Investigating the Application of Plastic Bottle as a Sustainable Material in Building Construction

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Abstract— One of the main disadvantages in constructing houses is high cost of the building materials. Building materials are the primary requirement for constructing the house in places where people are below poverty line and is becoming one of the most significant problems of peoples. On the other hand, urbanization growth will increase rubbish wastes especially non-renewable ones. Eco friendly architectural principles are being incorporated into more buildings every day in the world but they are still out of reach of many poor people due to lack of knowledge and awareness. In this project we implemented strategies and systems based on Eco-friendly environment that could still be built at very low costs, with waste materials that is plastic bottle, providing adequate thermal comfort while being sustainable. At the end, it concluded that in different factors such as time of execution, load capacity, flexibility, reducing waste, cost and energy efficiency, plastic bottles can be more effective compared to some conventional building materials such as brick and concrete blocks. By filling the PET bottles with different filling materials compression strength is determined, from which best filling material can be known. Cubes of size 300 mm were prepared by placing the PET bottles in three different layers in different pattern and compression strength is determined, from which best pattern for bottles arrangement can be known. Freezing and thawing test has been performed for continuous 56 cycles and 4-hour fire resistance test is performed on a specimen of size 300x300x100 mm having 3 PET bottles in its core to know the Durability aspect.

Key words: Application of Plastic Bottle, Sustainable Material in Building Construction

I. INTRODUCTION

Plastics are produced from the oil that is considered as non-renewable resource. Because plastic has the insolubility about 300 years in the nature, it is considered as a sustainable waste and environmental pollutant. So reusing or recycling of it can be effectual in mitigation of environmental impacts relating to it. It has been proven that the use of plastic bottles as innovative materials for building can be a proper solution for replacement of conventional materials. The use of this material has been considered not only for exterior walls but also for the ceiling of the building. The objective of this project is to investigate the key and positive characteristics of this product and the benefits obtained by using it in building. It also intends to compare the characteristics of some construction materials such as brick, ceramic and concrete block with bottle.

The PET bottles that are not recycled end up in landfills or as litter, and they take approximately 1000 years to biodegrade. This has resulted in plastic pollution problems in landfills, water ways and on the roadside, and this problem continues to grow along with the plastic bottle industry.

This paper has been driven by two main concerns. First the thriving problem with plastic bottle environmental issues and Second, the application of PET bottles in construction as masonry. This can provide a good amount of confidence in safety and durability design of structures built with PET bottles

Furthermore, not all soils suitable for construction. First the type of soil used to fill the bottles may have an influence on the strength of the PET bottle masonry The objective of this paper is to investigate the using of plastic bottles as municipal wastes in the buildings, the key and positive characteristics of this product and the benefits obtained by using it in building. It also intends to compare the characteristics of some construction materials such as brick and concrete block with bottle wall. It also intends to compare the strength of the cubes of plastic bottles of same size with different arrangements of bottles.

II. NEED FOR THE STUDY

In the past, the glass was common in packing some foods such as milk and etc. They could be returned to the factory for using again for the same purpose. But now by changing the human's disposal culture, glass bottles have been replaced by plastic bottles, as they have increasingly become one of the substances of destruction of the landfills because they decompose in a long time. Two alternative solutions against the plastic bottle disposal are recycling and reusing process.

A. Problem of Reuse

Bacteria from user's hand and mouth accumulate when the bottle is not washed between uses. Repeated hot water washing and handling of PET water bottles may breakdown the plastic and leaching toxic compounds such as DEHA in to beverages. Consumer who reuse plastic water bottle are unaware of potential health risk associated with high bacterial levels found on the bottle and leaching of plastic compounds in to the beverages.

B. Plastic in Recycling

Recycling represents a potential means of reducing the negative environmental impact of plastic disposal. However, presently, only a very small percentage of plastic is actually recycled. Approximately 15 to 27 percent of polyethylene terephthalate (PET) plastic is recycled annually. PET plastics are primarily used for soft-drink bottles. High-density polyethylene (HDPE) plastic is commonly used for shampoo bottles, milk jugs and other types of so-called rigid plastic containers. Approximately 10 percent of HDPE plastic is recycled annually. Lack of awareness regarding the quality of recycled plastic leads to its categorization as ecofriendly which is a great myth.

C. Problem of Recycled Plastic

1) Major chemicals that are used in making plastic are highly toxic and are a serious threat to living of all species on earth, therefore recycle of a hazard put back toxic waste in the market place and eventually in to the environment.
2) Recycling of plastic is uneconomical, dirty and labour intensive as per study conducted by public interest research group based in Delhi, India.
3) Plastic recycling causes skin and respiratory problem resulting from exposure to inhalation of toxic fumes due to hydrocarbons and residues released during process.
4) Recycled plastic degrades in quality and necessitates the production of more new plastic to make original product. Since the problem associated with plastic disposal has taken a giant shape and continued reuse of plastic and recycling does not provide ideal solution due to health risk and other associated problem discussed above.

D. Problem with Plastic Disposal

The major problem with disposing of plastic is that it is non-biodegradable. This is one reason plastic is so durable. However, it differs in this respect from paper and organic substances. Instead, plastic photo degrades, which means that the sun breaks plastic down into smaller pieces of plastic, rather than down to the basic elements which make up the plastic.

1) Plastic in Landfills

Plastic accounts for approximately 25 percent of all refuse in landfills. This fact alone makes the disposal of plastic a major problem. Combined with the fact that plastic is nonbiodegradable, this makes the presence of plastic in landfills a critical issue.

2) Plastic in Incinerator

Incineration is generally an environmentally unfriendly means of plastic disposal. It results in polluting agents being released into the atmosphere, often without any filtering or treatment of any kind. A similar process called pyrolysis, designed to make plastic reusable in oil and chemical refineries, bakes plastics into a sort of hydrocarbon soup. Both processes are more expensive than recycling.

3) Plastic in Waterways

Much plastic waste is improperly disposed. A large percentage of improperly disposed plastic winds up floating in the ocean. For example, in 2003, a collection of plastic debris approximately the size of the state of Texas was discovered to be floating in the North Pacific. Plastic debris in waterways is often torn by photo degradation into small pieces which are eaten by marine animals, some of which wind up in the human die.

The present project is an attempt to provide solution to the never ending global plastic disposal problem by making shelter out of the PET plastic bottles which are easily available and have properties of thermal and electrical insulator substances. These houses present low cost, ecofriendly housing to poor and needy people and are equally strong as brick houses. They are an effective solution for the reduction of PET plastic from the environment and will solve the various problem related with the disposal of plastic.

III. Objectives

- To find out the best filling material for filling the plastic bottles which is easily available, economical and gives more strength.
- To find out the best pattern for arrangement of bottles for wall construction which gives more strength.
- To study the compressive, split tensile and flexural behavior of bottle brick used in construction.
- To study the fire resisting and freezing and thawing properties of plastic bottle brick used in construction.
- To make cost comparison between PET bottle construction and conventional brick masonry construction.

IV. Materials Used

A. Filling Material

The best filling material is chosen by considering various parameters like strength, availability, cost and their property. Therefore before using any material as a filling material some of its properties are required to know. In this study different filling materials used are

- Natural sand
- Manufactured sand
- Soil
- Wood dust
- Ash

Natural sand, manufactured sand and soil are the most common materials required in most of the constructions. These materials are used as filling materials in this study and best out of which is determined. Natural sand is used in casting cubes for various tests.

Cork or wood dust is considered as an impenetrable insulation that is used in cylinder parts for blocking the bottle and glass. About 60% of the world total production of cork are used as the bottle caps, and are discarded after being used that can be used as recycled product in these panels which can bring a good and effective work. Therefore this material is also used as a part of filling material in this study.

B. Plastic Bottles

In the past, the glass was common in packing some foods such as milk and etc. They could be returned to the factory for using again for the same purpose. But now by changing the human's disposal culture, glass bottles have been replaced by plastic bottles, as they have increasingly become one of the substances of destruction of the landfills because they decompose in a long time. Two alternative solutions against the plastic bottle disposal are recycling and reusing process. Recycling needs additional energy to treat the materials for producing something usable. Moreover, the recycling process produces wastewater and air pollutants. So the best solution is reusing for which no additional energy is required and does not contribute to pollution. Indeed, when we reuse junk, we are helping to save the obtained energy which would otherwise be wasted. It is focused on not only the financial aspect but also the environmental aspect. Plastics are produced from the oil that is considered as non-renewable resource. Because plastic has the insolubility about 300 years in the nature, it is considered as a sustainable waste and environmental pollutant. So reusing or recycling of it can be effectual in mitigation of environmental impacts relating to it.

It has been proven that the use of plastic bottles as innovative materials for building can be a proper solution for replacement of conventional materials. The use of this material has been considered not only for exterior walls but also for the ceiling of the building.

C. Nylon Rope

Nylon rope is gotten from coal, Petroleum, air and water. It is a polyamide thermoplastic produced by series of condensation reaction between an amine and organic acids. Nylon rope has a very high tensile strength so that it is used as the main binder for PETE bottles masonry.

D. Cement

Cement is the important binding material. In this project it is used to bind the plastic bottles to make the masonry wall more durable so that the quality of cement is checked by various tests as per IS standards.

E. Water

Water is an important ingredient for tests and construction as well as it is actively involved in chemical reactions with cement, particularly hydration. In the present investigation potable water is used.

V. METHODOLOGY

A. Collection of material

Initially the materials required for finding the best filling material includes soil, natural Soil, manufactured Soil, wood dust, and ash was collected from the surrounding places of Gubbi. Later for further testing and construction waste PETE bottles of ½ and 1 liter capacity with caps were collected from film theater, choutries and gujari shops of gubbi.

B. Preliminary tests on material

The basic required tests on materials includes sieve analysis, water content determination and specific gravity tests for soil and all Soil materials, liquid limit test and plastic limit test for soil, normal consistency test, initial and final setting time test and specific gravity test for cement and compression strength test of cement mortar cube were performed as per IS standards in laboratory and test results were noted down.

C. Determining the best filling material

The plastic bottle bricks were then prepared by

- completely filling with Soil
- completely filling with Natural sand
- completely filling with M-Sand
- filling in three layers, two soil and one M-Sand
- filling in three layers, two soil and one wood dust
- filling in three layers, two soil and one ash

Fig. 1: Plastic Bottle Bricks

- The material is filled into plastic bottle in three layers by tamping the each layer 20 times by using a tamping rod for proper compaction. When the bottle is completely filled, excess material is trimmed off and bottle is sealed or caped tightly.
- The specimens were placed under compression testing machine and based on results obtained; the best filling material is decided.

Once the best filling material is known all the collected PET bottles were filled with best filling material in the specified manner and hence bottle bricks were ready for further tests and construction.

D. Determination of best arrangement pattern

- Casting of mould: For determining the best pattern of arrangement of bottle bricks moulds of 300*300*300 mm were casted using a thick 16 gauge steel metal sheet.
- By filling the best filling material, plastic brick bottles were prepared and are arranged in different patterns in a cubic mould of size 300*300 mm and using cement mortar cubes were prepared. It is as shown in figure.

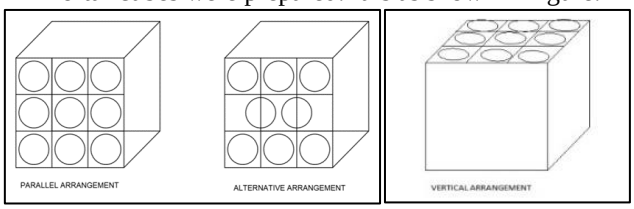

Fig. 2: Determination of best arrangement pattern

While placing the bottles, they are tied with nylon ropes in a specific manner. Water/cement ratio should be chosen carefully so as to obtain a proper bonding with smooth plastic surface.

- The cubes were tested in compression testing machine and the arrangement pattern which gives more strength is determined.
- In the same procedure cubes were prepared by placing conventional bricks instead of plastic bottle bricks and its 7, 14 and 28 days strength is determined.
- For all the arrangements cubes were prepared and tested for 7, 14 and 28 days curing period and compression strength behavior is compared and studied

E. Study of split tensile characteristic behaviour

Cylinders were casted using plastic bottle brick and cement mortar and split tensile strength characteristic behaviour is studied by testing for 7, 14 and 28 days.

Fig. 3: Study of split tensile characteristic behaviour

F. Study of flexure strength characteristic behaviour

Specimens of 500*100mm and 100mm height were casted and tested for 7, 14 and 28 days to study the flexure strength behaviour.

Fig. 4: Study of flexure strength characteristic behaviour

G. To study the fire resisting property

A specimen of 300*300 mm and 100mm height is prepared and is tested for fire resisting strength test by applying fire over one face and observing the temperature using a digital thermometer over other face for every 10 minutes for 4 hours and also the cracks if any occurred.

Fig. 5: To study the fire resisting property

H. To study the freezing and thawing resisting property

A specimen is prepared and is kept in a temperature of -6° Celsius for about 6 hours in a minimum 2 cm depth salt solution and then cooled under room temperature for 2 hours and again it is kept in an oven at 45° Celsius for 4 hours to complete one cycle. 56 such cycles were repeated and specimen is observed, if no significant changes and not more than 1% weight loss occurred then it can be said to withstand freezing and thawing effect.

Freezing Thawing

Fig. 6: To study the freezing and thawing resisting property

I. Construction

After all the tests were completed a park bench is constructed by choosing the best filling material and best arrangement pattern to the required height and width along with foundation,

Fig. 7: Construction

J. Rate Analysis

Rate analysis is made for the wall constructed with bottle brick technique and for the same wall if constructed using conventional bricks. The cost is compared between those two.

VI. TEST RESULTS AND DISCUSSIONS

A. Material Testing Results

1) Tests on Soil

Sl. No.	Tests	Test results
01	Fineness Modulus	U_c=0.83, U_u= 3.3
02	Specific gravity	2.67
03	Water content	9.28 %
04	Atterberg Limits	W_L= 42 % W_P = 56%

Table 1: Tests on soil

2) Tests on Natural Sand

Sl. No.	Tests	Test results
01	Fineness Modulus	4.45
02	Specific gravity	2.47 %
03	Water content	

Table 2: Tests on Natural Sand

3) Tests on Manufactured Sand

Sl. No.	Tests	Test results
01	Fineness Modulus	5.2
02	Specific gravity	2.68
03	Water content	7%

Table 3: Tests on

4) Tests on Cement

Sl. No.	Tests	Test results
01	Normal consistency	32%
02	Initial & Final setting time	30 min. & 10 hours
03	Specific gravity	3.07
04	Compression test on CM cubes	
	3days	20.14 MPa
	7days	27.89 MPa
	28days	37.61 MPa

Table 4: Tests on Cement

B. Compression Strength Tests

1) Compression strength test for bottle bricks

- About 3 plastic bottle bricks were prepared for 3 trials by
  - Completely filling with Soil
  - Completely filling with natural sand
  - Completely filling with M-Sand
  - Filling in three layers, two soil and one M-Sand
  - Filling in three layers, two soil and one wood dust
  - Filling in three layers, two soil and one ash
- The material is filled into plastic bottle in three layers by tamping the each layer 20 times by using a tamping rod

for proper compaction. When the bottle is completely filled, excess material is trimmed off and bottle is sealed or caped tightly.

- The area of plastic bottle brick is determined using the appropriate formula and is noted down.
- The specimen is placed under compression testing machine and load is applied at uniform rate till specimen fails or kickback of needle occurs. The load is noted down for each bottle brick.
- Compression strength is obtained by taking the ratio of load to area of bottle brick and is expressed in terms of N/mm^2
- The results were compared and best filling material is chosen as the one which gives more strength.
- Compression strength test for brick is carried out as per IS 3495-Part 1-1992 and the results were compared with that of bottle bricks.

a) Bottle brick dimensions

- Diameter d=65 mm
- Length of uniform diameter l=160 mm

Sl. No.	Filling material			Load P (KN)	Compressive Strength 2P/πdl MPa
	1st layer	2nd layer	3rd layer		
1	Soil			210	12.86
2	Natural Sand			84	5.14
3	M-Sand			76	4.65
4	soil	M-Sand	soil	94	5.75
5	soil	Wood waste	soil	152	9.30
6	soil	Ash	soil	120	7.35

Table 5: Bottle brick dimensions

Therefore from the above results the best filling material is found to be Soil.

2) Compression strength of conventional bricks

Sl. No.	L (mm)	B (mm)	H (mm)	Weight (kg)	Area A mm2	load (KN)	Compression strength MPa
01	210	95	70	3.04	19950	120	6.01
02	210	95	70	3.06	19950	125	6.26
03	210	95	70	3.04	19950	122	6.11

Table 6: Compression Strength of Conventional Bricks

Therefore average compression strength of brick= 6.12 MPa

3) Compressive strength test for cubes

- Cubes (30cm x 30cm x 30cm) were made to prepare the desired bottle brick inserted cement mortar cubes. The cement mortar for the cubes were made of 1:3 (Ordinary Portland Cement: Soil) by weight with a water cement ratio of 0.5.
- A 3cm thick layer of mortar was placed in the mold which is compacted with 20 even blows of the tampering rod. Once the first layer had been compacted, three same sized (500ml) soil filled plastic bottles were placed on this first layer of mortar. Then another layer of mortar is placed in the mold covering the bottles evenly. Approximately 10 blows of the tampering rod were given. The second and third layers of bottles were placed similarly with cement mortar in between the bottles. The step by step process in which a total of nine bottles are inserted into the cube mold is shown in Figure for horizontal parallel bottles arrangement.

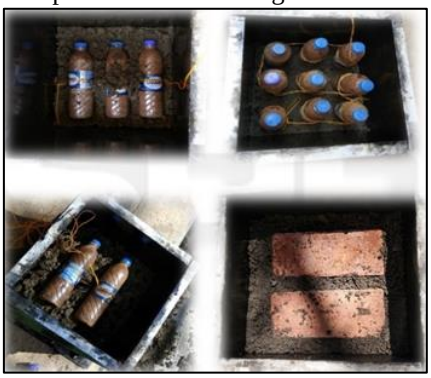

Fig. 8: Compressive strength test for cubes

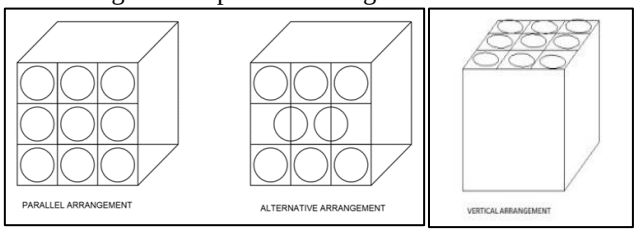

Fig. 9: Cubes

- Second set of cubes were prepared in the same way but with 8 bottle bricks with 3 layers having 2 bottles in middle layer between top and bottom layer having 3 bottles for horizontal alternative bottles arrangement as shown in Figure.
- Third set of cubes were prepared by placing the 9 bottles vertically over the bottom 3 cm cover morter
- In all the above cubes attach the bottles to one another by using nylon rope while laying them on the mortar layer to ensure that the bottom of the cube is leveled and to get good bonding.
- Fourth set of cubes were prepared with 6 conventional bricks by placing 2 bricks over 2 cm 1:3 cement morter cover in 3 layers as shown in figure.4.
- Prepared cubes were removed from the mold after 24 hours and are put in curing pit for a curing period of 7, 14 and 28 days.
- All these cubes were tested in a Universal Testing Machine (UTM) of 600 KN capacity. The specimens were placed in the UTM for testing with 2 mm thick top and bottom steel cover plates.
- Weight and dimensions of cube to be tested is noted down before placing in to UTM
- Load is applied at constant rate till the failure of specimen occurs, failure load is noted down and cracks were observed.
- Compressive Strength is calculated by dividing the load with cross sectional area and results were compared.
- The best pattern of arrangement is chosen based on the results.

a) Compressive Strength of Cubes with Horizontal Parallel Arrangement of Bootle Bricks [A]

- Length=0.3 m
- Breadth=0.3 m
- Height=0.3m

- Area= 0.09m^2
- Volume=0.027 m^3
- Weight=53.40 Kg
- Density=1977.78Kg/m^3

Sl. No	Days of Curing	Load (P) KN	Area (A) m^2	Compressive Strength (F=P/A) kN/m^2	Average Compressive Strength kN/m^2
1	7	174.45	0.09	1938.33	1958.05
2		178.00	0.09	1977.77	
1	14	196.50	0.09	2183.33	2202.78
2		200.00	0.09	2222.22	
1	28	219.00	0.09	2133.33	2280.55
2		218.50	0.09	2427.78	

Table 7: Compressive Strength of Cubes with Horizontal Parallel Arrangement of Bootle Bricks [A]

b) Compressive Strength of Cubes with Horizontal Alternative Arrangement of Bootle Bricks [B]

- Length=0.3m
- Breadth=0.3m
- Height=0.3m
- Area= 0.09m^2
- Volume = 0.027m^3
- Weight =56.01Kg
- Density = 2074.44Kg/m^3

Sl. No	Days of Curing	Load (P) KN	Area (A) m^2	Compressive Strength (F=P/A) kN/m^2	Average Compressive Strength kN/m^2
1	7	208.95	0.09	2321.67	2327.5
2		210.00	0.09	2333.33	
1	14	280.00	0.09	3111.11	3102.78
2		278.50	0.09	3094.44	
1	28	295.00	0.09	3277.78	3280.56
2		295.50	0.09	3283.33	

Table 8: Compressive Strength of Cubes with Horizontal Alternative Arrangement of Bootle Bricks [B]

c) Compressive strength of cubes with vertical arrangement of bootle bricks [c]

- Length=0.3 m
- Breadth=0.3 m
- Height=0.3m
- Area= 0.09m^2
- Volume=0.027 m^3
- Weight=53.40 Kg
- Density=1977.78Kg/m^3

Sl. No	Days of Curing	Load (P) KN	Area (A) m^2	Compressive Strength (F=P/A) KN/ m^2	Average Compressive Strength KN/ m^2
1	7	159.00	0.09	1766.67	1761.12
2		158.00	0.09	1755.56	
1	14	178.50	0.09	1983.33	1972.22
2		176.50	0.09	1961.11	
1	28	188.00	0.09	2088.89	2102.78
2		190.50	0.09	2116.67	

Table 9: Compressive Strength of Cubes with Vertical Arrangement of Bootle Bricks [C]

d) Compressive Strength of Cubes with Conventional Bricks [D]

- Length=0.3 m
- Breadth=0.3 m
- Height=0.3m
- Area= 0.09m^2
- Volume=0.027 m^3
- Weight=53.40Kg
- Density=1977.78Kg/m^3

Sl. No	Days of Curing	Load (P) KN	Area (A) m^2	Compressive Strength (F=P/A) KN/m^2	Average Compressive Strength KN/m^2
1	7	150.50	0.09	1672.22	1666.67
2		149.50	0.09	1661.11	
1	14	174.30	0.09	1936.67	1907.23
2		169.00	0.09	1877.78	
1	28	182.50	0.09	2027.78	2030.56
2		183.00	0.09	2033.33	

Table 10: Compressive Strength of Cubes with Conventional Bricks [D]

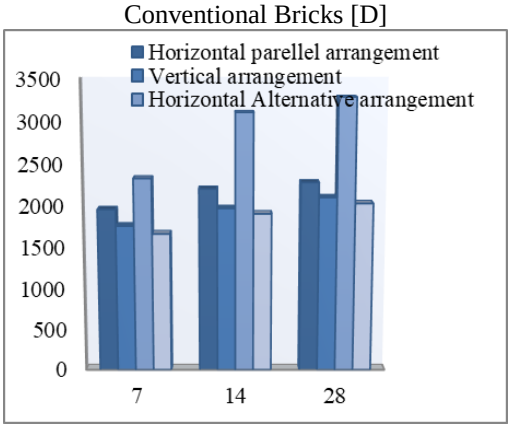

Fig. 10: Comparison of Compression strength

C. Fire Resistance Test Results

When a fire jet of 1200°C is made to impact over one surface for continuous 4 hours, the temperature transferred to other face will only be 55°C and no cracks were found except few minor cracks on testing face. Hence the specimen is said to have fire and heat resisting property.

Fig. 11: Cracks After Testing

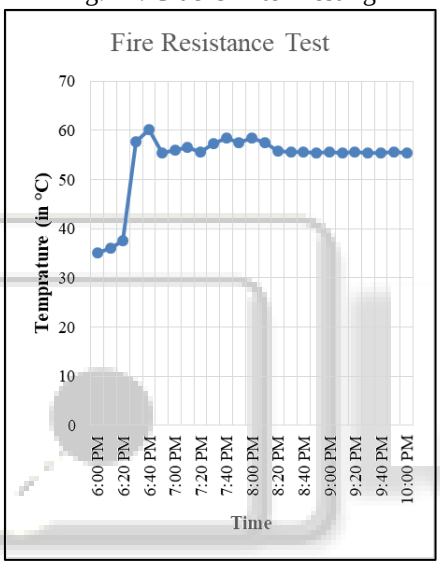

Fig. 12: FRT Graph

D. Freezing and Thawing Test Results

When specimen is subjected to freezing and thawing test, no considerable changes were seen and weight loss was found to be less than 1% therefore it is said to withstand freezing and thawing effect.

VII. CONCLUSION

- When PET bottles were filled with filling materials and tested for compression strength, the bottle completely filled with soil gives more strength than any others. Soil is easily available & is cheaper than any other filling materials; therefore the SOIL is considered to be the best filling material.
- The PET bottles are found to give more compressive strength (12.86MPa) than the conventional bricks (3.5MPa) by 3.6 times
- When cubes prepared with different pattern of bottles arrangement, cured for 7,14 & 28 days and tested for compression strength, the cube with Horizontal Alternative Pattern of Bottles Arrangement is found to bear mare compressive strength than others, therefore it is concluded to be the best pattern for bottles arrangement. The same test is conducted on cube of conventional bricks from the results it can be known that PET bottles cubes will gives more strength than the brick cubes.
- 7, 14 and 28 days split tensile strength of cylinders is found to be 0.56, 0.75, & 0.98 N/mm2 respectively
- 7, 14 and 28 days flexural strength of beams is found to be 2.34, 3.56 & 5.00 N/mm2 respectively.
- The PET bottle walls can resist fire and heating effect and gives thermal comfort to users
- The PET bottle bricks can resist freezing and thawing effect
- The structure(park bench) constructed with PET bottle technique saves the cost up to 40 to 45 %

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