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Production and Carbon Emission Calculation of Bricks Incorporating Construction And Demolition Waste and Pet Pellets

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1 ABSTRACT

The study aims to incorporate solid wastes in the brick where cement is the binding agent and perform the comparative analysis of mechanical properties (compressive strength, density and water absorption). Polyethylene Terephthalate (PET), and Construction and Demolition waste are the wastes that partially replace sand in the mixture of cement and sand. The compressive strength, water absorption, and dry density of the waste-incorporated bricks are determined which are compared with all parameters of the traditional bricks. The brick with 2% PET showed the best compressive strength of 13.515 MPa. While determining the carbon emissions of composite bricks it showed 0.6 to 0.9 kg CO_2 had been generated from the raw material extraction and processing phase, however, the production phase involved no carbon emission because the process was manual and involved no heating or firing. The composite bricks have the potential to be used as structural elements, however, the composite bricks require further study for the optimization of binder content with respect to cost, compressive strength, and carbon emission.

Keywords: Solid waste, Construction and Demolition Waste, Production, Composite bricks, Carbon emission, Traditional bricks, Comparative study, Life cycle assessment

2 INTRODUCTION

Brick is one of the widely used masonry building elements. The composition of conventional bricks is mainly raw materials, sand, clay, plastic [high-density polyethylene (HDPE) and polyethylene (PE)], and non-plastic materials. Traditionally, they are heated in brick kilns at temperatures of 800-1100ºC [1]. With the manufacture of these burnt bricks, the by-product is smoke, contaminating the air and releasing larger toxic substances hence making it responsible for energy, economic, environmental, health, and ecological issues [2] which led researchers to find an environment-friendly alternative with low impact on health. Even though there are rules for setting up brick kilns at least 3 kilometers away from residential areas and forest areas, no such rules are implemented [3]. This has resulted in the depletion of fresh arable land, loss of soil nutrients, and less amount of organic matter [4].

While searching for an alternative for burnt bricks, many researchers[5], [6] have come across incorporating different elements into bricks. Non-recyclable plastic wastes and construction and demolition wastes are some of the wastes that are now being used in the construction industry [7] which reduces critical environmental challenges such as problems related to the degradation of plastic, preventing them from being dumped into rivers and oceans[8]

Construction and demolition activity is among those activities which generate and contribute about 35% of the total waste and is treated as one of the biggest industries[9]. The urban solid waste consists of 50% of construction and demolition waste. Every project that includes the construction of a new building, termination of the old building, and modernization of the existing structures generates C&D materials which consist of concrete, steel, wood, bricks, glass, gypsum, and so on [10] that are usually being dumped in an improper place, making it a worldwide problem with substantial environmental and economic problems [11].

The problems coming from traditional burnt bricks and construction and demolition wastes can be merged into a common solution: Unburnt bricks by incorporating construction and demolition waste into the building material. The incorporation of C&D waste in brick may lead to a reduction in depository problems that exist due to the lack of proper management of C&D waste. This research aims to incorporate Construction and Demolition waste as a raw ingredient for the production of brick. This study also investigates the use of PET as an additive agent to improve the mechanical properties of the brick. Cementitious binder has been used instead of high thermal treatment for the hardening of the brick.

Cradle-to-gate Method for Life Cycle Assessment of bricks

Cradle-to-gate is the partial life cycle assessment from raw material accession to the factory gate (i.e., before supplying it to the consumer) whereas cradle-to-grave is full life cycle analysis from material excavation till its end of life [12]. The primary purpose of cradle-to-gate analysis is to calculate the impact of carbon emission of a product from its production till termination[13]. It helps designer and producer to shift their focus from economic aspect to environmental aspect [14].

Carbon Emission Calculation

Carbon emission is calculated for raw material extraction, raw material processing and production phase by calculating total inputs and outputs. For example, in raw material extraction phase, the total input is calculated for raw materials, their transportation and extraction and in output phase, the emissions from the extraction and transportation of raw materials (e.g., CO_2, methane, nitrous oxide) is calculated.

The formula is: CO_2 Emissions = Raw Material Inputs x CO_2 Emissions Factor + Energy Inputs x CO_2 Emissions Factor [15]

Carbon emission factor is the rate of release of greenhouse gases into the atmosphere[16].

Carbon emission factors:

CO_2 emission factor of cement = 0.9kg CO_2/kg of cement [17]
CO_2 emission factor of Sand = 0.004985 kg / ton of sand [18]
In case of Nepal, the river sand processing undergoes only sand handling, transfer and storing and screening phases [19]. But in countries such as North America, the industrial sand mining process consists of mining, transport, storage, crushing, grinding, screening, wet processing, draining, drying, cooling and final classification [18]. Hence, only the sum of sand handling, transfer and storing and screening phases emission factors are taken as carbon emission factors for sand extraction in Nepal.

CO_2 emission factor of petrol = 2.3 kg of CO_2/liter [20]
CO_2 emission factor for electricity Consumption = 0.015kg CO_2 equivalent/kWh [21]

3 MATERIAL AND METHODS

The study consists of two parts i. Experimental program that incorporate PET in C&D waste brick for improvement of mechanical properties which consists of experimental design and ii. Carbon Emission Calculation for the energy use assessment of carbon footprint of the produced brick.

4 EXPERIMENTAL PROGRAMME

4.1 Materials

Cement: Cement of 43 grade was used in the process of making brick as a binding material.

Sand: River sand was used in the study as granular material passing through 4.75 mm IS sieve no. (4). The specific gravity of sand was calculated using IS 2386-Part 3, 1963 and the zone of sand was found out using IS 383: 1970.

Construction and Demolition Waste: Construction and Demolition Waste was collected from Sundarijal area of Gokarneshwor municipality-01, Kathmandu under the construction residence of Luku Kumari Shrestha. The construction and demolition wastes were sieved through the standard sieve sizes for both coarse and fine materials. The construction and demolition wastes consisted of a mix of various materials such as hardened concrete, broken tiles, marble, aggregates and sand which were then separated after the sieve analysis was done. The C&D waste passing through 4.75 mm IS sieve no. (4) was used in the study. The specific gravity of C&D waste was calculated using IS 2386-Part 3, 1963 and the zone of sand was found out using IS 383: 1970.

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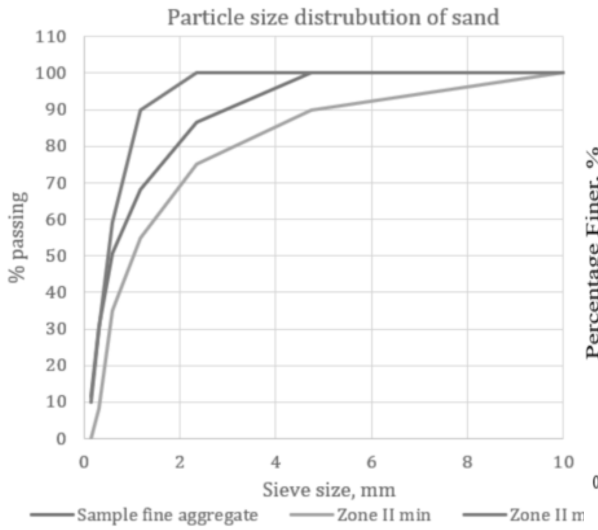


Figure 1:Size distribution of sand (sp.gr. 2.667)

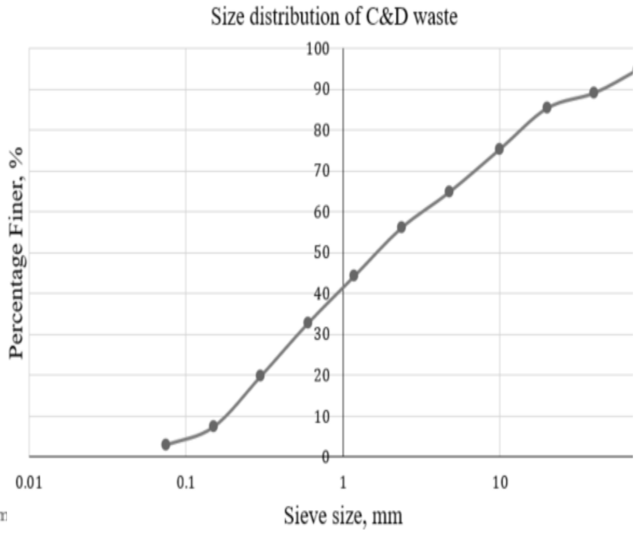


Figure 2: Size distribution of C&D Waste (sp.gr. 2.105)

PET: PET bottles were collected from houses, cut into smaller pellets using scissors. Additional quantity of PET pellets was collected from a plastic recycler store at Mahalaxmi Municipality, Lalitpur. The maximum nominal size of PET was found to be 4.75 mm.

Figure 3: PET PELLETS

Mix Proportion

There are no specific mix designs involving C&D waste, and plastic as raw materials. So, for initial reference the mix design was calculated by following IS code 456-2000. 10 N/mm^2 strength was taken as characteristic strength. The calculation resulted in 17.5% cement content. However, in the use of C&D waste as a raw material for brick, the edge spalling and edge cracking were observed. This might be due to the presence of impurities and burnt clay materials in the C&D waste. So, the binder content had to be increased. The mixture was prepared with 20% and 25% cement, which still resulted in the same. Finally, the binder content of 30% was adopted. The mix was workable as well as edge spalling was not noted in the brick sample. Thus, a standard brick sample of 30% cement and 70% sand was used as a reference sample and all the other test samples were based on 30% binder content with partial replacement of sand. The C&D waste comprised of mortar masonry which comprised hydrated cement paste which also contains sand and thus the sand to C&D waste was maintained in the ratio of 1:6 by weight. The amount of PET in the mix was varied from 0 to 3% by weight.

Table 1: PET bricks with C&D waste and cement as binder, w/c ratio=0.8

Brick proportion in percentage (%)				Sample Name	Remarks
Cement	Sand	C&D waste	PET		
12.5	87.5	0	0	F1,F2, F3	
30	70	0	0	N1, N2, N3	Ref. Sample
30	10	60	0	G1,G2, G3	Ref. Sample
30	10	60	3	A1,A2,A3	
30	10	60	2	B1,B2,B3	
30	10	60	1	C1,C2,C3	

4.2 Production of brick

The construction and demolition wastes were sieved through the standard sieve sizes for both coarse and fine materials. The construction and demolition wastes consisted of a mix of various materials such as hardened concrete, broken tiles, marble, aggregates and sand which were then separated after the sieve analysis was done.

Figure 4: Sieve analysis of C&D waste

All the raw materials collected were stored in the institution laboratory at room temperature.

Batching of the materials were done on the weight basis. It was done according to the mix proportion Table 1: PET bricks with C&D waste and cement as binder, w/c ratio=0.8. The table has been included above. After batching, hand kneading was done by slowly adding the water to the mix. Then, it was placed in the mould in three equal parts. Each part was hand compacted with 10 kg weight. After the completion of compaction, it was left for 7 days to set properly. The bricks were molded out after 7 days and the initial dimensions were measured and noted.

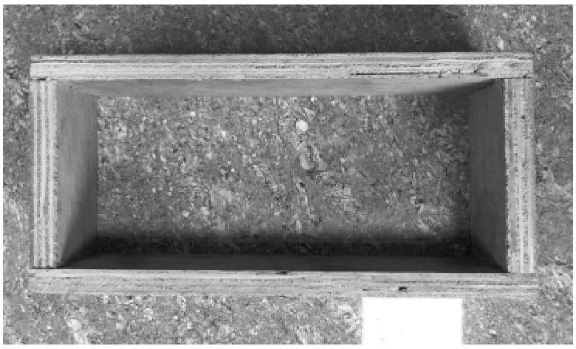


Figure 5: Wooden mold (230mm x 115mm x 55 mm)

4.2.1 Curing and testing

The bricks were initially cured at room temperature of 24 °C for 14 days. For mineralogical and chemical composition XRD was performed. The engineering properties viz. 28th day Compressive strength, density and water absorption were tested. The compressive strength test was carried out to determine the load carrying capacity of the bricks under compression with the help of a compression testing machine. The test procedure was conducted from IS 3495 (1992) Part 1 in order to conduct the compressive strength test of the brick [22]. IS 1077:1992 clause 4.1, suggests that the minimum compressive strength of the brick should be 3.5 MPa [23].Water absorption tests on bricks were conducted to determine durability properties of bricks such as degree of burning, quality and behavior of bricks in weathering. It helps to determine the capability of brick to withstand dampness. IS 3495 (Part 2): 1992 was followed to determine the water absorption capacity of the brick. IS 1077:1992 clause 7.2, suggests that the water absorption of the brick should not be more than 20 % by weight up to class 12.5 and not more than 15% for the higher class [23]. NBC 109: 1994 was followed to check the appropriate class of the composite brick. The maximum value of water absorption for first class brick is taken as 15% of its weight and for hand-made bricks with key, it is taken as 25% of its weight [24].

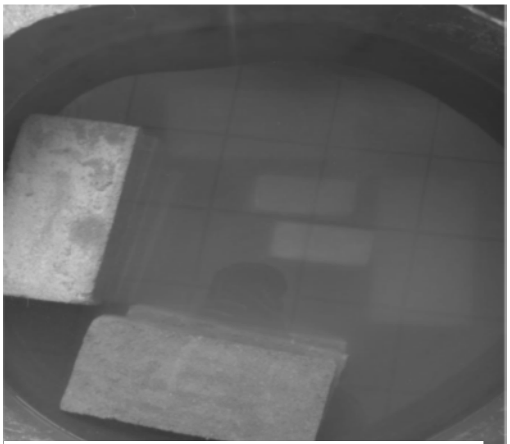
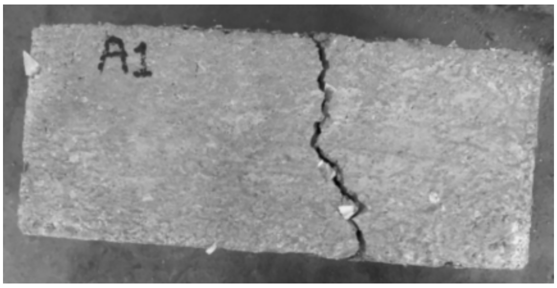
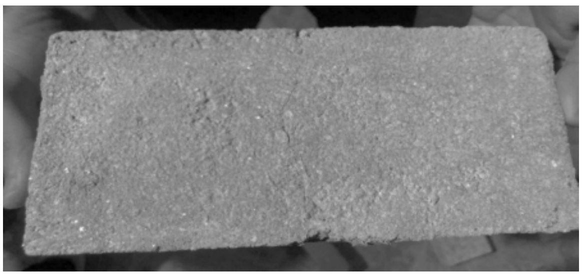


Figure 7: Water Curing

Figure 6: Oven Drying

	
Sample A	Sample B
	
Sample C	Sample F
	
Sample G	Sample N

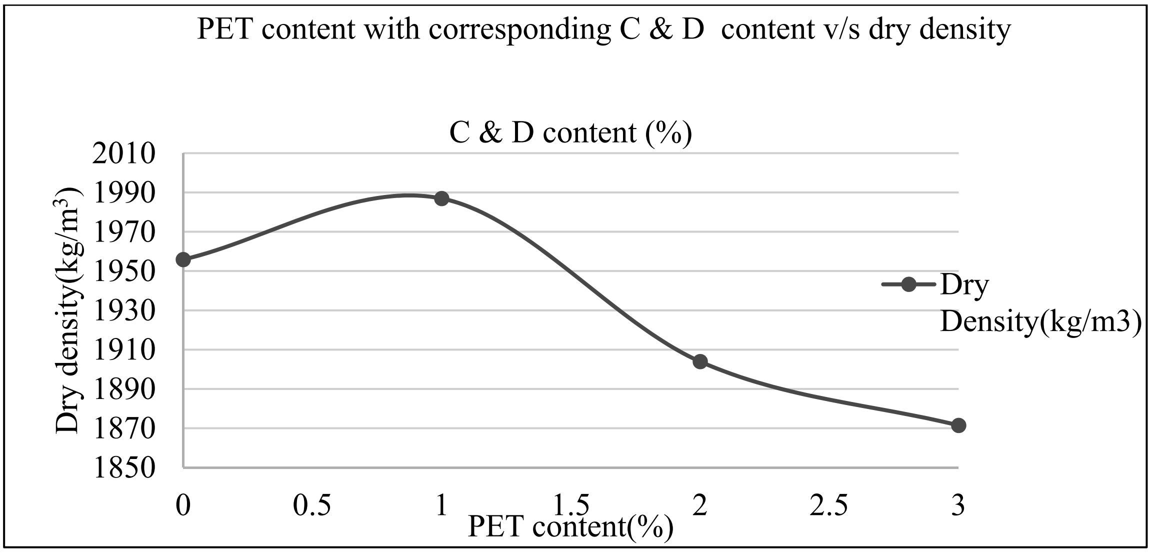
5 RESULTS AND DISCUSSION

5.1 Physical Properties of brick

Table 2: Average final dimensions of brick

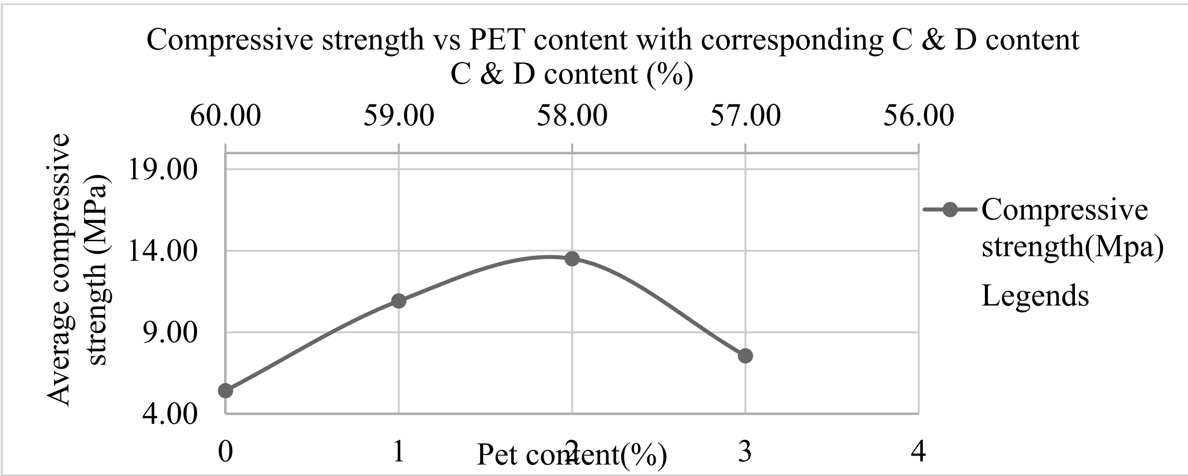
Brick made from PET and C&D waste					
Brick name	Length(L)(m)	Breadth(B)(m)	Height(H)(m)	Area(A)(m^2)	Volume(V)(m^3)
A1	24.00	11.30	5.70	271.20	1545.84
A2	23.65	10.93	5.70	258.38	1472.74
A3	23.45	11.48	5.63	269.09	1513.62
B1	23.38	11.35	5.50	265.31	1459.18
B2	23.13	10.93	5.58	252.64	1408.47
B3	23.25	11.38	5.75	264.47	1520.70
C1	24.10	11.68	5.48	281.37	1540.49
C2	23.38	11.38	5.50	265.89	1462.40
C3	24.05	11.48	5.30	275.97	1462.66
Brick made from C&D waste					
G1	23.58	11.13	5.68	262.27	1488.39
G2	23.25	11.20	5.55	260.40	1445.22
G3	24.03	11.55	5.63	277.49	1560.87
Standard brick made from cement and sand					
F1	23.80	11.18	5.43	265.97	1442.86
F2	23.40	11.48	5.48	268.52	1470.12
N1	24.00	11.43	5.50	274.20	1508.10
N2	23.93	11.18	5.78	267.36	1544.01
N3	23.93	11.53	5.63	275.74	1551.01

5.2 Dry Density



The graph shows the comparison of density of PET bricks with the standard bricks containing only cement and sand. When C&D was added to the standard brick the density decreased. With addition of 1% PET in the bricks containing C&D, cement and sand, the density slightly increased which may have occurred because of segregation of PET in the bricks. Upon further increasing the PET content further, the density decreased further and was lowest at PET 3%. This shows that with the addition of PET in the mix, the density of the bricks decreases.

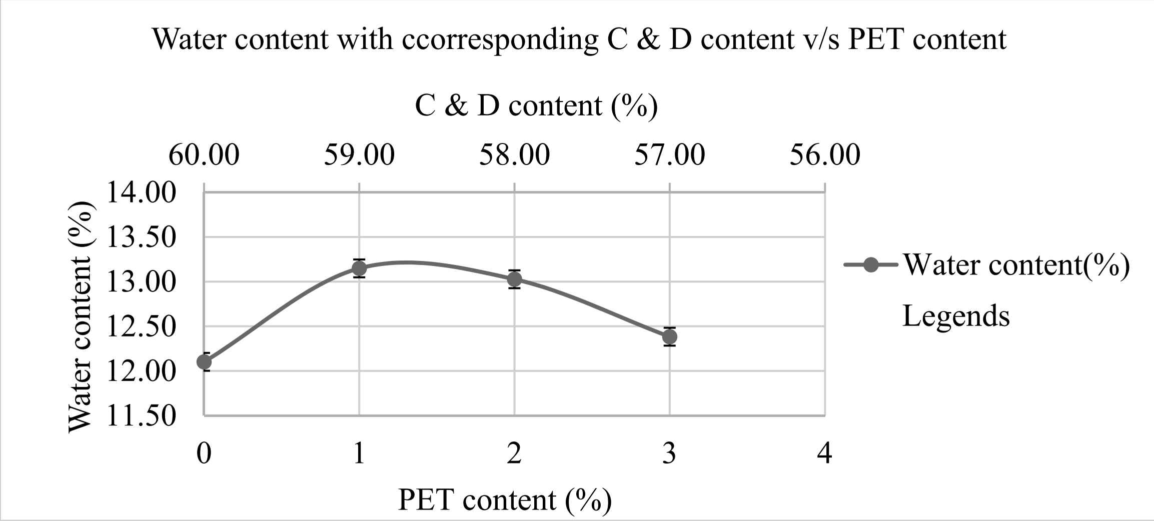
5.3 Compressive strength



The graph shows the comparison of compressive strength of PET bricks with varying percentage of PET and also with brick made from cement, sand and C&D (5.422 MPa). The compressive strength increased after introducing PET to the mix of cement, sand and C&D waste. PET corresponding to 2% gave the maximum compressive strength i.e., 13.515 MPa however all the bricks containing PET have surpassed the minimum strength criteria of 3.5 MPa conforming to IS 1077:1992 clause (7.2) with the lowest strength of brick being at PET 3% i.e., 7.563 MPa.

5.4 Water absorption test

Table 3Average water absorption (%)



The graph shows the comparison of water absorption of PET bricks with brick containing cement, sand and C&D. The water absorption of PET brick with 1% was found to be highest i.e., 13.149% and decreased gradually with the increase in PET content and the lowest water absorption of PET bricks was found to be at 3% i.e., 12.383%. This result indicates that PET brick absorbs less water when it's content in brick is increased. However, the water absorption values for all varying contents of PET do not exceed the maximum absorption value criteria for first class brick stated NBC 109:1994 i.e., 15%.

XRD test of C&D waste

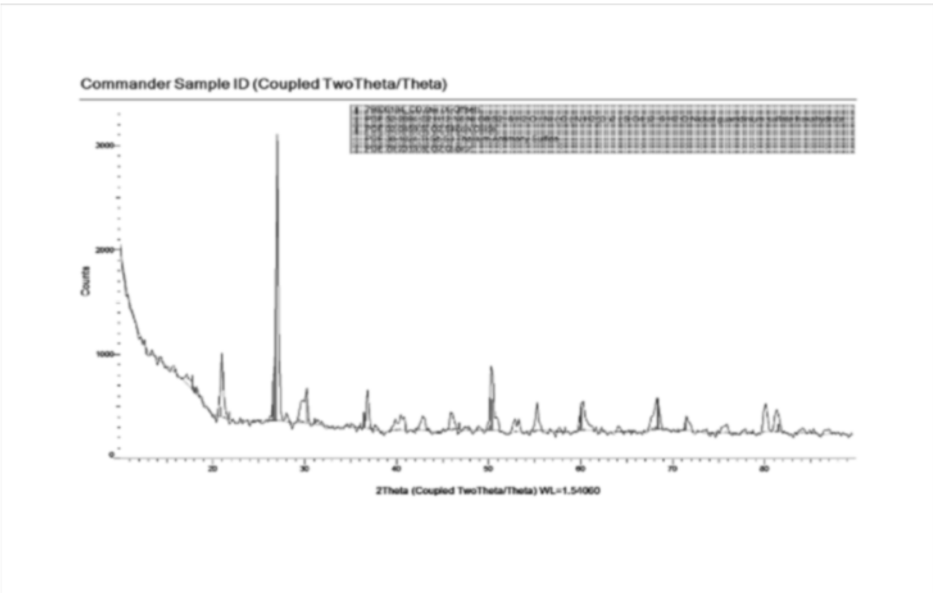


Figure 8: XRD pattern of C&D waste

XRD pattern of the C&D used is shown by figure 1. The peak around 27 degrees is noticeable which represents the presence of Quartz. The Silicon dioxide, present in the C&D material, is considered as an important ingredient as it yields strength to the cement. The formation of di-calcium silicate and tri-calcium silicate aids in increasing the strength of the cement [25].

5.5 Carbon Emission Calculation

1. Sample Calculation; Brick made with PET (2%), Cement, sand and C&D

Raw material extraction:

S.N.	Materials	Proportion
1.	Cement	30%
2.	Sand	10%
3.	PET	2%
4.	C&D	58%

Weight of cement = 0.835kg
CO_2 emission factor of cement= 0.9kg CO_2/kg of cement
Weight of sand = 0.2785 kg
CO_2 emission factor of Sand= 0.000004985 kg CO_2/kg of sand

Energy inputs for transportation of PET and cement:
Total up and down trip for PET = 23.4 km
Mileage of vehicle = 66kmpl
Petrol consumed for transporting PET = $\frac{23.4}{66}$ = 0.355 liters
Total petrol consumed for PET per brick = $(\frac{0.355}{5} * 0.0556)$=0.00394 liter per brick

Total up and down trip for C&D = 49.2 km
Mileage of vehicle = 66 kmpl
Petrol consumed for transporting C&D = $\frac{49.2}{66}$ = 0.745 liters
Total petrol consumed for C&D per brick = $(\frac{0.745}{82.87} * 1.614)$=0.0145 liter per brick
Total petrol consumed = 0.00394+0.0145 = 0.0184 liters per brick
CO_2 emission factor of petrol = 2.3 kg of CO_2/liter

CO_2 emissions = Raw materials * CO_2 emission factor + energy sources * CO_2 emission factor
∴ CO_2 emission= (0.835* 0.9 +0.2785* 0.000004985) +(0.0.184 *2.3)
= 0.793 kg of CO_2

Raw Material Processing:
Mechanical Sieve
Operating hours for C&D = 5hrs
Total weight sieved in mechanical sieve = Total weight of C&D
= 55
Total weight sieved = 1.615 kgs
Operating hours for 1.615 kgs = $\frac{5}{55}$ x 1.615 = 0.146 h
Voltage = 110 V
Motor power = 0.37KW
Total energy consumption = 0.37*0.146 =0.0540 kWh
CO_2 emission factor = 0.015 kg CO2/kWh

∴ CO_2 emission = Total energy consumption* CO_2 emission factor
=0.015*0.0540
=0.00081 kg CO_2

Production phase

Since, the production phase involved all manual process. So, no carbon emission produced.
Total carbon emissions = ∑ (Raw material extraction + Raw material processing + Production phase)

∴ Total CO_2 emission= 0.793+0.00081 + 0 = 0.7938 kg CO_2

Table 4: Carbon emission from bricks made with PET (1%), Cement, Sand and C&D

Bricks made with PET (1%), Cement, Sand and C&D			
Average dry weight		2.958	kg
S.N.	Material	Proportion	Weight (kg)
1	PET	1%	0.02958
2	Cement	30%	0.88740
3	Sand	10%	0.29580
4	C&D	59%	1.74522
Description		**Quantity**	**Units**
1) Raw material extraction phase data			
Total distance for C&D		49.2	km
Mileage		66	kmpl
Petrol		0.75	liters
Total distance for PET		23.4	km
Mileage		66	kmpl
Petrol		0.355	liters
Total petrol		1.10	liters
Total Petrol consumed		0.05	litre per brick
2) Raw material processing phase data			
i) Total energy consumption for C&D			
Weight to be sieved		1.745	kg
Operating hours of seive machine		0.159	hr
Motor power		0.37	kW
Total energy consumption for C&D		0.059	kWh

Phases	CO_2 emission	
Raw material extraction phase	0.921	kg CO_2
Raw material processing phase	0.001	kg CO_2
Production phase	0	kg CO_2
Total CO_2 emission	0.922	kg CO_2

Table 5: Carbon emission from bricks made with PET (3%), Cement, Sand and C&D

Bricks made with PET (3%), Cement, Sand and C&D			
Average dry weight		2.827	kg
S.N.	Material	Proportion	Weight (kg)
1	PET	3%	0.08481
2	Cement	30%	0.84810
3	Sand	10%	0.28270
4	C&D	57%	1.61139
Description		**Quantity**	**Units**
1) Raw material extraction phase data			
Total distance for C&D		49.2	km
Mileage		66	kmpl
Total petrol		0.75	liter
Total petrol per brick of C&D		0.01	
Total distance for PET		23.4	km
Mileage		66	kmpl
Petrol		0.355	liters
Total petrol		1.10	liters
Total petrol per brick of PET		0.02	
Total Petrol consumed		0.03	litre per brick
2) Raw material processing phase data			
i) Total energy consumption for C&D			
Weight to be sieved		1.611	kg
Operating hours of seive machine		0.146	hr
Motor power		0.37	kW
Total energy consumption for C&D		0.054	kWh
Phases		**CO_2 emission**	
Raw material extraction phase		0.840	kg CO_2
Raw material processing phase		0.001	kg CO_2
Production phase		0	kg CO_2
Total CO_2 emission		0.840	kg CO_2

6 Conclusion

The compressive strength of the composite bricks at the end of 28 days was found to be 13.51 MPa for PET bricks. The correlation between improved strength of the composite bricks can be established from the dense packing of material, i.e., higher density giving higher strength. The water absorption of composite bricks was found to be 13.03% PET bricks. XRD of the C&D waste indicated the presence of unhydrated calcium silicates and quartz which indicate that these materials have binding agents which eventually increase the strength when added in the brick.

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