

**Republic of Iraq**

**Ministry of Higher Education and Scientific Research**

**University of Babylon**

**College of Materials Engineering**

**Department of Polymer Engineering and Petrochemical Industries**



# **Manufacturing and Characterization of Polymeric/ Fillers Bricks**

A Thesis

Submitted to the Council of the College of Materials  
Engineering/ University of Babylon in Partial Fulfillment of  
the Requirements for the Master Degree in Materials  
Engineering/ Polymer

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

قَالُوا سُبْحَانَكَ لَا عِلْمَ

لَنَا إِلَّا مَا عَلَّمْتَنَا إِنَّكَ

أَنْتَ الْعَلِيمُ الْحَكِيمُ

صدق الله العلي العظيم

سورة البقرة (الآية 32)

# **Dedication**

**To**

**My Father, Mother, Brothers and Sisters**

**The unique family who gave me all the love and  
support that I need.**

**My friends**

**For being my guardian during my educational  
career**

**With respect and love**

## Acknowledgements

Firstly, all the thank and praise be to **ALLAH** for enabling me to achieve this study.

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I would like to express my sincere thanks and deepest gratitude to my supervisor **Assist. Prof. Ahmed Fadhil Hamzah** for his continued encouragement, knowledgeable advice, guidance and support throughout this study.

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Finally, I do not forget to present, big thanks to all who participated in helping and assistance me during the period of the study as well as the experimental work and to complete this thesis in every the places and the times.

***RUSUL MOHAMMED/ 2022***

## **Abstract**

Polymers are an important part of modern life and have a wide range of applications. Where there are rising uses in packaging, agriculture, cars, and biomedical due to the availability of fabrication of desired shape, color, and specification to clients, because of the non-degradable nature of polymer, the disposal of polymer waste after its use has become a major problem in modern society. Therefore, there is great interest in recycling this non-biodegradable chemical and converting it into other products, and benefiting from it.

Therefore, recycling such polymer waste as building materials is a viable solution not only to this pollution problem but also to the problem of the economic design of buildings. This research aims to study the possibility of using polymer waste in the manufacture of unconventional bricks that are light in weight, environmentally friendly, and inexpensive and this polymer brick can be used to pave floors in public spaces such as sidewalks, automobile parking, garden walkways, pedestrian paths, and surface tiles, as well as utilized as a brick for building construction and partitioning walls.

In this study, two types of waste polymer are used: PET with fillers of sand and fly ash and LDPE with fillers of sand and sawdust. The melting and molding process is used in the manufacturing of polymer bricks. Various proportions of polymer waste with fillers are taken for the manufacturing of bricks.

Mechanical and Physical properties are measured (compressive strength, hardness, density, and water absorption) and the characterization properties are done using Fourier transform infrared and scanning electron microscopy.

The results of Fourier transform infrared of polymer waste (PET or LDPE) with fillers (sand, fly ash, and sawdust) reveal that there is no a chemical reaction between the components and just a physical reaction.

The results of compressive strength show an increase by the addition of sand and fly ash but reduced with the greater addition of sawdust. Although the greatest result is obtained for LDPE sample with 20% sawdust with a value (66.89MPa).

The results of this study show an increase in density and hardness for both addition sand and fly ash but a decrease with sawdust addition where the highest value is obtained from density test for 40% PET/60% sand with a value of (1.7614 g/cm<sup>3</sup>) and the lowest value is obtained for 50% LDPE/50% sawdust with a value of (0.7065 g/cm<sup>3</sup>) and the highest and the lowest value obtained from the hardness test is (77.5 shore D) for 40% PET/60% sand and (44.8 shore D) for 50% LDPE/50% sawdust. In addition it shows excellent performance of water absorption test for all samples except when increased adding sawdust, especially in the 50% LDPE/ 50% sawdust sample with a value of 21.05%.

The scanning electron microscope results show good homogeneity and dispersion between the base materials (polymer) and additives. It is also noted that there are no defects or voids, which indicates the success of the preparation and mechanical mixing of the composite material.

## List of Symbols

Symbols	Meaning	Unit
<b>A</b>	Cross-sectional area	mm <sup>2</sup>
<b><i>f</i></b>	Compressive strength	MPa
<b>P</b>	Fracture load	N
<b>T<sub>g</sub></b>	Glass transition temperature	°C
<b>T<sub>m</sub></b>	Melting temperature	°C

## List of Abbreviations

Abbreviation	Meaning
ASTM	American Society for testing materials
BHET	Hydroxyl ethylene terephthalate
DMT	Dimethyl terephthalate
EG	Ethylene glycol
EPA	United states environmental protection agency
FTIR	Fourier transform infrared
HDPE	High density polyethylene
IQS	Iraqi standard specifications
IR	Infrared rays
LDPE	Low-density polyethylene
LLDPE	Linear low density polyethylene
MSW	Municipal solid waste
MWP	Municipal waste polymer
PET	Polyethylene terephthalate
SEM	Scanning electron microscope
TPA	Terephthalic acid
UV	Ultraviolet spectra

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# Chapter One

## Introduction

## 1.1 Introduction:-

The disposal of waste polymers has become a major environmental problem all over the world [1]. The amount of generation of polymer waste is increasing day by day and proper disposal methods for waste polymers are not channelized even today. Polymer is classified into two types, thermoplastic and thermoset polymer. Thermoplastic is a type of polymer that is recyclable and further moulded into another shape. These polymers are polyethylene, polypropylene, polyamide, polyoxymethylene, polytetrafluoroethylene and polyethylene terephthalate and so on. The second type is thermosetting polymer this type of polymer have the property of unchangeable molecular chains because molecular chains are strongly bonded with crosslinks. Some examples are melamine, epoxy resin, polyurethane, phenolic and silicone. Reuse of thermopolymer waste can help in reducing the pollution caused due to burning, and costs will also be reduced up to some extent [2].

The properties of polymers such as lightness, strength, corrosion-resistant materials, transparent, durable, easy to process, resistance to solvents and many chemicals, easy to coloring with high thermal and electrical insulation properties, etc. [3, 4, 5]. These properties led to an increase in the amount of polymer generated annually. Approximately, every 10 years the rate of expansion is doubled. This also can be attributed to some factors such as population growth, urbanization, industrialization, and change in trend and lifestyle [6, 7]. Thus disposal of waste polymer is a serious problem globally since they are non-biodegradable but only photodegrades into smaller pieces. The chemical bonds between the molecules that comprise polymer not only make them resilient but also impenetrable to natural degradation and also polymers are expected to remain in the environment for hundreds or even thousands of years without degradation [8, 9, 10].

Looking forward the scenario of present lifestyle a complete ban on the use of polymer cannot be put even though the waste polymer is taking the face of devil for the present and future generation. But polymer is an effective raw material because of its large scale production witnessed after the industrial revolution. Today, it is impossible for any vital sector of the economy to work efficiently without usage of polymer starting from agriculture to packaging [11]. However, due to its non-biodegradable nature, it is affecting the environment through pollution. For this reason, there is an urgent need to remove polymer waste from the environment. These polymers can be removed by burning, reusing, landfilling or recycling. Burning polymer waste produces hazardous toxic fumes, whereas reusing it is not an attractive alternative because of contamination, and landfilling releases less gas emission but space given for landfills is limited. Providing layers for landfills will lead to releasing or leaking of toxins which contaminate soil and nearby. For these reasons, recycling to other products turns out to be a more attractive choice [12, 13].

Hence recycling polymer waste in the building construction industry is considered one of the most feasible applications and can solve the problem of eliminating polymer waste as well as reducing the demand for construction materials [11, 14].

The applications of polymer bricks can be as versatile as external walls as a brick and can be used to pave floors in public spaces such as sidewalk, car parking, walkways in gardens, pedestrian paths and surface tiles, also can be used as a brick for building construction and partitioning walls.

## 1.2 Aims of This Work

To produce lightweight, economical and environmental friendly bricks from waste materials (polymer, fly ash, sand and sawdust).

## 1.3 Objective

1. Preparation of polymer waste by:
  - A- Collection
  - B- Removing of caps and plastic stickers
  - C- Washing and drying
  - D- Shredding
2. Preparation of filler by:
  - A- Sieving of fillers is done by 600  $\mu\text{m}$
  - B- Drying fillers at 100<sup>0</sup> C for about 20 to 30 min
3. Adding fillers to polymer waste
4. Manufacturing a polymer brick by:
  - A- Mixing polymer waste with filler
  - B- Melting the mixture
  - C- Pouring the mixture into the mold
  - D- Contact pressure is applied
  - E- Leave the sample in the mold for at least 3 hours
  - F- Finished bricks
5. Testing
  - A- Compressive strength Test
  - B- Hardness Test (Shore D)
  - C- FTIR

D- SEM

E- Density

F- Water Absorption Test

## **2.1 Introduction:**

In today's world, the utility of polymer-based products is increasing day by day resulting in the generation of more amount of polymer waste, leading to a waste disposal crisis [15]. Where the production of polymers has increased substantially over the last 60 years from around 0.5 million tons in 1950 to over 260 million tons today [16]. Polymers are largely utilized and therefore contribute to an ever-increasing of solid waste volume. Among the polymer waste, polyethylene forms the largest fraction, followed by polyethylene terephthalate, most known as PET. The last is obtained in large quantity from polymer bottles utilized as containers of beverages and mineral water [17]. Common polymer items that are used are covers, bottles, and food packages. The great problem with polymer is its decomposition. Polymer is made of polymer chemicals and they are non-biodegradable. This means that polymer will not decompose when it is placed in the earth [18].

At present, the disposal processes of polymer wastes are mainly incineration and landfill. The incineration and landfill deposition of municipal waste polymers (MWP) may cause environmental problems and is becoming more expensive. Due to increasing volume of MWP and decreasing landfill capacity for disposal, landfill becomes more challenging [19]. The disposal of polymer waste in an open environment leads to various environmental problems due to their low biodegradability and presence in large quantities which are disturbing the ecological balance of nature and is the major cause of health hazards to living beings [20, 21, 22].

## 2.2 Municipal Solid Waste (MSW)

Municipal solid waste (MSW) is generally defined as non-hazardous waste. The United States Environmental Protection Agency (EPA) characterizes MSW as “waste consisting of everyday items, used and then thrown away, such as product packaging, bottles, food scraps and newspapers which comes from homes, schools, hospitals and businesses.” MSW is classified into three broad categories according to where it is generated: household waste, commercial waste, and institutional waste [23, 24]. Figure (2.1.a) shows global polymer waste contributes to about 10-13% of the entire MSW. And figure (2.1.b) polymer waste composition and it is clear that Polyethylene (PE) and Polypropylene (PP) is the major utilized polymers in different applications amid all the other types [25].

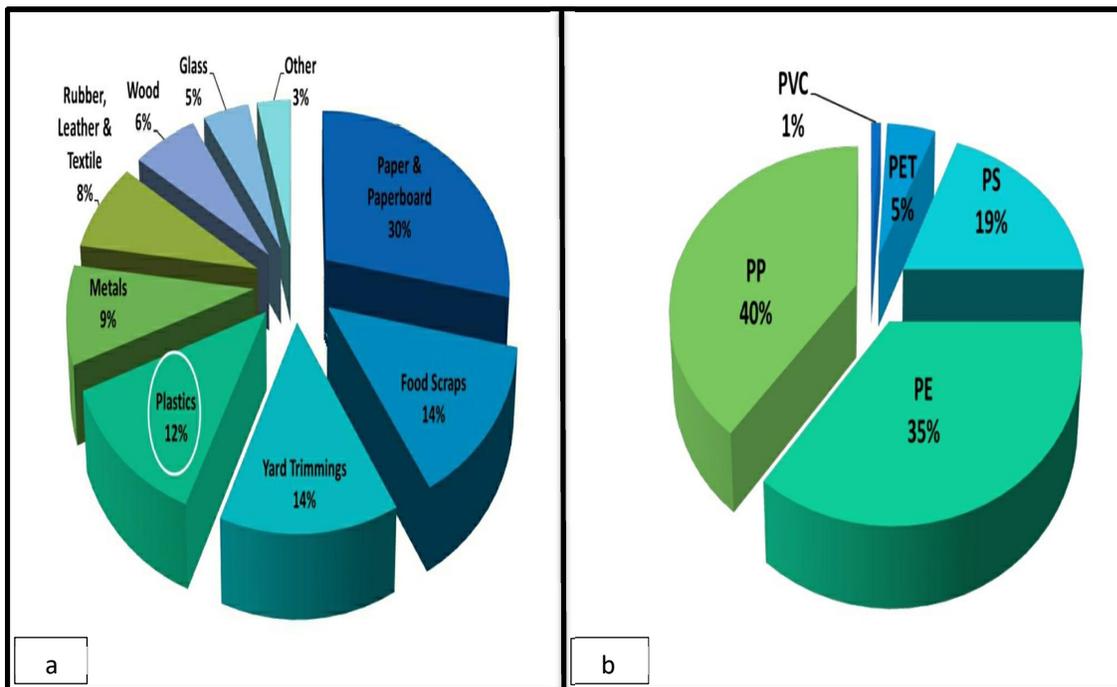


Figure (2.1): (a) Sources of MSW. (b) Polymer Waste Composition [25].

The increased uses of polymers products as packaging applications in recent years have increased the quantity of polymers in the solid waste stream to a

great extent. The quantum of solid waste is ever increasing due to the increase in population, development activities, changes in lifestyle, and socio-economic conditions [26].

### **2.2.1 Management Methods for Municipal Solid Waste**

The concept of waste management includes: (I) source reduction (II) reuse (III) recycling (IV) landfill and (V) waste-to energy conversion [27].

- Source reduction

An important aspect of the integrated waste management approach is to minimize the amount of polymers used [28].

- Reuse

To reuse is to use an item again after it has been used. This includes conventional reuse where the item is used again for the same function and new-life reuse where it is used for a different function [26].

- Recycling

Recycling converts materials and products that would otherwise become waste into valuable resources [24].

- Incineration with energy recovery [waste-to-energy conversion (WTE)]

Incineration with energy recovery is the only waste-to-energy (WTE) technology that is commercially used in the United States. The heat generated by burning waste can be used directly for heating, to produce steam, or to produce electricity [29,30].

Polymer wastes are a good fuel source because most resins have a heating value almost equivalent to that of coal. In addition to providing an attractive source of alternative energy, preserving natural resources and minimizing the

impact of dependency on energy. But, there is always public resistance emerging against incineration because of the emission of some toxic fumes [27].

- Landfill

Landfill describes engineered areas of land used for the controlled deposit of solid waste onto or into the land.

Figure (2.2) shows a flowchart of this waste management system [24]. And figure (2.3) shows waste management hierarchy [31]. Where describes the preferred course of action for managing waste. Different versions of the hierarchy are adopted, but they all follow a step-wise process for waste where prevention, minimization, and reuse (& recycling) of waste products are prioritized [32].

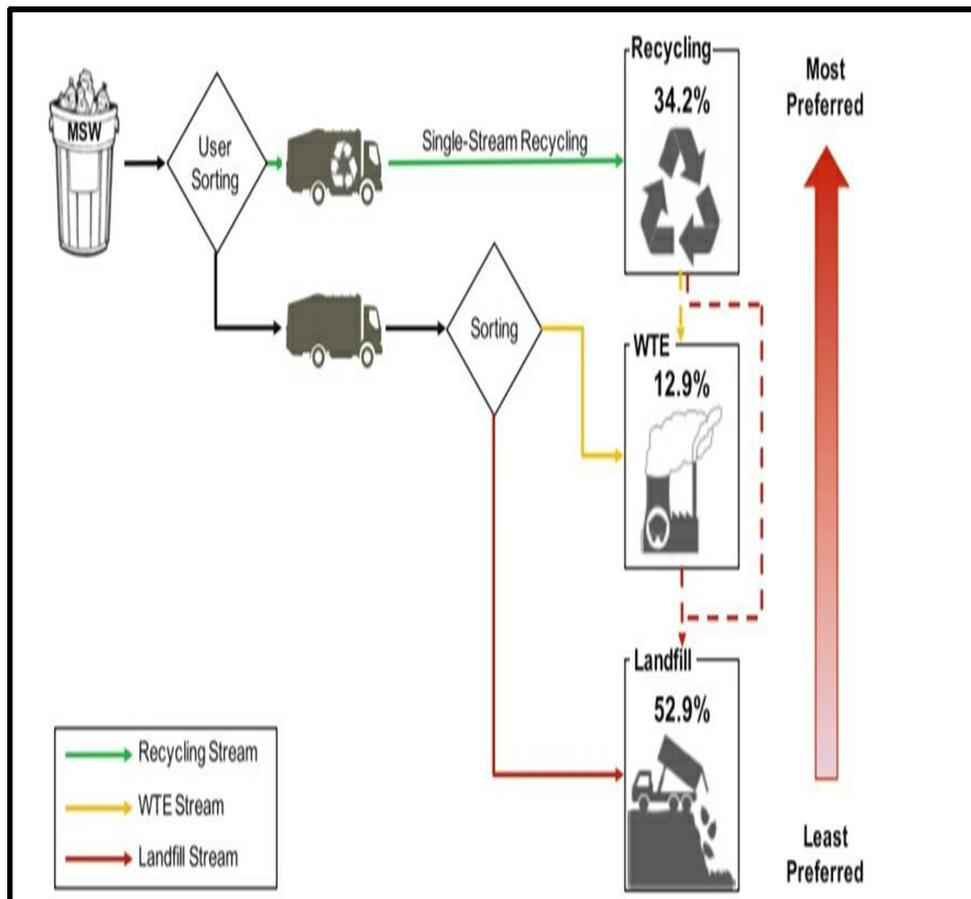


Fig.(2.2): Flowchart of the waste management stream in the United States in 2013 [24].



Figure(2.3): Waste management hierarchy [31].

## 2.3 Polymer Pollution

Events in the 20th and early in the 21st century and compendia of waste researches indicate that wastes in whatever form or classification solid, liquid or toxic have become a major sequel of modernization and economic development. The global waste generation rates are rising faster than ever, estimated at 1.3 billion tons/year in that year 2015 and expected to increase to roughly 2.2 billion tons/year by 2025. Specialists have therefore cautioned that the growth will not decrease unless individuals revised how to use and reuse natural resources[33].

The prominence of polymer pollution is correlated with polymers being inexpensive and durable, which leads to high levels of polymers used by humans. However, it is slow to degrade. Polymer pollution can unfavourably affect lands, waterways and oceans. Living organisms, particularly marine animals, can also be affected through entanglement, direct ingestion of polymer waste, or exposure to chemicals within polymers that cause interruptions in

biological functions. Humans are also affected by polymer pollution, such as through the disruption of the thyroid hormone axis or sex hormone levels [26]. There are some studies proposing that if this trend continues, by 2050 there will be more polymers in the world's oceans than fish [34]. Also without waste management infrastructure improvements, the cumulative quantity of polymer waste available to enter the ocean from land is predicted to increase by an order of magnitude by 2025 [35].

## 2.4 Recycling of Polymers

Polymer can be degraded in the environment by four mechanisms: photodegradation, thermo-oxidative degradation, hydrolytic degradation, and biodegradation by microorganisms. The natural degradation of polymer begins with photodegradation due to the UV light from the sun which provides the activation energy required to initiate the incorporation of oxygen atoms into the polymer, leading to thermo-oxidative degradation. In this step, the polymer becomes brittle and fracturing into smaller pieces until the polymer chains reach sufficiently low molecular weight to be metabolized by microorganisms. The microorganisms convert the carbon of the polymer chains to carbon dioxide or incorporate it into biomolecules, but this process will take at least 50 years. So, a solution to these problems will be recycling, because most commodity polymers are relatively stable, making monomer recovery poor [36].

Recycling of polymers is one method for reducing environmental impact and resource depletion. Recycling can therefore decrease energy and material usage per unit of output, leading to improved eco-efficiency. The only way to decrease the environmental problems caused by polymeric waste accumulation produced from day-to-day applications of polymer materials such those used in packaging and construction is by recycling. This helps to conserve natural resources because most polymer materials are made from oil and gas [37,38].

## 2.5 Various Stages of Recycling Polymer Wastes

There are various stages of recycling:

**2.5.1 Collection:** Polymer waste is collected from different locations. This can be achieved by keeping special containers at home, in public places, farms, and so on. These wastes are then collected by professional waste collectors and transported to the recycling sites.

**2.5.2 Cleaning:** The cleaning stage consists of washing and drying the polymer items. Cleaning is important since clean waste materials fetch better prices and they improve the quality of end products. Polymers can be washed at various stages of the recycling process: before, after, or even during sorting.

**2.5.3 Sorting:** This involves not only the separation of the polymers from recoverable foreign bodies but also the separation of these polymers themselves.

**2.5.4 Size Reduction:** It aims to reduce the size of the waste, which in turn facilitates not only the separation of different polymers but also recovery of the micronized powder which is used to feed processing machines. The end products of shredding can be irregularly shaped pieces of polymers, which can be sold to reprocessing industries and workshops.

After processing, these materials are further subjected to various techniques such as extrusion, injection moulding, blow moulding, and film moulding. Finally, the processed materials are converted into various products such as pipes, tubes, bags, sheets, and miscellaneous items [39].

The major polymers recycled are polyolefin (high-density polyethylene (HDPE), low-density polyethylene (LDPE), and polypropylene (PP)) and poly(ethylene terephthalate) (PET), poly(vinyl chloride) (PVC), polystyrene (PS), and polycarbonate (PC). The recyclable polymers and the recycling codes are shown in Table (2.1) [39].

Table(2.1): Various polymers with their characteristic recycling codes for particular applications [39].

Symbol	Acronym	Full name and uses
	PET	Polyethylene terephthalate - Fizzy drink bottles and frozen ready meal packages.
	HDPE	High-density polyethylene - Milk and washing-up liquid bottles
	PVC	Polyvinyl chloride - Food trays, cling film, bottles for squash, mineral water and shampoo.
	LDPE	Low density polyethylene - Carrier bags and bin liners.
	PP	Polypropylene - Margarine tubs, microwaveable meal trays.
	PS	Polystyrene - Yoghurt pots, foam meat or fish trays, hamburger boxes and egg cartons, vending cups, plastic cutlery, protective packaging for electronic goods and toys.
	Other	Any other plastics that do not fall into any of the above categories. For example melamine, often used in plastic plates and cups.

## 2.6 Recycling Techniques

There are several methods of recycling: primary recycling, mechanical or secondary recycling, chemical or tertiary recycling and energy recovery or quaternary recycling.

### 2.6.1 Primary Recycling

In this type of recycling, waste polymer is reprocessed into the same or similar types of products from which it was produced. The recycled scrap or waste is either mixed with virgin material to assure product quality or used as second-grade material. Primary recycling is very simple without any precautions except the proper and clean collection of waste in the plant [40,41].

### **2.6.2 Secondary Recycling (Mechanical Recycling)**

The polymer is ground down and then reprocessed without affecting the basic structure of the material and compounded to produce a new component that may or may not be the same as its original use [42,43].

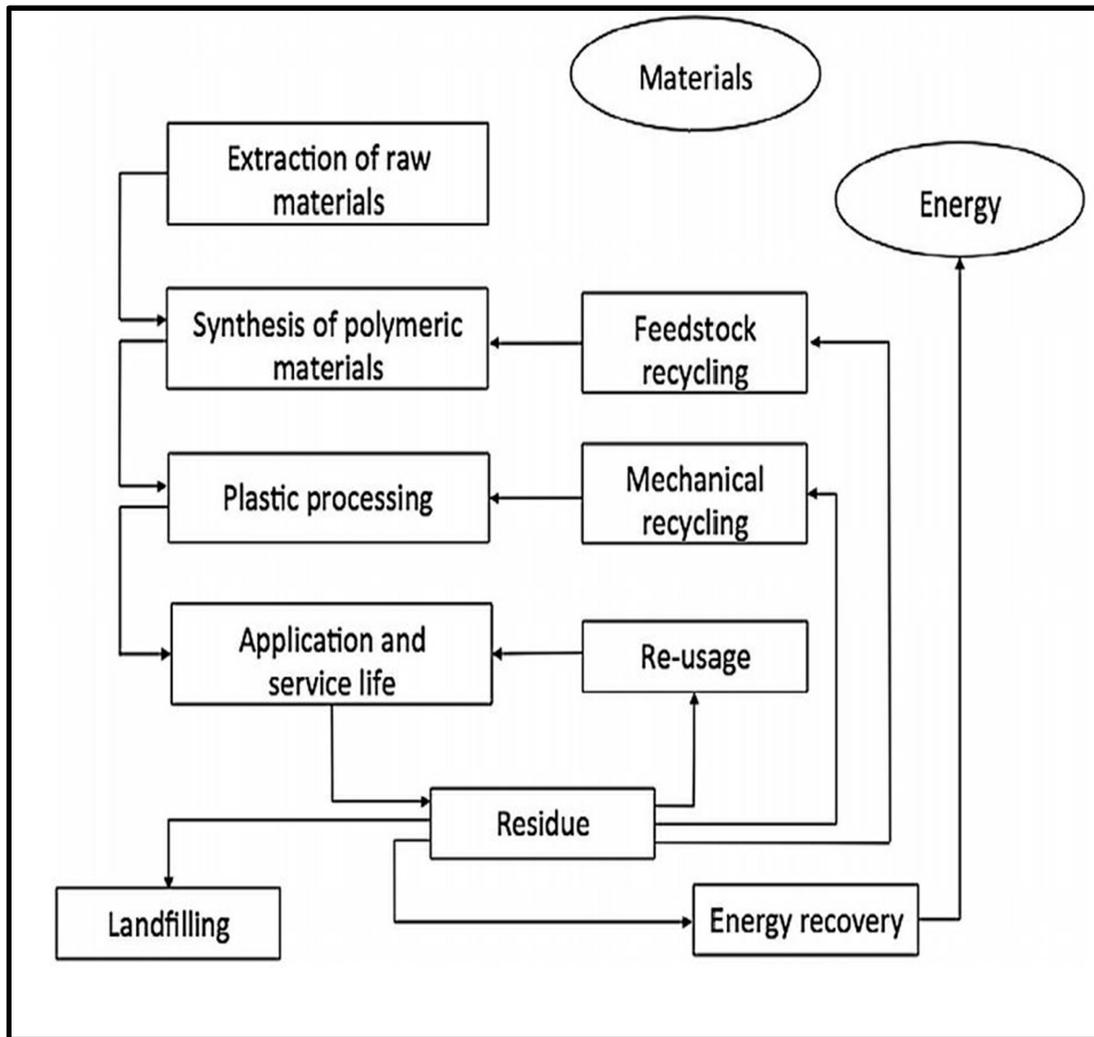
### **2.6.3 Tertiary Recycling (Chemical Recycling)**

Tertiary (chemical) recycling: the polymer waste is turned back into its oil/hydrocarbon component in the cases of polyolefin and monomers in the case of polyesters and polyamides, which can be used as raw materials for new polymer production and petrochemical industry, or into the pure polymers using suitable chemical solvents [43]. Chemical recycling is not commonly implemented on an industrial scale because present methods require sizable energy inputs [44].

### **2.6.4 Quaternary Recycling (Energy Recovery)**

This method refers to the recovery of the polymer's energy content. The most effective way to reduce the volume of organic materials which involves the recovery of energy is represented by incineration. This method is a good solution because it generates considerable energy from polymers, but it's not ecologically acceptable because of the health risk from airborne toxic substances [36].

An overview of the different pathways for recycling is shown in Fig. (2.4), including where their respective end products re-enter the lifecycle of polymers [45].



Figure(2.4): Polymer waste management options in terms of the life cycle of polymeric products [45].

In this study, mechanical recycling was adopted and will be explained below.

## 2.7 Mechanical recycling (or secondary recycling)

Mechanical recycling is the reprocessing of materials of waste polymers by physical means, like cutting, shredding, washing, and so on, into polymer products. In this approach, the polymer is separated from its associated contaminants, and it can be readily reprocessed into granules by conventional melt filtration extrusion. The size of the waste polymer is reduced after it is sorted, cleaned, and dried, and then directly processed into end products or

flakes of consistent quality, which can be further used for manufacturing other goods. The succeeding steps for recycling can vary from operation to operation and the end use [46]. The basic polymer is not altered during the process. The main disadvantage of this type of recycling is the deterioration of product properties in every cycle. This occurs because the molecular weight of the recycled resin is reduced because of chain-scission reactions caused by the presence of water and trace acidic impurities. Strategies for maintaining the polymer's average molecular weight during reprocessing include intensive drying, reprocessing with vacuum degassing, the use of chain extender compounds, and so on [47]. In mechanical recycling, only thermoplastics can be used because they can be re-melted and reprocessed into end products [46].

Thermoset polymer cannot be melted and reprocessed, so mechanical recycling is not suitable for recycling such polymers. Thermoset polymer can be processed through its use in cement kilns or tarring roads [46].

## **2.8 Steps of Mechanical Recycling**

The steps involved in mechanical recycling are the following [48]:

1. Cutting/shredding: Large polymer parts are cut by shear or saw for further processing into chopped small flakes.
2. Contaminant separation: Paper, dust and other forms of impurities are separated from polymer usually in a cyclone.
3. Floating: Different types of polymer flakes are separated in a floating tank according to their density.
4. Milling: Separate, single-polymer plastics are milled together. This step is usually taken as the first step with many recyclers around the world.

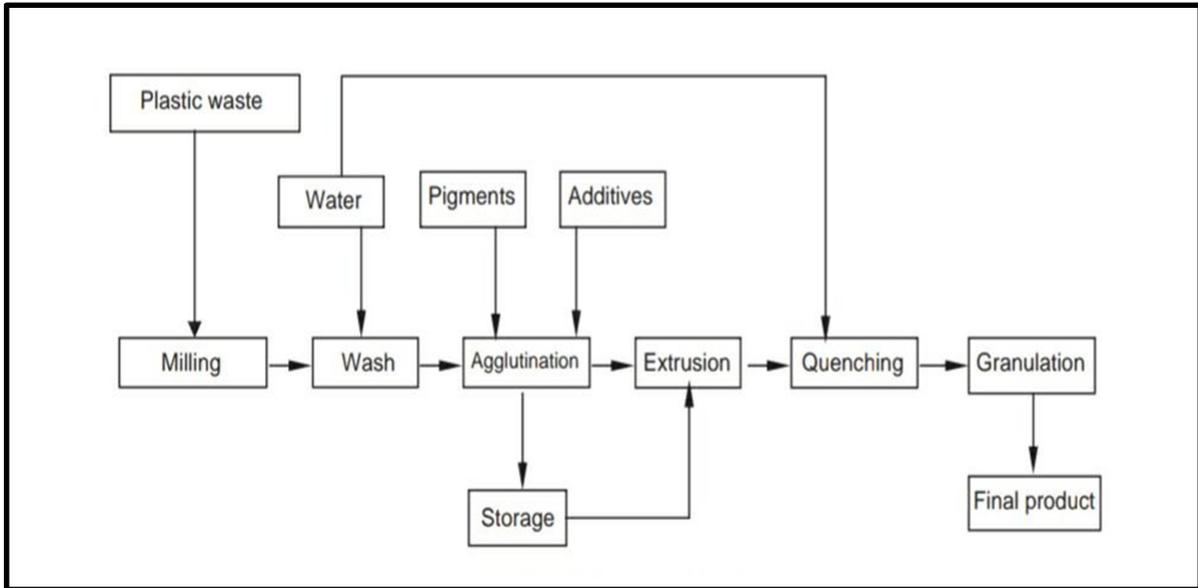
5. Washing and drying: This step refers to the pre-washing stage (beginning of the washing line). The actual polymer washing process occurs afterwards if further treatment is required. Both washing stages are executed with water. Chemical washing is also employed in certain cases (mainly for glue removal from polymer), where caustic soda and surfactants are used.

6. Agglutination: The product is gathered and collected either to be stored and sold later on after the addition of pigments and additives or sent for further processing.

7. Extrusion: The polymer is extruded to strands and then pelletized to produce a single-polymer plastic.

8. Quenching: Involves water-cooling the polymer by water to be granulated and sold as a final product.

During the grinding or melting phases, the reprocessed material can be blended with virgin material to obtain superior results. Mechanical recycling requires homogenous polymers and relatively clean material. It is one of the traditional and most used methods in many countries for polymer recycling. Its cost is relatively low but needs substantial initial investment [46]. In figure (2.5) the stages of mechanical recycling are shown [49].



Figure(2.5): Stages of mechanical recycling [49].

## 2.9 Advantages of Recycling and Reuse of Polymers

Recycling polymer wastes has so many advantages to human beings and the ecosystem when compared with all other methods of solid waste management adopted. Some of the numerous advantages of recycling polymer wastes are [50]:

1. As polymer wastes that litter the streets and choke drainages which serve as the breeding ground for mosquitoes and flies are reduced, diseases associated with these vectors will also reduce [50].
2. The emission of poisonous gases such as carbon dioxide, carbon monoxide, nitrogen-oxide and sulphur-oxide are reduced [50].
3. It creates job opportunities [50].
4. That recycling would reduce the amount of polymer wastes in the environment [51].
5. That recycling would create employment for the populace for collecting the polymer wastes thus bettering the economic status of the populace [51].
6. Reduces demand for virgin polymer [52].

## 2.10 Use of Waste Polymer as Construction Materials

In the last decades, due to the increasing cost of raw materials and the continuous reduction of natural resources, the recycling of industrial waste has become an interesting option for the building industry [53]. On the other hand, world human population continually increase so needed more houses and land for construction. Now a day, it is difficult for the working class to own a house due to high cost of construction materials [54].

Green-efficient construction is defined as an environmentally sustainable building constructed, operated with the basic aim of mitigation of environmental impacts such as natural resource depletion as well as CO<sub>2</sub> emission. Polymer waste can be used in the production of bricks. The utilization of polymer waste in the production of bricks could aid in saving the energy consumed in the firing of the clay brick, as well as reducing the CO<sub>2</sub> emission by reducing the amount of cement and natural soil usage in bricks production [55]. Thus the use of polymer waste for construction applications holds a high capability of decreasing environmental pollution [56].

The use of polymer waste in construction may also represent an effective solution to both the problem of reducing the environmental impact of polymer and the development of increasingly sustainable construction industry as well as the economic impact since they are available in large quantities, everywhere and low value[53,57].

The main benefits of using polymer waste as a building material are due to having good properties of insulation of heat, cold and acoustic materials and also because it is cheap and lightweight and easily available and reduced the manufacturing cost [58]. In addition, the non-biodegradable properties of polymer waste are able to assist the long-term working of construction materials [56].

### 2.10.1 Benefits of Polymer Waste in Construction

There are many benefits to using polymer waste in the construction process, including [54]:

**1- Environmental benefits:** Reducing the problem of global warming by reducing carbon dioxide emissions as well as providing a safe way to disposal of polymer.

**2- Cost effective:** The use of recycled material makes it more affordable than conventional building methods and will increase the accessibility to suitable housing. It is a well-insulated solution that will reduce energy consumption to control temperatures.

**3- Absorbs abrupt shock loads:** Flexibility is a characteristic which makes the buildings performance higher against the unexpected load. Since the polymer waste are not fragile, they can be flexible and tolerates sudden loads without failure. This characteristic can also increase the buildings bearing capacity against the earthquake.

**4- Green Construction:** Polymer bricks can cause green construction by saving energy and resources, recycling materials, minimizing the emission, having significant operational savings and increasing work place productivity.

**5- Solve Housing Problems:** The world is experiencing a global housing crisis. About 1.6 billion people live in substandard housing and 100 million are homeless. Polymer bricks are affordable and can contribute to solving these crises.

### **2.10.2 Application of Polymer Waste for Construction Purposes**

Several types of polymers can be applied in the construction industry and have recycling potential. It should be noticed that the polymers are engineered material and possess excellent mechanical properties such as, tensile strength, toughness, elongation at break and less water absorption which are critical for the durability and high performance of the construction materials. Also depending on the type and properties of the polymer waste, they may have potential use in various applications after recycling. Thus, high-density polyethylene (HDPE) is a relatively hard and rigid material and can find application in the manufacture of polymer lumber, tables, chairs, and other furniture. The low-density polyethylene (LDPE) is a flexible material and can potentially be used in the production of bricks and blocks. Polypropylene (PP) is hard and flexible, and due to these properties, its potential applications are aggregates in asphalt mixtures. Polystyrene (PS) is hard and brittle, so it is mainly used for parts that are not highly stressed mechanically, for example insulation materials. Polyvinyl chloride (PVC) is hard and rigid, which indicates its potential use as an aggregate in cement-based materials. PET, on the other hand, is hard and flexible and the most common secondary application is as fibers in cementations composites [59,60].

## **2.11 The Most Important Polymers Used in Construction**

There are many polymers that can be recycled but the important recycled polymers used in this study are shown below:

### **2.11.1 Polyethylene Terephthalate (PET)**

Polyethylene terephthalate (PET) is thermoplastic polyester which is a major member of the synthetic polyester family and of great importance in industrial applications [61,62,63]. During the last four decades, PET has found itself in commercial markets for a variety of applications such as textiles and

industrial fibers, films, foamed articles, containers for various beverage products such as carbonated soft drinks, water, tea, and fruit juices as well as thermoformed applications [63].

The big success of PET is a direct result of the combination of its low manufacturing cost and its excellent balance of properties, including ease of melt processing, high strength, high gaseous barrier, optical clarity, ability to strain induced crystallize, thermal resistance, high impact strength, good creep resistance, dyeability, environmental safety, and recyclability [63,64]. Table(2.2) show some of the physical properties of polyethylene terephthalate [65].

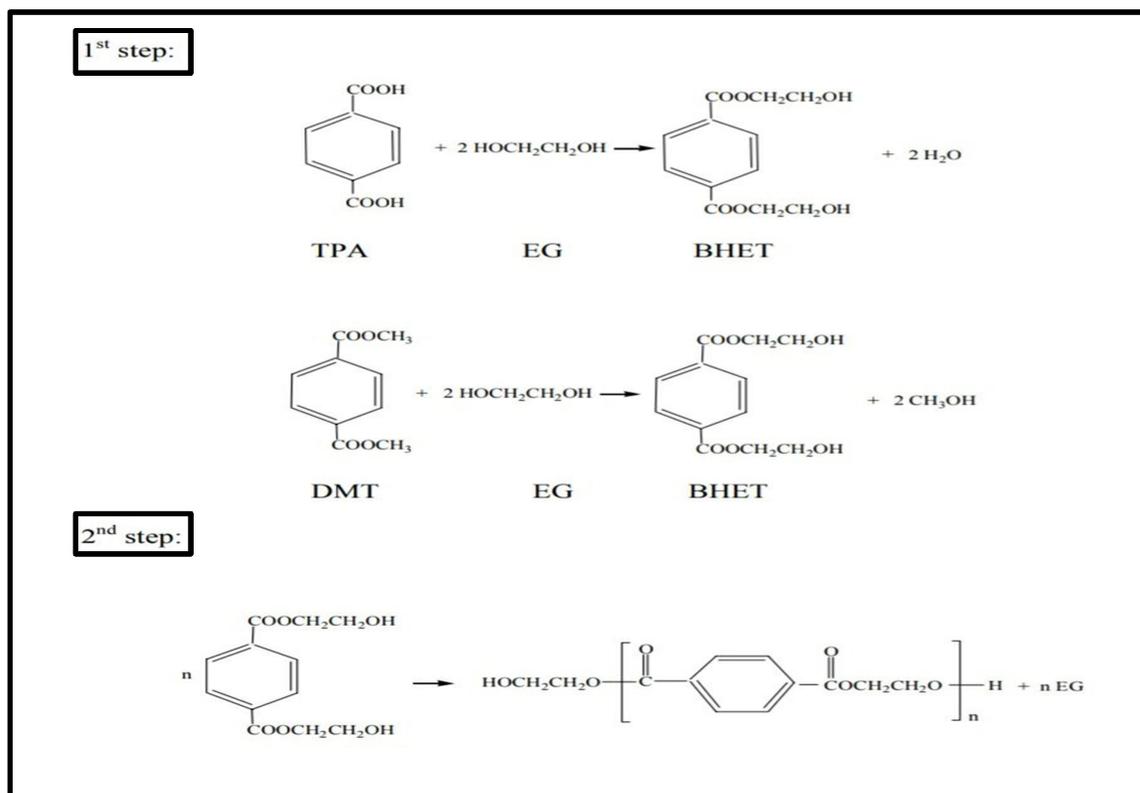
**Table(2.2): Physical properties of polyethylene terephthalate [65].**

Property	Unit	Value
Density:		
– amorphous PET	g/cm <sup>3</sup>	1.33
– crystalline PET	g/cm <sup>3</sup>	1.45
– both amorphous and crystalline PET	g/cm <sup>3</sup>	1.38 – 1.40
Break point:		
– ultimate tensile strength	MPa	172
– transverse strength	MPa	50 – 70
– compressing strength	MPa	80 – 120
Modulus of tensile elasticity	MPa	1.41·10 <sup>4</sup>
Ultimate elongation	%	12 – 55
Impact elasticity	kJ/m <sup>2</sup>	30
Brinell hardness	MPa	100 – 120
Water adsorption for 24 h	%	0.3
Temperature of fusion	°C	255 – 265
Softening point	°C	245 – 248
Breakdown temperature	°C	350
Factor of thermal expansion		6.55·10 <sup>-4</sup>
Thermal conductance	W/mK	0.14
Freezing resistance	°C	-50
Dielectric capacitvity at 10 <sup>6</sup> Hz		3.1

PET is a crystallizable polymer because of its regularity in chemical and geometric structures. It is either in the semi-crystalline state (opaque and white) or the amorphous state (transparent). The levels of crystallinity and morphology significantly affect the properties of the polymers.

Polymers with high crystallinity have a higher glass transition temperature  $T_g$  ( $T_g$  is  $67^{\circ}\text{C}$  for amorphous PET and  $81^{\circ}\text{C}$  for crystalline PET) and have higher modulus, toughness, stiffness, tensile strength, hardness and more resistance to solvents, but less impact strength while the amorphous PET has better ductility [66,67].

There are two major approaches for the production of PET differing in the starting raw materials used: the terephthalic acid (TPA) and ethylene glycol (EG) approach, and the dimethyl terephthalate (DMT) and EG approach. In both methods, first, the diesterbis (hydroxyl ethylene terephthalate) (BHET) is formed either by the direct esterification of purified TPA and EG or by the transesterification of DMT and EG, with water or EG as the byproducts. Secondly, BHET is polymerized by melt phase polycondensation reactions to produce PET, as shown in Fig.(2.6). Common catalysts used are acetates or oxides of antimony, germanium or lead [68].



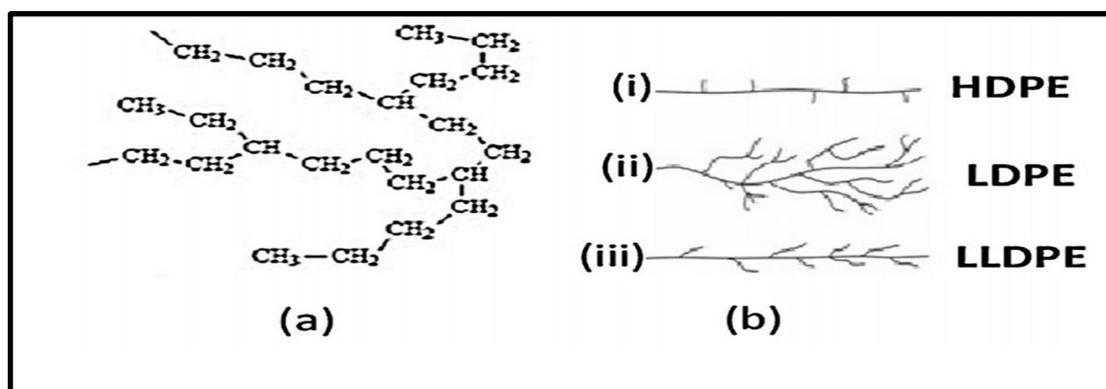
Figure(2.6): Main reactions involved in PET polymerization [68].

Because of the difficulty in the purification of TPA the earlier PET plant production schemes were based on DMT technology. All the modern PET plants, however, follow the TPA route because of the increased availability of purified TPA as a result of technology advances in the TPA purifying processes [68].

### 2.11.2 Low-Density Polyethylene (LDPE)

Low-density polyethylene (LDPE) is so named because such polymers contain substantial concentrations of branches that hinder the crystallization process, resulting in relatively low densities. The branches primarily consist of ethyl and butyl groups together with some long chain branches [69].

Due to the nature of the high-pressure polymerization process of ethylene by which low-density polyethylene is produced, the ethyl and butyl branches are frequently clustered together, separated by lengthy runs of unbranched backbone. Long-chain branches occur at random intervals along the length of the main chain [69]. Figure (2.7) shows polyethylene structures [70].



Figure(2.7): (a) Low density polyethylene (b) structure of polyethylene [70].

The long-chain branches can themselves in turn be branched. The numerous branches characteristic of low-density polyethylene molecules inhibit their ability to crystallize, reducing resin density relative to high-density

polyethylene. Low-density polyethylene resins typically have densities falling in the range of approximately 0.90–0.94 g/cm<sup>3</sup> [69].

LDPE has light-weight, good impact resistance, toughness, no moisture absorption, translucent to opaque, robust enough to be virtually unbreakable and at the same time quite flexible and has high chemical and corrosion-resistivity. It is used mainly for the blown and cast film, extrusion products as well as coatings, rotational and injection moulding [71,72].

## 2.12 Literatures Review

Polymer is one of the most common environmental issues in the contemporary world. Disposal of these polymers is considered to be a big challenge due to its non-biodegradable nature. In order to mitigate these hurdles, several researchers have made significant efforts to utilize waste polymers in construction industry.

**In 2013, Arora, et al,** studied utilization of E- waste and plastic bottle waste in concrete. This study dealt with the grinding, rubbing and mixing technique to use E-waste and plastic waste in concrete. E-waste from electrical and electronic equipment, that might be old or might have reached end of life and plastic waste from polymer mineral and cold drink bottles were collected and grinded to size of 2 mm using pulverizing machine. Ordinary Portland cement of 43 grade was selected. Grinded E-waste and polymerwaste were replaced by 0%, 2%, and 4% of the fine aggregates. Compressive strength and flexural strength were tested and compared with control concrete. Experiments done showed an increase in the compressive strength by 5% and reduce cost of concrete production by 7% at optimum percentage of grinded waste. Grinded waste greater than 4.75mm in certain proportion acted as a good filler material in concrete and on-going experiments were done to apply gap gradation by grinding the waste into specific sizes. This ensured better packing density and hence good strength [73].

In 2014, Wahid, et al, studied utilization of plastic bottle waste in sand bricks. They studied sand bricks which was made up by adding plastic bottle waste in crush form in sand bricks. The properties of sand bricks which contained varying percentages of polymer of 0% to 15% that were added to the raw material to develop polymer waste sand bricks were tested for compressive strength, water absorption and efflorescence. Results showed that the comprehensive strength decreases with increasing waste polymer ratios. The virgin (0% polymerwaste) sand brick showed the highest value of compressive strength of 12.40403MPa. This followed by 5%, 10% and 15% polymer waste which are 11.61856MPa, 5.95631MPa and 2.97839MPa [74].

In 2015, Mansour and Ali, studied reusing waste plastic bottles as an alternative sustainable building material. In this study plastic bottles (PET) were examined both structurally and thermally to be utilized as building units, replacing traditional concrete blocks. Tests were conducted after filling the bottles with either dry sand, saturated sand, or air, bound by cement mortar to produce stable masonry walls of reduced thermal conductivity. The effect of the infill material on the bulk unit weight and the compressive strength of the polymer bottle masonry blocks showed slight effect of the used infill material on the strength. Although the gross strength of these polymer bottles was much less than the traditional blocks, 670 kN/m<sup>2</sup> (0.67 MPa) compared to 3670 kN/m<sup>2</sup> (3.67 MPa) , but calculations showed that the blocks of air filled bottles still could be used as suitable construction units for partition walls or as bearing walls for one roof slab. Thermal wise, air filled bottles showed better thermal insulation than the tradition block construction, which could act as thermal insulation material [75].

In 2016, Z Muyen , et al, studied strength properties of plastic bottle bricks and their suitability as construction materials in Bangladesh. This study looked into the strength properties of waste PET bottles filled with fine sand. Five

different sizes (250, 500, 1250, 1500 and 2000ml) of waste PET bottle bricks were tested for compressive strength and the largest bricks gave a compressive strength of 17.44MPa. The 1000ml bottle brick filled cubes with 9 and 12 bottles were prepared and tested. The 9 bottle brick filled cubes gave a compressive strength of 35MPa and the 12 bottle bricks filled cubes gave a compressive strength of 33.7MPa. These bottle brick filled cylinders exhibited double the compressive strength of conventional concrete cylinders [76].

**In 2016, Nivetha, et al,** studied production of plastic paver block from the solid waste (quarry dust, fly ash & PET). In this study the polymer waste(PET) was carried to melt and mixed with a varying proportion of solid waste fly ash and quarry dust (PET 25-35 % fly ash 25 % and quarry dust 40-50% in weight). The measurements of physical and mechanical properties showed that polymer waste paver blocks and these proportion in polymer gave better results than concrete paver blocks [77].

**In 2017, Manjarekar, et al,** studied utilization of plastic waste in foundry sand bricks. In this work an attempt has been made to manufacture the bricks by using waste polymers (PET,PP) in range of 60 to 80% by weight of Foundry Waste sand and 60/70 grade bitumen was added in range of 2 to 5% by weight of sand in molten form and this bitumen- polymer resin was mixed with Foundry waste sand to manufacture the bricks. Results showed that the compressive strength of brick is more than that of conventional brick, the bricks were not broken after falling from height of 1 m, also this brick has a lesser water absorption than conventional brick and using the foundry sand brick in a building, total cost will be reduced from 20% to 25% [78].

**In 2017, Anand Daftardar, et al,** studied use of waste plastic as a construction material. The materials used in this study are LDPE polymer beads and Fly Ash - Grade F, Polymer beads were generated from polymers and

were effectively converted into polymer blocks. Some samples were prepared with different ratios (100% LDPE polymer beads, 90% LDPE polymer beads+10% fly ash, 80% LDPE polymer beads+20% fly ash, 70% LDPE polymer beads+30% fly ash). It was noted that the maximum compressive load which the LDPE polymer beads brick could sustain was 13.69 MPa. This was followed by LDPE fly ash composite brick with a strength of 11.48 – 10.42 MPa, which was higher than the compressive strength of the conventional bricks available in the market made up of clay which had a compressive strength of 3-5 MPa [79].

**In 2018, Puttaraj , et al,** studied utilization of waste plastic in manufacturing of plastic-soil bricks. In this work an attempt had been made to manufacture the bricks using waste polymers (PET bottles) in range of 60 to 80% by weight of laterite quarry waste and 60/70 grade bitumen was added in range of 2 to 5% by weight of soil in molten form and this bitumen- polymer resin was mixed with laterite quarry waste to manufacture the bricks. The bricks manufactured possess the properties such as neat and even finishing, with negligible water absorption and satisfactory compressive strength in comparison with laterite stone to satisfy the increasing demand of conventional building material [80].

**In 2018, Kumi-Larbi, et al,** studied recycling waste plastics in developing countries: Use of low-density polyethylene water sachets to form plastic bonded sand blocks. In this study, waste LDPE water sachets had been melted and mixed with sand to form LDPE-bonded sand blocks. The effect of sand particle size and sand to polymer ratio on density, the compressive strength and water adsorption are reported. LDPE-bonded sand was a strong, tough material with compressive strengths up to ~ 27 MPa when produced under optimum processing conditions. The compressive strength of these samples was mainly dependent on the LDPE content with little contribution from the interfacial

bond between the sand and LDPE. Increasing the sand addition reduces sample porosity. However, sand additions above 75 wt% reduce the compressive strength because the LDPE binder volume is not sufficient to properly coat and bind the sand grains together [81].

**In 2019, Intan and Santosa**, studied utilization of PET and LDPE plastic waste and building material waste as bricks. Research is carried out by mixing both materials, namely polymer heated at a temperature of 180-220<sup>0</sup> C and building material waste that had been crushed and sized to 30-40 mesh with homogeneous stirring. The ratios of PET and LDPE polymer to building material waste were 9 : 1, 8 : 2, 7 : 3, 6 : 4 and 5 : 5. After heating and printing, density, water absorption and compressive strength tests were carried out. Addition of PET and LDPE polymer could increase compressive strength, and reduce water absorption, porosity and density. A maximum compressive strength of 10.5 MPa was obtained at the ratio of 6 : 4 [82].

**In 2019, Reddy, et al**, studied utilization of low density polyethylene waste in the manufacturing of paver brick. The LDPE polymer bags were recycled and used as total replacement for cement to prepare polymer paver bricks were prepared based on different polymer to fine aggregate ratio. The polymer bags are added into the heater and these bags were heated till it turns to viscous form. About 150<sup>0</sup> C to 160<sup>0</sup> C heat was required to melt the polymer bag. A long rod could be used for mixing the polymer waste. When the polymer changed to viscous form fine aggregate was added. The both materials were mixed properly like concrete. The mixture was molded in molds. Compressive strength, melting point and water absorption and environmental factors had been found out for the results to avoid the effects on environment. Results showed that the compressive strength of the polymer paver brick had high, low water absorption rate, high melting point for the polymer brick is 200<sup>0</sup> C as compared to conventional bricks [83].

**In 2020, Ganesh N, et al,** studied manufacturing of polymersand bricks from polypropylene and polyethylene waste polymer. In this study six polymersand brick samples were prepared based on different polymer to sand ratio. PP and HDPE waste were added into the heater and heated up to 180<sup>0</sup> C. Mix 5 gms of red oxide along with the melted mixture to impart dark red color. The mixture was mixed properly using a steel rod and poured into the moulds. Testing was performed to determine compressive strength, efflorescence, water absorption, soundness, and fire resistance test. Results showed that the polymer sand bricks had higher compressive strength up to 12.43 MPa for polymer sand brick with a ratio of 2:1, as compared to the normal concrete bricks, low water absorption rate and zero effloresce and a good fire resistance and was an effective source to reduce polymer waste [84].

**In 2020, Kedare,** studied physical characterization of waste-polymer brick and development of material for pothole filling. In this work an attempt has been made to make bricks from waste polymer (LDPE) and sand. The polymer is melted and sand is added to the mixture in a molten form to make bricks. Results showed that this brick is resistant to oil, water, salts and acids. It is more durable as compared to other bricks and can withstand temperature up to 180<sup>0</sup> C and it can withstand compressive strength of 11.82 MPa [85].

**In 2020, Alaloul, et al,** studied mechanical and thermal properties of interlocking bricks utilizing wasted polyethylene terephthalate. The polymer bottles were shredded and grinded to a size of 0.75 mm and mixed with the polyurethane (PU). The mixed later cast and compacted in the interlocking brick machine mould. The tests performed on the interlocking bricks were compressive strength, impact, flexural strength and thermal conductivity for obtaining the mechanical and thermal properties. The results showed that good compressive strength of 5.3MPa was obtained for a PET/PU of 60/40 ratio, Low thermal conductivity, poor tensile strength and the highest tensile strength

obtained was 1.3 MPa for a PET/PU of 60/40 ratio, good impact strength also the highest impact strength obtained was for the PET/PU of 60/40 ratio with a value of 23.3 J/m (23.3 N). Based on the results it was concluded that PET/PU of 60/40 ratio was suitable as non-load-bearing masonry brick and recommended to be used as partition walls [86].

**In 2021, Mak, et al,** studied a review on utilization of polymer wastes in making construction bricks. It was found to implore lightweight, durable, cost-effective, and low thermal conductor bricks. Compressive strength and water absorption tests were found as the key test methods for measuring the effectiveness of high-volume content of polymer waste in bricks. Notably, a high percentage of polymer waste in proportion to sand was found to improve the compressive strength of the bricks besides allowing negligible water to seep through [87].

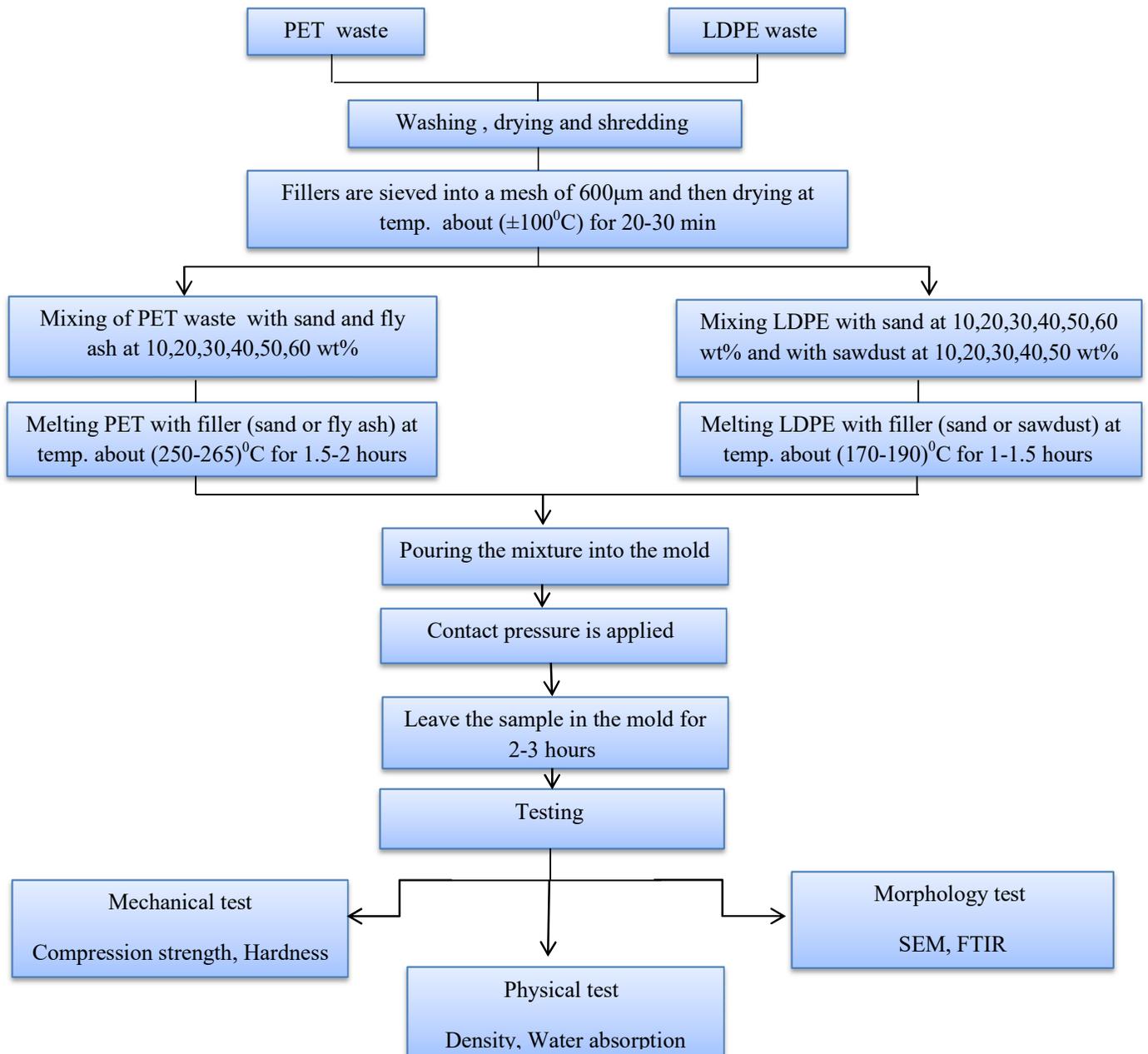
## 2.13 Conclusions and Remarks

The previous paragraphs covered some of the previous works of many researchers who studied the possibility of using polymer waste in construction processes in terms of mechanical and physical properties, and the researcher's conclusion can be summarized as follows:

- 1- Study the effect of adding different waste polymers (PET, LDPE, E-waste polymer, and PP) with some additives (sand, quarry dust, fly ash, etc.) on the physical and mechanical properties. Such as the compressive strength, water absorption, and efflorescence properties as it showed improvement in compressive strength, low water absorption and no efflorescence.
- 2- Studies show different methods to prepare polymer bricks, some of them grind the polymer waste into crushed flakes and then mix it with some fillers, press it and leave the bricks for a certain time. Others melt the polymer waste and mix it with the fillers and pour it into the mould, thus making bricks. There is also another method, which involves filling polymer bottles with fillers. The best method in terms of bonding and mechanical properties is the method of melting, but in terms of environmental effects in the way of filling the bottles with fillers, but this method is not feasible because of the weakness interconnection between polymer bottles and cement.

### 3.1 Introduction

This chapter contains the experimental methods and instrumentation used for the preparations and characterization of the materials and preparing mixtures of PET waste with different percentages of sand and fly ash and also preparing mixtures of LDPE waste with different percentages of sand and sawdust. Figure (3.1) show the practical steps used in this research to gain a full idea about the production of samples and tests.



**Figure (3.1): Flow chart of experimental part steps**

## 3.2 Materials Used

This section provides information on the properties of materials used in the manufacture of plastic bricks (PET, LDPE, and fillers).

### 3.2.1 Polyethylene Terephthalate (PET)

PET was obtained from plastic bottle waste. Where these plastic wastes were prepared by passing through several steps:

- 1- Plastic bottle waste collection.
- 2- Draining of remaining fluids from plastic bottles.
- 3- Removing of caps and plastic stickers.
- 4- Washing in water and then drying.
- 5- Shredding is suitable for smaller pieces. A used shredder has a series of rotating blades driven by an electric motor. Materials are fed into the shredder via a hopper which is sited above the blade rotor. The product of shredding is a pile of coarse irregularly shaped plastic flakes which can then be further processed. Figure (3.2) shows the methods for preparing PET waste and table (3.1) shows the most important characteristics of PET obtained practically.



**Figure(3.2): Preparation of PET waste. where (1) collection plastic bottles (2) washing, drying and cutting plastic bottles (3) shredding machine (4) shredded plastic.**

Table (3.1): Properties tested of PET

Properties	Unit	Value
Density	g/cm <sup>3</sup>	1.2898
Hardness	shore D	68.43
Water absorption	%	0

### 3.2.2 Low Density Polyethylene (LDPE)

The low-density polyethylene material used is the syringe piston waste from the medical syringe factory in Babylon, which failed during the manufacturing process. The most important characteristics of LDPE obtained practically are given in table (3.2).

Table (3.2): Properties tested of LDPE

Properties	Unit	Value
Density	g/cm <sup>3</sup>	0.8985
Hardness	shore D	60.1
Water absorption	%	0

### 3.2.3 Fillers

There are three types of fillers

A- Fly ash

Obtained from local wood burning process

B- Sand

Obtained from a local market

C- Sawdust

Collected from a local sawmill

Table (3.3) shows the most important characteristics of these fillers obtained practically.

**Table (3.3): Some properties of fillers**

<b>Filler type</b>	<b>Apparent density(g/cm<sup>3</sup>)</b>	<b>Aperture size (μm)</b>
<b>Fly ash</b>	0.5163	≤600
<b>Sand</b>	1.3775	≤600
<b>Sawdust</b>	0.7260	≤600

### 3.3 Sample Preparation

The same procedure was used for both PET and LDPE bricks, the only difference being the time and temperature used.

#### 3.3.1 Batching

Measurement of materials for making brick is called batching. After the collection of materials and the removal of any other waste presented in the collected material then weights of collected materials were measured. Sieving of fillers was done by 600-micron sieve and these fillers were used for making bricks. Various proportions of plastic waste with fillers are taken for bricks Table(3.4) shows the number of specimens and coding.

#### 3.3.2 Melting

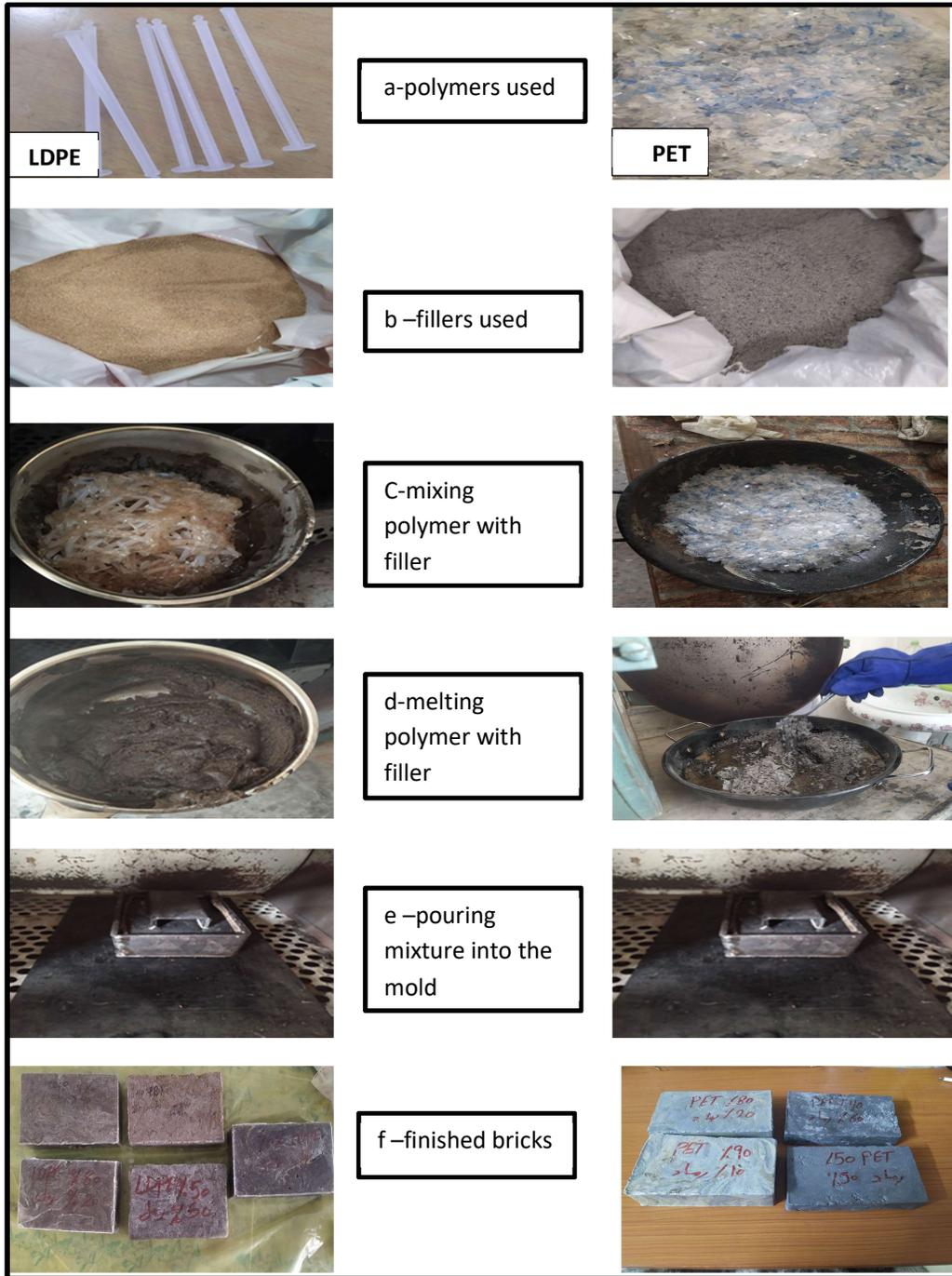
After batching was completed, the plastic waste was taken for melting in which the plastic waste was dropped all in one container. These would be done in a closed vessel to prevent the toxic gases released into the atmosphere. These were at the temperature of 170-190<sup>0</sup> C and the time of 1-1.5 hours for LDPE samples and at the temperature of 250-265<sup>0</sup> C and the time 1.5-2 hours for PET samples.

### 3.3.3 Mixing

The method of mixing was done manually. Pieces of plastic were added into the container for melting until the proportion was required. The filler was used for addition in the plastic mixture. Before adding filler drying at temperature about  $\pm 100^{\circ}$  C and then mix with plastic waste. The filler and the melted plastic were mixed so that both get bonded perfectly. As the plastic pieces melt they start getting bonding with the filler particles and hence the mixture required for brick was created.

### 3.3.4 Molding

In the molding process, the prepared mixture was then filled into a steel mold, in this project using the brick sizes (145x85x30 mm). The pressure was applied was contact pressure so as the mixture got filled properly in the mold. Then it was left for cooling in the air but before filling the mold apply oil on the walls of mold so that at last brick to be removed easily. The application of oil on the inner surfaces of the mold is a must because after solidification the brick will not come out easily and to remove the mold some pressure must be applied that would wear the edges of the brick. So proper oiling was needed before filling the mixture in the mold. After 2-3 hours remove the brick from the mold. Figure (3.3) shows the method of producing plastic bricks in all its stages for both PET and LDPE.



Figure(3.3): Method for preparing bricks.

Table (3.4): Shows the number of specimens and coding.

<b>Sample code</b>	<b>PET wt%</b>	<b>Sand wt%</b>
<b>A1</b>	90	10
<b>A2</b>	80	20
<b>A3</b>	70	30
<b>A4</b>	60	40
<b>A5</b>	50	50
<b>A6</b>	40	60
<b>Sample code</b>	<b>PET wt%</b>	<b>Fly ash wt%</b>
<b>B1</b>	90	10
<b>B2</b>	80	20
<b>B3</b>	70	30
<b>B4</b>	60	40
<b>B5</b>	50	50
<b>B6</b>	40	60
<b>Sample code</b>	<b>LDPE wt%</b>	<b>Sand wt%</b>
<b>C1</b>	90	10
<b>C2</b>	80	20
<b>C3</b>	70	30
<b>C4</b>	60	40
<b>C5</b>	50	50
<b>C6</b>	40	60
<b>Sample code</b>	<b>LDPE wt%</b>	<b>Sawdust wt%</b>
<b>D1</b>	90	10
<b>D2</b>	80	20
<b>D3</b>	70	30
<b>D4</b>	60	40
<b>D5</b>	50	50

### 3.4 Tests

#### 3.4.1 Mechanical Tests

##### 3.4.1.1 Compressive Strength Test

The compressive strength is the ability of a material to hold out loads. In this test, it was adopted Iraqi Standard Specifications No. 25 of 1988 (IQS 25 – 1988). The compressibility of all samples was measured by a compression device which is available in the laboratory of Materials Engineering college /University of Babylon as shown in figure (3.4).

The following equation was used to determine the compressive strength:

$$f = \frac{P}{A} \quad (3-1)$$

where:

$f$ : is the compressive strength measured in MPa

$P$ : is the fracture load measured in N

$A$ : cross-sectional area of the specimen in ( $\text{mm}^2$ ).



Figure(3.4): Compression device

### 3.4.1.2 Hardness Test

Shore D hardness device model (TH 210 FJ) made in Germany, which is available in the laboratory of the Department of Polymer Engineering and Petrochemical Industries /Materials Engineering College /University of Babylon as it is shown in figure(3.5) was used to measure the hardness of the sample. Shore instrument is similar to compass containing needle placed in a position perpendicular to the sample and it takes waiting (0.5 min) to read the value and to have some accuracy an average of three readings have to be taken in different locations and at different points for each sample.



Figure(3.5): Shore D hardness device

## 3.4.2 Physical Tests

### 3.4.2.1 Density Test

Figure(3.6) shows the high precision density tester, that the specification of this machine is digital accuracy =  $\pm 0.0001 \text{ g/cm}^3$ , type GP-120 S, which work according to ASTM D-792, made in Matsu Haku, china. Where the

Liquid density mode GP-120S device was used to measure the density of the sample.

In this test, samples from any previously performed test have been measured their density, this method can be used with sheet, rod, tube and molded articles also powders, the specimen was weighed in the air then in distilled water at 23°C using a sinker and wire to hold the specimen completely submerged as required.

$$\text{Density} = W_{\text{body in air}} / (W_{\text{body in air}} - W_{\text{body in water}}) * \text{fluid density} \quad (3-2)$$



Figure(3.6): Density device

### 3.4.2.2 Water Absorption Test

In this test, it was adopted Iraqi Standard Specifications No. 25 of 1988 (IQS 25 - 1988).

As the method of work was to dry the examination model in a drying oven at a temperature of  $(100 \pm 10)$  until its weight was stabilized, then it was cooled to room temperature and weighed and let it be the dry weight ( $w_1$ ).

The dry model was immersed in pure water at a temperature of (15-30)°C for 24 hours, then it was lifted and dries the surface with a piece of cloth and weighed within 3 minutes of taking it out of the water and let the weight be (W2).

$$\text{Water absorption in \% by wt.} = \frac{w_2 - w_1}{w_1} \times 100. \dots\dots(3-3)$$

### 3.4.3 Morphology Test

#### 3.4.3.1 Fourier Transform Infrared Spectroscopy Analysis (FTIR)

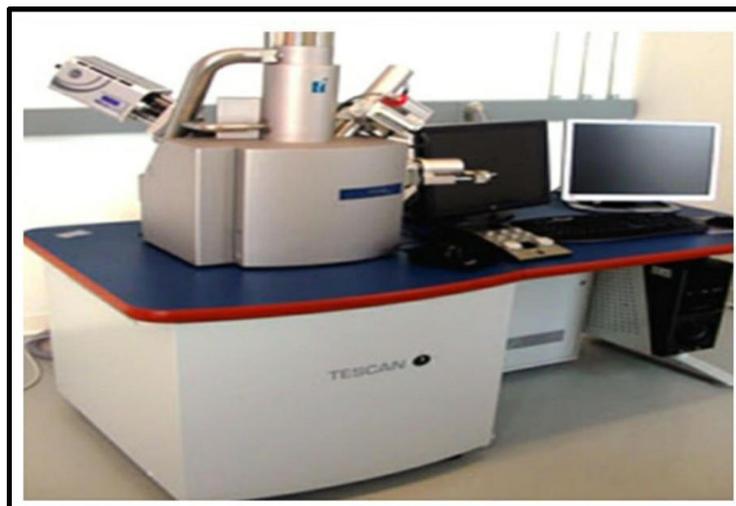
Fourier transform infrared spectra technique is used for the characterization of very complex mixtures by FTIR analysis instrument Type(IR Affinity-1) made in (Kyoto Japan), which is available in the laboratory of Materials Engineering college /University of Babylon, shown in Figure (3.7). In order to measure a sample, calibrate the device using the KBr, and then prepare powder of the sample to be examined , and mixed with KBr (mixing ratio 99% KBr). The mixing process achieved thoroughly then pressed as tablet-shaped semi-transparent to the possibility of penetrating radiation.



Figure (3.7): Shows the FTIR analysis device.

### 3.4.3.2 Scanning Electron Microscopy (SEM):

Scanning electrons microscope is utilized powerful techniques that allow the observations and characterizations of the surfaces of both organic and inorganic material, providing important data concerning the morphologies of the sample. In this work was carried out to investigate the distribution of fillers in the plastic waste. The samples were tested using (SEM/ TESCAN/ VEGA II Series/ USA / Amir kaber University/ Iran) as shown in figure (3.8).



Figure(3.8): SEM Instrument

## 4.1 Introduction

This chapter includes all the experimental results that are obtained from the mechanical and physical tests for the polymer bricks under investigation. The experimental tests and the results of polymer bricks were used to investigate at first, the mechanical properties including (compressive strength test, hardness test) and physical properties including (density test, water absorption test) and finally the most important morphology for polymer brick were performed using Scanning electron microscopy (SEM) and Fourier transform infrared spectroscopy analysis (FTIR).

Group (A):- includes the preparation of polymer bricks from PET waste with the addition of 10, 20, 30,40,50,60 weight ratios of sand.

Group (B):- includes the preparation of polymer bricks from PET waste with the addition of 10,20,30,40,50,60 weight ratios of fly ash.

Group (C):- includes the preparation of polymer bricks from LDPE waste with the addition of 10,20,30,40,50,60 weight ratios of sand.

Group (D):- includes the preparation of polymer bricks from LDPE waste with the addition of 10,20,30,40,50 weight ratios of sawdust.

## 4.2 Physical Properties

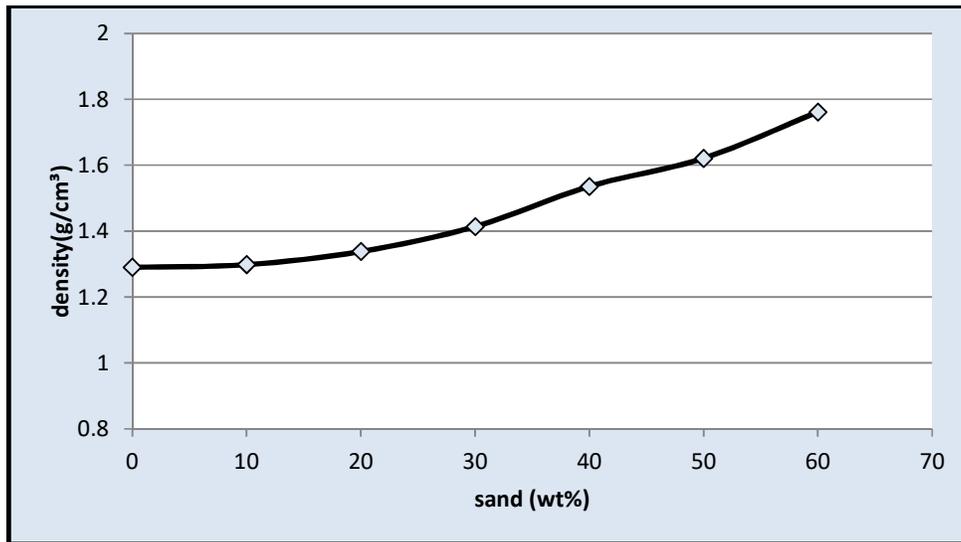
### 4.2.1 Density Test

#### 4.2.1.1 PET with Fillers

The density result of PET and sand samples are shown in Table (4.1) and Figure (4.1), It can be noticed that the density increased with increasing the proportion of the addition sand percent which is (10,20,30,40,50,60)%. This behavior was expected due to the density of sand being higher than that of PET where the sand density is  $1.3775\text{g/cm}^3$  and the density of pure PET is  $1.2898\text{g/cm}^3$  according to rule of mixture.

**Table (4.1): Density results of PET/sand bricks**

Sample code	Density (g/cm <sup>3</sup> )
Pure PET	<b>1.2898</b>
A1	<b>1.2980</b>
A2	<b>1.3380</b>
A3	<b>1.4137</b>
A4	<b>1.5357</b>
A5	<b>1.6210</b>
A6	<b>1.7614</b>

**Figure (4.1): The effect of adding sand on the density of PET/sand bricks**

The density result of PET and fly ash samples are shown in Table (4.2) and Figure (4.2). It can be seen that the density decreases with the increase in the percentage of added fly ash which is (10,20,30)% and the density increases with the increase in the percentage of additional fly ash which is (40,50,60)%. This behavior may be explained by the fact that when small percentages of fly ash are added, and because the density of fly ash is low which is  $0.5163\text{g/cm}^3$  compared to the base polymer (PET) which is  $1.2898\text{g/cm}^3$  when small percentages are added to the polymer, the density of the final product decreases, according to the rule of mixtures, since this small percentage is not enough to make a cement phase, but when fly ash is added in high proportions exceeding 40%, the amount of fly ash is sufficient to make the cement phase, which serves to close the pores in the polymer and thus increase the density.

**Table (4.2): Density results of PET/fly ash bricks.**

Sample code	Density ( $\text{g/cm}^3$ )
Pure PET	<b>1.2898</b>
B1	<b>1.2035</b>
B2	<b>1.2378</b>
B3	<b>1.2638</b>
B4	<b>1.3166</b>
B5	<b>1.3888</b>
B6	<b>1.4819</b>

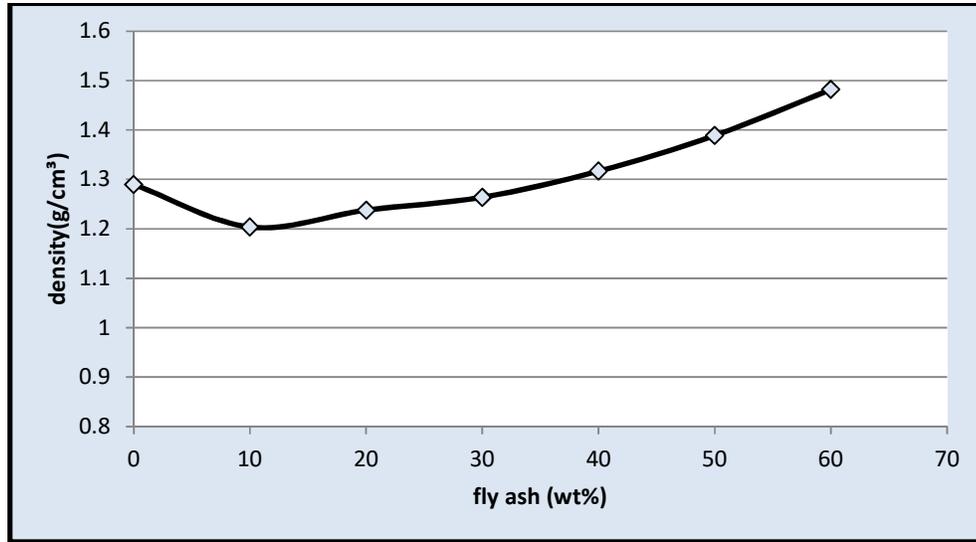


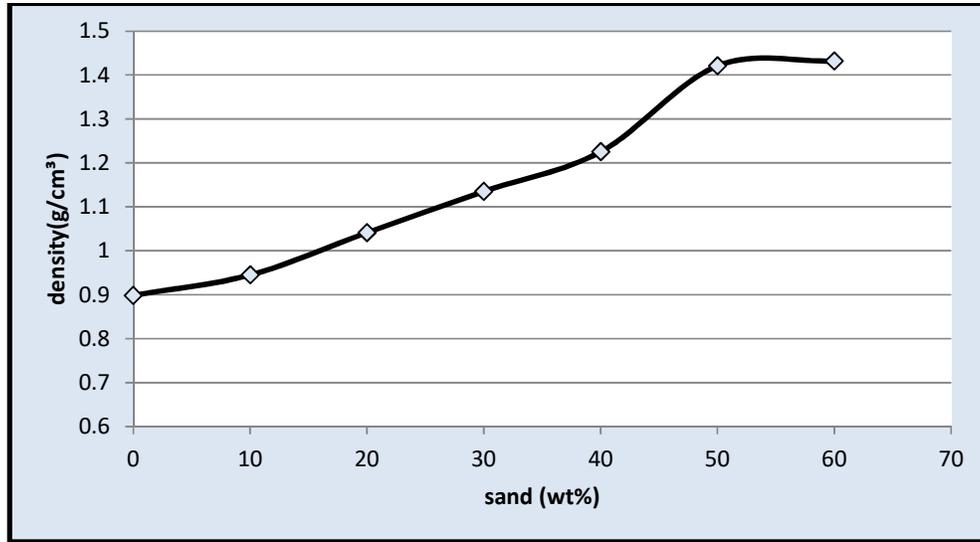
Figure (4.2): The effect of adding fly ash on the density of PET/fly ash bricks.

#### 4.2.1.2 LDPE with Fillers

The density result of LDPE and sand samples are shown in Table (4.3) and Figure (4.3). It can be seen that the density increased by increasing the percentage of additional sand which is (10,20,30,40,50,60)%. This behavior was expected because the density of sand is higher than that of LDPE where the density of sand is  $1.3775 \text{ g/cm}^3$  and the density of pure LDPE is  $0.8985 \text{ g/cm}^3$  according to the rule of mixture.

Table (4.3): Density results of LDPE/sand bricks.

Sample code	Density(g/cm <sup>3</sup> )
Pure LDPE	<b>0.8985</b>
C1	<b>0.9449</b>
C2	<b>1.0411</b>
C3	<b>1.1350</b>
C4	<b>1.2254</b>
C5	<b>1.4208</b>
C6	<b>1.4321</b>



**Figure(4.3):** The effect of adding sand on the density of LDPE/sand bricks.

The density result of LDPE and sawdust samples are shown in Table (4.4) and Figure (4.4). It can be noticed that the density decreases with the increase in the percentage of adding sawdust which is (10,20,30,40,50)%. The reason is that the density of sawdust is low which is  $0.7260\text{g/cm}^3$ , which is less than the density of the base polymer(LDPE), which is  $0.8985\text{g/cm}^3$ , so the density decreases as the percentage of addition increases according to the rule of mixture.

**Table (4.4):** Density results of LDPE/sawdust bricks

Sample code	Density(g/cm <sup>3</sup> )
Pure LDPE	<b>0.8985</b>
D1	<b>0.8662</b>
D2	<b>0.8526</b>
D3	<b>0.8545</b>
D4	<b>0.8183</b>
D5	<b>0.7065</b>



Figure(4.4): The effect of adding sawdust on the density of LDPE/sawdust bricks

In general, it is noted that all the bricks that were mentioned previously have a density lower than the density of ordinary bricks, which were measured and it was  $2.3661 \text{ g/cm}^3$ , this means that it has lightweight, which is an important characteristic for the manufacturing of bricks.

## 4.2.2 Water Absorption

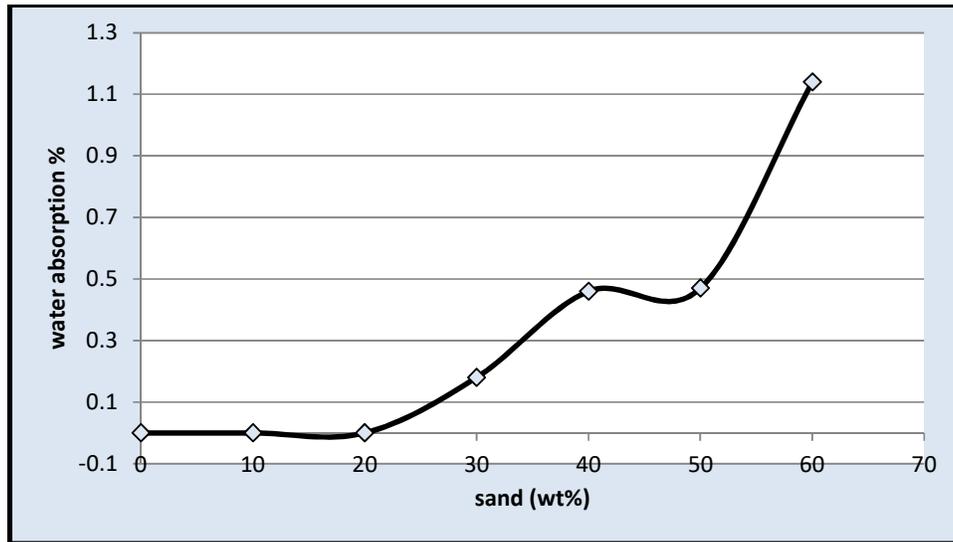
### 4.2.2.1 PET with Fillers

Table (4.5) shows the results of water absorption for PET and sand bricks, and Figure (4.5) shows the relationship between water absorption with sand additions. The results show an increase in water absorption with increasing sand addition and the highest percentage obtained is 1.14% for A6. The reason for this is may be due to the ability of sand to absorb water.

Whereas, good quality bricks should not absorb more than 20% of water according to Iraqi Standard No. 25 of 1988. So it means that the water absorption test shows excellent performance of waste polymer bricks.

**Table(4.5): Water absorption results of PET/sand bricks**

Sample code	Water absorption %
Pure PET	<b>0</b>
A1	<b>0</b>
A2	<b>0</b>
A3	<b>0.18</b>
A4	<b>0.46</b>
A5	<b>0.47</b>
A6	<b>1.14</b>

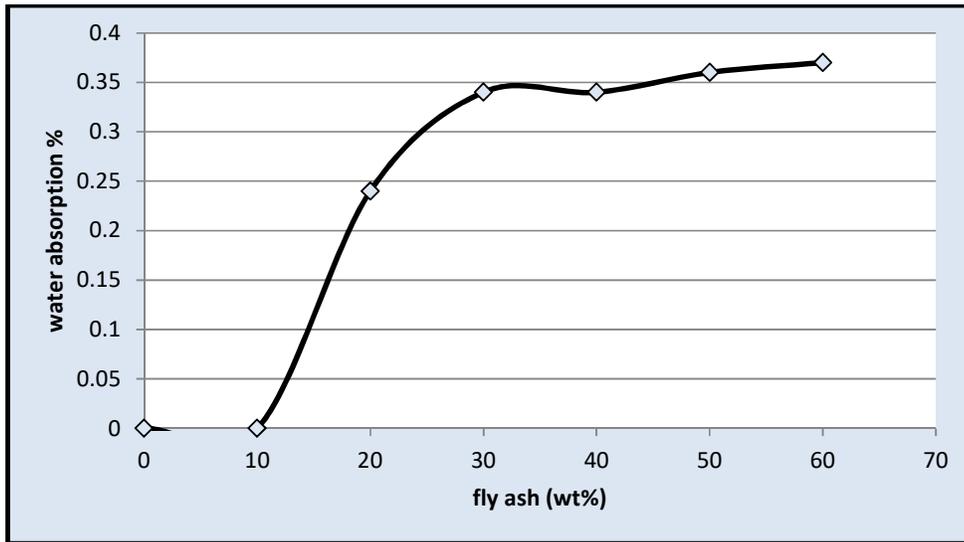
**Figure(4.5): The effect of adding sand on water absorption of PET/sand bricks**

The water absorption result of PET and fly ash bricks are shown in Table (4.6) and Figure (4.6). The results show an increase in water absorption with increasing fly ash addition and the highest percentage obtained is 0.37% for B6.

This increase is very small because the size of the fly ash particles is very small, so high porosity does not occur.

Table(4.6): Water absorption results of PET/fly ash bricks

Sample code	Water absorption%
Pure PET	0
B1	0
B2	0.24
B3	0.34
B4	0.34
B5	0.36
B6	0.37



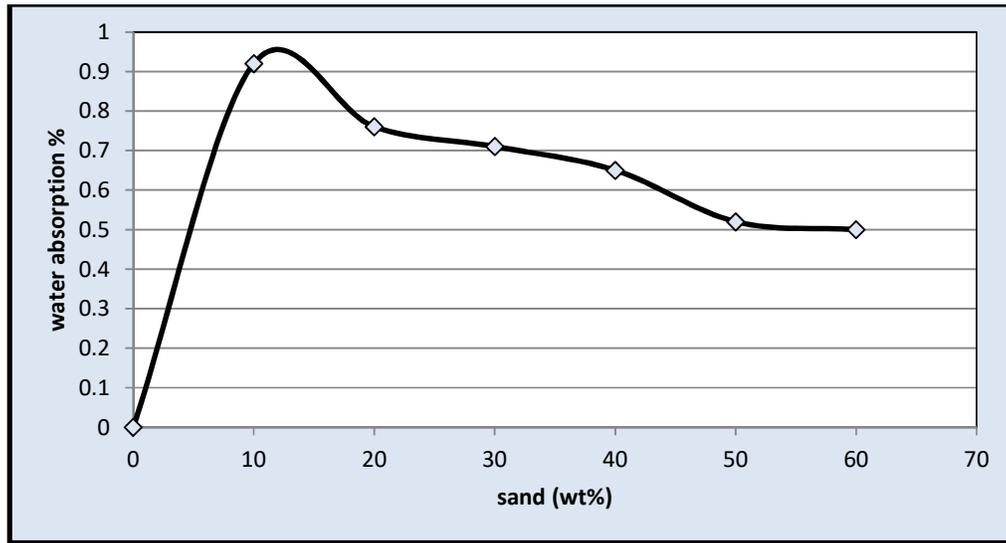
Figure(4.6): The effect of adding fly ash on water absorption of PET/fly ash bricks.

#### 4.2.2.2 LDPE with Fillers

The water absorption result of LDPE and sand bricks are shown in Table (4.7) and Figure (4.7). The results show that the absorbance increased at C1, but with the increase in the sand percentage it started to decrease. The reason for this behavior may be due to the molecular structure of the LDPE, which makes it flexible due to the presence of many sub-chains. When adding a few percentages of sand, it will enter between these chains and separate them, which increases the porosity of the polymer and thus increases the absorption, but when the ratio of sand to polymer increases, the sand particles will form agglomerates between these chains that lead to restricting the movement of these chains and filling the voids present in it and thus the absorption decreases with the increase in the percentage of addition this result has a good agreement with the result of Kumi-Larbi [81].

**Table(4.7): Water absorption results of LDPE/sand bricks**

Sample code	Water absorption %
Pure LDPE	<b>0</b>
C1	<b>0.92</b>
C2	<b>0.76</b>
C3	<b>0.71</b>
C4	<b>0.65</b>
C5	<b>0.52</b>
C6	<b>0.50</b>

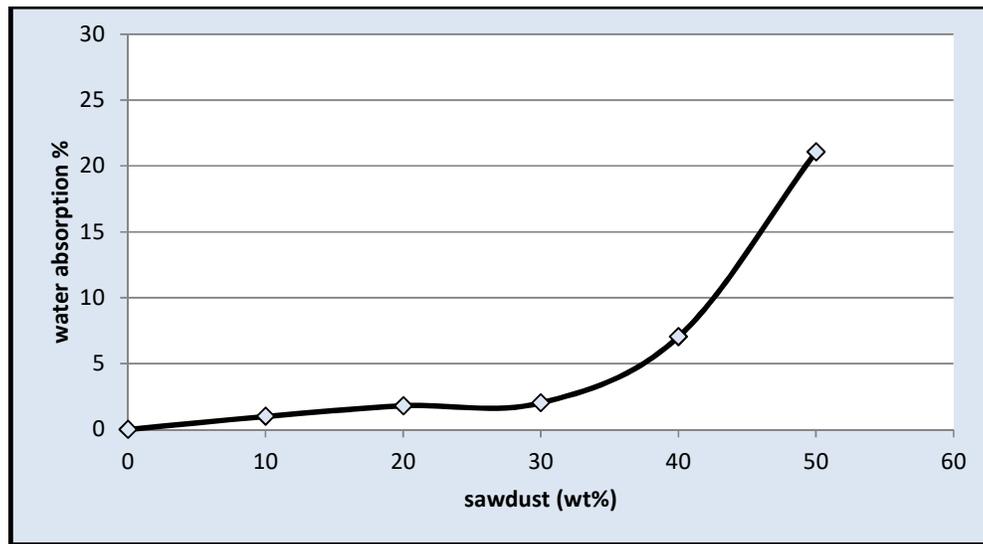


**Figure(4.7): The effect of adding sand on water absorption of LDPE/sand bricks**

The water absorption result of LDPE and sawdust bricks are shown in Table (4.8) and Figure (4.8). The results show an increase in water absorption with increasing sawdust addition and the highest percentage obtained is 21.1% for D5. The reason for this is due to the high ability of sawdust to absorb water due to its high porosity.

**Table(4.8): Water absorption results of LDPE/sawdust bricks**

Sample code	Water absorption%
Pure LDPE	0
D1	0.99
D2	1.80
D3	2.02
D4	7.03
D5	21.05



Figure(4.8): The effect of adding sawdust on water absorption of LDPE/sawdust bricks

## 4.3 Mechanical Properties

### 4.3.1 Compressive Strength Test:-

The main aspect to be considered when introducing material in the construction field is compressive strength. A compressive strength test is used to find the resistance of polymer brick under compression. To carry out a compressive strength test on polymer brick, the surface of the brick should be plane on all the sides so that the load can be distributed evenly. The importance of finding compressive strength is to measure the load-bearing capacity of the brick.

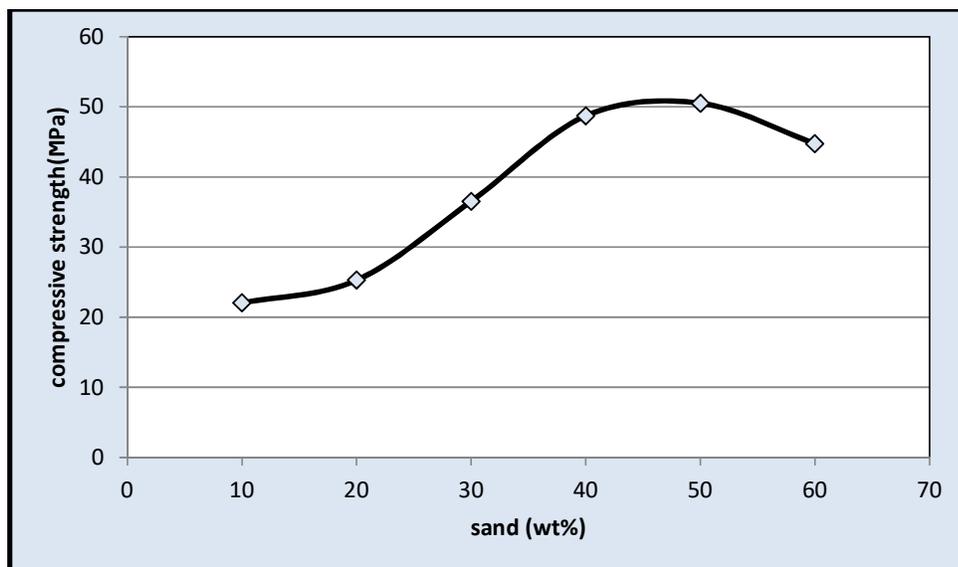
#### 4.3.1.1 PET with Fillers

The compressive strength results of PET and sand bricks are shown in Table (4.9) and Figure (4.9). It is found that the increase in the added ratios leads to an increase in the compressive strength. This maybe because of good homogeneity between sand and polymer and increase adhesion strength between them. However, the value of compressive strength at A6 decrease and became 44.76 MPa this maybe due to agglomeration that made sand particles.

In addition, the increase in the sand gives strength and durability due to its excellent mechanical properties. It may also be due to the size of small sand particles where the relationship between particle size and compressive strength is reversed.

**Table (4.9): Compressive strength results of PET/sand bricks**

Sample code	Compressive strength(MPa)
A1	<b>22.04</b>
A2	<b>25.28</b>
A3	<b>36.53</b>
A4	<b>48.7</b>
A5	<b>50.51</b>
A6	<b>44.76</b>



**Figure (4.9): Relationship between the addition sand and compressive strength of PET/sand bricks.**

The compressive strength result of PET and fly ash bricks are shown in Table (4.10) and Figure (4.10). The results show an increase in compressive strength with increasing fly ash addition and the highest percentage obtained was 48.49MPa for B6. This is due to the good homogeneity between the fly ash and the PET and the low porosity which leads to higher density as well as the small particle size of fly ash, all these reasons can lead to increased compressive strength.

Table (4.10): Compressive strength results of PET/fly ash bricks

Sample code	Compressive strength(MPa)
B1	14.15
B2	24.45
B3	26.4
B4	27.01
B5	25.58
B6	48.49

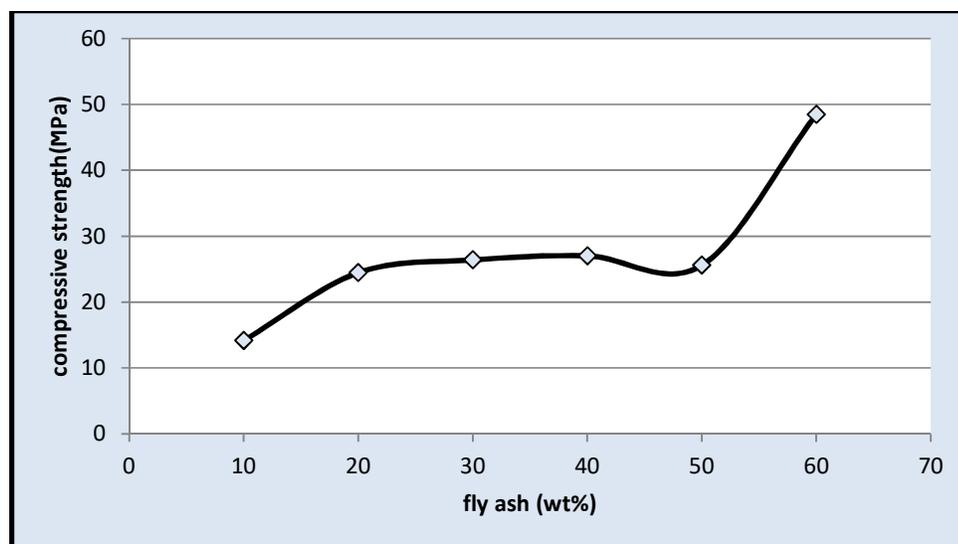


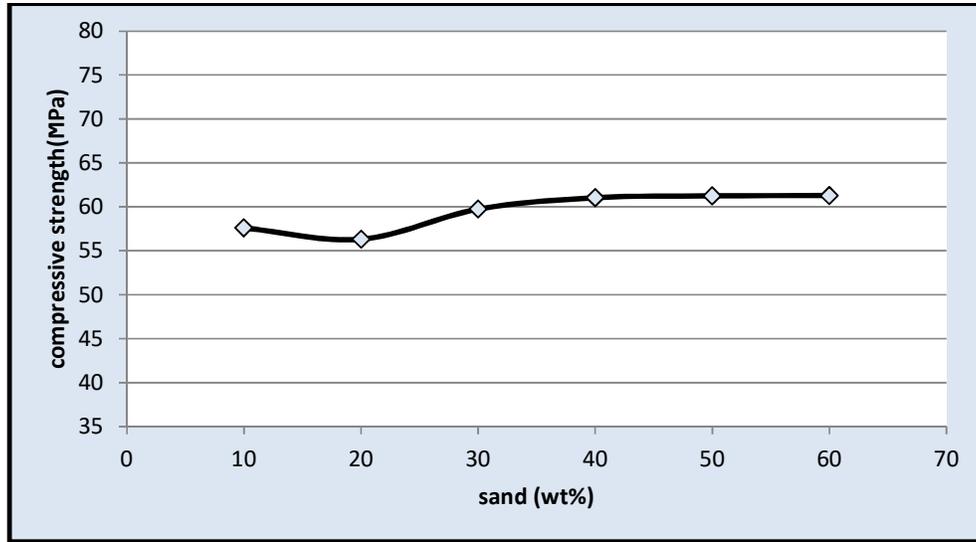
Figure (4.10): Relationship between the addition fly ash and compressive strength of PET/fly ash bricks.

#### 4.3.1.2 LDPE with Fillers

The compressive strength results of LDPE and sand bricks are shown in Table (4.11) and Figure (4.11). It can be notice that the compressive strength increases slightly with the increasing proportion of sand addition and the highest percentage obtained is 61.29MPa for C6. The slight increase in compressive strength may be due to the fact that the LDPE polymer contains many sub-chains and the sand particles do not sufficiently impede the movement of the chains.

**Table (4.11): Compressive strength results of LDPE/sand bricks**

<b>Sample code</b>	<b>Compressive strength(MPa)</b>
<b>C1</b>	57.59
<b>C2</b>	56.31
<b>C3</b>	59.73
<b>C4</b>	61.04
<b>C5</b>	61.24
<b>C6</b>	61.29



**Figure (4.11): Relationship between the addition sand and compressive strength of LDPE/sand bricks.**

The compressive strength results of LDPE and sawdust bricks are shown in Table (4.12) and Figure (4.12). It is found that in a small percentage of sawdust the bricks give high strength but when added in a high percentage the strength will decrease as the highest compressive strength is 66.89MPa for D2 and the smallest compressive strength is 16.97MPa for D5. This behavior may be attributed to the high porosity of sawdust which leads to poor interfacial strength between LDPE and sawdust and poor dispersion between them and also the material(LDPE) is insufficient to encapsulate and bind the sawdust.

**Table (4.12): Compressive strength results of LDPE/sawdust bricks**

Sample code	Compressive strength(MPa)
D1	58.45
D2	66.89
D3	62.58
D4	49.44
D5	16.97



Figure(4.12): The effect of adding sawdust on compressive strength of LDPE/sawdust bricks.

### 4.3.2 Hardness Test

#### 4.3.2.1 PET with Fillers

The results of the hardness of PET and sand bricks are presented in Table (4.13) and Figure (4.13) and the results of PET with fly ash are shown in Table (4.14) and Figure (4.14). It can be seen that the hardness improved greatly with the increase of sand and fly ash percentages, which means the material's resistance to deformation by wear, cutting, scratching, penetration and perforation. This improvement belongs to the strength of the good bond between the brick parts.

Table (4.13): Hardness results of PET/sand bricks

Sample code	Hardness(shore D)
Pure PET	68.43
A1	68.4
A2	70.52
A3	70.9
A4	71

<b>A5</b>	77
<b>A6</b>	77.5

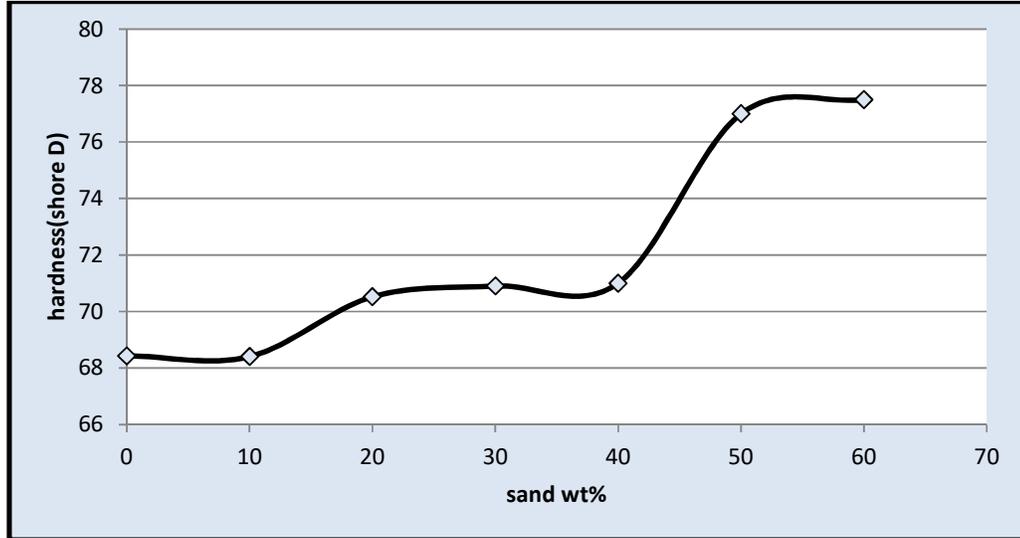
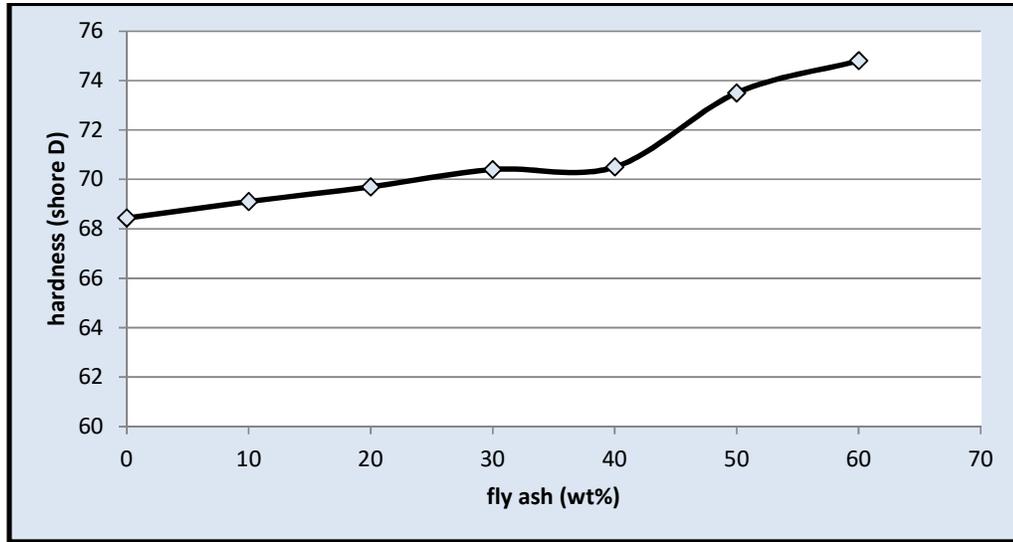


Figure (4.13): Relationship between the addition sand and hardness of PET/sand bricks.

Table(4.14): Hardness results of PET/fly ash bricks.

<b>Sample code</b>	<b>Hardness(shore D)</b>
<b>Pure PET</b>	68.43
<b>B1</b>	69.1
<b>B2</b>	69.7
<b>B3</b>	70.4
<b>B4</b>	70.5
<b>B5</b>	73.5
<b>B6</b>	74.8



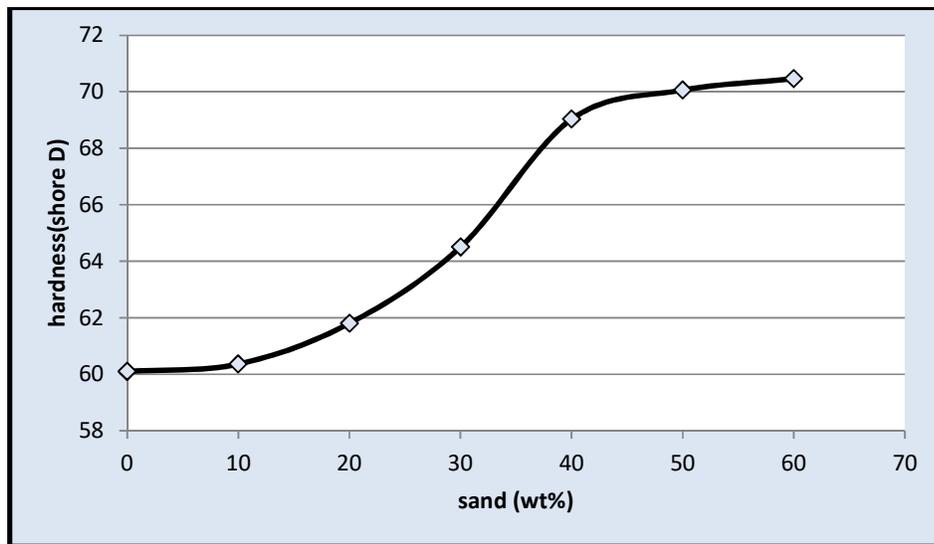
**Figure (4.14): Relationship between the addition of fly ash and hardness of PET/fly ash bricks.**

#### 4.3.2.2 LDPE with Fillers

The results of the hardness of LDPE and sand bricks are presented in Table (4.15) and Figure (4.15). It can be notice that the hardness increases with the increasing proportion of sand addition. Hardness is a property of a material that enables it to resist plastic deformation, penetration, etching and scratching. This increase in hardness can be attributed to the sand structure that contains high proportions of silicon dioxide in the form of quartz, and quartz is known for its high hardness. Thus, when sand is added at high rates, and good spreading and binding occurs, it gives high hardness.

Table(4.15): Hardness results of LDPE/sand bricks.

Sample code	Hardness(shore D)
Pure LDPE	60.1
C1	60.36
C2	61.8
C3	64.5
C4	69.03
C5	70.06
C6	70.46



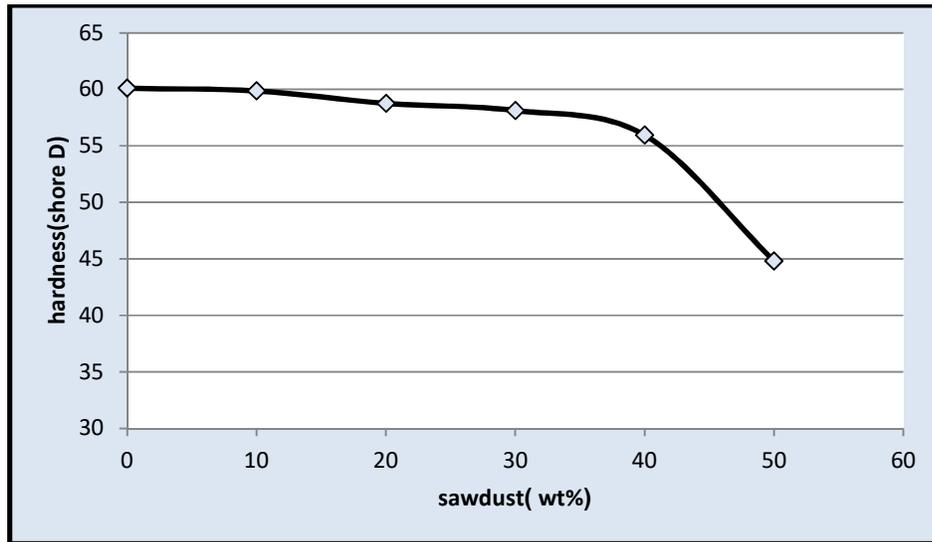
Figure(4.15): Show the effect of adding sand on the hardness of LDPE/sand bricks.

The results of the hardness of LDPE and sawdust bricks are presented in Table (4.16) and Figure (4.16). The results show a decrease in hardness with increasing sawdust addition. This may be attributed to the fact that sawdust has a high porosity, and therefore the higher the percentage of sawdust, it will increase the porosity of the finished product, give it a rough surface and also

weaken the bonding between the polymer and the sawdust. Thus, it reduces hardness and is easily penetrated.

Table(4.16): Hardness results of LDPE/sawdust bricks.

Sample code	Hardness(shore D)
Pure LDPE	60.1
D1	59.86
D2	58.76
D3	58.13
D4	55.94
D5	44.8



Figure(4.16): The effect of adding sawdust on the hardness of LDPE/sawdust bricks.

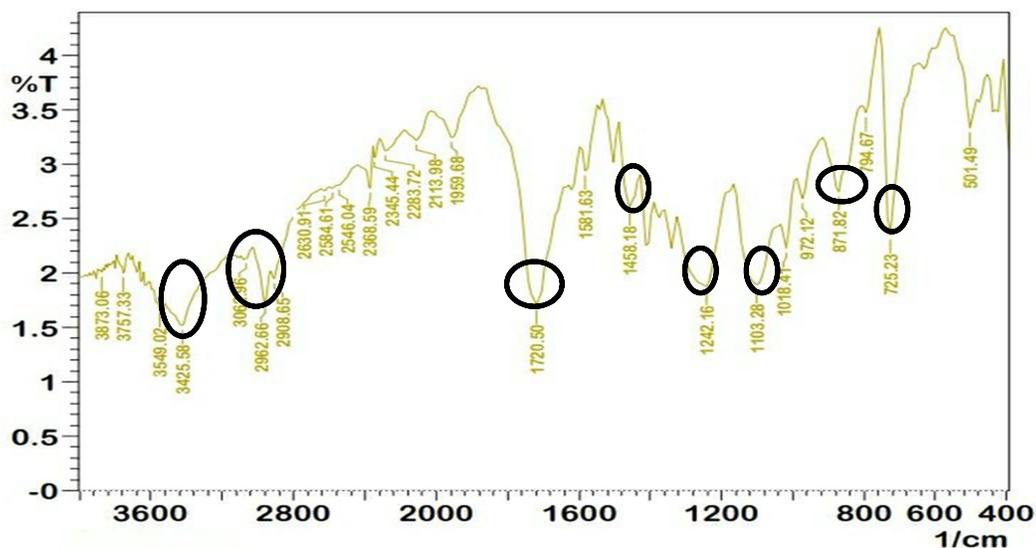
## 4.4 Morphology Test

### 4.4.1 Fourier Transform Infrared Spectroscopy Analysis (FTIR)

#### 4.4.1.1 PET with Fillers

FTIR was used to determine if there was a change in the chemical composition of the polymer bricks, where the highest proportion of sand and fly ash was taken and compared with the pure substance(PET). The range values and change in intensity or offset of peaks for these compounds recorded by FTIR are shown in Table (4.17), which were derived from Figures (4.17), (4.18), and (4.19).

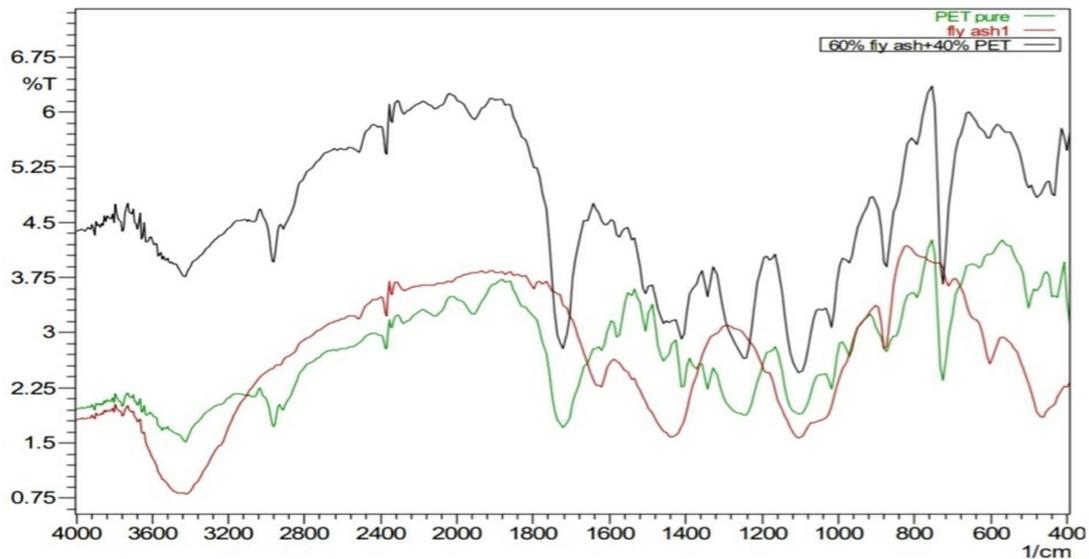
FTIR for PET shows many bands such as the bands at 2962.66 and 2908.65  $\text{cm}^{-1}$  are attributed to  $-\text{CH}_2-$  stretching and the band at 3062.96  $\text{cm}^{-1}$  for aromatic C-H stretching, and the band at 1720.50  $\text{cm}^{-1}$  for carbonyl C=O stretching and the bands at 1242.16 and 1103.28  $\text{cm}^{-1}$  for C-O stretching and the band at 3425.58  $\text{cm}^{-1}$  is attributed to O-H stretching. Also, the band at 1458.18  $\text{cm}^{-1}$  is attributed to the stretching vibration of the benzene ring skeleton. The 871.82 and 725.23  $\text{cm}^{-1}$  are assigned to the coupled vibrations of the aromatic out-of-plane C-H bending mode and the out-of-plane O=C-O bending mode, respectively. This corresponds to reference [88].



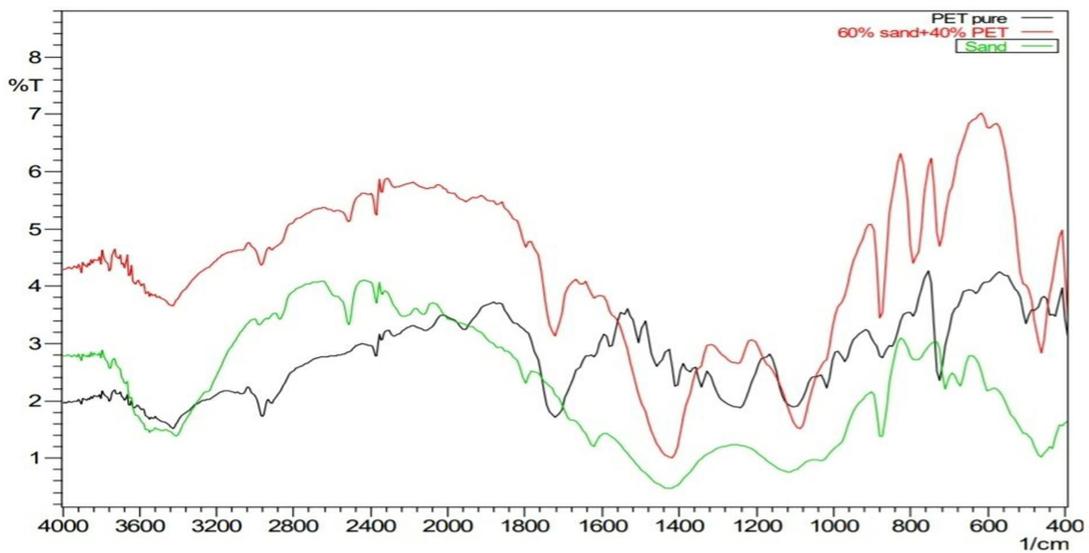
Figure(4.17): Show The FTIR spectrums of PET sample.

Table (4.17): The transmission bands of IR spectrum characteristic of PET and composites.

Type of bond	PET standard	PET exp.	PET/Fly ash	PET/Sand
CH <sub>2</sub> stretching[89]	2962	2962.66	2962.66	2970.38
	2908	2908.65	2908.65	2908.65
C-H aromatic[90]	3060	3062.96	3062.96	3078.39
C=O stretching[90]	1720	1720.50	1720.50	1720.50
O-H stretching[91]	3570-3200	3425.58	3433.29	3433.29
Aromatic ring stretch[91]	1510-1450	1458.18	1458.16	1419.61
C-O stretching[92]	1260-1000	1103.28	1103.28	1087.85
		1242.16	1242.16	1249.87
C-H bending	873.35	871.82	871.82	879.54
O=C-O bending	725.64	725.23	725.23	725.23



**Figure (4.18): FTIR spectrum for PET, pure fly ash and 40%PET/60% fly ash.**



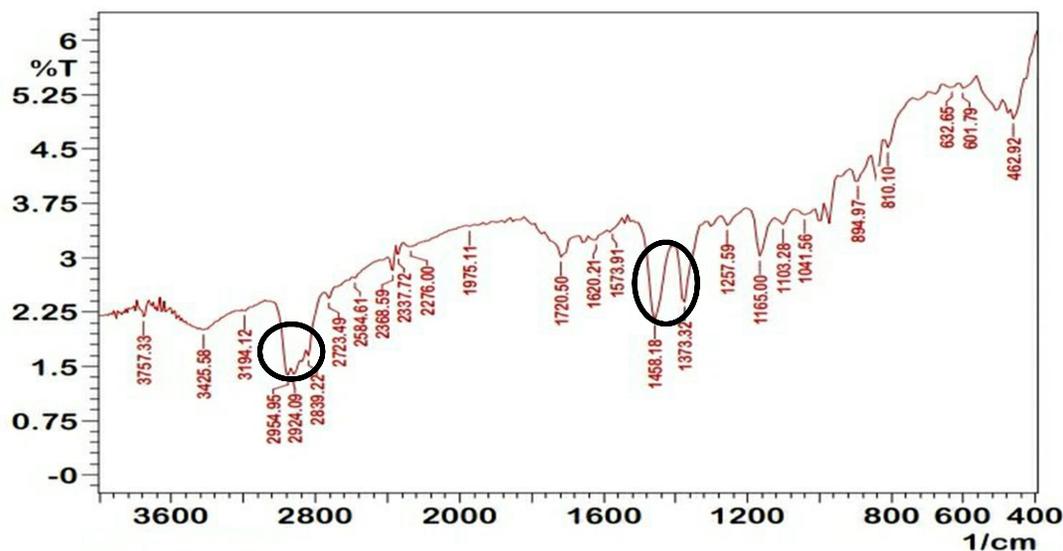
**Figure (4.19): FTIR spectrum for PET, pure sand and 40%PET/60% sand.**

Generally, all these variations can be attributed to the interaction between the addition filler and PET because it transfers spectra to higher and lower wavenumbers such interaction is physical interaction. So its effect is mainly on the secondary bond not on the primary bond. Thus the FTIR spectrum shows a small effect on the transmission band, which indicate no effect on the primary bond. So no chemical reaction occurred.

#### 4.4.1.2 LDPE with Fillers

A series of Fourier transform infrared (FTIR) spectra were obtained to detect any chemical interaction in the polymer bricks. Where the highest percentage of sand and sawdust was taken and compared with the pure material (LDPE). It is summarized in Table (4.18), which is derived from Figures (4.20), (4.21) and (4.22).

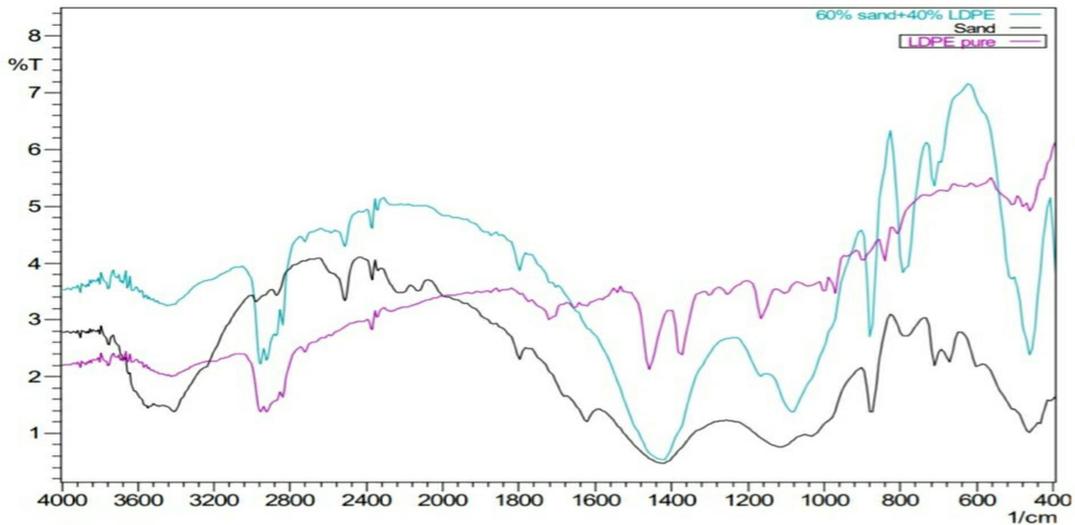
FTIR for LDPE shows many bands such as the bands at  $2924.09\text{ cm}^{-1}$ ,  $2954.95\text{ cm}^{-1}$  and  $2839.22\text{ cm}^{-1}$  for  $-\text{CH}_2-$  stretching, bands at  $1458.18\text{ cm}^{-1}$  and  $1373.32\text{ cm}^{-1}$  for  $\text{CH}_2$  bending.



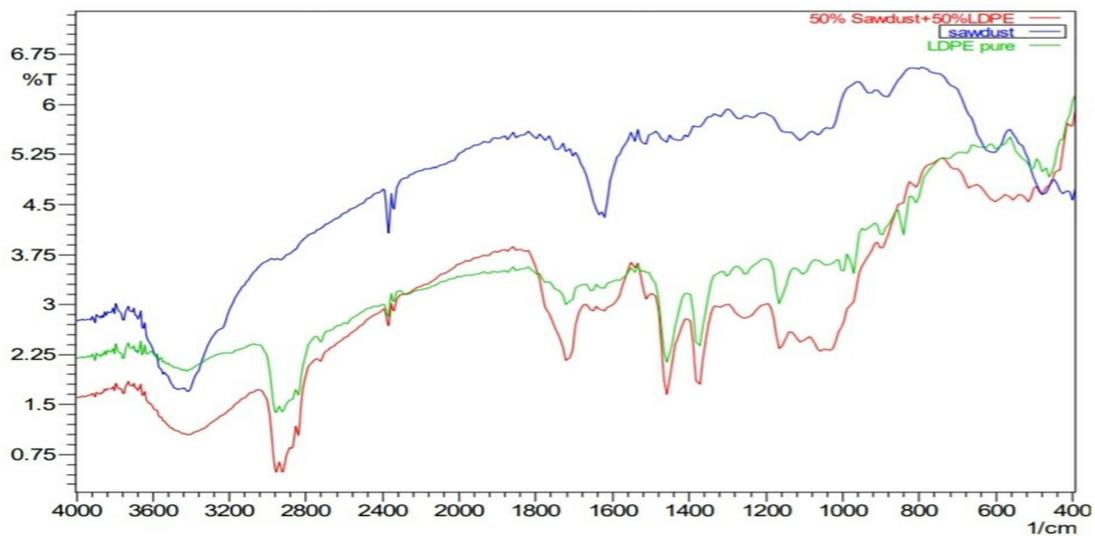
Figure(4.20): Show The FTIR spectrums of LDPE sample.

Table(4.18): The transmission bands of IR spectrum characteristic of LDPE and composites.

Type of bond	LDPE standard[93]	LDPE exp.	LDPE/sand	LDPE/sawdust
<b>CH<sub>2</sub> stretching</b>	2918	2924.09,2954.95	2924.09,2954.95	2924.09,2954.95
	2851	2839.22	2839.22	2839.22
<b>CH<sub>2</sub> bending</b>	1468	1458.18	1427.32	1458.18
	1373	1373.32		1373.32



**Figure(4.21): Shows the FTIR spectrums of samples compared between pure LDPE and 40%LDPE/60% sand and pure sand.**



**Figure(4.22): Shows the FTIR spectrums of samples compared between pure LDPE and 50%LDPE/50% sawdust and pure sawdust.**

It is noticed by examination that there is no definitive change in the bricks made of sawdust and LDPE, only a slight change resulting from the physical interaction between the components. While in the bricks made of sand and LDPE, two bonds are broken and a new bond is formed, which is found in the sand structure and this is probably due to the manufacturing process with a high

temperature exceeding the melting temperature with the presence of sand (silica), which is conductive compared to sawdust, so it works to concentrate the heat in certain areas and thus this may lead to a break in the bonds and formed bond at  $1427.32\text{ cm}^{-1}$  which is present in the sand structure. Thus the FTIR spectrum shows no chemical reaction and only physical reaction occurred.

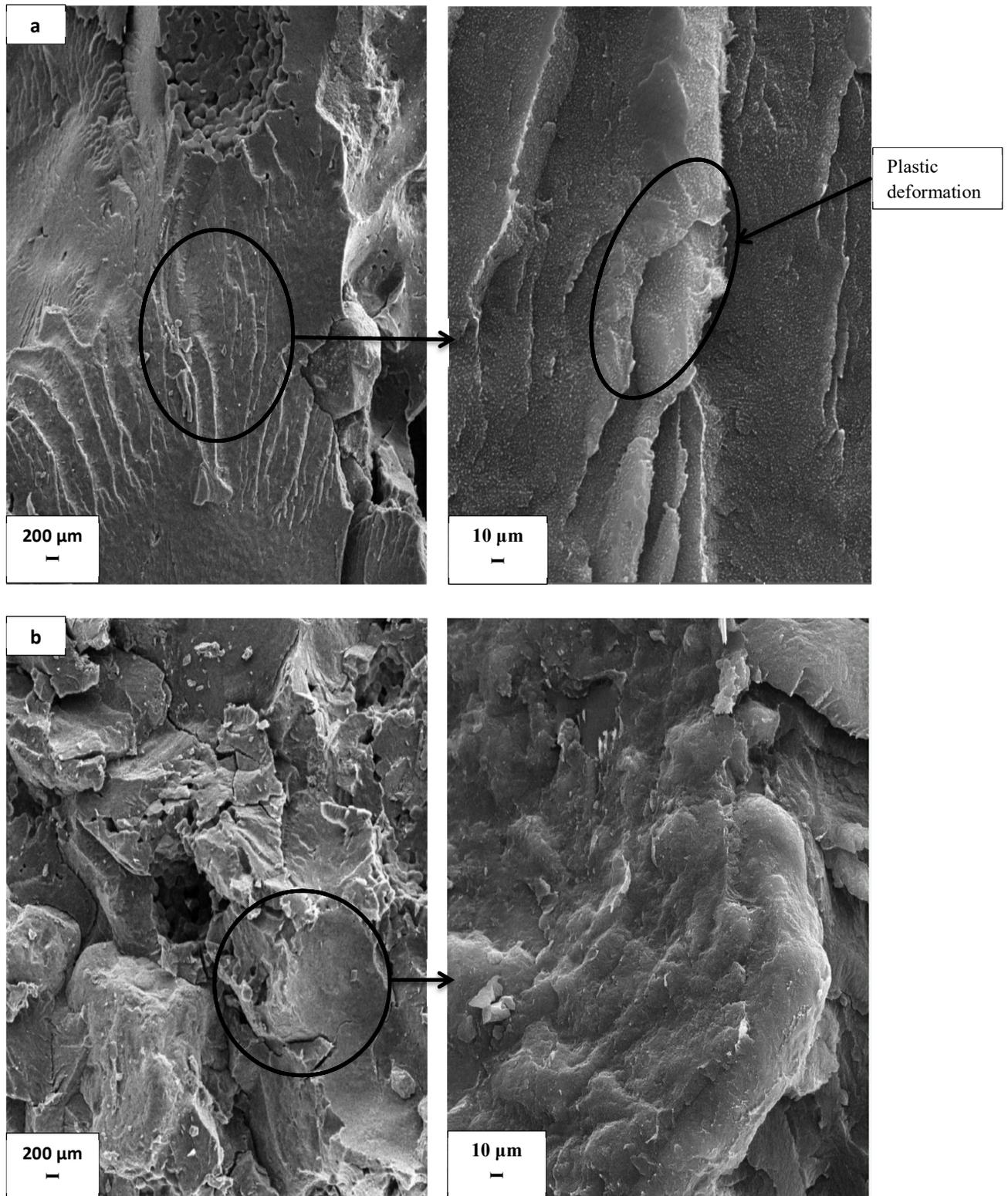
#### 4.4.2 Scanning Electron Microscopy (SEM)

Figures (4.23) to (4.26) show SEM images of the samples. The samples that gave the highest and lowest values in the compressive strength test were taken. In general, through the figures, it is noted that there is homogeneity between the base material (polymer) and additives and the absence of defects, which indicates the success of the preparation and mechanical mixing of the composite material.

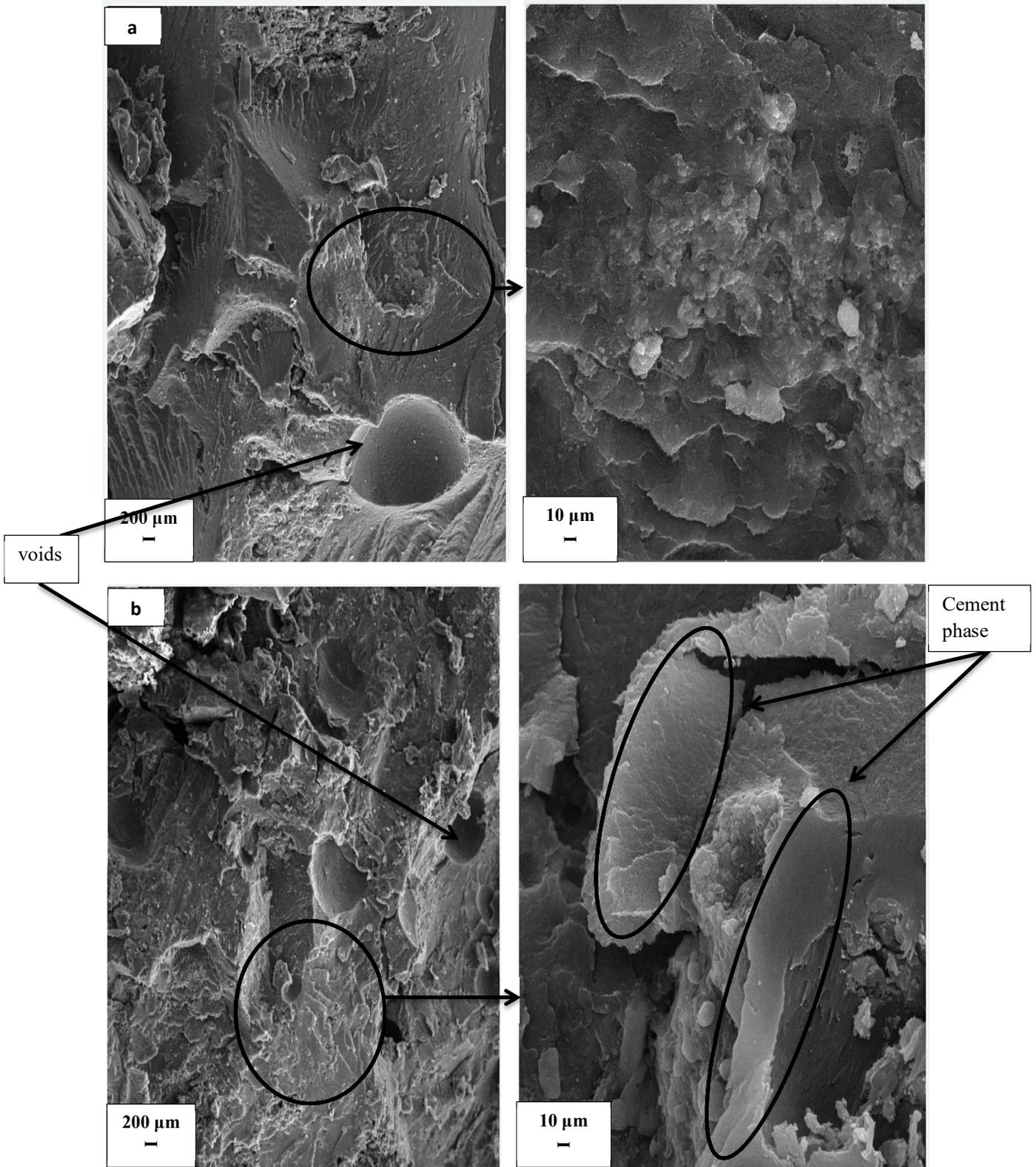
In Figures (4.23) and (4.25), it is clear that by increasing the percentage of sand to polymer, whether it is PET or LDPE, the fracture type changes from polymer deformation to brittle fracture, and this explains the high mechanical properties. Although in the case of LDPE, the polymer deformation turns into a brittle fracture, but in a very small way, there is no very clear brittle fracture, so there is a convergence of the compressive strength for these samples.

In figure(4.24, a, b) it is noted that adding fly ash in general works causes voids and defects, which leads to a lower compressive resistance compared to sand. This may be due to the difficulty of wetting the fly ash surface by polymer (PET) due to the high surface energy of the fly ash, which leads to difficulty during mixing and may lead to heterogeneity in the resulting material. However, When adding fly ash in high proportions, it will increase its mechanical properties clearly, because the fly ash acts as cementitious and works to reduce the size of the voids and increase compressive strength.

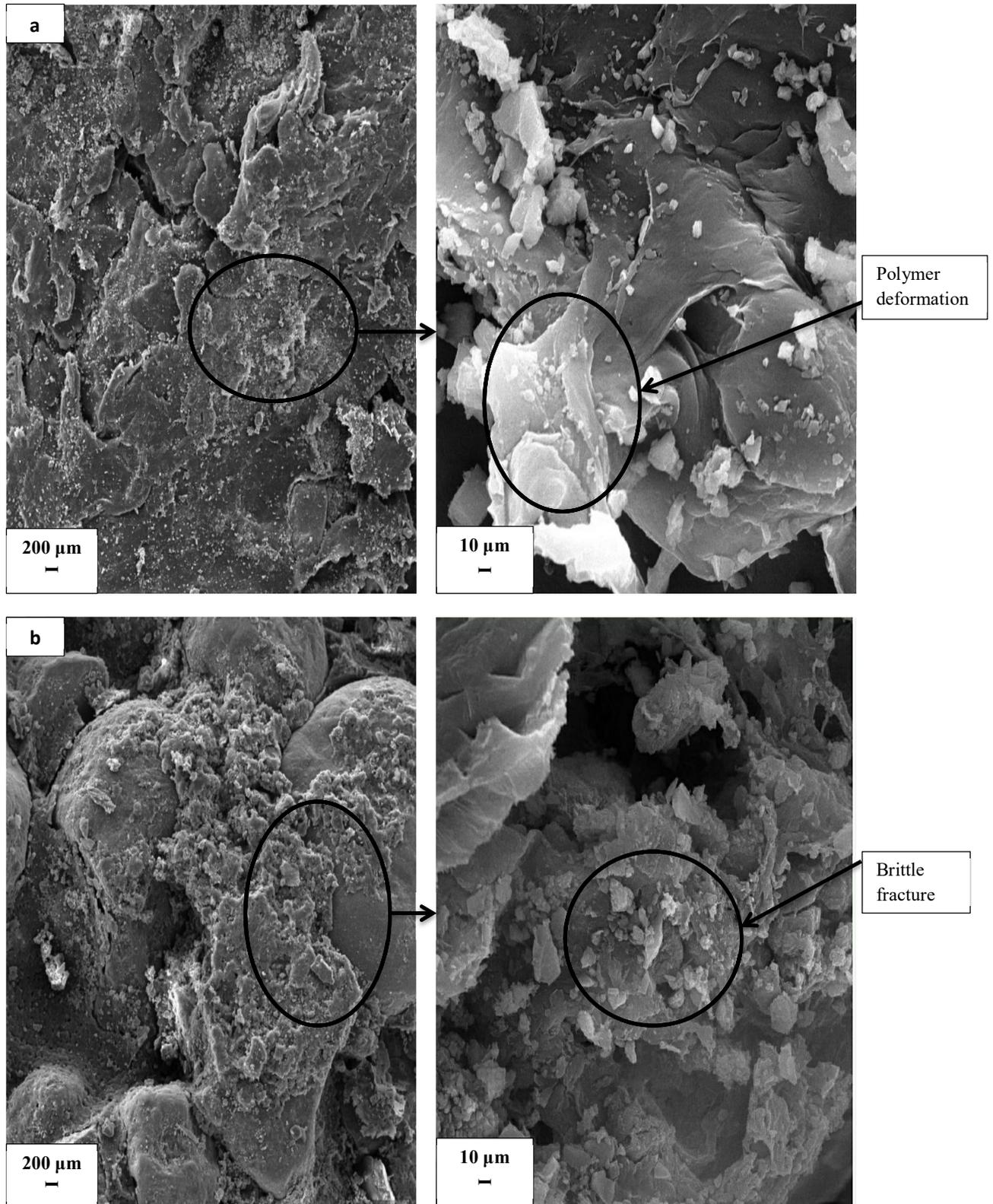
In Figure (4.26, a), the bonding of sawdust with the base polymer (LDPE) is good, because the surface wettability of sawdust by the base polymer is high compared to sand, which gives the highest compressive strength. This may be due to the porous nature of the sawdust and the low interfacial surface tension between the polymer and the sawdust. However, a significant increase in the proportion of sawdust significantly reduces the mechanical properties. Perhaps because the sawdust is of low density and therefore its size is large, so the material (LDPE) is insufficient to encapsulate and bind the sawdust particles, which leads to poor adhesion and thus poor mechanical properties, as shown in the figure (4.26, b).



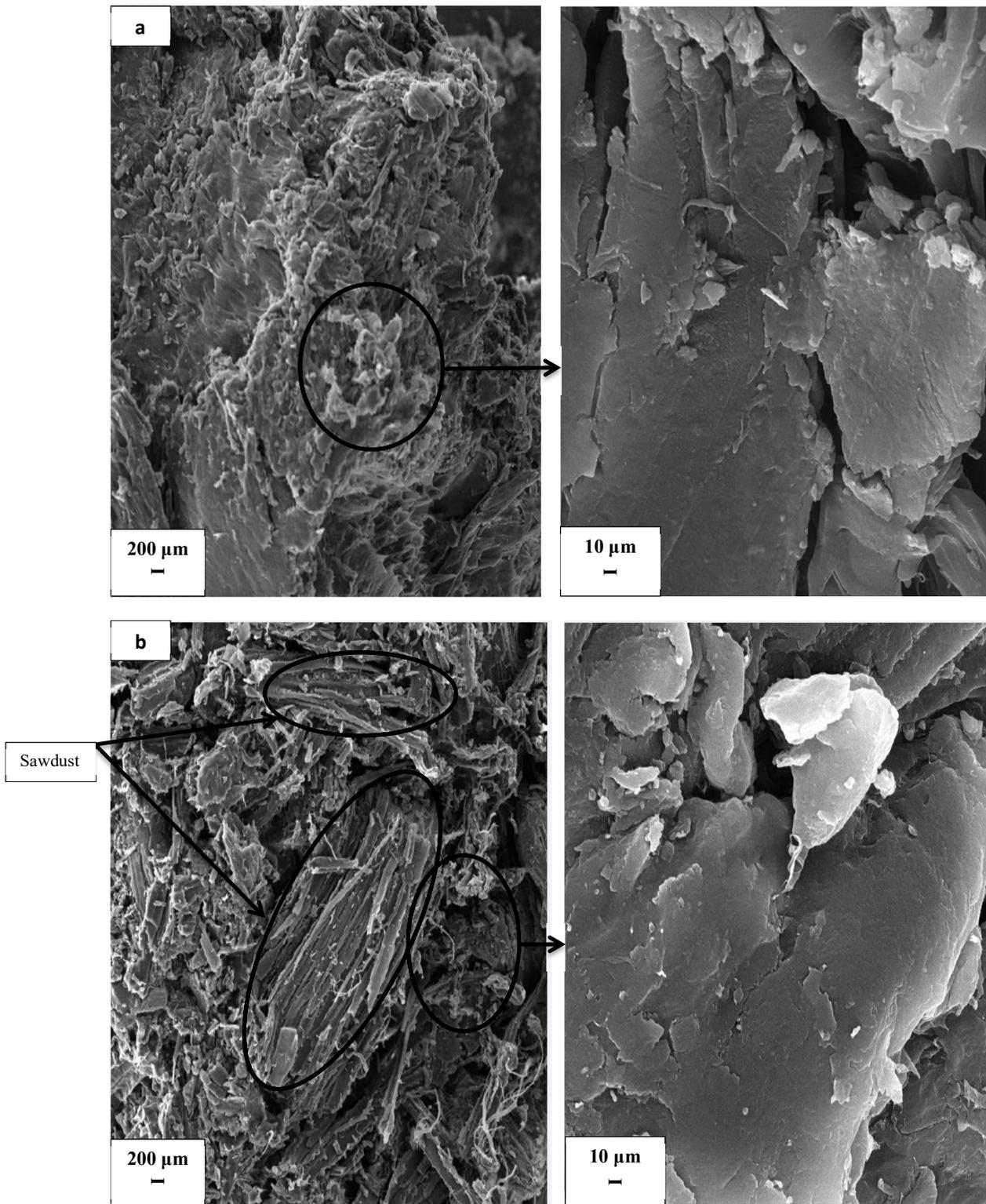
Figure(4.23): Scanning electron micrograph of (a) A1 sample that has the lowest compressive strength. (b) A5 sample that has the highest compressive strength.



Figure(4.24): Scanning electron micrograph of (a) B1 sample that has the lowest compressive strength. (b) B6 sample that has the highest compressive strength.



Figure(4.25): Scanning electron micrograph of (a) C2 sample that has the lowest compressive strength. (b) C6 sample that has the highest compressive strength.



**Figure(4.26):** Scanning electron micrograph of (a) D2 sample that has the highest compressive strength. (b) D5 sample that has the lowest compressive strength.

## 5.1 Introduction

This chapter includes the main conclusions we have reached through this study and the effect of adding fillers to plastic waste to produce plastic brick. This chapter also includes the most important recommendations that we will recommend for subsequent studies.

## 5.2 Conclusions

From this work, the following conclusions can be summarized:

- 1- FTIR results show no chemical reaction between fillers (fly ash, sand and sawdust) with polymer (LDPE or PET).
- 2- The density increases with the addition of sand for both PET and LDPE and also increases for mixtures of PET with fly ash after 40% of fly ash addition while it decreases with the addition of sawdust.
- 3- The hardness increases with the addition of sand and fly ash, but decreases with the addition of sawdust.
- 4- The compressive strength is improved by the addition of sand and fly ash but decreased with the increased addition of sawdust although the highest value is obtained for the 80%LDPE/20%sawdust sample.
- 5- The type of fracture in the compressive strength test differs between PET with fillers and LDPE with fillers where PET samples have a brittle fracture and LDPE samples are tends to have a ductile fracture.
- 6- The water absorption results are excellent for all samples except when increased adding sawdust, especially in the 50%LDPE/50%sawdust sample.
- 7- SEM results show good homogeneity and dispersion of fillers (sand, sawdust and fly ash) in polymers (LDPE or PET).

### **5.3 Recommendations**

From the present study, the following recommendation can be helpful for further studies:

- 1- Use flame retardants such as calcium carbonate or magnesium carbonate to increase their fire resistance even more.
- 2- Study of thermal and acoustic properties of plastic bricks.
- 3- Use other methods of preparation such as extrusion.
- 4- Use a fire-resistance thermoset such as epoxy.
- 5- Study other types of waste plastics such as PP, HDPE, and others in the brick industry.

## References

- [1] M. F. Ali and M. N. Siddiqui, "Thermal and catalytic decomposition behavior of PVC mixed plastic waste with petroleum residue," *J. Anal. Appl. Pyrolysis*, vol. 74, no. 1–2, pp. 282–289, 2005, doi: 10.1016/j.jaap.2004.12.010.
- [2] C. V. Alkunte, P. Vashisth, K. Aditya, R. Nilesh, and M. Amey, "Use of Thermoset in Manufacturing of Flyash Bricks with Economic Feasibility," *Int. J. Eng. Manag. Res. Page*, vol. 5, no. 2, pp. 49–52, 2015.
- [3] I. M. Susila, N. P. G. Suardana, C. I. P. K. Kencanawati, I. N. A. Thanaya, and I. W. B. Adnyana, "THE EFFECT of COMPOSITION of PLASTIC WASTE LOW DENSITY POLYETHYLENE (LDPE) with SAND to PRESSURE STRENGTH and DENSITY of SAND/LDPE COMPOSITES," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 539, no. 1, 2019, doi: 10.1088/1757-899X/539/1/012043.
- [4] Y. N. Kim, J.-H. Yoon, and K.-H. Kim, "Microplastic contamination in soil environment – a review," *Soil Sci. Annu.*, vol. 71, no. 4, pp. 300–308, 2021, doi: 10.37501/soilsa/131646.
- [5] D. Panaitescu, M. Iorga, A. Ciucu, S. Serban, A. Crucean, and C. Bercu, "New methods for recycling plastic materials from end-of-life vehicles," *WSEAS Trans. Environ. Dev.*, vol. 4, no. 12, pp. 1099–1108, 2008.
- [6] S. S. Chauhan, B. Kumar, P. S. Singh, A. Khan, and H. Goyal, "Fabrication and Testing of Plastic Sand Bricks," *IOP Conf. Ser. Mater. Sci. Eng.*, 2019, doi: 10.1088/1757-899X/691/1/012083.
- [7] M. Chavan, S. Tamhane, S. Chavan, and R. Phuge, "Manufacturing of pavement block by using waste plastic and sea sand," *Int. Res. J. Eng. Technol.*, vol. 6, no. 3, pp. 4354–4359, 2019, [Online]. Available: [www.irjet.net](http://www.irjet.net).
- [8] A. Gawande, G. Zamare, V. C. Renge, S. Tayde, and G. Bharsakale, "AN OVERVIEW ON WASTE PLASTIC UTILIZATION IN ASPHALTING OF ROADS," *J. Eng. Res.*, vol. III, no. II, pp. 1–5, 2012.
- [9] M. Sigler, "The effects of plastic pollution on aquatic wildlife: Current situations and future solutions," *Water. Air. Soil Pollut.*, vol. 225, pp. 1–9, 2014, doi: 10.1007/s11270-014-2184-6.
- [10] B. Gewert, M. M. Plassmann, and M. Macleod, "Pathways for degradation of plastic polymers floating in the marine environment," *Environ. Sci. Process. Impacts*, vol. 17, no. 9, pp. 1513–1521, 2015, doi: 10.1039/c5em00207a.
- [11] M. K. Sahu and L. Singh, "CRITICAL REVIEW ON TYPES OF BRICKS TYPE 14: PLASTIC SAND BRICKS," *Int. J. Mech. Prod. Eng.*, vol. 5, no. 11, pp. 84–88, 2017.
- [12] N. Gebremedhin and G. K. Rotich, "Manufacturing of Bathroom Wall Tile Composites from Recycled Low-Density Polyethylene Reinforced with Pineapple Leaf Fiber," *Int. J. Polym. Sci.*, vol. 2020, 2020, doi: 10.1155/2020/2732571.

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## References

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- [13] M. A. Kamaruddin, M. M. A. Abdullah, M. H. Zawawi, and M. R. R. A. Zainol, "Potential use of plastic waste as construction materials: Recent progress and future prospect," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 267, no. 1, 2017, doi: 10.1088/1757-899X/267/1/012011.
- [14] R. C. Rafiq Karbhari, Ali Yusuf Khan, Shantilal Palesha, Abhishek C Shirle, "Partial Replacement of Soil by Plastic Waste for Manufacturing of Bricks," *Int. J. Sci. Res. Eng. Trends*, vol. 6, no. 2, pp. 828–833, 2020.
- [15] M. Batayneh, I. Marie, and I. Asi, "Use of selected waste materials in concrete mixes," *Waste Manag.*, vol. 27, no. 12, pp. 1870–1876, 2007, doi: 10.1016/j.wasman.2006.07.026.
- [16] R. C. Thompson, C. J. Moore, F. S. V. Saal, and S. H. Swan, "Plastics, the environment and human health: Current consensus and future trends," *Philos. Trans. R. Soc. B Biol. Sci.*, vol. 364, no. 1526, pp. 2153–2166, 2009, doi: 10.1098/rstb.2009.0053.
- [17] D. Foti, "Use of recycled waste pet bottles fibers for the reinforcement of concrete," *Compos. Struct.*, vol. 96, pp. 396–404, 2013, doi: 10.1016/j.compstruct.2012.09.019.
- [18] R. Bhushaiah, S. Mohammad, and D. S. Rao, "Study of Plastic Bricks Made From Waste Plastic," *Int. Res. J. Eng. Technol.*, vol. 06, no. 04, pp. 1122–1127, 2019.
- [19] C. Wang, H. Wang, and Y. Liu, "Separation of polyethylene terephthalate from municipal waste plastics by froth flotation for recycling industry," *WASTE Manag.*, 2014, doi: 10.1016/j.wasman.2014.09.025.
- [20] M. Merbouh, B. Glaoui, A. Mazouz, and M. Belhachemi, "Use the plastic bag waste in cement concrete," *Eurasia 2014 waste Manag. Symp.*, no. November, 2014.
- [21] Z. Z. Ismail and E. A. AL-Hashmi, "Use of waste plastic in concrete mixture as aggregate replacement," *Waste Manag.*, vol. 28, no. 11, pp. 2041–2047, 2008, doi: 10.1016/j.wasman.2007.08.023.
- [22] H. R. K. 1P. G. S. C. Pramod S. Patil<sup>1</sup>, J.R.Mali<sup>2</sup>, Ganesh V.Tapkire<sup>3</sup>, "INNOVATIVE TECHNIQUES OF WASTE PLASTIC USED IN CONCRETE MIXTURE," *IJRET Int. J. Res. Eng. Technol.*, vol. 03, no. 09, pp. 29–32, 2014.
- [23] USEPA, "Municipal Solid Waste Landfills Economic Impact Analysis for the Proposed New Subpart to the New Source Performance Standards," no. June, p. 62, 2014.
- [24] N. Rudolph, R. Kiesel, and C. Aumnate, *Understanding Plastics Recycling*. 2020.
- [25] R. V. Moharir and S. Kumar, "Challenges associated with plastic waste disposal and allied microbial routes for its effective degradation: A comprehensive review," *J. Clean. Prod.*, vol. 208, 20AD, doi: 10.1016/j.jclepro.2018.10.059.

## References

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- [26] P. Singh and V. P. Sharma, "Integrated Plastic Waste Management: Environmental and Improved Health Approaches," *Procedia Environ. Sci.*, vol. 35, pp. 692–700, 2016, doi: 10.1016/j.proenv.2016.07.068.
- [27] R. Siddique, J. Khatib, and I. Kaur, "Use of recycled plastic in concrete: A review," *Waste Manag.*, vol. 28, no. 10, pp. 1835–1852, 2008, doi: 10.1016/j.wasman.2007.09.011.
- [28] P. M. Subramanian, "Plastics recycling and waste management in the US," *Resour. Conserv. Recycl.*, vol. 28, no. 3–4, pp. 253–263, 2000, doi: 10.1016/S0921-3449(99)00049-X.
- [29] E. Lantz, D. Olis, and A. Warren, "U . S . Virgin Islands Energy Road Map : Analysis U . S . Virgin Islands Energy Road Map : Analysis," no. September, 2011.
- [30] S. Combs, "Texas Comptroller of Public Accounts," pp. 257–267, 2008.
- [31] R. Roth, "From Waste Management to clean Materials." 2020.
- [32] H.-W. Schiffer, *World Energy Resources 2016*. 2016.
- [33] S. Agyeman, N. K. Obeng-Ahenkora, S. Assiamah, and G. Twumasi, "Exploiting recycled plastic waste as an alternative binder for paving blocks production," *Case Stud. Constr. Mater.*, vol. 11, no. e00246, pp. 1–8, 2019, doi: 10.1016/j.cscm.2019.e00246.
- [34] J. O. Akinyele, U. T. Igba, and B. G. Adigun, "Effect of waste PET on the structural properties of burnt bricks," *Sci. African*, vol. 7, p. e00301, 2020, doi: 10.1016/j.sciaf.2020.e00301.
- [35] J. R. Jambeck *et al.*, "Plastic waste inputs from land into the ocean," *Ciencia*, vol. 347, no. 6223, pp. 768–771, 2015, [Online]. Available: <http://www.sciencemag.org/cgi/doi/10.1126/science.1260879> <https://www.sciencemag.org/lookup/doi/10.1126/science.1260352>.
- [36] M. E. Grigore, "Methods of recycling, properties and applications of recycled thermoplastic polymers," *Recycling*, vol. 2, no. 4, pp. 1–11, 2017, doi: 10.3390/recycling2040024.
- [37] J. Hopewell, R. Dvorak, and E. Kosior, "Plastics recycling: Challenges and opportunities," *Philos. Trans. R. Soc. B Biol. Sci.*, vol. 364, no. 1526, pp. 2115–2126, 2009, doi: 10.1098/rstb.2008.0311.
- [38] J. Cui and E. Forsberg, "Mechanical recycling of waste electric and electronic equipment: A review," *J. Hazard. Mater.*, vol. 99, no. 3, pp. 243–263, 2003, doi: 10.1016/S0304-3894(03)00061-X.
- [39] R. Francis, G. P. Gopalan, and A. Sivadas, *Recycling of Polymers*. 2017.
- [40] S. Kumar, A. K. Panda, and R. K. Singh, "A review on tertiary recycling of high-density polyethylene to fuel," *Resour. Conserv. Recycl.*, vol. 55, no. 11, pp. 893–910, 2011, doi: 10.1016/j.resconrec.2011.05.005.
- [41] M. Chanda and S. K. Roy, *Plastics Fabrication and Recycling*, Fourth Edi. 2007.

## References

---

- [42] G. Dodbiba, K. Takahashi, J. Sadaki, and T. Fujita, "The recycling of plastic wastes from discarded TV sets: comparing energy recovery with mechanical recycling in the context of life cycle assessment," *J. Clean. Prod.*, vol. 16, no. 4, pp. 458–470, 2008, doi: 10.1016/j.jclepro.2006.08.029.
- [43] K. Hamad, M. Kaseem, and F. Deri, "Recycling of waste from polymer materials : An overview of the recent works," *Polym. Degrad. Stab.*, vol. 98, no. 12, pp. 2801–2812, 2013, doi: 10.1016/j.polymdegradstab.2013.09.025.
- [44] A. R. Rahimi and J. M. Garcíá, "Chemical recycling of waste plastics for new materials production," *Nat. Rev. Chem.*, vol. 1, pp. 1–11, 2017, doi: 10.1038/s41570-017-0046.
- [45] K. Ragaert, L. Delva, and K. Van Geem, "Mechanical and chemical recycling of solid plastic waste," *Waste Manag.*, vol. 69, pp. 24–58, 2017, doi: 10.1016/j.wasman.2017.07.044.
- [46] M. D. Jagtap, S. S. K. Khatavkar, and T. Z. Quazi, "Methods for Waste Plastic Recycling," *Int. J. Recent Technol. Mech. Electr. Eng.*, vol. 2, no. 6, pp. 120–122, 2015.
- [47] Dimitris S. Achilias et al., "Recent Advances in the Chemical Recycling of Polymers(PP, PS, LDPE, HDPE, PVC, PC, Nylon, PMMA)," *Mater. Recycl. – Trends Perspect.*, p. 63, 2012.
- [48] S. M. Al-Salem, P. Lettieri, and J. Baeyens, "Recycling and recovery routes of plastic solid waste (PSW): A review," *Waste Management*. 2009, doi: 10.1016/j.wasman.2009.06.004.
- [49] M. P. Aznar, M. A. Caballero, J. A. Sancho, and E. Francés, "Plastic waste elimination by co-gasification with coal and biomass in fluidized bed with air in pilot plant," *Fuel Process. Technol.*, vol. 87, no. 5, pp. 409–420, 2006, doi: 10.1016/j.fuproc.2005.09.006.
- [50] T. AK, A. OO, and R. AO, "A Pilot Recycling of Plastic Pure Water Sachets/Bottles into Composite Floor Tiles: A Case Study from Selected Dumping Site in Ogbomoso," *J. Mater. Sci. Eng.*, vol. 04, no. 06, pp. 1–5, 2015, doi: 10.4172/2169-0022.1000201.
- [51] A. Charles Abugri, "Recycling of plastics waste in Ghana: A way to reduce environmental problems/pollutions," *Arcada*. pp. 1–40, 2012.
- [52] S. Sharma and S. Mallubhotla, "Plastic Waste Management Issues, Solutions and Case Studies," *Zero Waste*, no. March. pp. 105–113, 2019, doi: 10.1201/9780429059247-7.
- [53] F. Iucolano, B. Liguori, D. Caputo, F. Colangelo, and R. Cioffi, "Recycled plastic aggregate in mortars composition: Effect on physical and mechanical properties," *Mater. Des.*, vol. 52, pp. 916–922, 2013, doi: 10.1016/j.matdes.2013.06.025.
- [54] P. Chaudhary, N. Soni, and M. T. S. Assistant, "Studies on Eco-Friendly Soil and Sawdust Filled Plastic Bottles to Promote Sustainable Development for Partition Walls," *Int. J. Sci. Res. Dev.*, vol. 5, no. 03, pp. 1133–1139, 2017.

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## *References*

---

- [55] A. F. Ikechukwu and C. Shabangu, "Strength and durability performance of masonry bricks produced with crushed glass and melted PET plastics," *Case Stud. Constr. Mater.*, vol. 14, pp. 1–15, 2021, doi: 10.1016/j.cscm.2021.e00542.
- [56] T. O. Ogundairo, D. O. Olukanni, I. I. Akinwumi, and D. D. Adegoke, "A review on plastic waste as sustainable resource in civil engineering applications," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1036, no. 1, pp. 1–14, 2021, doi: 10.1088/1757-899x/1036/1/012019.
- [57] Muhammad Maqbool Sadiq Muhammad Rafique Khattak, "Literature Review on Different Plastic Waste Materials Use in Concrete," *J. Emerg. Technol. Innov. Res.*, vol. 2, no. 6, pp. 1800–1803, 2015.
- [58] M. . Shabiimam, T. Kazi, A. Pandey, T. Ansari, and R. Chaurasia, "Reusing Plastic Waste by Manufacturing of Paver and Solid Block," *Constr. Manag. Pract.*, no. October, pp. 154–162, 2019.
- [59] T. R. da Silva *et al.*, "Application of plastic wastes in construction materials: A review using the concept of life-cycle assessment in the context of recent research for future perspectives," *Materials (Basel)*, vol. 14, no. 13, pp. 1–19, 2021, doi: 10.3390/ma14133549.
- [60] V. S. N. S. Goli, A. Mohammad, and D. N. Singh, "Application of Municipal Plastic Waste as a Manmade Neo-construction Material: Issues & Wayforward," *Resour. Conserv. Recycl.*, vol. 161, no. June, 2020, doi: 10.1016/j.resconrec.2020.105008.
- [61] V. Jankauskait, G. Macijauskas, and R. Lygaitis, "Polyethylene Terephthalate Waste Recycling and Application Possibilities : a Review," *Mater. Sci.*, vol. 14, no. 2, pp. 119–127, 2008, [Online]. Available: <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.557.3593&rep=rep1&type=pdf>.
- [62] S. Fakirov, *Handbook of Condensation Thermoplastic Elastomer*. 2005.
- [63] J. Scheirs and T. E. Long, *Modern Polyesters: Chemistry and Technology of Polyesters and Copolyesters*. 2003.
- [64] Sirisha R Kesaboina, "Kinetics and Chemical Reactions of Acetaldehyde Stripping and 2-methyl-1,3-dioxolane Generation in Poly (ethylene terephthalate)." pp. 1–135, 2011.
- [65] A. Sudakov, I. Chudyk, D. Sudakova, and L. Dziubyk, "Innovative technology for insulating the borehole absorbing horizons with thermoplastic materials," *Ukr. Sch. Min. Eng.*, vol. 123, pp. 1–13, 2019, doi: 10.1051/e3sconf/201912301033.
- [66] B. Demirel, A. Yaraş, and H. Elçiçek, "Crystallization Behavior of PET Materials," *BAÜ Fen Bil. Enst. Derg. Cilt*, vol. 13, no. 1, pp. 26–35, 2011.
- [67] J. Li-Na, "Study on preparation process and properties of polyethylene terephthalate (pet)," *Appl. Mech. Mater.*, vol. 312, pp. 406–410, 2013, doi: 10.4028/www.scientific.net/AMM.312.406.

## References

---

- [68] Q. Fu, "Solid State Polymerization, Processing and Properties of PEN/PET Blends," no. August. pp. 1–285, 2005.
- [69] A. J. Peacock, *Handbook of Polyethylene : Structures , Properties and Applications*, vol. 15, no. C. 2000.
- [70] S. Kumar Sen and S. Raut, "Microbial degradation of low density polyethylene (LDPE): A review," *J. Environ. Chem. Eng.*, vol. 3, no. 1, pp. 1–13, 2015, doi: 10.1016/j.jece.2015.01.003.
- [71] C. A. Harper, *Handbook of Plastics Technologies, the complete guide to properties and performance*. 2006.
- [72] K. Chrissafis and D. Bikiaris, "Can nanoparticles really enhance thermal stability of polymers? Part I: An overview on thermal decomposition of addition polymers," *Thermochim. Acta*, vol. 523, no. 1–2, pp. 1–24, 2011, doi: 10.1016/j.tca.2011.06.010.
- [73] A. Arora, D. Urmil, and V. Dave, "Utilization of E-Waste and Plastic Bottle Waste in Concrete," *Int. J. Students Res. Technol. Manag.*, vol. 1, no. 04, pp. 398–406, 2013, [Online]. Available: [www.giapjournals.com/ijsrtm/](http://www.giapjournals.com/ijsrtm/).
- [74] S. A. Wahid, S. M. Rawi, and N. Desa, "Utilization of Plastic Bottle Waste in Sand Bricks," *J. Basic Appl. Sci. Res.*, vol. 5, no. 1, pp. 35–44, 2015.
- [75] A. M. H. Mansour and S. A. Ali, "Reusing waste plastic bottles as an alternative sustainable building material," *Energy Sustain. Dev.*, vol. 24, pp. 79–85, 2015, doi: 10.1016/j.esd.2014.11.001.
- [76] Z. Muyen, T. N. Barna, and M. N. Hoque, "Strength properties of plastic bottle bricks and their suitability as construction materials in Bangladesh," *Progress. Agric.*, vol. 27, no. 3, pp. 362–368, 2016.
- [77] C. Nivetha, M. Rubiya, S. Shobana, V. R. G. Viswanathan, and R. Vasanthi, "Production of plastic paver block from the solid waste (quarry dust, flyash & PET)," *ARPJ. Eng. Appl. Sci.*, vol. 11, no. 2, pp. 1078–1079, 2016.
- [78] P. A. S. Manjarekar, R. D. Gulpatil, V. P. Patil, R. S. Nikam, and C. M. Jeur, "Utilization of Plastic Waste in Foundry Sand Bricks," *Int. J. Res. Appl. Sci. Eng. Technol.*, vol. 5, no. IV, pp. 977–982, 2017.
- [79] H. G. Anand Daftardar, Rashmi patel, Ronak Shah, Parth Gandhi, "Use of Waste Plastic as a Construction Material," *Int. J. Eng. Appl. Sci.*, vol. 4, no. 11, pp. 148–151, 2017.
- [80] M. Puttaraj, S. Hiremath, N. Shetty, and P. P. G. T. B. Rai, "Utilization Of Waste Plastic In Manufacturing Of Plastic-Soil Bricks," *Int. J. Technol. Enhanc. Emerg. Eng. Res.*, vol. 2, no. 4, pp. 102–107, 2014.
- [81] A. Kumi-Larbi, D. Yunana, P. Kamsouloum, M. Webster, D. C. Wilson, and C. Cheeseman, "Recycling waste plastics in developing countries: Use of low-density polyethylene water sachets to form

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## References

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- plastic bonded sand blocks," *Waste Manag.*, vol. 80, pp. 112–118, 2018, doi: 10.1016/j.wasman.2018.09.003.
- [82] S. K. Intan and S. Santosa, "Utilization of PET and LDPE plastic waste and building material waste as bricks," *Korean J. Mater. Res.*, vol. 29, no. 10, pp. 603–608, 2019, doi: 10.3740/MRSK.2019.29.10.603.
- [83] C. S. K. Reddy, B. S. Chandra Kumar, and S. S. Asadi, "Utilization of low density polyethylene waste in the manufacturing of paver brick," *Int. J. Recent Technol. Eng.*, vol. 7, no. 6C2, pp. 62–67, 2019.
- [84] L. N. R. Ganesh N. Patil, Marwa al Yahmedi, Santosh M. Walke, "Manufacturing of plastic sand bricks from polypropylene and polyethylene waste plastic," *Int. J. Adv. Sci. Technol.*, vol. 29, no. November, pp. 2062–2068, 2020.
- [85] R. Kedare, "Physical Characterization of Waste-Plastic Brick and Development of material for pothole filling," *Int. J. Sci. Dev. Res.*, vol. 5, no. 1, pp. 38–42, 2020.
- [86] W. S. Alaloul, V. O. John, and M. A. Musarat, "Mechanical and Thermal Properties of Interlocking Bricks Utilizing Wasted Polyethylene Terephthalate," *Int. J. Concr. Struct. Mater.*, vol. 14, no. 1, pp. 1–11, 2020, doi: 10.1186/s40069-020-00399-9.
- [87] S. L. Mak, T. M. Y. Wu, F. W. F. Tang, J. C. H. Li, and C. W. Lai, "A Review on Utilization of Plastic Wastes in Making Construction Bricks," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 706, pp. 1–7, 2021, doi: 10.1088/1755-1315/706/1/012001.
- [88] Z. Ge, H. Yue, and R. Sun, "Properties of mortar produced with recycled clay brick aggregate and PET," *Constr. Build. Mater.*, vol. 93, pp. 851–856, 2015, doi: 10.1016/j.conbuildmat.2015.05.081.
- [89] R. Chércoles Asensio, M. San Andrés Moya, J. M. De La Roja, and M. Gómez, "Analytical characterization of polymers used in conservation and restoration by ATR-FTIR spectroscopy," *Anal. Bioanal. Chem.*, vol. 395, no. 7, pp. 2081–2096, 2009, doi: 10.1007/s00216-009-3201-2.
- [90] B. J. Holland and J. N. Hay, "The thermal degradation of poly(vinyl acetate) measured by thermal analysis-Fourier transform infrared spectroscopy," *Polymer (Guildf.)*, vol. 43, no. 8, pp. 2207–2211, 2002, doi: 10.1016/S0032-3861(02)00038-1.
- [91] J. Coates, "Interpretation of Infrared Spectra, A Practical Approach," *Encycl. Anal. Chem.*, pp. 1–23, 2006, doi: 10.1002/9780470027318.a5606.
- [92] S. Carmona-Téllez *et al.*, "SPECTROMETRIC IDENTIFICATION OF ORGANIC COMPOUNDS," 2005.
- [93] H. Rajandas, S. Parimannan, K. Sathasivam, M. Ravichandran, and L. Su Yin, "A novel FTIR-ATR spectroscopy based technique for the estimation of low-density polyethylene biodegradation," *Polym. Test.*, vol. 31, no. 8, pp. 1094–1099, 2012, doi: 10.1016/j.polymertesting.2012.07.015.



جمهورية العراق  
وزارة التعليم العالي والبحث العلمي  
جامعة بابل  
كلية هندسة المواد  
قسم هندسة البوليمرات والصناعات البتروكيمياوية

## تصنيع وتوصيف الطابوق من نفايات البوليمر/الاضافات

رسالة

مقدمة إلى مجلس كلية هندسة المواد/ جامعة بابل  
وهي جزء من متطلبات نيل درجة الماجستير في  
هندسة المواد/ البوليمر

من قبل الباحثة

رسل محمد عبد الزهرة راضي

بإشراف

أ. م. د. أحمد فاضل حمزة

2022م

1443هـ

## الخلاصة

تعد المواد البوليمرية جزءًا مهمًا من الحياة الحديثة ولها مجموعة واسعة من التطبيقات حيث زاد استهلاك البوليمر في السنين الاخيره بشكل كبير ولكن بسبب طبيعه البوليمر الغير قابله للتحلل اصبح التخلص من مخلفات البوليمر بعد استخدامها مشكله رئيسيه في المجتمع الحديث ولهذا اصبح الاهتمام كبير بإعادة تدوير هذه المادة الغير القابلة للتحلل و تحويلها الى منتجات اخرى والاستفاده منها.

لذلك ، فإن إعادة تدوير مثل هذه النفايات كمواد بناء هو حل قابل للتطبيق ليس فقط لمشكلة التلوث هذه ولكن أيضًا لمشكلة التصميم الاقتصادي للمباني. يهدف هذا البحث إلى دراسة إمكانية استخدام المخلفات البوليمرية في صناعة الطابوق غير التقليدي خفيف الوزن وصديق للبيئة وغير مكلف ويمكن استخدام هذا الطابوق البوليمري لرصف الأرضيات في الأماكن العامة مثل الأرصفة ومواقف السيارات وممرات الحدائق والبلاط السطحي، وكذلك يستخدم كطوب لتشييد المباني والجدران الفاصلة.

في هذه الدراسة تم استخدام نوعين من نفايات البوليمر: البولي ايثيلين تريفثاليت مع نوعين من الاضافه (الرمل ورماد الخشب) و البولي ايثيلين واطئ الكثافه مع نوعين من الاضافه (الرمل ونشارة الخشب). تم استخدام عملية الصهر والقولبة في صناعة الطابوق البوليمري. تم أخذ نسب مختلفة من النفايات البوليمرية مع الاضافه لصناعه الطابوق.

أجريت العديد من الفحوصات التي تعتبر مهمة في مجال البناء وبالأخص فحوصات الطابوق القياسيه،حيث تم إجراء العديد من الاختبارات مثل مقاومة الانضغاط والصلادة والكثافة وامتصاص الماء وتحويل فورييه بالأشعة تحت الحمراء والمسح المجهرى الإلكتروني.

تكشف نتائج تحويل فورييه للأشعة تحت الحمراء للنفايات البوليمرية (PET أو LDPE) مع مواد المضافه (الرمل ورماد الخشب ونشارة الخشب) أنه لم يكن هناك تفاعل كيميائي بين المكونات وأن هناك تفاعل فيزيائي فقط. وتظهر نتائج مقاومة الانضغاط زيادة مقاومه الانضغاط بإضافة الرمل و رماد الخشب ولكن تقل مع زيادة إضافة نشارة الخشب. على الرغم من الحصول على أكبر نتيجة لعينة LDPE بأضافه 20% نشارة الخشب بقيمة (MPa66.89).

ايضا تظهر نتائج هذه الدراسة زيادة في الكثافة والصلادة لكل من إضافة الرمل ورماد الخشب ولكن انخفاض مع زياده إضافة نشارة الخشب. كذلك تظهر النتائج أداءً ممتازًا لاختبار امتصاص الماء لجميع العينات ما عدا عند زيادة إضافة نشارة الخشب ، خاصة في عينة LDPE بأضافه 50 % نشارة الخشب بقيمة 21.05%.

تظهر نتائج المجهر الإلكتروني الماسح تجانس وتشتت جيد بين المواد الأساسية (البوليمر) والمواد المضافة, ويلاحظ أيضاً عدم وجود عيوب مما يدل على نجاح التحضير والخلط الميكانيكي للمادة المركبة.