are plastic due to particle size, geometry as well as water content and become hard, brittle and non−plastic upon drying or firing [7].

Sand (S): Natural river sand is a naturally occurring granular material composed of finely divided rock and mineral particles. Its composition is mostly silica (silicon dioxide), usually in the form of quartz. It is mined from the river beds and is used as a fine aggregate. Indiscriminate mining of sand causes damages to the environment. Recently due to the difficulty in the availability of natural sand its cost is quite high [8].

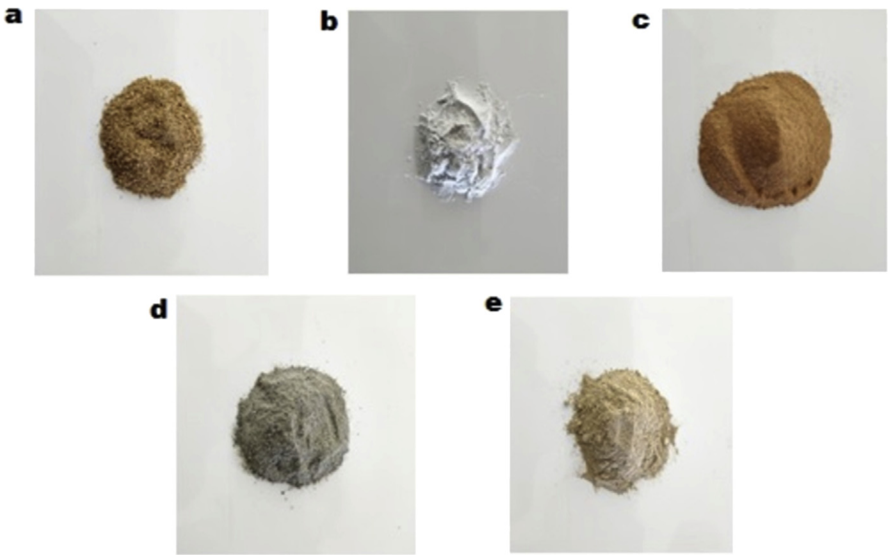


**Fig. 1.** (a) sand (b) glass powder (c) red earth (d) quarry dust (e) clay.


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Red earth (RE): It is generally derived from crystalline rock and is commonly found in warm, temperate, moist climate under deciduous or mixed forest, having thin organic and inorganic-mineral layers overlying a yellowish-brown leached layer resting on an alluvial red layer. Their red colour is contributed mainly due to ferric oxides occurring as thin coatings on the soil particles. Its chemical composition includes non-soluble material 90.47%, iron 3.61%, aluminum 2.92%, organic matter 1.01%, magnesium 0.70%, lime 0.56%, carbon dioxide 0.30%, potash 0.24%, soda 0.12%, phosphorus 0.09% and nitrogen 0.08% [9].

Quarry dust (QD): It contains silica which is a colourless crystalline compound which is mainly found in natural sand, quartz, flint etc. and is an important constituent in enhancing the strength property in materials. Quarry dust is a byproduct of the crushing process and is disposed to landfills. Quarry dust contains silica and can satisfy the requirement of a fine aggregate. With its incorporation into brick as a substitute for natural sand, the requirement of land fill area for its disposal gets reduced and can also help in solving the problem of natural river sand scarcity because of its low cost and similar properties [10].

Glass Powder (GP): It is principally composed of silica. Once waste glass is formed it is disposed into landfills, million tons of waste glass is being generated annually all over the world. The practice of dumping into landfills is quite un-sustainable as glass does not decompose into the environment. Use of ground waste glass in brick as partial replacement of sand could be an important step towards finding a way to safely dispose waste glass [11].

## 2.2. Method

This work is an attempt to reduce the firing temperature conventionally adopted in brick kiln and also to find a sustainable disposal method for industrial wastes such as quarry dust and glass powder. The work started with a visit to the brick kiln from where the collection of all the raw materials was done. Bricks were cast with varying proportions of quarry dust and glass waste being incorporated on a trial and error basis. Sand, clay and red earth needed for the work were collected from Peruva brick manufacturing unit. Quarry dust was collected from a Quarry at Thrissur and glass powder was collected from Coimbatore. Moulds with size $8 \times 4 \times 4$ cm were made for casting bricks. This helped in the small scale production of bricks for the work [12].

### *2.2.1. Casting of samples*

The materials required for the casting such as quarry dust, glass powder, sand, red earth, and clay were collected and the materials of proper sieve sizes were mixed manually in dry state till a uniform colour was achieved and then water was added gradually as per the requirement to achieve the required consistency during the


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mixing stage, the proportions were fixed based on a trial and error basis. The inner surface of the mould was properly oiled and the prepared mix was then filled in the mould up to the brim in layers by providing proper tamping and the top surface was finished with a trowel to get a proper surface finish as shown in Fig. 2 [12].

### 2.2.2. *Drying of prepared clay brick samples*

Firstly, the bricks were kept for shade drying for duration of 3 days, this is done to prevent plastic shrinkage cracks formed as a result of evaporation of water from the surface of brick in the early stages. After which the bricks are subjected to direct sun rays drying for a period of 5days. After sun drying the bricks are to be kept in the muffle furnace for 3 days at a temperature of 600 °C.Various stages of drying process are shown in Fig. 3.

### 2.2.3. *Testing of prepared clay brick samples*

- The samples were then taken out for testing process. The properties such as compressive strength, water absorption etc. were tested as shown in Fig. 4. Those samples which give compressive strength more than 5 $N/mm^2$ can be treated as a building unit. The water absorption of a good brick should not exceed 20% as per the standards.

## 3. Results and discussion

## 3.1. Compressive strength

In every set of proportions, 40% replacement of natural river sand is done with glass powder and quarry dust thereby reducing the percentage of sand to 10%. The red

**Fig. 2.** (a) mixing of materials (b) filling into the mould (c) levelling of surface.

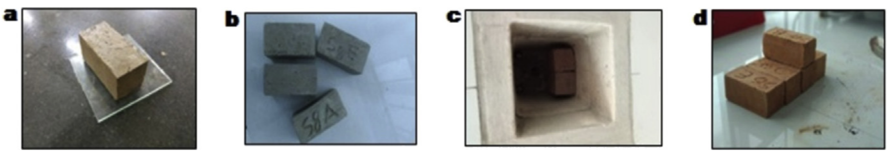

**Fig. 3.** (a) Raw brick (b) Sun dried brick (c) Brick in muffle furnace (d) Fired brick.


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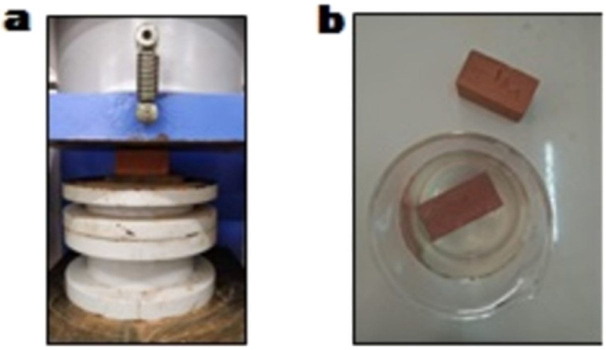

**Fig. 4.** (a) Testing for compressive strength (b) Test for water absorption.

earth was added for about 10 % during casting to impart colour. The percentage replacement of glass powder was done from 5% to 30% with simultaneous alteration of the quantity of quarry dust being used. Table 1 shows the percentages of different constituents used for all proportions.

#### 3.1.1. Proportion No.1 C: S: RE: QD: GP = 4: 1: 1: 3.5: 0.5

In this proportion, 40% of natural river sand is replaced by the combination of quarry dust and glass powder. Here, QD replaces 35% and GP replaces 5% of natural sand. Five samples were casted using this proportion and the samples were tested for compressive strength, the results of which are given in Table 2 and the graph showing the compressive strength results of different samples are shown in Fig. 5.

#### 3.1.2. Proportion No 2 C: S: RE: GP: QD = 4:1:1:1.5:2.5

In this proportion, 40% of natural river sand is replaced by the combination of quarry dust and glass powder. Here, QD replaces 25% and GP replaces 15% of natural sand. Five samples were casted using this proportion and the samples were tested for compressive strength, the results of which are given in Table 3 and the graph showing the compressive strength results of different samples are shown in Fig. 6.

#### 3.1.3. Proportion No.3 C: S: RE: GP: QD = 4:1:1:2.5:1.5

In this proportion, 40% of natural river sand is replaced by the combination of quarry dust and glass powder. Here, QD replaces 15% and GP replaces 25% of natural sand.

**Table 1.** Brick sample proportions.

| Proportion no: | Clay (%) | Sand (%) | Red earth (%) | Quarry dust (%) | Glass powder (%) |
|---|---|---|---|---|---|
| 1 | 40 | 10 | 10 | 35 | 5 |
| 2 | 40 | 10 | 10 | 25 | 15 |
| 3 | 40 | 10 | 10 | 15 | 25 |
| 4 | 40 | 10 | 10 | 10 | 30 |


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**Table 2.** Observation table of proportion 1.

| Sample no. | Load (N) | Length (mm) | Width (mm) | Area (mm²) | Compressive strength (N/mm²) |
|---|---|---|---|---|---|
| A | 40000 | 75 | 37 | 2775 | 14.41 |
| B | 40000 | 76 | 38 | 2888 | 13.85 |
| C | 35000 | 77 | 38 | 2926 | 11.96 |
| D | 45000 | 75 | 39 | 2925 | 15.38 |
| E | 0 | 75 | 37 | 2775 | 0 |

Average compressive strength = 11.12 N/mm$^2$.
Sample standard deviation = 6.33.

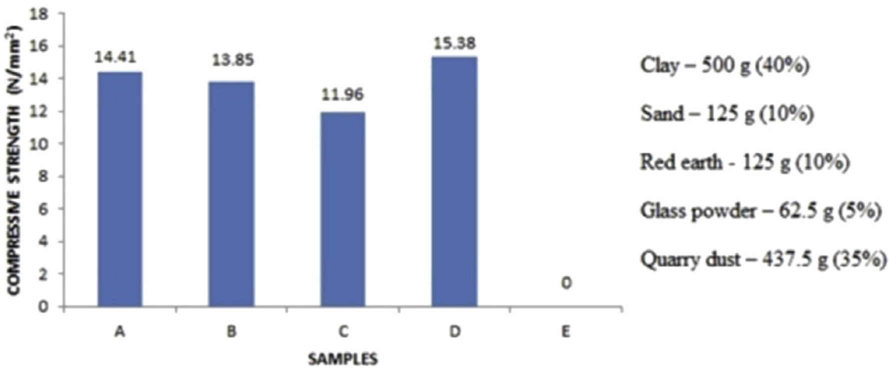


**Fig. 5.** Graph showing compressive strength of proportion no: 1.

Five samples were casted using this proportion and the samples were tested for compressive strength, the results of which are given in Table 4 and the graph showing the compressive strength results of different samples are shown in Fig. 7.

### *3.1.4. Proportion No.4 C: S: RE: GP: QD = 4: 1:1:3:1*

In this proportion, 40% of natural river sand is replaced by the combination of quarry dust and glass powder. Here, GP replaces 30% and QD replaces 10% of natural sand. Five samples were casted using this proportion and the samples were tested for

**Table 3.** Observation table of proportion 2.

| Sample no. | Load (N) | Length (mm) | Width (mm) | Area (mm²) | Compressive strength (N/mm²) |
|---|---|---|---|---|---|
| A | 55000 | 74 | 38 | 2812 | 19.55 |
| B | 55000 | 75 | 36 | 2700 | 20.37 |
| C | 60000 | 75 | 36 | 2700 | 22.22 |
| D | 63000 | 76 | 38 | 2888 | 22.50 |
| E | 60000 | 74 | 37 | 2738 | 21.91 |

Average compressive strength = 21.31 N/mm$^2$.
Sample standard deviation = 1.28.

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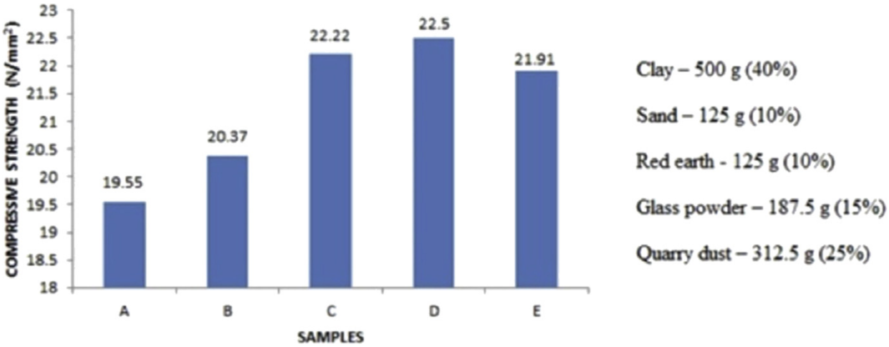


**Fig. 6.** Graph showing compressive strength of proportion no: 2.

**Table 4.** Observation table of proportion 3.

| Sample no. | Load (N) | Length (mm) | Width (mm) | Area ($mm^2$) | Compressive strength ($N/mm^2$) |
|---|---|---|---|---|---|
| A | 50000 | 76 | 38 | 2888 | 17.313 |
| B | 50000 | 78 | 38 | 2808 | 17.80 |
| C | 50000 | 78 | 36 | 2808 | 17.80 |
| D | 54000 | 77 | 37 | 2849 | 18.95 |
| E | 55000 | 76 | 38 | 2888 | 19.04 |

Average compressive strength = 18.18 $N/mm^2$.
Sample standard deviation = 0.77.

compressive strength, the results of which are given in Table 5 and the graph showing the compressive strength results of different samples are shown in Fig. 8.

### 3.1.5. *Comparative study*

The comparative study of average compressive strength obtained for various proportions are given in Fig. 9. The graph indicates that the compressive strength of sample

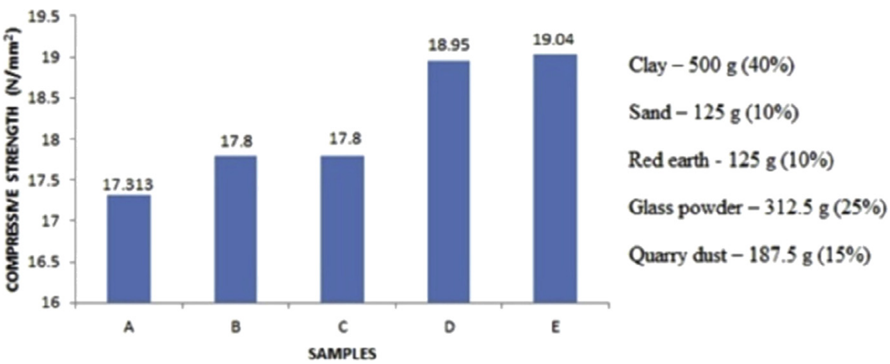


**Fig. 7.** Graph showing compressive strength of proportion no.3.


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**Table 5.** Observation table of proportion 4.

| Sample no. | Load (N) | Length (mm) | Width (mm) | Area ($mm^2$) | Compressive strength ($N/mm^2$) |
|---|---|---|---|---|---|
| A | 35000 | 77 | 39 | 3003 | 11.65 |
| B | 25000 | 77 | 38 | 2926 | 8.54 |
| C | 30000 | 74 | 35 | 2590 | 11.58 |
| D | 45000 | 76 | 38 | 2888 | 15.58 |
| E | 50000 | 74 | 37 | 2738 | 18.26 |

Average compressive strength = 13.12 $N/mm^2$.
Sample standard deviation = 3.8.

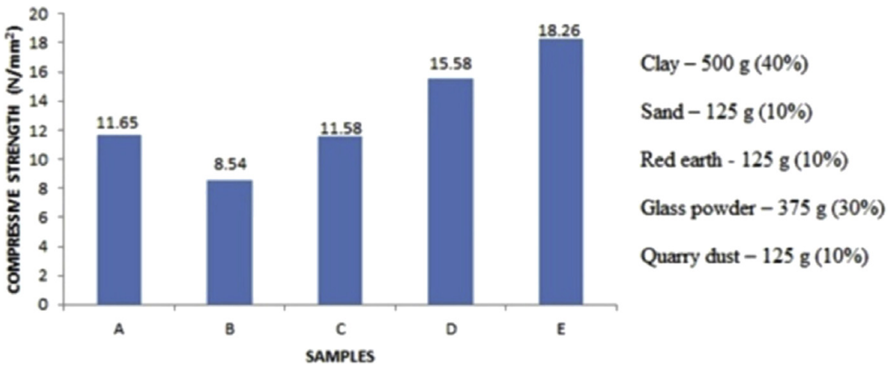


**Fig. 8.** Graph showing compressive strength of proportion no.4.

proportion P2 is higher than the other samples. The mix proportion P2 shows that more strength is achieved when quarry dust is more than the glass powder.

## 3.2. Water absorption

Table 6 represents the results of water absorption test. All the four samples which gave maximum compressive strength were tested for water absorption and are

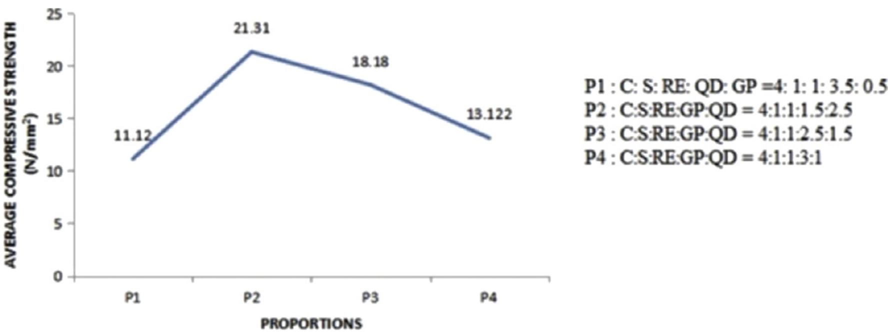


**Fig. 9.** Comparative study of average compressive strength.


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**Table 6.** Observation table for water absorption.

| Sample | Initial weight (gm) | Final weight (gm) | Water absorption (%) |
|---|---|---|---|
| A | 188.4 | 214.6 | 13.906 |
| B | 188.2 | 214 | 13.70 |
| C | 189.6 | 215.3 | 13.55 |
| D | 186.8 | 211.9 | 13.43 |

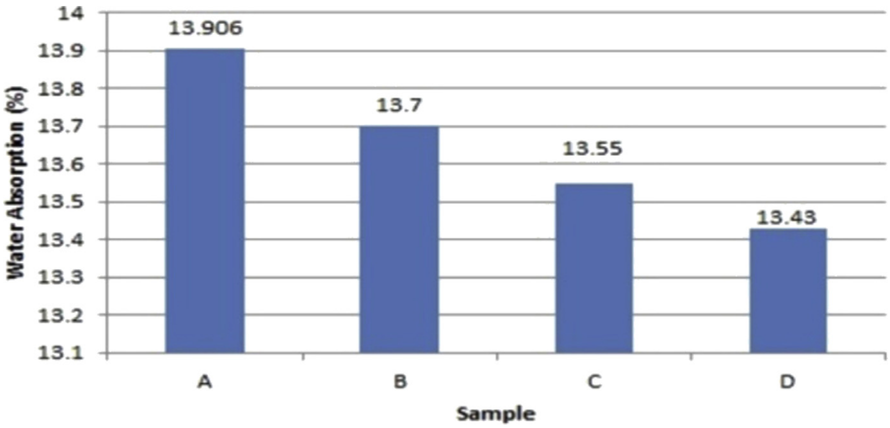


**Fig. 10.** Graph showing water absorption.

represented in Fig. 10. It shows that all the water absorption percentage arelesser than 15 % which suits the criteria of first class brick.

## 4. Conclusion

Proposed method for the manufacturing of energy efficient fired clay bricks using industrial derbies introduce an effective means for waste disposal. This work focuses on the partial replacement of natural river sand by industrial wastes such as quarry dust and glass powder. The clay brick samples fired in the muffle furnace at a reduced temperature of $600^0$Cwere tested for compressive strength after 3 days of firing which showed that the value ranges from 11N/mm$^2$ to 21N/mm$^2$. Experimental results inferred that glass powder and quarry dust in the ratio 1.5:2.5 gave higher compressive strength of 21.31 N/mm$^2$ with a standard deviation of 1.28. The water absorption of the sample was also checked and the results showed less than 15% which corresponds to the water absorption of a first class brick. The compressive strength and water absorption results show that these samples belong to first class bricks category with a class designation of 20 as per IS 1077:1992. These bricks casted with reduced temperature incorporating industrial debris will put forward a new aspect to revolutionize the clay brick manufacturing sector in India and can be used for the construction of external walls and load bearing structures.

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## Declarations

### Author contribution statement

Carolin Peter, Kavya Mohan, Shone Greens, Sneha George: Conceived and designed the experiments, Performed the experiments, Analyzed and interpreted the data, Contributed reagents, materials, analysis tools or data, wrote the paper.

Mary Lissy P N: Conceived and designed the experiments, Analyzed and interpreted the data.

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### Competing interest statement

The authors declare no conflict of interest.

### Additional information

No additional information is available for this paper.

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