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Effectiveness of waste plastic bottles as construction material in Rohingya displacement camps

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ABSTRACT

Bangladesh is currently hosting about 1.30 million Rohingya people in its southeastern region, the most persecuted ethnic minority of the world. The present semi structured living shelters mostly made of bamboo and plastic sheets, are not resistant to environmental disasters like- monsoon rain, cyclone, mudslide, and prone to cause vector borne diseases. This study developed *plastic brick*, where a waste 500 mL polyethylene terephthalate bottle was utilized which was manually compacted with air dried fine sand as the filler material. Cardboard frame was used to shape the brick like a normal clay brick. The filled bottle was placed at the central portion of the frame where hand blended mortar was used to cover the whole frame up to the marked dimensions. The prepared brick samples were subjected to compression test and the average strength obtained was 2.88 and 3.29 N/mm^2 for 14- and 28-day crushing age samples, respectively and demonstrated a high potential for the bricks to be used in construction works. The hazard due to environmental disasters in the displacement camps along with managing plastic waste, utilization of plastic brick can be a low cost, useful, and sustainable way towards a safe and rigid living structure.

1. Introduction

Rohingya is a generic term referring to the Sunni Muslim inhabitants of Arakan, the historical name of a Myanmar border region. In 1989, this region has officially designated as the Rakhine State (Kiragu et al., 2011). Historically, the Rohingyas are an ethnolinguistic and religious minority, have been living in Rakhine state for centuries (Uddin, 2019). Majority of them are not counted to be inhabitants by the Government of Myanmar, which claims that Rohingyas are originally from Bangladesh (Wali et al., 2018) and considers them as “illegal immigrants” (Azad and Jasmin, 2013). (Uddin, 2019) reported that a huge influx of the Rohingya people fled to Bangladesh to avert away the unprecedented atrocities (i.e., harassment, violence, arrest, persecution, and expulsion to neighboring countries) committed by the Myanmar Military Forces in 2017. The Rohingya people are one of the largest groups of stateless refugees in the globe, accounting to one in seven of the global population of stateless people (Wali et al., 2018).

Bangladesh has been the preferred terminus for the majority of refuge seeking Rohingyas due to the early recognition of their humanitarian needs alongside with proximity and matching religion (Milton et al., 2017). Bangladesh has hosted the majority of Rohingya refugees in three major arrivals occurred during the years 1977-78, 1991-92, and 2016-17 (Wali et al., 2018). In August 2017, the Myanmar Military began unprecedented campaign that forced more than 750,000 Rohingya people to cross the border in Bangladesh and summed up with the previous 550,000 people, Bangladesh is now hosting about 1.30 million Rohingyas in its southeastern part (Uddin, 2019). With more than 20 years of continuous camp settlements, absence of a specific refugee policy, and politicization of the refugee situation, integration of Rohingyas has always been a challenging task for Bangladesh (Milton et al., 2017). Whether residing in registered refugee camps or local community areas, the Rohingyas have been subjected to poor living conditions indicated by insufficient access to basic needs (i.e., food, shelter, health, WASH, etc.), exposure to violence, restricted movement, local enmity, and discrimination in different forms (Wali et al., 2018).

Rohingya refugees in Bangladesh are now completely dependent on humanitarian aid for basic needs, and displacement camps provide only temporary infrastructure to ensure safety, security, and basic needs (Landry and Tupetz, 2018). (Landry and Tupetz, 2018) recorded feeble access to health services, meagre shelters, whereas (Ahmed et al., 2018)

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listed food and nutritional insecurity, poor hygiene, hazardous environment for women and children, unsafe housing and lack of meaningful occupation, are the major confronts of life in the Rohingya displacement camps. Fig. 1 depicts the number of Rohingya population and their settlement in different camps along the Myanmar and Bangladesh border region. Chittagong and Cox's Bazar are prone to natural disasters, where most of the refugee settlements are currently located (Chan et al., 2018). The Rohingya people are housed in semi-permanent structures which are overcrowded and in serious need of repair (UNHCR, 2007). The risk to the refugee population is very high due to the camps' location in low-lying areas that are mostly vulnerable to flash flooding (Ahmed et al., 2018), landslide and flooding hazard due to the cutting of hilly

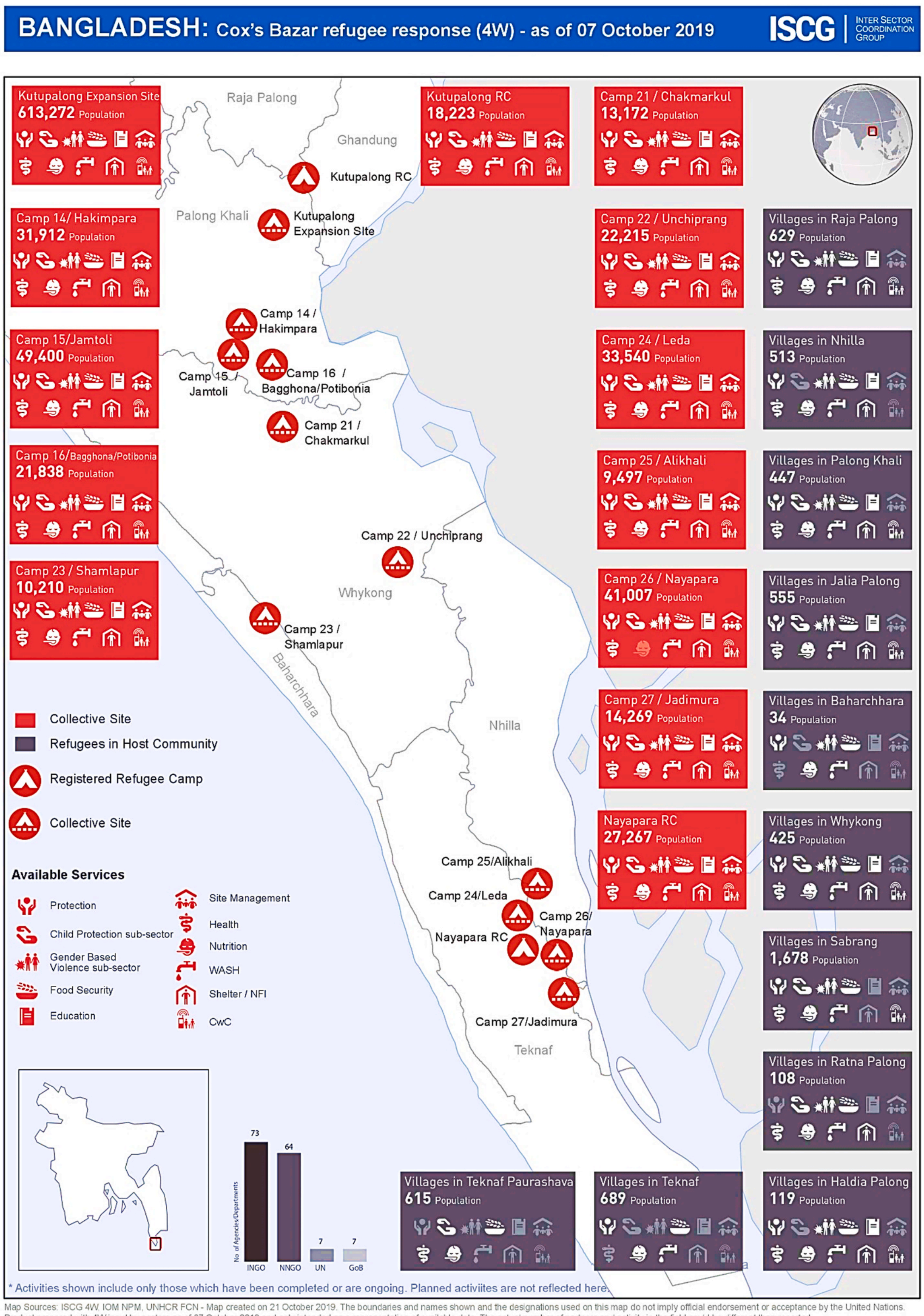

Fig. 1. Map showing Rohingya refugees' settlement in different camps along with the Bangladesh and Myanmar border region, Cox's Bazar and Teknaf (ISCG, 2019).

areas and deforestation, to build makeshift shelters (HPN, 2018). For some instance, air impermeable plastic sheets are used in shelter construction (Chan et al., 2018), but mostly they are built of bamboo and thatch which are not resilient against the heavy rains or wind, and in need of constant repair (UNHCR, 2007). Some refugees reportedly have used bamboo material from latrines or bathing cubicles to repair their sheds (UNHCR, 2007). (Ahmed et al., 2018) reported that refugee shelters of the camps are highly vulnerable towards rainfall induced landslides during monsoon season (from May to September), flash flooding, and cyclones which are also reported by the studies from (Chan et al., 2018) and (HPN, 2018). Cox's Bazar has been hit by one cyclone annually and the Cyclone Mora in May 2017, killed 6 people and injured 218, damaged at least 70% of shelters in makeshift settlements, and around 70–80% of latrines (ACAPS, 2017). Fig. 2 illustrates the recent tragic accident of a health care center, caused by mudslide after a heavy rainfall event in Kutupalong-Balukhali extension. It is certain that any occurrence of the prevailing environmental hazards would intensely affect the current humanitarian support and put severe challenges to meet the health and living shelters requirement in this region (Ahmed et al., 2018).

For more than 50 years, plastics have played a key role in fast-forwarding the standard lives of human beings around the globe (Sharuddin et al., 2016). Many new innovations have only been possible to the sectors including - construction, packaging, industrial applications, medical and health care facilities, and others because of plastic (Siddique et al., 2008). But due to its excessive long biodegradation period in nature, plastic waste has now become a global issue as unregulated disposal of plastic waste causes harmful effects on the environment (Ismail and AL-Hashmi, 2008), such as air, land, and marine pollution, damaging the ecosystem, adverse effects on aquatic species, and so on (Verma et al., 2016). Fig. 3 categorically shows the harsh effects (both physical and chemical) of plastic waste on physical wellbeing. In many parts of the world to avert away the damaging consequences of plastic waste, *Eco brick or Plastic brick* was developed to construct shelters for the people having indigent living condition and particularly, in low-income societies, where a waste polyethylene terephthalate (PET) plastic bottle is recycled and reused as building material. At present, plastic bottles are ubiquitous, hoarding a significant portion of waste and greenhouse gases around the world (BTI, 2019), with no exception for Bangladesh (Haque, 2019). Reuse is better than recycling, and PET bottles are easy to reuse in building projects with the following benefits (BTI, 2019) -

Fig. 2. After a night of heavy rainfall event, a health care center was destroyed in Kutupalong-Balukhali camp - the largest refugee camp of the world - due to a rainfall induced landslide (HPN, 2018).

- Reduces waste.
- Locally sourced.
- Preserves natural resources.
- Lowers carbon footprint.
- Low cost.
- Low tech and easy to use.

The aim of this present study is to analyze the efficiency and suitability of integrating plastic brick as the building material in constructing firm and secure shelters for the Rohingya people in their displaced settlements where a 500 mL waste PET plastic bottle has been utilized in preparing each brick samples and subjected for the compressive strength test.

2. Plastic pollution scenario in Bangladesh

Plastic is an immensely popular and widely used material around the globe from its invention in 1907. Plastics are the major environmental problem due to its non-biodegradable nature, the materials used in its production (hydrocarbon molecules derived from the refining oil and natural gas) and the challenges behind correctly dumping its waste (EDN, 2018a). Since 2000, the world has produced as much plastic as all the preceding years combined and 75% of all plastic ever produced is waste. Due to the mismanagement of this plastic waste, one third of it is projected to have appeared in nature as land, freshwater, or marine pollution (Advisors et al., 2019). The rate at which plastic waste is generated as of 2015, the total was estimated to be around 6300 million metric tons and of that 79% accummulates in landfills and the environment, and made its way to the ocean. In ocean, plastic continually breaks apart and gets smaller which is ingested by the marine species and other organisms (EDN, 2018b). By 2050, it is estimated that there will be more plastic in the world's oceans than fish (EDN, 2018a, b). Macro, micro and nano plastics have polluted the earth's soil, freshwater and oceans (Advisors et al., 2019), and such pollution kills wildlife, damages natural ecosystems, and contributes to climate change (UNEP, 2016).

Mismanaged waste is a direct cause of plastic pollution and it is greatest in low- and middle-income countries because of inadequate waste management infrastructure. These countries have limited recycling capacity and fewer effective end-of-life waste management systems, plastic waste ends up in inadequately controlled landfills or open dumping zones (Advisors et al., 2019). In 2016, over 76% of total plastic waste in low-income countries was mismanaged (Kaza et al., 2018).

Bangladesh is ranked 10th as the major contributor to the plastic pollution out of 20 countries, ranked by mass mismanaged plastic waste in the globe (EDN, 2018a). A total 89% of waste is not effectively managed, out of which 8% of waste is plastic (see Table 1), an equivalent to 790,000 tons in a year with a generation rate of 0.43 kg per capita per day (Jambeck et al., 2015).

Most of the plastic industries in Bangladesh are based on the capital city, Dhaka and some in the major port city, Chittagong, and few of them are in Narayanganj, adjacent to the capital city (Islam, 2011). The recycling practices in Bangladesh are still in the preliminary stage and people find it simpler to dump the plastic waste recklessly near the roadside (see Fig. 4), or in the river, or even in the seashore rather than

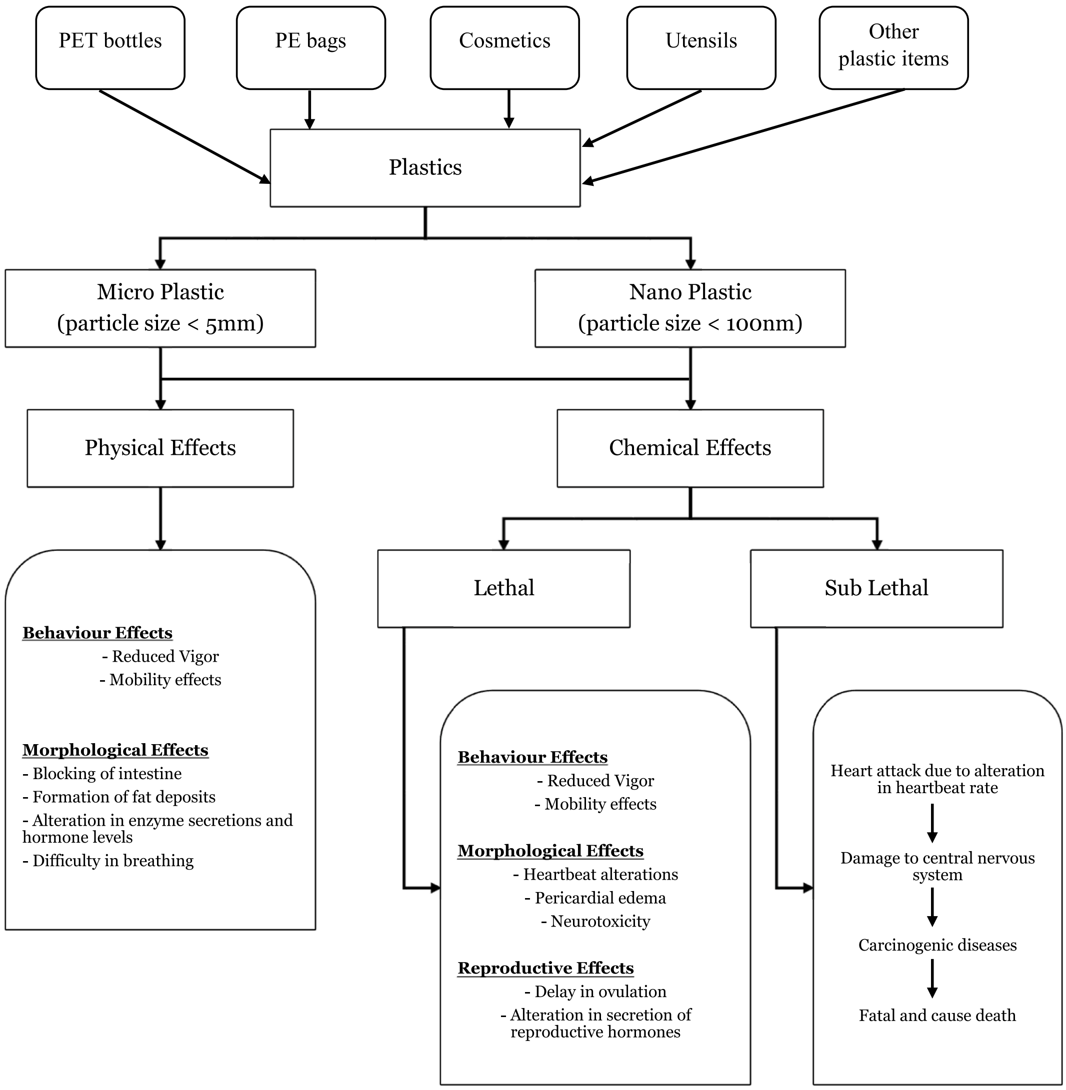

Fig. 3. Adverse impacts of plastic waste on physical health (Haque, 2019).

Table 1
Ten chief plastic polluter countries of the globe.

Rank	Country	Waste generation rate (kg/ppd)	% of plastic waste	Plastic waste (MMt/Year)	% of total mismanaged plastic waste
1.	China	1.10	11	8.82	27.7
2.	Indonesia	0.52	11	3.22	10.1
3.	Philippines	0.50	15	1.88	5.9
4.	Vietnam	0.79	13	1.83	5.8
5.	Sri lanka	5.1	7	1.59	5.0
6.	Thailand	1.2	12	1.03	3.2
7.	Egypt	1.37	13	0.97	3.0
8.	Malaysia	1.52	13	0.94	2.9
9.	Nigeria	0.79	13	0.85	2.7
10.	Bangladesh	0.43	8	0.79	2.5

ppd - persons per day; *MMt* - million metric tons. Source (Jambeck et al., 2015).

reusing through recycling (Mourshed et al., 2017).

There is no effective plastic waste management process due to the lack of available technologies, high operation and recycling cost (Mourshed et al., 2017), and a limited quantity of recyclable plastic materials for use (Advisors et al., 2019). These factors are the reason behind landfilling or discarding of plastic waste in the water bodies - channels, lakes, rivers, and ocean - which subsequently affects in the infertility of soil, contamination of surface water (Mourshed et al., 2017) and aquatic life to a greater level (EDN, 2018a). Moreover, open dumping trend of waste among the lay people causes adverse effects to the environment by the emission of greenhouse gases (Mourshed et al., 2017).

3. Concept of plastic brick and its efficiency

Recycling means turning waste materials into financial, environmental, and social resources (Afroz et al., 2017). It is the process where waste materials (which are recycleable) are utilized to explore their potential by reusing or turning it to useful materials. With considerations to a more environmental friendly future, utilization of PET waste plastic bottle for the production of bricks are being researched for their low cost and lightweight properties, and to be used as building materials. This procedure was developed in a manner to solve the constraints on managing the plastic waste, disposal site in both urban and rural areas, and the environmental degradation due to it (Wahid et al., 2015).

The idea of using waste PET plastic bottles in building construction was first initiated by German Architect - Andrias Froese - in South America during 2000-2001, where PET plastic bottles were installed within the walls along with mortars to shape a structure (i.e., houses, water tanks) as reported by (Safinia and Alkalbani, 2016). Mud, sand,

Fig. 4. A common practice of dumping plastic and other hazardous wastes in the streets and open drainage channels of urban areas in Bangladesh which creates problem of waterlogging and a potential breeding site for vector borne diseases (e.g., dengue) during monsoon period.

soil or landfill dirt were used as the filler content in these plastic bottles. The campaign till date has recovered and reused more than 300,000 PET bottles and used in more than 50 construction projects in Hondurus, Columbia and Bolivia. The technology was quickly adopted in different countries including Nigeria, South Africa, Norway, Philippines, and India (Muyen et al., 2016).

In 2004, the government of Nigeria established a plan to provide 8.0 million new homes - 5.0 million in urban and 3.0 milllion in rural areas - to meet the existing and future needs of its population (Pati et al., 2014). In comprisng this new plan, recycling of waste plastic bottles to use as construction material was involved due to its suitability for the hot Nigerian climate and to control the overgrowing concern over plastic pollution (Mokhtar et al., 2016). In Yelwa, a Nigerian village, thrown out PET plastic bottles were used successfully as construction material in building houses (Pati et al., 2014) and built houses are completely bullet proof as the place is known for violence (Mokhtar et al., 2016).

(Guzman and Munno, 2015) used polymer based bonding agent to mechanically mix waste sawdust collected from sawmills in Mexico and waste low-density polyethylene (LDPE) in preparing a WPC – wood plastic composite – brick. The design and validation of prepared WPC bricks were conducted through computer simulated modelling approach where the triangular vertical hole containing WPC bricks demonstrated sound absorption (acoustic) value of 29.9 dB but lower compressive strength value of 0.123 N/mm^2. Similar study was conducted by (Alaloul et al., 2020) where shredded waste PET plastic bottle was mixed with the polyurethane (PU) binder in order to prepare interlocking plastic brick. The prepared brick having mixed compositon of PET/PU with ratio 0.60/0.40 obtained an average compressive strength value of 4.30 MPa and found to be useful in constructing partition walls.

(Muyen et al., 2016) reported that, plastic brick made walls are better against earthquakes due to the compaction of filling material in the bottles and 20 times more load resistant than conventional bricks. This study utilized 1.0L waste PET plastic bottles filled with sand to prepare plastic bottle made cylinders. The obtained compressive strength (19.9 MPa) showed a better compatibility of using plastic bottle made cylinders against the commonly used concrete cylinders. Similarly, (Safinia and Alkalbani, 2016) utilized 8 hollow 500 mL PET plastic bottles in concrete blocks with dimensions (L x B x H) = (400 mm x 200 mm x 200 mm) where the maximum compressive strength was obtained for 28 day sample (10.20 MPa) but a lower strength for a 7 day sample (6.03 MPa).

(Pati et al., 2014) pointed out that, plastic brick made houses are bullet proof along with the strength to protect the built shelters from the hazardous effect of cyclones and other disasters. They also presented an example of a hospital building at West Bengal in India, where plastic bricks were utilized from the excavation level to the floors, strong against the hazardous effect of cyclones.

Most of the plastic brick based construction projects are social projects where communities work together to fulfill a common goal such as living structures, educational centers and recreational spaces (Antico et al., 2017). Besides (Antico et al., 2017) identified that communities, governmental and non-governmental organizations (NGOs) consider plastic brick as a potential recycling method to reduce plastic waste disposal volumes and a low cost construction material for social projects.

Brick manufacturing is one of the most polluting processes in Bangladesh which contributes about 23.30 Kt, 302 Kt, 15.50 Kt, 6 Kt and 1.80 MMt of $PM_{2.5}$, CO, SO_2, black carbon and CO_2 emissions every year, respectively to produce 3.50 billion bricks. Usage of intensive energy, inefficient technology, and coal and agricultural wastage as fuel have led to a higher mortaility and morbidity rate from poor air quality, water and soil pollution largely responsible for the manufacturing processes at brick kilns (~ 4500), located in major cities – Dhaka, Khulna, Chittagong and Rajshahi – of Bangladesh (Guttikunda et al., 2013). In view of the current pollution and public health crises associated with the plastic waste and brick manufacturing process, the present study considered the research needs to address these aspects and assessed the suitability of integrating 500 mL waste PET bottle in its full form to prepare a brick shaped plastic brick to substitute the commonly used clay brick as a valid construction material for the people in humanitarian needs. In contrast with the other studies, waste PET bottles have not been ever used in the mortar mixture in its full form and the prepared plastic bricks in the shape of a common clay brick. Moreover, the manufacturing process of a plastic brick with locally available material, plastic and cardboard waste, and human resource were the viable considerations embedded under the current study.

4. Materials and method

4.1. Materials

The materials used in this study are as following -

Cement: Portland cement (Type-1) was used in preparing the mortar mixture to cover up the plastic bottle and shape the plastic brick as like a normal clay brick for suitable use.

Fine Sand: Fine sand was used as the filler material in the plastic bottle and used to prepare the mortar mixture. The sand was air dried in the laboratory temperature of 25 °C (±2 °C) and fineness modulus (FM) calculated after the sieve analysis was 1.98 which implies that the average particle size is in between 0.15 and 0.30 mm.

Plastic Bottle: PET bottles are the most used material with a density of 1.38–1.39 g/cm^3 (Avio et al., 2017). A total eight 500 mL PET plastic bottles were used of different shapes and sizes as to check for the better compressive strength. These bottles with the sealing corks were chosen randomly from household and roadside dumped wastes as to keep the sole integrity of the study objective.

Cardboard Box: Along with the increment with the other wastes, paper and food wastes have contributed a lot in the solid waste stream in Bangladesh. In 2014, paper and food waste were about 7.22% and 75.64%, respectively (Enayetullah et al., 2014), which intrigued the study to incorporate cardboard as the framing material as it is one of the essential components in these two waste streams. Moreover, the focus of the study is to provide shelter alternatives to the Rohingya people which also motivate the study to incorporate locally available materials which can be reused and recycled to a valuable resource.

4.2. Waste PET bottle utilization and frame development

The plastic brick for this study was prepared by utilizing a 500 mL PET waste plastic bottle, utilizing sand as the filler material. At first the 500 mL bottles were washed properly with freshwater and dried before proceeding to the next step. After that, with the help of a funnel fine sand was poured in these sample bottles fully and compacted in three layers where each layer was compacted by 25 blows with a tamping bar. A general quality check was performed to improve the layers which were less compacted, minimizing any type of voids in the compaction.

Later, frames were assembled by utilizing cardboards which have been used to prepare each of the brick samples. The casing measurement was chosen as (L x B x H) = (9.5 in x 3.5 in x 3 in) = (241 mm x 88.9 mm x 76.2 mm). Cardboard was stiffened and severed according to the chosen mark dimensions and packing tape was assembled around the whole casing to bind it in the shape of a conventional clay brick. Followed by this procedure, each casing was prepared for the testing samples. Figs. 5 and 6 illustrate the sand filled PET bottle and cardboard frame used in this study to prepare *plastic brick* samples, respectively.

4.3. Mixing mortar and sample brick preparation

The cement-sand blend utilizing water was prepared with mortar proportion and water-cement proportion of 1:2, respectively. The mortar was hand mixed with 15 min of blending. After the blend was completed, a layer of 0.5 in was cast in the base of the cardboard frame. At that point, the plastic bottle compacted with sand was put in the center of the casing such that 0.5 in clear cover can be kept on the rest of the faces of the frame. After that, the mortar was poured in the frame up to the marked dimensions (see Fig. 7). After the completion of pouring mortar, the plastic brick was kept in the laboratory room temperature of 25 °C (±2 °C) for 24 h before unraveling it from the cardboard frame. A one-day period later the brick samples were brought out of the cardboard frame and submerged in fresh water for the curing purpose. A total 14 and 28 days of curing period were selected for the plastic brick samples, respectively (see Fig. 8).

Fig. 5. A sample 500 mL waste PET plastic bottle fully compacted with sand as the filler material and tightly sealed with a cork.

Fig. 6. Casing prepared by using a cardboard box with dimensions selected as (L x B x H = 9.5 in x 3.5 in x 3.0 in).

Fig. 7. Preparing a plastic brick sample with blended mortar cast in the cardboard frame and the PET plastic bottle set in the center.

4.4. Testing of compressive strength

Compressive strength is defined as the maximum compressive stress that a material is capable of withstanding without fracture (Mokhtar et al., 2016). From the prepared samples, three samples of 14-day and two samples of 28-day curing period were subjected to the compression test in the UTM (universal testing machine) with a capacity and precision of 1000 KN and 0.1 KN, respectively. Unlike the conventional brick testing, the plastic brick samples were tested in its full form due to its containment of plastic bottle in the centered portion of the sample. Each sample brick was laid horizontally on the testing plate (see Fig. 9) of the UTM so that it can be subjected to diametric compression mode as it

Fig. 8. Three plastic brick samples after removing from the cardboard case and completion of curing period of 14 and 28 days with a similitude like the normal clay brick.

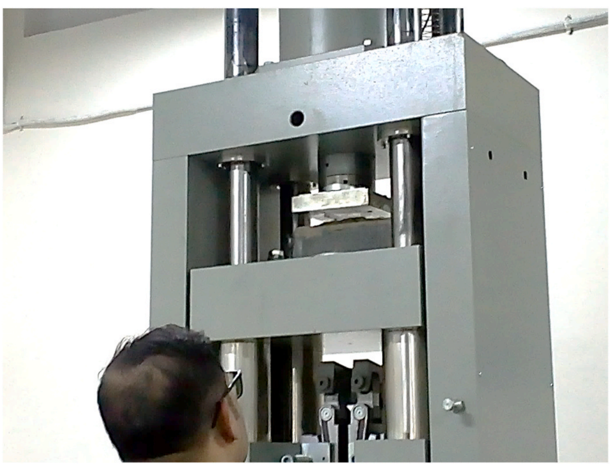

Fig. 9. One brick sample placed in the UTM for the compressive strength test.

resembles the way of use in the wall structure. The compressive strength of the samples was later calculated by eq. (1) (Mansour and Ali, 2015) -

$$C = P/A \quad (1)$$

were.

C = compressive strength
P = max. load at failure
A = cross-sectional area of the prepared brick sample

5. Results and discussion

Table 2 presents the compressive strength test value of the prepared plastic brick samples. The maximum compressive strength achieved from 14-day crushing age (sample no. 3) is 3.60 N/mm^2 and 28-day crushing age (sample no. 4) is 4.46 N/mm^2. According to the Public Works Department (PWD), the minimum permissible average compressive strength should be of 5.20 N/mm^2 for clay bricks, 2.80 N/mm^2 for hollow blocks and 2.50 N/mm^2 for concrete blocks per 10 samples taken at random from the contractor's stockpile of 1000 or part thereof (Mokhtar et al., 2016). In comparison with the compressive strength standard set by (PWD, 2005), the average strength value of the brick samples of 14-day crushing age (2.88 N/mm^2) and 28-day crushing age (3.29 N/mm^2) have passed the standard value of concrete and hollow blocks but failed to meet the clay brick standard. The samples failed with lower compressive strength value can be explained as the tensile stresses developed in the prepared brick samples were due to a substantial difference between the modulus of elasticity of the mortar binder and used plastic bottles' outer surface. However, by applying simple scratch or mild perforation in the bottles' outer surface a higher friction among the used bottles and mortar binder (Mansour and Ali, 2015) can be maintained which can overcome this problem and expected to provide a better compressive strength for the plastic brick.

Rohingya people are residing in semi-structured shelters often out of bamboo and thin plastic sheet with destitute living conditions and often vulnerable to monsoon rains, landslides, cyclones, and heavy wind as reported by the studies from (Wali et al., 2018), (HPN, 2018) and (ACAPS, 2017). The undulating surface of the plastic sheets of shelters and bamboo poles can encourage the accumulation of stagnant water, which also provides an ideal breeding site for disease vectors such as flies and mosquitoes (Chan et al., 2018). Over 2000 acres of forestry has been cut for firewood and building of shelters which exacerbate the effects of flooding and cyclone as low-lying lands are getting more exposed (ACAPS, 2017). There is a dire need to provide strong and sustainable solution of living shelters for these people residing in miserable living conditions, and these can be solved by integrating plastic brick as the construction material. In Table 3, a comparison between wall structures made of plastic brick and normal clay brick is shown which reveals that plastic brick has the better suitability in terms of factors like- construction speed, structural strength, used materials and construction cost than normal clay brick used in construction works.

To prepare a shelter with plastic brick, first the waste PET bottles need to be washed properly and dried thereby. Then, the bottles should be stuffed only with non-biodegradable materials, such as soil, sand, fragmented plastic wastes, etc. These inorganic materials need to be tightly packed in the bottles using tamping bar or stick without leaving any voids and sealed off the bottles. Then the earth on which the shelter will be built, should be dug with a 10 cm base laying underneath it, and

Table 2
The test result summary of the prepared plastic brick samples.

Curing period	Sample no.	Crushing age at	Length, L (mm)	Width, B (mm)	Height, H (mm)	Area, A (mm^2)	Weight (kg)	Max. load at failure, P (KN)	Compressive strength, C (N/mm^2)	Avg. strength (±S.D.) (N/mm^2)
14 Days	1	14 Days	241.3	88.9	76.2	21,451.57	2.90	46.60	2.17	2.88 (±0.715)
14 Days	2	14 Days	241.3	88.9	76.2	21,451.57	2.89	52.50	2.86	
14 Days	3	14 Days	241.3	88.9	76.2	21,451.57	3.0	77.30	3.60	
28 Days	4	28 Days	241.3	88.9	76.2	21,451.57	2.70	95.70	4.46	3.29 (± 1.662)
28 Days	5	28 Days	241.3	88.9	76.2	21,451.57	2.70	45.30	2.11	

S.D. – std. deviation.

Table 3
A comparison between wall structures constructed out of plastic and normal clay brick.

Factors	Considerations	Plastic brick	Normal clay brick	References
Speed of construction	A team of 5 persons working one day	Construction of 140 m^2 of wall	Construction of 120 m^2 wall	Raut et al., (2015)
Used materials		Recycling and reuse of waste plastic bottles with filler content used as sand, dirt, mud, soil, and wood particles.	Usage of clay soil accompanied by an energy intensive burning process, a major contributing process to the air pollution	(Raut et al., 2015), (Haque, 2019)
Strength comparison	Based on the usage of 250 mL PET plastic bottle in wall structure	34.69 N/mm^2 - 4 times higher strength than the normal clay brick made wall	8.58 N/mm^2 - Lower strength than the wall built out of 250 mL plastic bottles	(Mokhtar et al., 2016), (Shoubi et al., 2013), (Haque, 2019)
Thermal comfort	Based on a two-bedroom house built out of plastic bricks in Nigeria	Interior temperature recorded as 18 °C	Temperature ranges between 29°C and 34 °C	(Muyen et al., 2016), (Sharma, 2017)
Construction cost	A comprehensive cost value for constructing 10 m^2 wall	7733.42 BDT	16,837.58 BDT	Haque, (2019)

large or medium stones will be placed and filled with cement-sand mix ratio of 1:7. This process will give the foundation for the proposed shelter to be constructed. Then, the plastic bricks prepared using the method of this study should laid down on the draft foundation, made of concrete. Only a maximum of 75% of the bricks need to be covered by the concrete at the bottom layer. Cob mixture can be used as mortar to bind the plastic bricks together and a layer of 5 cm should be maintained to lay the bricks on above another (Ecobricks, 2015, 2017). In case of unavailability or to reduce cost, clay can be used as mortar to bind the bricks in place (Wasteaid UK, 2017). This process will provide a strong wall structure for the shelters, capable of resisting the hazards induced by cyclones, mudslides, heavy wind, and rain. Moreover, the bottles can be replaced with another one in case of any damage to the used one. In the context of Bangladesh, it will cost only 2.32 BDT to prepare a plastic brick (Muyen et al., 2016), whereas a conventional brick costs only about 10.80 BDT (BBS, 2019), a cost-effective solution with suitable building materials for these refugee population. The process is so simple and easy that Rohingya refugees can prepare their own living shelters by themselves without any involvement of labor forces, externally (see Fig. 10).

The poor socio-economic condition in Bangladesh with poverty, over population and susceptibility to natural disasters and climate change complicates finding a durable solution for the Rohingya refugees in the region they have settled (Wali et al., 2018). UNHCR (United Nations High Commissioner for Refugees) and other humanitarian actors can access and assist only 10% of the Rohingya population, living in makeshift settlements. Majority of them have been subjected to miserable living conditions (Wali et al., 2018) marked by vulnerability due to

Fig. 10. Local people constructing their own living shelters by utilizing waste plastic bottle as plastic brick in Nevada (Haque, 2019).

cyclones, heavy rains, floods, mudslides, and other environmental issues. The proposed two long term solutions to the Rohingya crisis followed by, return of the refugees to their native land which is far remote to be in effect and/or to shift them in an uninhabited low-lying island, off the coast of Bangladesh - *Bhasan Char* - with inadequate cyclone centers or evacuation procedures and livelihood opportunities, which will eventually lead to high mortality (Ahmed et al., 2018). To improve the fate and well-being of the Rohingya refugees which is not only about respecting life and preserving dignity, but also to ensure the survival of these forgotten, stateless people (Haque, 2019), utilization of these low-cost plastic bricks as building material in the displacement camps and in the shelters proposed to be built in *Bhasan Char*, can be a promising living solution against the environmental hazards and shelter issues. Strength of plastic bricks has been doubted by the public due to the use of plastic bottles in them (Mokhtar et al., 2016). The present study along with other similar studies - (Muyen et al., 2016), (Safinia and Alkalbani, 2016), (Antico et al., 2017), (Mansour and Ali, 2015) - has revealed that plastic brick is a useful way to manage waste plastic bottles in regions where recycling is not present or in effect accompanied by a sustainable way to provide safe and rigid shelters for Rohingya population with recyclable and low-cost materials.

6. Conclusion and recommendations

The plastic brick samples prepared and the compressive strength (max. 4.46 N/mm^2 and 3.60 N/mm^2 for 28-day and 14-day samples, respectively) obtained through them in this present study suggest that, utilization of this recycling procedure to build shelters in displacement camp instead of bamboo and plastic sheet, are a sustainable way to support the Rohingya refugees with safe shelters along with mitigating country's plastic waste and degradation responsible for it. This hand mixture of cement-sand blend accompanied by waste plastic bottles proved to be an ecofriendly and low-cost construction solution against the environmental hazards and lack of economic support issues, to provide safe and sufficient shelters for Rohingya people.

The developed plastic bricks as presented in previous studies through shredding and mixing or integrating in concrete blocks and its obtained compressive strength properties were much lower - see for example (Guzman and Munno, 2015), (Alaloul et al., 2020), (Mansour and Ali, 2015) - than the plastic bricks developed in the current study. In addition to that, this study evaluated the newly devised plastic brick, shaped that of a universally used clay brick material and utilized a 500 mL waste PET bottle in its full form without any mechanical interference (i.e., shredding, grinding, mixing), and obtained satisfactory compressive strength values which suggest that the bricks can be used in one-storied houses as load bearing walls and partition or non-load bearing walls in multistoried infrastructures, and for this case it is proposed to incorporate in building one-storied makeshift settlements for Rohingya refugees in their displacement camps. Besides, as a substitute material of common clay brick along with the simple manufacturing procedure, this study will also help in redirecting the construction industry (i.e., brick manufacturing sector) and plastic recycling sector to jointly endeavor in integrating a “green business model” by preparing plastic bricks which is resource efficient, ecofriendly, and recyclable through utilizing locally produced plastic waste. However, refinement through testing more samples, the present study can broaden up the future scope of understanding the dispersion and crushing pattern of compressive strength test over these bricks. Moreover, it is recommended to investigate - flexural bending and bond strength of mortar binder (with and without perforation in bottles), combined compression and bending with different filler content (e.g., dirt, mud, paper waste), modulus of elasticity and modulus of rupture for understanding the comprehensive structural behavior of plastic brick to reliably utilize as masonry (Kusimwiragi, 2011). Also, future research should address the environmental impact associated with the utilization of plastic waste as brick materials which can be conducted through the carbon, energy, and plastic footprint comparison before and after the waste utilization and brick manufacturing process along with the air quality index calculation for the areas that contain brick kilns and landfill zones. In this study, the average compressive strength attained of the plastic brick samples has laid a foundation and demonstrated the potential of using these bricks as construction material where disposal of plastic waste along with low-cost housing solution for the impoverished people are concerned.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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