

# Recycling Waste Plastic Bags as a Replacement for Cement in Production of Building Bricks and Concrete Blocks

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## Abstract

Plastics play an important role in modern society and are used daily in diverse applications due to their low cost, ease of manufacturing and attractive qualities. About 300 million tons of plastic are produced globally each year of which only about 25% is recycled. An estimated 7 million tons ends up as trash in the sea each year causing significant environmental and health problems for fish and sea animals. Plastic waste brings serious environmental challenge to modern society because it is made of several toxic chemicals that can pollute soil, water and air if not managed properly. However, the percentage of recycled plastic can be increased by transforming waste plastic into mortar and concrete products suitable for housing and construction. In this study, the use of melted waste plastic bags as a replacement for cement in production of building bricks and concrete blocks was evaluated. The results showed that thermal conductivity depended upon the plastic content of the molded materials. Decreases in the thermal conductivity were observed with increases in the plastic content of both the bricks and concrete blocks. Increasing the plastic content from 33.33% to 66.67% (100%) in the bricks decreased the thermal conductivity from  $1.70 \times 10^{-3}$  W/m.K to  $1.43 \times 10^{-3}$  W/m.K (16 %) while increasing the plastic content from 20% to 50% (150%) in the concrete blocks decreased the thermal conductivity from  $1.61 \times 10^{-3}$  W/m.K to  $1.50 \times 10^{-3}$  W/m.K (7 %). It was also noticed that bricks and concrete blocks with similar plastic contents (50%) have similar thermal conductivity values. The thermal conductivity apparatus and the transient measurement methods used in this study provided consistence results with high degree of accuracy. The variations in  $\Delta T$  were within the range (1-3%) reported in the literature for the thermal conductivity transient measurement technique and resulted in very small variations in the thermal conductivity measurements (0.59-0.70% for bricks and 0.62-0.69% for concrete blocks). The results obtained from the flexure test showed that the bending moment and thus the bending stress increased with increasing the plastic content in both the bricks and concrete blocks. Increasing the plastic content of the brick from 33.33% to 66.67% (100%) increased the bending moment from 540.00 N.m to 1711.25 N.m (216%) and the bending stress from  $3.24 \text{ N.m}^{-2}$  to  $10.26 \text{ N.m}^{-2}$  (216%) and increasing the plastic content of the concrete blocks from 20 % to 50 % (150%) increased the bending moment from 901.40 N.m to 1442.55 N.m (60%) and the bending stress from  $5.40 \text{ N.m}^{-2}$  to  $8.65 \text{ N.m}^{-2}$  (60%). It was also noticed that for similar plastic contents (50%), the concrete blocks had a lower bending moment (1442.55 N.m) than that of the bricks (1711.25 N.m) and thus a lower bending stress ( $8.65 \text{ N.m}^{-2}$ ) than that of the bricks ( $10.26 \text{ N.m}^{-2}$ ). Using waste plastic in making construction materials such as bricks and concrete blocks is advantageous due to its light weight, extreme versatility and ability to be tailored to meet specific technical needs. Also replacing cement with waste plastic will reduce environmental problems associated with the disposal of waste plastic as well as those associated with the cement industry.

**Keywords:** Waste Plastics; Environment; Recycling; Gravels; Sand; Cement; Concrete; Blocks; Bricks

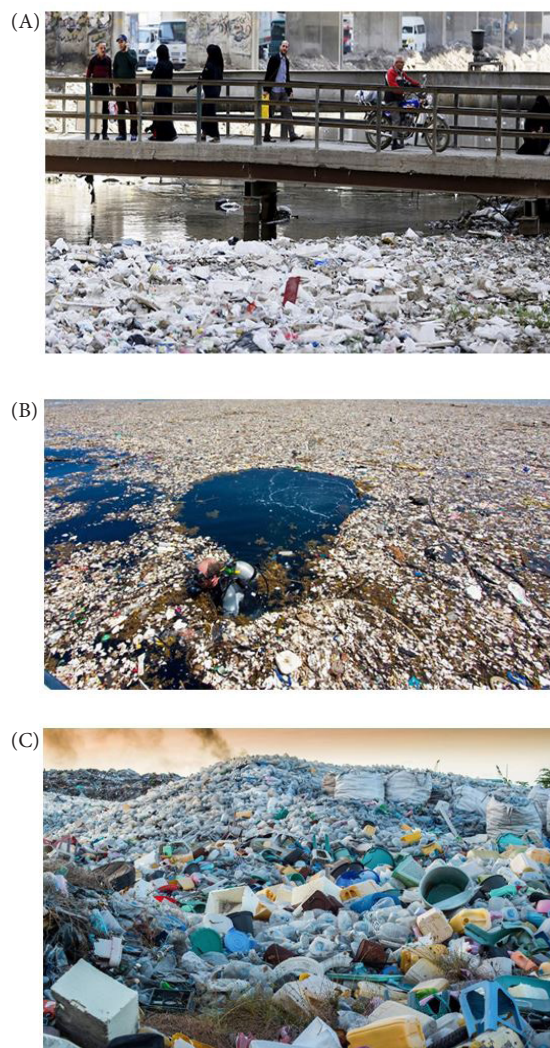
## Introduction

Plastics play an important role in modern society and are used daily in diverse industrial, food, agricultural, medical and pharmaceutical applications. The application of plastic materials and their composites are growing rapidly due to their low cost, ease of manufacturing and attractive qualities [1]. Plastic is lightweight, water resistant, water retainer, expandable, strong, durable and cheap. These qualities contributed to over consumption of plastic-based products. Plastic waste makes about 13% of the total solid waste. About 300 million tons of plastic are produced globally each year of which only about 25% is recycled and the rest is landfilled [2]. Plastics frequently find their way into rivers, oceans and land as shown in Figure 1 [3]. An estimated 7 million tons ends up as trash in the sea each year which cause significant environmental and health problems for fish and sea animals. Consequently, plastic waste brings serious environmental challenge to modern society because it is made of several toxic chemicals that can pollute soil, water and air if not managed properly [3]. Plastics are made from nonbiodegradable-harmful materials and land filling them would increase the volume of the waste and pollute ground water and may hinder its movement [1,4].

Egyptians use about 12 billion plastic bags each year. Egypt's waste output is 16.2 million tons, of which plastic represents 6%. That is the equivalent of 970,000 tons of plastic waste, of which 45 percent is recycled and only 5% reused. The menace of these non-biodegradable plastic bags causes severe problems to the Nile River and the seas and thus, it negatively affects environmental tourism and diving. In addition, many animals die after swallowing these plastic bags after their disposal. Plastic bags are also often incinerated in Egypt, releasing toxic fumes into the air and having a negative effect on climate change. The Ministry of Environment has launched a public advertisement campaign to raise awareness on the hazard of plastic bags. Also, the Ministry of Environment launched the EU-funded initiative on June 5, 2017, targeting Egypt's strong dependency on plastic bags and aiming to reduce their use due to the negative effects on the environment and the economy. The Ministry of Environment has also partnered up with the United Nations and the Center for Environment and Development for the Arab Regions and Europe (CEDARE) to carry out the initiative. The initiative campaign included distributing 4,500 non-woven bags as alternatives to traditional non-recycled plastic bags. These are eco-friendly biodegradable plastic bags that decompose through living organisms [5].

However, since waste plastics are generally a threat to the global environment and the production of plastics in its varied forms cannot be halted, recycling may be a solution to the threat waste plastics pose to the environment. Recycling of waste plastic is sustainable and can conserve natural resources. However, recovery and recycling of plastics remain insufficient, and millions of tons end up in landfills and oceans every year [6]. The percentage of recycled plastic can be increased by transforming waste plastic into mortar [3,4,6-9] and concrete [8-18] products suitable for housing and construction, applying it in road construction and pavement to improve strength and increase durability [19-25], using it as thermal and acoustic insulator in building construction [26-32], using it as fibers in textile industry [33-35] or using to produce new plastic [1,2]. Other uses of waste plastics include producing twist ties for bulk item tying, manufacturing low strength plastic furniture, manufacturing automotive parts and home appliances, producing mulches and making films [1,36-39]. Plastic is derived from hydrocarbon-based materials and as such it exerts high calorific value that could be used to fuel boilers [8]. Table 1 shows a summary of the common plastics, their characteristics and uses as well as the potential uses of the recycled waste plastics.

Concrete is made up from coarse aggregates (gravels), fine aggregates (sand), cement and water. It is the most prevalent construction materials because the raw materials are easily available at relatively low cost. It also provides better fire resistance than any other building material [40]. In normal concrete mix, aggregates account for 65-85% of the concrete volume and play a significant role in concrete strength and durability [12].



**Figure 1:** Images of waste plastic in the environment (A) Plastic in Rivers; (B) Plastic in oceans; (C) Plastic in Landfills

Plastic Type	Characteristics	Uses of Original Plastic	Possible Uses of Recycled Plastic
Polyethylene Terephthalate (PET)	Clear, hard, stiff, strong, dimensionally stable, absorbs very little water, has good gas barrier properties and good chemical resistance except to alkalis.	Soft drink and mineral water bottles, capacitors, graphics, film base and recording tapes, making fibers for wide range of textile and industrial uses	Clear and soft films for packaging and wrapping, automotive parts, luggage, fibers for carpets, T-shirts, long underwear, raincoats, sweaters, sleeping bags, upholstery
Low Density Polyethylene (LDPE)	Soft, flexible, milky white (if pigment is not added), density range of 0.917–0.930 g/cm <sup>3</sup> , not reactive at room temperature, withstand temperatures of 80 °C continuously and 90 °C for a short time.	Lids of food containers, garbage bags, garbage bins, trays, containers, dispensing and wash bottles, tubing, plastic parts for computer components, molded laboratory equipment.	Soft film for wrapping and packaging, grocery bags, garbage cans, paneling, furniture, flooring.
Linear Low-Density Polyethylene (LLDPE)	Higher tensile strength, superior impact and puncture resistance, higher retention of physical properties and color than the low-density polyethylene. This has allowed converters to make thinner films without sacrificing strength, saving material and reducing costs	Stretch films, flexible packaging, carrier bags, electrical boxes, housewares, containers, toys, doormats, dust bins, hardware, caps, water pipes, threaded closures	Garbage cans, paneling, furniture, flooring and bubble wrap.
High Density Polyethylene (HDPE)	White or colored, high strength-to-density ratio, density ranges from 0.93–0.97 g/cm <sup>3</sup> , harder and more opaque, withstands higher temperature (120 °C for short periods), cannot withstand autoclaving conditions	Shopping bags, freeze storage bags, plastic bottles, corrosion-resistant piping, boats, geomembranes and plastic lumber, banners, back-bag frames, electrical and plumbing boxes, fuel tanks, water pipes	Compost bins, detergent bottles, crates, garbage bins, wood plastic composites, plastic lumber, plastic furniture
Un-Plasticized Polyvinyl Chloride (UPVC)	Clear, hard, rigid, extremely good tensile strength, very dense compared to most plastics (specific gravity of 1.4)	Plumbing pipes and fittings, building and construction materials, health care equipment, electronic parts, automobile parts, siding, blood bags and tubing, wire and cable insulation, windshield components	Ground into small pieces that can be easily processed into new PVC compounds ready to be melted and formed into new products such as detergent bottles, tiles, plumbing fittings, tubing and various building and construction materials
Plasticized Polyvinyl Chloride (PPVC)	Clear, flexible, tough, oil resistance, high electrical resistance, non-inflammability,	Garden hoses, shoe soles, blood bags and tubes, medical devices, electronics	Hose inner core, industrial flooring, wire insulation, composite materials
Polypropylene (PP)	Hard, flexible, non-toxic, transparent, resists attack from UV rays, rugged, high resistance to different chemicals, solvents, acids and bases, withstand higher temperatures	Ice cream containers, potato chips bags, lunch boxes, stools and chairs, flexible tubing, packaging for consumer products, plastic parts for automotive industry, living hinges, fibers for textiles, small fluid system support structures, liner in metal piping systems	Compost bins, recycling organic green bin, worm fabrics, margarine containers, yogurt pots, syrup bottles, prescription bottles.
Polystyrene (PS)	Lightweight, amorphous, colorless, glossy, transparent, rigid, brittle, relatively hard, excellent gamma radiation resistance, good electrical properties, poor chemical and UV resistance, waterproof material	Transparent kitchen ware, disposable plastic cutlery and dinnerware, light fixtures, bottles, toys, food containers, smoke detector housings, license plate frames, plastic model assembly kits	Laundry bags, coat hangers, CD and DVD jewel cases, plastic forks, life rafts, picture frames
Polyester (PE)	λStaple and strong fibres due to their crystalline nature, lightweight, energy absorbing, high thermal efficiency, moisture resistance, shock absorption, resistant to most chemicals, stretching, shrinking, wrinkle, mildew and abrasion	Plastic bottles, yarns and ropes, car tire reinforcements, fabrics for conveyor belts, safety belts, coated fabrics and plastic reinforcements with high-energy absorption, fibers are used as cushioning and insulating material in pillows, comforters and upholstery padding, outerwear because of its high tenacity and durability and ability to withstand repetitive movements.	Recycled polyester is toxic to the earth and the wearer. It can be converted to PET (the raw material used in clear plastic water bottles) and prevents it from going to landfill.
Polyamides (PA)	The two most important polyamides are Nylon 6,6 (poly-hexamethylene adipamide) and Nylon 6 (polycaprolactam). Both have compact molecular structure, superior colorfastness and excellent mechanical properties including high tensile strength, high flexibility, good resilience, low creep and high impact strength (toughness), abrasion resistance	Co-polymers and compounded with other materials. These fillers include glass beads, glass fibres and carbon fibres, toothbrush bristles, fishing lines, films, medical apparel,	The raw material source for recycled polyamide can be old fishing nets and carpets, and waste from manufacturing industry. Recycled polyamide is used in swim wear. Collected carpet can be processed to produce various products, depending on the composition.



Plastic Type	Characteristics	Uses of Original Plastic	Possible Uses of Recycled Plastic
Polypropylene (PP)	White, mechanically rugged material and has a high chemical resistance, high impact strength and heat resistant but low strength, hardness, rigidity and low friction.	Packaging for consumer products, plastic parts for various industries, automotive parts, living hinges, textiles, tubing for transferring hot liquids and gases in food and beverage industry, liner in metal piping systems.	Clothing fibers, plastic lumber, picnic tables, lawn furniture, playground equipment, recycling bins
Polylactic Acid (PLA),	Polylactic Acid is biodegradable natural polymer designed to substitute widely used petroleum-based plastics such as PET (polyethylene terephthalate). Like most plastics, it has the potential to be toxic if inhaled and/or absorbed into the skin or eyes as a vapor or liquid during manufacturing processes, Heat-resistant PLA can withstand temperatures of 110 °C.	Used in food handling and medical implants that biodegrade within the body over time.	Packaging, plastic films and food containers, biodegradable fibers

**Table 1:** Plastic types, characteristics, use and potential recycle

Sustainability is becoming a top priority for the construction industry worldwide. Different types of waste materials and industrial byproducts (such as recycled concrete aggregate, glass, ceramic, fly ash and slag) are being used with and without natural aggregates (sand and gravels) and Portland cement to make concrete for traditional construction. It has been shown that the properties of these materials are suitable to produce new concrete up to a certain limit. Therefore, numerous studies have been conducted to find the optimum content of these materials in concrete that does not negatively influence the engineering properties of concrete. Waste materials such as plastics, which present environmental hazards and are often landfilled, can be used in concrete for different applications. Compared to other materials, plastics have lower cost, a higher strength-to-weight ratio, are more durable (resistant to deterioration), easy to work and shape and have a low density [2]. There are two forms of waste plastic that can be used in concrete: aggregates (PAs) and plastic fibers (PFs). PAs are used to replace coarse aggregates (gravels) and fine aggregates (sand). They have lower bulk density than granite, limestone and basalt and, therefore, used in lightweight concrete. In contrast, PFs are used as reinforcement to replace steel, which is subject to corrosion and, thus, enhance concrete durability [40,41]. Incorporating plastics in concrete will not only provide safe disposal but may also improve the concrete properties including tensile strength, chemical resistance, drying shrinkage and creep [15]. Furthermore, recycling plastic waste in the construction industry will shift the industrial process from linear processing system in which the resources and capital investments are moved through producing waste materials to ecological closed loop system in which waste becomes input for creating new products.

There are reported work on various types of plastics used as aggregates in concrete mix. These included polyethylene terephthalate (PET) bottles [7,8,9,12-14,18,20,22] polyvinyl chloride (PVC) pipe [31], high density polyethylene (HDPE) [13], spent plastic waste [35], expanded polystyrene foam (EPS) [14,32], glass reinforced plastics (GRP) [24,36], polycarbonate [35], thermoplastic recycled polystyrene [14], polypropylene fibers [37]. Although utilization of this type of waste plastic in concrete is beneficial from an economic and environmental point of view, its mechanical and thermal properties are different from natural aggregates [6,7,11,14,18,28]. The aim of this study was to use waste plastic as a replacement to cement for production of construction building bricks and concrete blocks.

## Objectives

The main aim of this study was to evaluate the use of waste plastic bags as a replacement for cement in production of construction bricks and concrete blocks. The specific objectives were (a) to produce construction bricks using sand and waste plastics and (b) to produce concrete blocks using sand, gravels and waste plastics. In both cases, waste plastics was use as a total replacement to cement

## Materials and Methods

### Experimental Materials

The materials used in this study to make the bricks and blocks are sand, gravels and recycled plastic bags. Plastic bags were obtained from a Solid Waste Management Facility in Giza City. The sand and gravels were obtained from a Local Supplier of Concrete and Construction Materials in Giza City. Firewood was used to provide the heat required for melting the plastics. The wood was obtained from the Carpentry Workshop of the Faculty of Agriculture, Cairo University. A 6-hole mold was built from wood and used to cast the bricks and blocks. The dimensions of each brick or block were 20 cm in length, 10 cm in width and 5 cm in height. Figure 2 shows the plastic, sand, gravels used in the study. The mold used to cast the bricks and blocks is shown in Figure 3.

### Experimental Design

Two experiments were carried out in this study. In the first experiment, building bricks were made using sand and plastics. No cement was use in this experiment and melted plastic was use as a replacement for cement. Three treatments were carried out having plastic: sand ratios of 2: 1, 1: 1 and 1: 2. Table 2 shows the weights of the plastic and sand used in each treatment. In the second experiment, concrete blocks were made using sand, gravels and recycled plastics. No cement was use in this experiment and melted plastic was use as a replacement for cement. Three treatments were carried out having plastic: sand: gravels ratios of 2: 1: 1, 1: 1: 1 and 1: 2: 2. Table 3 shows the weights of the plastic, sand and gravels used in each treatment.

## Preparing the Mixtures and Casting the Bricks and Blocks

In the first experiment, the required amount of plastic was placed in the melting cast iron pot and the pot was heated using firewood. When the plastic was completely melted and became liquid, the desired amounts of sand and plastic were added according to the ratios presented in Table 2. The sand-plastic mixture was mixed thoroughly and then placed in the mold. The bricks were left to cool down and then removed from the mold for testing. The same procedure was followed for making the concrete blocks with plastic, sand and gravels. After the required amount of plastic was melted, the desired amounts of sand and gravels were added to the melted plastic according to the ratios shown in Table 3. The plastic-sand-gravel mixture was mixed thoroughly and placed in the mold. The concrete blocks were left to cool down and then removed from the mold for further testing.

## Thermal Conductivity Measurement

Thermal conductivity measures the heat conducting capacity of a material. The thermal conductivity ( $\lambda$ ) is defined as the thermal energy (heat)  $Q$  transmitted through a thickness  $d$  in the direction normal to a surface  $A$  under a temperature gradient  $\Delta T$  K ( $T_h - T_c$ ) according to the following equation [42]:

$$Q = -\lambda A \Delta T / d \quad (1)$$

Where:

$Q$  = The heat flux (W)

$\lambda$  = The thermal conductivity of the material ( $\text{W m}^{-1} \text{K}^{-1}$ )

$A$  = The surface area of the material ( $\text{m}^2$ )

$\Delta T$  = The temperature gradient ( $T_1 - T_2$ ) between the two surfaces of the material (K)

$d$  = The thickness of the material (m)

$T_h$  = Hot side temperature (K)

$T_c$  = Cold side temperature (K)

Heat transfer occurs at a higher rate across materials of high thermal conductivity like copper (385 watt/m. K) than those of low thermal conductivity such as air (0.024 watt/m. K at 0 °C). The most commonly used measurement techniques for thermal conductivity are steady state methods and transient methods. The steady state methods measure thermal conductivity by establishing a temperature difference that does not change with time while transient method usually measures time dependent energy dissipation process of a sample [43]. The transient technique overcomes the drawbacks associated with the steady state technique such as parasitic heat loss, contact resistance of temperature sensor and long waiting time to establish steady



**Figure 2:** The materials used in the study (A) Waste plastic; (B) Sand; (C) Gravels



**Figure 3:** The mold used to form the bricks and blocks

Treatment	Plastic: Sand Ratio	Weight of Plastic (g)	Weight of Sand (g)
1	2: 1	300	150
2	1: 1	225	225
3	1: 2	150	300

**Table 2:** Ratios and weights of the plastic and sand used to make plastic bricks

Treatment	Plastic: Sand: Gravel Ratio	Weight of Plastic (g)	Weight of Sand (g)	Weight of Gravels (g)
1	2: 1: 1	225	112.5	112.5
2	1: 1: 1	150	150	150
3	1: 2: 2	90	180	180

**Table 3:** Ratios and weights of the plastic, sand and gravels used to make plastic concrete blocks

state temperature difference [44] and it is also suitable for the configuration of the sample used in this study [43].

An apparatus for quick measurement of thermal conductivity of the sample brick or block was designed and constructed in the Bioengineering Laboratory. The apparatus is like those reported in literature for the transient technique [45-50]. A box was constructed using 7.5 cm thick Styrofoam materials with internal dimensions of 20x15x10 cm and external dimensions of 35x30x25 cm. The brick (or block) was placed in the middle of the box (between the heat source and the heat sink) on the side of its depth (5 cm) leaving an air chamber on each side of 20x10x5 cm as shown in Figure 4. The system is equipped with a heating coil with a known steady state power input (placed in the heat source chamber) and the heat flow was assumed to be one dimensional with no lateral heat loss. Thermocouples were placed in both chambers for measuring the temperatures. An electronic circuit was used to read the temperatures. The temperature drop  $\Delta T$  across the thickness  $d$  of the brick or block was measured after 5 and 15 min and the thermal conductivity ( $\lambda$ ) was calculated using equation 1.

## Bending Stress Test

When a beam experiences a load at the middle of its span (3 point flexure loading), the top fibers of the beam undergo a normal compressive stress and the bottom fibers of the beam undergo a normal tensile stress while the stress at the horizontal plane of the neutral is zero. Calculating the maximum bending stress is crucial for determining the adequacy of beams. The bending stress is calculated as follows [51]:

$$\sigma = My/I \quad (2)$$

Where:

$\sigma$  = Bending stress ( $\text{N.m}^{-2}$ )

$M$  = Bending moment and is equal to  $PL/4$  ( $\text{N.m}$ )

$y$  = Vertical distance from neutral axis and is equal  $h/2$  (m)

$I$  = Moment of inertia around the neutral axis and is equal to  $bh^3/12$  ( $\text{m}^4$ )

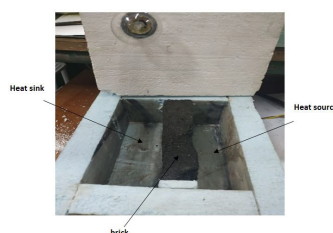
$h$  = height of the beam (m)

$b$  = Width of the beam (m)

$L$  = Length of the beam

$P$  = Load

The purpose of this experiment was to determine the relationship between the load ( $P$ ) and the bending stress ( $\sigma$ ) and calculate the maximum bending stress  $\sigma_{\max}$ . A fracture and toughness testing machine (model ASTM E399, Norwood, Maryland, USA) was used. The brick or block to be tested was placed on the testing machine and the loads were applied on the sample till fracture took place. The recorded data was used to calculate the  $M_{\max}$  and  $\sigma_{\max}$ .



**Figure 4:** Placement of the brick in the insulated box for thermal conductivity measurement.

## Results and Discussion

### Wight of Molded Materials

In this study, plastic was used as a replacement for cement to form bricks and concrete blocks. In the first experiment, plastic was used as replacement for cement to form bricks with 3 different plastic: sand ratios (2:1, 1:1 and 1:2). In the second experiments, plastic was also used as a replacement to cement to form concrete blocks with different plastic: sand: gravels ratios (2:1:1, 1:1:1 and 1:2:2). Samples of the bricks and concrete blocks are shown in Figure 5. The results showed that increasing the amount of plastic in the mixture decreased the final density of the molded bricks and concrete blocks.

Using waste plastics in making bricks and concrete blocks is advantageous due to its extreme versatility and ability to be tailored to meet specific technical needs. Also, plastic is light weight compared to other competing material which reduces fuel consumption during transportation of these construction materials. In addition, replacing cement with waste plastic will reduce environmental problems associated with the disposal of waste plastic as well as those associated with the cement industry including cement dust, air pollution, water pollution, solid pollution, noise pollution, ground vibration and resources depletion due to raw material extraction.

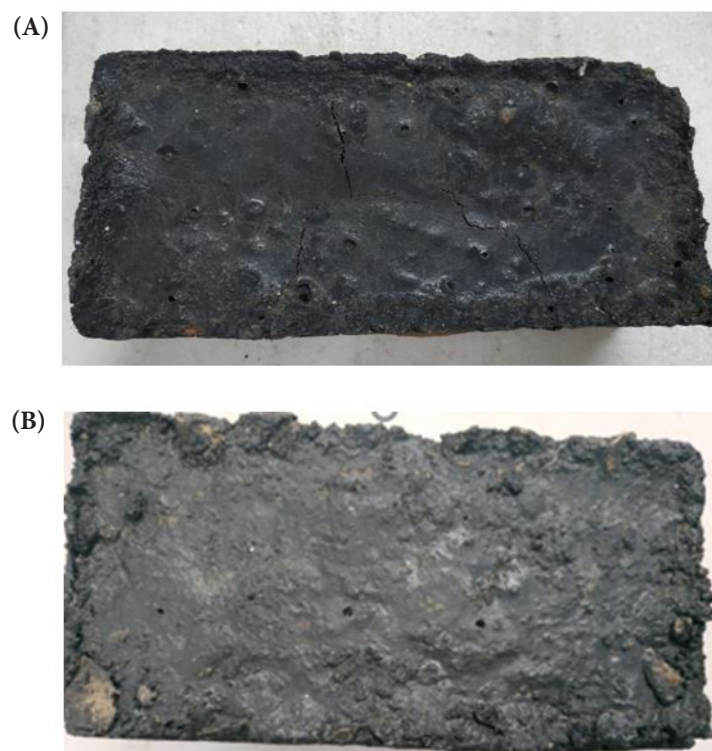
Jassim [1] mixed high-density polyethylene waste with Portland cement with percentages varying from 15% to 85% to investigate the possibility of producing plastic cement and reported a decrease in density with increases in the percentage of plastic. The author considered this process to be environmentally friendly method for manufacturing lightweight construction materials that has many benefits including simplicity, low cost, energy saving and clean recycling of waste plastic.

Binici *et al.* [6] investigated the production of mortars with disposable polyethylene bottles without cement. The disposable polyethylene bottles were converted into fibers and molten with different types of sands at the temperature range of 180–200°C. They stated that this process would reduce the amount of plastic going to landfill and reduce the CO<sub>2</sub> emissions from cement and concrete production which is about 8% of the global emission.

Naik and Moricon [52] stated that the cement industry is a major contributor to global warming as the production of one-ton Portland cement creates approximately one-ton of CO<sub>2</sub> and other greenhouse gases. They suggested using recycled materials to produce alternative cement.

### Thermal Conductivity

Thermal conductivity is the measure of heat transfer through a body internally. Thermal conductivity has many important applications in heat transfer, construction materials and engineering applications. Thus, accurate measurements of thermal conductivity are required. The experimental setup was designed to measure transient heat transfer though the spacemen (a brick or a block) and the steady-state temperature distribution in both sides of the brick or block. Steady-state measurements of the temperature difference  $\Delta T$  were used to determine the thermal conductivity of the bricks and concrete blocks. The thermal conductivity measurements for the bricks and concrete blocks are shown in Tables 4 and 5.



**Figure 5:** Samples of plastic bricks and concrete blocks (A) A brick with a plastic: sand ratio of 2:1; (B) A concert block with plastic: sand: gravels ratio of 2:1:1



Sample	Plastic: Sand Ratio	Time (min)	Temperature Difference $\Delta T$ (K)	Thermal Conductivity $\lambda$ (W/m.K)
1	2:1	5	286	$1.43 \times 10^{-3}$
		15	294	$1.42 \times 10^{-3}$
2	1:1	5	284	$1.53 \times 10^{-3}$
		15	292	$1.52 \times 10^{-3}$
3	1:2	5	282	$1.71 \times 10^{-3}$
		15	288	$1.70 \times 10^{-3}$

$$\lambda = (Qd)/(A\Delta T)$$

**Table 4:** Thermal conductivity measurements for bricks

Sample	Plastic: Sand: Gravels Ratio	Time (min)	Temperature Difference $\Delta T$ (K)	Thermal Conductivity $\lambda$ (W/m.K)
1	2:1:1	5	289	$1.51 \times 10^{-3}$
		15	294	$1.50 \times 10^{-3}$
2	1:1:1	5	287	$1.53 \times 10^{-3}$
		15	292	$1.52 \times 10^{-3}$
3	1:2:2	5	285	$1.63 \times 10^{-3}$
		15	289	$1.62 \times 10^{-3}$

$$\lambda = (Qd)/(A\Delta T)$$

**Table 5:** Thermal conductivity measurements for concrete blocks

The results obtained in this study showed that thermal conductivity depended upon the plastic content of the molded materials. Decreases in the thermal conductivity were observed with increases in the plastic contents of the bricks and concrete blocks as shown in Figure 5. Increasing the plastic content in the bricks from 33.33% to 66.67% (100%) decreased the thermal conductivity from  $1.70 \times 10^{-3}$  W/m.K to  $1.43 \times 10^{-3}$  W/m.K (16 %) while increasing the plastic content from 20% to 50% (150%) in the concrete blocks decreased the thermal conductivity from  $1.61 \times 10^{-3}$  W/m.K to  $1.50 \times 10^{-3}$  W/m.K (7 %). The results also showed that bricks and concrete blocks with similar plastic contents (50%) have similar thermal conductivity.

Patel *et al.* [43] stated that the thermal conductivity is a property of the material and depends on the structure of the material and how closely atoms are packed in lattice. The higher the density of material, the more closely the atoms will exist. Insulating materials used in homes have a low thermal conductivity, indicating that they do not let heat pass through them easily due to higher distance between atoms in these materials. When thermal excitation is provided to an atom of dense material, its vibrational energy increases and energizes the adjacent atoms, thus transmitting energy in the form of kinetic energy (vibrational energy) instead of transmitting it. Therefore, a low thermal conductivity of bricks or blocks indicates a good insulating property of these materials.

Zhao *et al.* [48] reported that thermal conductivity is affected by the temperature, surface roughness, surface hardness, impurities, cleanness and contact pressure. The thermal conductivity measured in this study was slightly affected by the temperature difference  $\Delta T$ . Increasing the time from 5 min to 15 min increased the temperature difference  $\Delta T$  from 286 K to 294 K (2.7%), from 284 K to 292 K (2.7%) and from 282 K to 288 K (2.1%) for bricks having plastic: sand ratios of 2:1, 1:1 and 1:2, respectively. Also, the temperature difference  $\Delta T$  increased from 289 K to 294 K (1.7%), from 287 K to 292 K (1.7%) and from 285 K to 289 K (1.4%) for the blocks having plastic: sand: gravel ratios of 2: 1: 1, 1:1:1 and 1:2:2, respectively. However, the variation in  $\Delta T$  was with the reported range in the literature of 1-3% for the thermal conductivity transient measurement technique [44,49,50].

The thermal conductivity apparatus and the transient measurement methods used in this study proved adequate and provided consistence results with high degree of accuracy. The variations in the thermal conductivity measurements were 0.70%, 0.66% and 0.59% for bricks having plastic: sand ratios of 2:1, 1:1 and 1:2 and 0.69%, 0.66% and 0.62% for the blocks having plastic: sand: gravel ratios of 2: 1: 1, 1:1:1 and 1:2:2, respectively

## Bending Stress

Because concrete structures are subjected to flexural loading in typical applications, the flexure testing of these materials was commonly performed. Flexure testing is among the simplest of the tests to perform, yet the state of stress and failure modes produced within a flexure test specimen are among the most complex. Under three-point flexural loading, the tensile, compressive and shear stresses that are produced (Figure 6) vary along the length and through the thickness of the specimen. Depending on the span length as well as the material orientation of the specimen during the test, either a tensile, compressive or shear failure might be produced under flexural loading. In this study, the most common type of flexure test was performed, in which the specimen is designed to fail due to bending stresses.



The experimental work was carried out to determine the maximum load applied on the brick or block before fracture takes place. The bending moment and bending stress were then calculating. The results are shown in Tables 6 and 7 and presented in Figures 7 and 8.

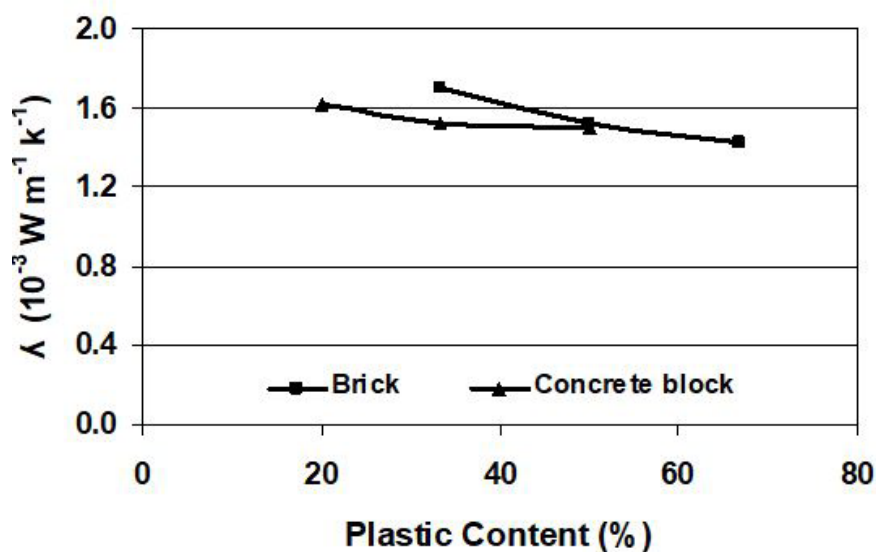


Figure 6: Effect of plastic content on the thermal conductivity of the molded materials

$M_y/(I)$

Sample	Plastic: Sand Ratio	M (N.m)	σ (N/m²)
1	2:1	1711.25	10,26
2	1:1	721.55	4.32
3	1:2	540.00	3.24

$$\sigma = \frac{M_y}{I}$$

Table 6: Maximum bending moment and bending stress for bricks

Sample	Plastic: Sand: Gravels Ratio	M (N.m)	σ (N/m²)
1	2:1:1	1442.55	8.65
2	1:1:1	1081.90	6.40
3	1:2:2	901.40	5.40

$$\sigma = \frac{M_y}{I}$$

Table 7: Maximum bending moment and bending stress for concrete blocks

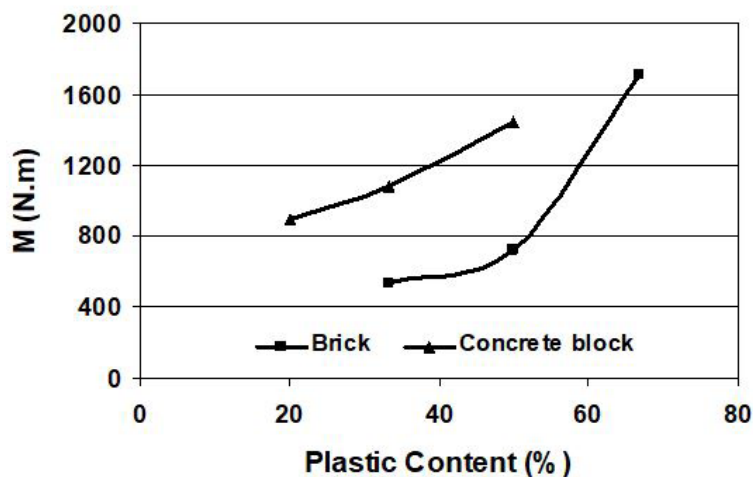


Figure 7: Effect of plastic content on the maximum bending moment of molded materials

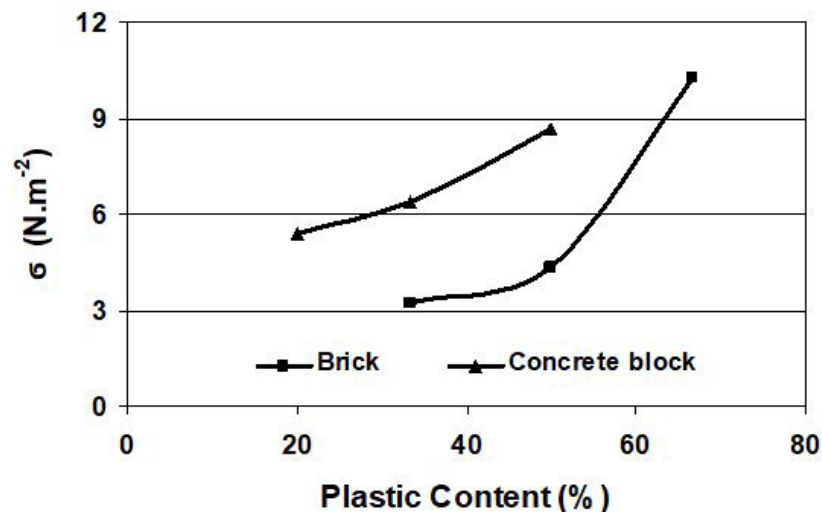


Figure 8: Effect of plastic content on the maximum bending stress of molded materials

The results showed that the bending moment and thus the bending stress increased with increasing the plastic content in the bricks and concrete blocks. Increasing the plastic content of the brick from 33.33% to 66.67% (100%) increased the bending moment from 540.00 N.m to 1711.25 N.m (216%) and the bending stress from 3.24 N.m<sup>-2</sup> to 10.26 N.m<sup>-2</sup> (216%) and increasing the plastic content of the concrete blocks from 20 % to 50 % (150%) increased the bending moment from 901.40 N.m to 1442.55 N.m (60%) and the bending stress from 5.40 N.m<sup>-2</sup> to 8.65 N.m<sup>-2</sup> (60%). The results also showed that, for similar plastic contents (50%), the concrete blocks had a lower bending moment (1442.55 N.m) and a lower bending stress (8.65 N.m<sup>-2</sup>) than the bending moment (1711.25 N.m) and bending stress (10.26 N.m<sup>-2</sup>) of the bricks.

Rebeiz [53] studied the strength properties and behavior of unreinforced and reinforced polymer concrete (PC) using an unsaturated polyester resin based on recycled polyethylene terephthalate (PET) plastic. The results obtained showed that resins based on recycled PET could be used to produce good quality PC for precast applications such as utility components, transportation components, machine bases and building components. The author stated that the use of recycled PET in PC helped in reducing the cost of the material, solving some of the solid waste problems posed by plastics and saving energy.

Jassim [1] mixed high-density polyethylene waste with Portland cement with different percentages (15% to 85% by volume) and evaluated the properties of product. The results show that there is a possibility to produce plastic cement from polyethylene waste and Portland cement using 60% plastic and 40% cement and mixing this with sand to produce lightweight materials. The density of this material was decrease, the ductility was increased, and the workability was improved compared to using cement only.

Binici *et al.* [6] investigated the production of mortars with disposable polyethylene bottles without cement. The bottles were crushed, converted into fiber and then molted with different types of sands at the temperature range of 180–200 °C. Some physical (water absorption and abrasion resistance) and mechanical (bending strength, compressive strength, toughness) properties of the mortar were tested. The results indicated that bending strength and toughness of mortars were improved, water absorption of mortar was negligible, and abrasion was nearly equal to zero. Polyethylene improved the flexibility of concretes and increased toughness.

Agyeman *et al.* [54] produced concrete paving blocks with a cement: quarry dust: sand ratio of 1:1:2 by weight to serve as control. They replaced cement with plastic and produced paving blocks with high plastic (HP) and low plastic (LP) contents with plastic: quarry dust: sand ratios of 1:1:2 and 1:0.5:1 by weight, respectively. All paving blocks were tested for compressive strength at 7, 14 and 21 days curing via water sprinkling. Water absorption test was done after 72 h of soaking. The study revealed that after 21 days, the control, HP and LP paving blocks had compressive strengths of 6.07 N/mm<sup>2</sup>, 8.53 N/mm<sup>2</sup> and 7.31 N/mm<sup>2</sup> and water absorptions of 4.9%, 0.5% and 2.7%, respectively. The authors recommended that paving blocks made from the recycled plastic waste should be used in non-traffic areas such as walkways, footpaths, pedestrian plazas, landscapes, monument premises and in waterlogged areas due to their low water absorption property and relatively low compressive strengths.

Other researchers used granular waste plastic as aggregates in concrete and reported their effects on weight loss, impact load, sulphate attack [55], porosity [56], abrasion resistance [57], oxygen permeability [55,56], splitting strength [58,59], density [60,61], modulus of elasticity [57,62], water absorption [59,62,63], compression [55,57-64], flexural strength [57,58,62,63], workability [60,61, 65,66] and strength [57,60,62,63]. Silva *et al.* [67] and Kumar and Baskar [68] reported reductions in both the fresh and dry density of concrete made with waste plastic aggregates. Coppola *et al.* [69] stated that increasing the percentage of plastic in concrete reduced the dry weight after 28 days. Akram *et al.* [59] and Hama and Halil [70] reported 50% reduction in dry weight of a concrete containing 50% plastic aggregates and referred that to the lower specific gravity of plastic.

## Conclusions

Plastics play an important role in modern society and are used daily in diverse applications due to their low cost, ease of manufacturing and attractive qualities. About 300 million tons of plastic are produced globally each year of which only about 25% is recycled and the rest is landfilled or find their way into rivers and oceans. An estimated 7 million tons of waste plastic end up as trash in the sea each year which cause significant environmental and health problems for fish and sea animals. Consequently, plastic waste brings serious environmental challenge to modern society because it is made of several toxic chemicals that can pollute soil, water and air if not managed properly.

Recycling waste plastic is sustainable and can conserve natural resources. The percentage of recycled plastic can be increased by transforming waste plastic into mortar and concrete products suitable for housing and construction. In this study, melted plastic bags were used as a replacement for cement in the production of construction building bricks and concrete blocks. Using waste plastic in making bricks and blocks is advantageous due to its extreme versatility and ability to be tailored to meet specific technical needs and its light weight compared to other competing material which reduces fuel consumption during transportation. Also replacing cement with waste plastic will reduce environmental problems associated with the disposal of waste plastic as well as those associated with the cement industry.

The results showed that the thermal conductivity depended upon the plastic content of the molded materials. Decreases in the thermal conductivity were observed with increases in the plastic content of both the bricks and concrete blocks. Increasing the plastic content from 33.33% to 66.67% (100%) in the bricks decreased the thermal conductivity from  $1.70 \times 10^{-3}$  watt/m.K to  $1.43 \times 10^{-3}$  Watt/m.K (16 %) while increasing the plastic content from 20% to 50% (5) in the concrete blocks decreased the thermal conductivity from  $1.61 \times 10^{-3}$  watt/m.K to  $1.50 \times 10^{-3}$  Watt/m.K (7 %). The results also showed that bricks and concrete blocks with similar plastic contents (50%) have similar thermal conductivity values.

The thermal conductivity measured in this study was slightly affected by the temperature difference  $\Delta T$ . Increasing the time from 5 min to 15 min increased the temperature difference  $\Delta T$  from 286 K to 294 K (2.7%), from 284 K to 292 K (2.7%) and from 282 K to 288 K (2.1%) for bricks having plastic: sand ratios of 2:1, 1:1 and 1:2, respectively. Also, the temperature difference  $\Delta T$  increased from 289 K to 294 K (1.7%), from 287 K to 292 K (1.7%) and from 285 K to 289 K (1.4%) for the concrete blocks having plastic: sand: gravel ratios of 2: 1: 1, 1:1:1 and 1:2:2, respectively. However, the variation in  $\Delta T$  is with the reported range in the literature of 1-3% for the thermal conductivity transient measurement technique.

The thermal conductivity apparatus and the transient measurement methods used in this study proved adequate and provided consistence results with high degree of accuracy. The variations in the thermal conductivity measurements were 0.70%, 0.66% and 0.59% for bricks having plastic: sand ratios of 2:1, 1:1 and 1:2 and 0.69%, 0.66% and 0.62% and for the blocks having plastic: sand: gravel ratios of 2: 1: 1, 1:1:1 and 1:2:2, respectively.

The results of the flexure testing showed that the bending moment and thus the bending stress increased with increasing the plastic content in both the bricks and concrete blocks. Increasing the plastic content of the brick from 33.33% to 66.67% (100%) increased the bending moment from 540.00 N.m to 1711.25 N.m (216%) and the bending stress from  $3.24 \text{ N.m}^{-2}$  to  $10.26 \text{ N.m}^{-2}$  (216%) and increasing the plastic content of the concrete blocks from 20% to 50 % (150%) increased the bending moment from 901.40 N.m to 1442.55 N.m (60%) and the bending stress from  $5.40 \text{ N.m}^{-2}$  to  $8.65 \text{ N.m}^{-2}$  (60%). The results also showed that, for similar plastic contents (50%), the concrete blocks had a lower bending moment (1442.55 N.m) and a lower bending stress ( $8.65 \text{ N.m}^{-2}$ ) than bending moment (1711.25 N.m) and bending stress  $10.26 \text{ N.m}^{-2}$  of the bricks.

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## Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript

## Competing Interests

The authors have declared that no competing interests exist.

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