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USE OF PLASTIC BOTTLE AS LOW COST BUILDING MATERIAL: A SUSTAINBLE MATERIAL

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Abstract: One of the main problems facing conventional building construction practices is high cost of building construction. High cost of construction materials discourages construction of houses particularly for people living below the poverty line. On the other hand, growth of cities has led to an increase in urban waste especially non-biodegradable wastes like plastics. A possible approach to solve this multifaceted problem is to use some part of urban waste for building construction. Plastic bottles which are an urban menace are non-biodegradable. This property lends them fitness to be used as a building material. This work intends to investigate the application of plastic bottles as one of the urban wastage in buildings construction and that how it can lead to sustainable development. At the end, it concluded that in different factors such as time of execution, cost, load capacity, flexibility, reducing waste and energy efficiency, plastic bottles can be more effective compared to some conventional building materials such as brick, concrete and ceramic block.

IndexTerms - Plastic Bottle, Urban Waste, Sustainable Material, Plastic.

1.Introduction

Plastics are typically organic polymers containing long chains of carbon, but they often contain other substances. Theyare usually synthetic, most commonly derived from petrochemicals. Due to their relatively low cost, ease of manufacture, versatility, and imperviousness to water, plastics are used in an enormous and expanding range of products, from paper clips to spaceships. They have already displaced many traditional materials.

2.Properties

Plastics are:

Low cost material: Compared to alternatives like wood and metals, plastics are cheaper to produce as the raw material required for production of plastics is a byproduct of petroleum refining and is therefore easily available.

Easy to manufacture: Plastics can be molded using modern manufacturing methods like injection molding, blow molding etc., which makes production of plastic objects faster and moreefficient.

Light in weight: With density around 1.38g/cu cm, plasticsare lighter than other materials like metals (2.7 to 7.5 g/cu cm), glass (2.4 – 2.8 g/cu cm), concrete (2.4 g/cu cm) or bricks (2 g/cu cm).

Impervious to water: Plastics are hydrophobic materials. The fact that plastics are impervious to water makes them suitable to carry water in the form of plastic bottles.

Inert to chemical agent: Most plastic is chemically inert and will not react chemically with other substances. One can store alcohol, soap, water, acid or gasoline in a plastic container without dissolving the container itself.

Non Bio-Degradable: Plastics cannot be easily decomposed by micro-organisms and take around 1000 years to degrade naturally. Because of this property of plastics, they have longer shelf lives and are therefore most commonly used for packaging.

Types of plastics:
Plastics are of different types:
PETE or PET (polyethylene terephthalate) - used for most water and soda bottles. The ingredients include resins made from methane, xylene and ethylene combined with the chemical ethylene glycol and other chemicals. These have flame retardants and UV stabilizersadded.
HDPE (high density polyethylene) - used for cloudy milk and water jugs and opaque food bottles. Resins made from ethylene and propylene resins and have flame retardants added. When burned these release formaldehyde and dioxin if chlorine was used duringmanufacturing.
PVC or V (Polyvinyl chloride) - used in some cling wrap, soft beverage bottles, plastic containers, plumbing pipes, children’s toys, vinyl windows, shower curtains, shades and blinds and many other items. They create toxic by-products when burned such as PCB’s and dioxins. Made from petroleum resins and have flame retardantsadded.
LDPE (low density polyethylene) - used in plastic grocery bags, plastic wrap, bubble wrap, drycleaningbags, andflexiblelids.ResinsmadefromethyleneandpropyleneresinsandhaveAtomic Mass Unit flame retardants added. When burned these release formaldehyde and dioxin if chlorine was used during manufacturing.
PP (polypropylene)- used in yogurt cups, some baby bottles, screw-on caps, toys, drinking straws. Resins made from ethylene and propylene resins and have flame retardants added. When burned these release formaldehyde and dioxin if chlorine was used during manufacturing.
PS (polystyrene)- used in egg cartons, foam meat rays, clear take out containers, plastic cutlery, toys, cups, CD containers. Resins made from ethylene and propylene resins and have flame retardants added. When burned they release styrene and poly-aromatic hydrocarbons.
Other (usually polycarbonate) - used in 5 gallon water bottles, some baby bottles, and lining of metal food cans. They create toxic by-products when burned such as PCB’s and dioxins. Made from petroleum resins and have flame retardants added.

Code	Name	Common Use	Recycle Rate	Recommendation
1	PET Polyethylene Terephthalate	Plastic bottles (soft drink, single-use water bottles, sport drinks), food jars, cosmetic containers.	23%	Be careful with products labeled No. 1. Designed for single use only. Extended use increases risk of leaching and bacterial growth.
2	HDPE High density polyethylene	Grocery Bags, detergent bottles, milk and juice jugs.	27%	Appears to be Safe
3	PVC Polyvinyl chloride	Garden hose, cable sheathing, window frames, blister packs, blood bags, meat wrap.	< 1%	Avoid Nicknamed the Poison Plastic, contains many dangerous toxins.
4	LDPE Low density Polyethylene	Heavy duty bags, drycleaning bags, bread bags, squeezable bottles, plastic food wrap.	< 1%	Appears to be Safe
5	PP Polypropylene	Medicine bottles, cereal liners, packing tape, straws, potato chip bags.	3 %	Appears to be Safe
6	PS Polystyrene	CD and video cases, plastic cutlery, foam packaging, egg cartons.	< 1%	Avoid May leach styrene, a possible human carcinogen. May be a hormone disruptor.
7	Other PC Polycarbonate	Baby bottles, water cooler bottles, car parts	< 1%	Caution Concern with leaching of Bisphenol A which appears to cause chromosonal damage.

TABLE 1: Different types of Plastics, their common use and recycle rates

3. Properties of Plastics are:
i) Low cost materials
ii) Easy to manufacture
iii) Light in weight
iv) Impervious to water
v) Chemically inert
vi) Non Bio-degradable

Low cost material: Compared to alternatives like wood and metals, plastics are cheaper to produce as the raw material required for production of plastics is a byproduct of petroleum refining and is therefore easily available.
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Environmental concerns

Plastics are durable and degrade very slowly; the chemical bonds that make plastics so durable make them equally resistant to natural processes of degradation. Since the 1950s, one billion tons of plastichave been discarded and may persist for hundreds or even thousands of years. Serious environmental threats from plastic include the increasing presence of micro plastics in the marine food chain along with the many other highly toxic chemical pollutants that plastic attracts and concentrates, and larger fragmented pieces of plastic called nurdles. In the 1960s the latter were observed in the guts of seabirds, and since then have been found in increasing concentration. In 2009, it was estimated that 10% of modern waste was plastics, although estimates vary according to region. Meanwhile, 50-80% of debris in marine areas is plastic.

Climate change

The effect of plastics on global warming is mixed. Plastics are generally made from petroleum. If the plastic is incinerated, it increases carbon emissions; if it is placed in a landfill, it becomes a carbon sink although biodegradable plastics have caused methane emissions. Due to the lightness of plastic versus glass or metal, plastic may reduce energy consumption. For example, packaging beverages in PET plastic rather than glass or metal is estimated to save 52% in transportation energy.

Incineration of plastics

Uncontrolled incineration of plastic produces polychlorinated di-benzo-p-dioxins, a carcinogen (cancer causing chemical).The problem occurs as the heat content of the waste stream varies.Open- air burning of plastic occurs at lower temperatures, and normally releases such toxic fumes.

USE OF PLASTIC BOTTLES IN CONSTRUCTION

Bridging the gap

With increasing population, the demand for housing units and other building types is increasing day by day. Rising price of fossil fuels coupled with rising inflation make the prices of building materials out of the reach of a large partof Indian population. Thus though there is a huge demand for housing units and thus building materials

While an increasing demand for housing units is posing a challenge to the nations of the world, increasing plastic waste has become a big ecological concern for the world. Non-biodegradability which makes plastic bottles an ecological menace may prove to be a boon thus making plastic bottles a suitable material for construction industry.

Plastic has many other properties like light weight, transparency, heat and sound insulation, durability, workability etc., which make it ideal for use in building construction. If proper construction techniques are developed to use plastic waste in construction, they would help in bridging the gap between demand for housing units and supply of raw material (plastic bottles)

Such attempts to use plastic bottles to meet local building demands were studied and documented in the next section of this report.

Table 2: Cost comparison of walls made from bricks and plastic bottles

COST OF 1 SQ MT OF WALLS MADE OF PLASTIC BOTTLE AND BRICKS						
		Empty Plastic bottles		**Plastic Bottles filled with sand**		
	Unit	**Plastic Bottle**	**Plastic bottle arrangement in traingular fashion**	**Plastic Bottle**	**Plastic bottle arrangement in traingular fashion**	**Brick (200 mm thick wall)***
Dimensions						
Length	mm	215	215	215	215	190
Breadth	mm	62	62	62	62	90
Height	mm	-	-	-	-	40
Volume	ml	500	500	500	500	-
Volume	cu mm	500000	500000	500000	500000	684000
Mortar calculations						
Thickness of mortar	mm	20	20	20	20	10
Volume of mortar per unit	cu mm	945660	751978	945660	751978	316000
Number of units per sq m of wall	no.	148.72	171.73	148.72	171.73	200
Total Volume of mortar per sq m of wall	cu mm	140639500.3	129135891	140639500.3	129135891	63200000
	cu m	0.14	0.13	0.14	0.13	0.06
Rate of mortar per cu m		694.59	694.59	694.59	694.59	694.59
Cost of mortar for 1 sq m of wall		97.69	89.70	97.69	89.70	43.90
Cost of each unit (bottle or		0.3	0.3	0.3	0.3	2

brick)						
Total cost of bottle/brick for 1 sq m of wall	INR	44.62	51.52	44.62	51.52	400
Volume of sand per bottle	cu mm			500000.00	500000.00	
Total volume of sand filled in bottle	cu mm			74360499.70	85864109.04	
Total volume of sand filled in bottle	cu ft			2.63	3.03	
Cost of sand per cu ft	INR/C ft			12.00	12.00	
Cost of sand filled for 1 sq mtr of wall	INR			31.51	36.38	
Total cost of 1sq mt wall	**INR**	**142.30**	**141.21**	**173.81**	**177.60**	**443.90**
Mason hire charges						
Time taken for construction		2	2	2.00	2	1.52
Mason's wage for 8 hrs		150	150	150	150	150
Mason hire charge		37.5	37.5	37.5	37.5	28.54

4.DESIGN IDEAS

i) Design Approach
ii) Identify Building Elements
iii) Identify major factors that influence the design of
iv) Evolve design to address these factors

A problem solving approach incorporating learning from the case studies for generating design ideas was followed as described below.
This approach helps in ensuring that all the basic requirements of a building component are considered in their design.

4.1 Design Element: Beam

Factors That Influence design:
A beam is subjected to flexural loads. This means that while one face of the beam bears compressive stress, the other face bears tensile stress. Neutral axis is the axis or zone where stresses in the beam are zero. In a typical RCC beam, compressive stresses are borne by concrete whereas steel reinforcement bars bear the tensile stress.Apart from flexural loads, beams are also subjected to shear forces. To take care of shear forces, reinforcement stirrups are provided in an RCC design.
Design Evolution It must be understood that though plastic bottles filled with sand or clay behave well under compressive stresses, an array of such plastic bottles can not bear flexural loads. Therefore we would need other materials to bear the tensile forces in a beam. Steel is the most common and preferred material for bearing tensile stress. However steel must be encased in concrete to provide it protection from corrosion.
It is worth noting that there are no stresses at the neutral axis in a beam. This means that theoretically if no material (steel or concrete) is present at the neutral axis, the beam will still perform its function well.
Therefore in an innovative beam design using plastic bottle, plastic bottle can be placed inside an RCC beam along the neutral axis as shown in the figure.

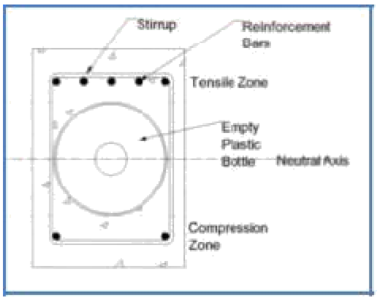
Advantages

The advantages of using plastic bottle in an RCC beam are

1. Light weight construction: An amount of concrete equivalent to the volume of plastic bottle is saved. This reduces the weight of the beam without affecting its performance.
2. Lower cost. By removing concrete from the neutral axis, cost of the displaced concrete is saved.
3. By carefully removing concrete cover between stirrups, faces of transparent plastic bottles can be exposed which will allow light to pass through the bottle and illuminate the built space.

Challenges

If bottles are too long, compaction of concrete may not be proper leading to honeycombing in concrete. However this can be avoided by using a needle vibrator or by using concrete with a higher slump.
After concrete sets up, it will be difficult to locate stirrups and chip off concrete to expose surface of plastic bottle. However this can be overcome by either marking location of stirrups on the formwork before concreting or by using a magnet to locate stirrups hidden inside concrete surface.



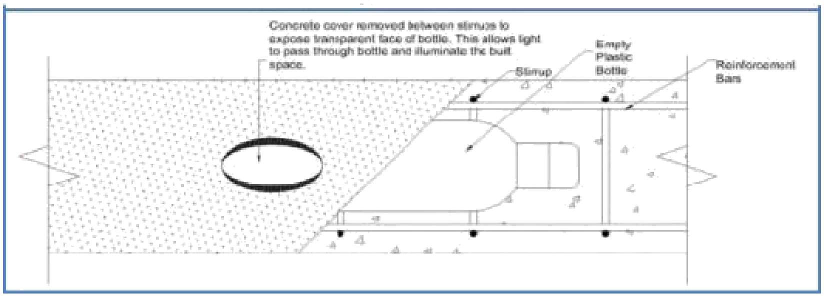


Figure1: Transverse section of a typical beam made with plastic bottles
Figure2: Longitudinal section of a typical beam made with plastic bottles.

4.2 Design Element: Column with Foundations

Factors That Influence design:

A column is primarily subjected to compressive loads. If a column is slender, it may experience buckling due to the compressive forces. Additionally lateral loads may induce shear stress in the column. In addition to these columns also resist bending moments at their junction with beams, slabs and footings.

Design Evolution

Plastic bottles filled with sand or clay can take good amount of compressive stress and are therefore ideal for making columns. Buckling can be avoided either by:

(i) Making columns thick enough to reduce their slenderness**.**

(ii) Wrapping the columns with a material that can bear tensile forces along its surface. Automobile rubber tires which are reinforced with steel are suitable for this purpose.

(iii) Bending moments can be resisted by using reinforcement bars at the edges of the columns or by fixing wooden or MS steel brackets.

Figure 3: Sand filled inside plastic bottle and compacted.

Construction technique:

Foundation construction

i) Fill plastic bottles with sand, seal and then paste them with a mixture made of earth, clay, sawdust and a little cement to provide additional strength and durability.

ii) Dig a cylindrical pit about 60cm in depth. The radius should be at least 10cm more than the length of the bottle that is being used for constructing the pillar.

iii) Make a cement bed (about 4cm thickness)in the pit. Insert a long iron/steel rod at the center. Tie a long nylon thread to the rod.

iv) Lay 10 or 11 bottles around this rod in the following manner.

a. First lay a bottle on the bed such that the bottle is radially oriented towards the center. (i.e., the cap is oriented towards the rod).

b. Take the thread and make a knot around the neck of the bottle just laid.

c. Put the next bottle in similar way such that the caps of the 2 bottles touch each other. Make a knotaround the 2nd bottle Figure 4: Bottles arranged in radial fashion to form a segment of column

d. Repeat the steps until all the 11 bottles are laid. First course of bottles is thus made.

e. Fill in the gaps between the bottles with rubble and cement.

f. Make the next bed and continue this process till the entire pit is filled. Foundation is complete.

Figure 5: Brick bats help in keeping the bottles in place

Column construction

a) Leave it for a few hoursso that the cement will solidify.

After foundation is made for all pillars, pillars can be built.

b) Lay the bottles in the same fashion as the foundation.

c) Put broken bricks or other construction wastes between the bottles

d) so that they don't move.

Plaster pillar with cement. This pillar is many times stronger much

Figure 6: Pillar is constructed

e) cheaper than an ordinary pillar made with bricks. For long and slender columns, the array ofbottles can be made inside automobile tire.

f) For this the sides of tire need to be cut and removed. Tire would

g) provide jacketing to the column and prevent buckling.

Figure 7: Column with plastered surface

4.3 Design Element: Floor

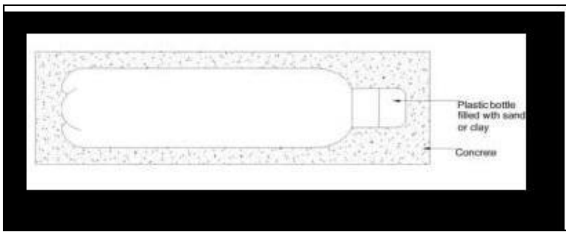
Factors That Influence design:

Floor takes all the live loads and some of the dead loads in a building. Live loads are mostly dynamic in nature. Live loads as well as most of the dead loads exert punching shear on the floor. Other important characteristic of good flooring material is its high modulus of elasticity so that the floor does not sink when point loads are applied on it. For intermediate floors (floors other than ground floor) live and dead loads cause flexure in the floor slab.

Design Evolution

Intermediate floors and roof floors can be constructed with plastic bottles in the similar fashion as jack arch roof is constructed with bricks. However, these floors may not be suitable for taking loads to which intermediate floors are usually subjected. This is because plastic bottles are round in shape and consequently friction between two plastic bottles is not strong enough to hold them in place in a jack arch roof if subjected to heavy loads. This problem can be overcome by encasing bottle filled with clay in concrete and making bricks out of them. Mud bricks can also be made from plastic bottles but they can be baked in kiln as plastic may melt in the high temperatures in the kiln.

Advantage: Rectangular profile and high coefficient of friction between surfaces of concrete will make stronger floor slab compared to plastic bottles alone.



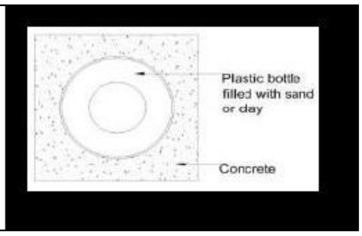


Figure 8: Concrete block made with plastic bottle Figure 9: Concrete block made with plastic bottle

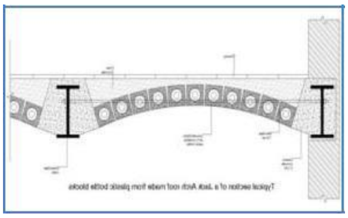


Figure 10: Jack arch roof made with plastic bottle blocks - Section
Figure 11: Floor being constructed from plastic bottle Figure 12: Tiles covering floor made from plastic bottles.

For ground floor made of plastic bottle, the role of the floor is limited to transferring loads to the ground. This can be achieved by leveling the ground surface and placing sand filled plastic bottles vertically and filling the gaps with sand. The sand is then compacted and cement slurry is laid to achievesmooth finish as shown in the figure below.

4.4Design Element: Wall

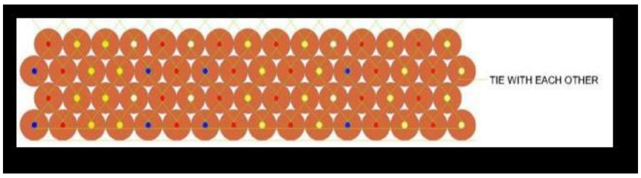


Figure 13: Typical arrangement of plastic bottles in a wall

Factors That Influence design:

While acoustics is a major concern for partition walls, thermal insulation and weather resistance become important considerations for external walls. Compressive strength is yet another attribute which becomes important for load bearing walls.

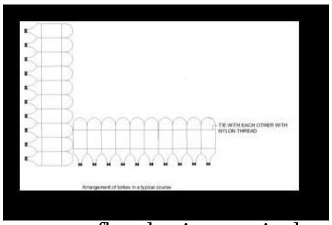
Design Evolution

Plastic bottles are non-biodegradable and therefore weatherproof to a great extent. They are least effected by sunlight and water. Also empty plastic bottles (filled with air) are good thermal and acoustic insulators. They can be easily bonded with cement mortar like clay bricks. The design therefore involves simply laying plastic bottles in courses as described below and bonding them together using cement mortar and tying their necks using nylon strings as shown in the figure.

Construction technique

As seen in case studies, there are several ways to construct a wall out of plastic bottles. Common technique using cement mortar and sand filled plastic bottles is shown below.

1. Dig a pit 600mm deep and approximately 500 mm wide along the length of the wall.
2. Lay a 40mm thick bed of Plain Cement concrete at the bottom of the pit to level the surface.
3. Lay a layer of mortar approximately 40 mm thick and place sand filled plastic bottles in a manner that the longer sides of the bottles are normal to the plane of the wall.



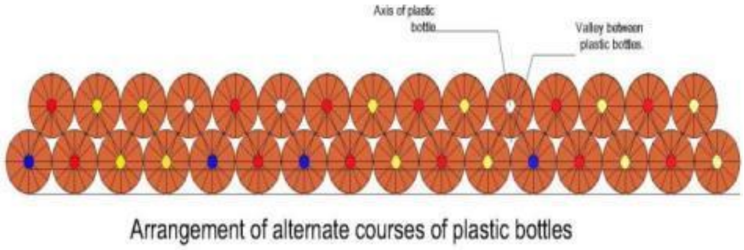


Figure14: Arrangement ofbottles in a typical course
Figure 15: Arrangement of alternate courses of plastic bottled in a wall.

Tie the bottles with a nylon string so that they are held together in place.

4. Lay a layer of mortar around 30 mm thick and place the next course of plastic bottles in such a way that the axes of bottles in the second course align with the valley between bottles in first course.
5. Lay courses of bottles in this fashion till desired height of wall is achieved.
6. Tie necks of bottles with nylon strings in alternate courses in a zigzag fashion as shown in the figure.
7. Plaster the surface of wall to achieve a smoother finish.

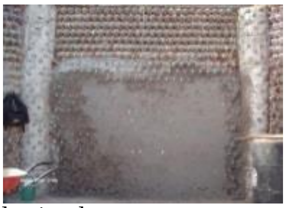


Figure 16: Plastic bottle necks tied together to keep bottles in place
Figure 17: Wall being plastered

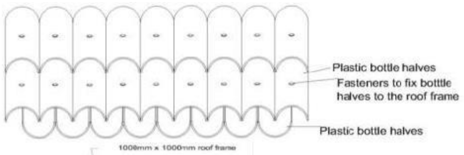
4.5 Design Element: Roof

Factors That Influence design:

Roof is a building element which always separates exterior from the interior. It therefore faces all the vagaries of nature in the form of sunlight, heat, wind, rains and sometimes snow. Attack by biological agents like moss, algae etc., on roof is also common. Plastic being a non-biodegradable material resists most of these factors well. However, plastics being light in weight cannot survive wind loads without proper construction detailing.

Construction technique:

The technique of constructing roof using plastic bottles involves removal of neck and base of bottle and cutting it into two equal halves.The half cylinders thus obtained arearranged in the fashion as shown in the diagram. These can then be fixed either to the roof frame with 300mm x 300mm grid size or to chicken mesh which can then in turn be fixed to a roof frame of bigger size.



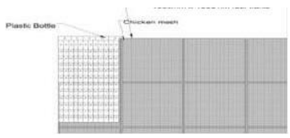


Figure 18: Arrangement of plastic bottle halves to form roof covering.
Figure 19: Details for fixing plastic bottle halves to roof

5. Conclusion

It can be concluded that it is possible and in fact economical to construct buildings with plastic bottles in almost all kinds of settings, be they rural or urban. Plastic bottles can be used for construction in any kind of climate from hot humid subtropical to hot and arid settings. They can be easily used in structural as well as non-structural elements in a low rise building and non-structural elements in a high rise building.

Use of plastic bottles in construction makes a huge environmental impact by avoiding them from being disposed in rivers and seas. Moreover, it also saves precious fossil fuels which are burnt to produce other construction materials.

The thermal performance of buildings made from plastic bottles helps in making the shelter habitable as seen in case of Nigerian houses.

Looking at the rate at which plastic bottles are produced in the world today, it is a promising material that can solve the housing problem across the world by reducing cost of construction. Also the technology required to construct buildings from plastic bottles is very simple. Construction can be carried out with the help of local semi-skilled labor which thus helps in providing more employment to local workforce.

Acknowledgement: Expression of feelings by words makes them less significant when it comes to making statement of gratitude".

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