Production of Lightweight Clay Bricks Using Polymer Wastes

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Abstract- *In this study, different percentages (2, 4, 6, 8, and 10% by weight of the soil) of chopped polymeric (plastic bottles with maximum particle size 2.36 mm and 1.18 mm in addition to rubber tires of 0.6 mm max particle size) wastes are incorporated with soil to produce lightweight clay bricks, to find the optimum percentage satisfying the requirements of bricks grade C using for non-structural walls (partitions).The effects of different types and percentages of the polymeric wastes on firing shrinkage, density, water absorption, compressive strength and thermal conductivity of the fired bricks were studied. Results indicate that it is possible to incorporate not more than 8% of chopped rubber tires or not more than 6% of chopped bottles to the clay soil to produce lightweight fired clay bricks satisfying the compressive strength and water absorption requirements for grade C of bricks (used for partitions) according to the Iraqi specification IQS 25/1988, in addition to reducing the thermal conductivity by 13-17% which is desirable as it will reduce the energy required for heating and cooling. Also, found that the size of the incorporated particles of plastic wastes in clay, used for bricks manufacturing, did not have a significant effect on the different studied properties of bricks. In addition to, the incorporation of chopped rubber tires, having smaller particles size and more sphere particles shape, produce fired clay bricks with more homogeneous pores distribution and smaller size compared with clay brick incorporating chopped plastic wastes having flaky shape and larger particles size, leading to produce clay brick with higher density and strength, with lower water absorption. As a total results, the incorporation different types of polymeric wastes (chopped plastic bottles with 2.36 and 1.18 max size and chopped rubber tires) with percentages (2, 4, 6, 8, and 10% by weight of soil) , cause the firing shrinkage and water absorption to increase by (0.6-20.2%) and (3-43.5%) respectively, while the density, compressive strength, and thermal conductivity decrease by (3.5-25.1%), (0.4-2.3%), and (2.1-31.9%) respectively with respect to the reference fired clay bricks, depending on the percentage, particles size, and type of the polymeric wastes addition.*

Keywords- *brick, bulk density, compressive strength, firing shrinkage, plastic wastes, rubber tires wastes, thermal conductivity.*

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1. Introduction

The quantum of solid wastes is ever increasing due to increase in population, developmental activities, changes in life style, and socio-economic conditions. Polymer wastes is a significant portion of the total municipal solid wastes. It is estimated that thousands of tons per day of those wastes are generated. Polymers are very common materials that is now widely used by everybody in the world. Polymers have many uses, as they are compact and light in weight. Common polymer items that are used are tires, bottles, containers and food packages. Disposal of this large quantity of polymeric wastes has emerged as an important environmental challenge due to their non-degradable nature. This means that they will not decompose when they are buried. Recycling is the process of converting waste materials into reusable objects or introducing them into certain industry. This can be useful in reducing the consumption of raw materials, energy usage, and reduce the environment pollution. The increase in the popularity of using environmental friendly, low cost and lightweight construction materials in building industry has brought about the need to investigate how this can be achieved by benefiting the available huge quantities of accumulated wastes[1]. In this study, polymeric (plastic and rubber tires) wastes are used to incorporate with soil to produce lightweight clay

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bricks. This is an optimal method to solve the problem of disposing these waste materials. Lightweight clay bricks is favorable to be used in Iraqi environment due to their low thermal conductivity. The thermal insulation provided by this product is a result of the small pores present in the fired clay.

2. Materials Used

I. Soil

Soil used throughout this work was brought from AL-Nahrawan region in Baghdad. It is the same soil used for one of the nearby brick-manufacturing factory. Tables 1 and 2 indicate the grain size distribution and the chemical analysis of the used soil.

Table 1: The Grain Size Distribution of the Used Soil

Type of test	Results
Grain size of soil:	
Sand%	20
Silt%	37
Clay%	43
Soil classification	Clay of low plasticity (CL)

Table 2: Chemical Composition of Soil

Chemical symbol	Content in soil (%)
SiO_2	41.75
L.O.I	17.22
CaO	16.34
$Al2O_3$	12.84
Fe_2O_3	2.40
MgO	5.20
K_2O	1.65
Na_2O	0.95
SO_3	0.59
Cl	0.21
Total	99.15

II. Chopped PET bottles and rubber tires wastes

PET refers to polyethylene terephthalate, and PET bottles are occupying an indispensable position in common man's life. The bottles and tires were chopped to the required maximum size after washing them from dust. The chopped wastes particles were passed through sieve size 0.6mm for rubber tires and through sieves 2.36mm and 1.18mm sieve for PET plastic wastes as two types of plastic wastes. Plates 1 and 2 show the two types of chopped wastes. Table 3 shows the sieve analysis of the three types of the wastes, using aggregate sieves size according to "Guidance manual for engineering uses of scrap tires" [1-2]. While Table 4 show the effect of 1000^{o}C temperature on weight loss of PET plastic and rubber tires wastes.

Plate 1: Chopped Rubber Tires

Plate 2: Chopped PET Bottles

Table 3: Sieve Analysis of the Three Types of the Wastes

Sieve Size (mm)	% Passing Rubber tires	% Passing Plastic wastes with max size 2.36 mm	% Passing Plastic wastes with max size 1.18 mm
4.75	100.00	100.00	100.00
2.36	100.00	100.00	100.00
1.18	100.00	7.71	100.00
0.60	100.00	4.05	52.50
0.30	50.15	1.24	16.09
0.15	10.05	0.84	10.93

Table 4: Effect of 1000^{o}C Temperature on Weight Loss of Polymer Wastes

Type of waste	Weight loss, %
rubber tires wastes	88
PET plastic wastes	95

3. Mixing Process

Different proportions of chopped bottles & chopped tires (2%, 4%, 6%, 8%, 10%) by weight were added to the soil to produce the required mixtures. After finding plasticity coefficient of mixtures by pfefferkorn method [3], the optimum quantity of water was added to the soil. Then soil mixed with water by hand for about 15 minutes to get the required consistency, after that the mixtures put in plastic bags and left for at least 24 hours to ensure homogeneity and disintegration of large soil particles to be ready to process of forming by extrusion.

3. Samples Formation

Laboratory samples of clay bricks formed by vacuum extruder as shown in Plates 3 and 4. Vacuum extruder form samples with 38 mm width, thickness of 25 mm and a continuous length. The length cut according to the required dimension of 75mm [4].

Plate 3: Extrusion Machine

Plate 4: Formation Process of Samples

4. Drying of Samples

After finding the weight and dimensions by vernier caliper, laboratory samples left to be dry in air in lab for 7days, then dried in drying oven for 48 hours with temperature (110±5) ^{o}C. [4].

5. Firing Procedure

Dried samples were transferred to an electric furnace where set the heating rate (4°C per minute). Samples have been arranged inside the oven to guarantee the arrival of the heat to all surfaces of the bricks evenly and get uniform burning process. The samples were then fired in a furnace at 1000°C with a soaking time one hour. After finishing the burning process it has been extinguished, the electric furnace and samples left in the oven until cool down to the laboratory temperature.

6. Results and Discussion

The effects of different types and percentages of polymeric wastes addition on the properties of fired clay bricks are shown in Table 5**.**

I. Firing shrinkage

The average linear firing shrinkage of ten samples recorded for each test in Table (5) and Fig (1), using the following equation:

$$\% (L.S) = \{(Hd - Hr) / Hd\} \times 100 \quad (1)$$

Where:

(L.S) = Linear firing shrinkage.

H d = Sample length before firing (mm)

H r = Sample length after firing (mm)

Results indicate that there is an increase in the longitudinal shrinkage with increase in the polymeric wastes content addition (2, 4, 6, 8, and 10%) to the clay brick mixture. The percentages of increase are (2.5, 5, 9.5, 14.5, and 20.2%), (1.8, 3.1, 5.7, 10.1, and 15.2%), and (0.6, 2.5, 4.4, 6.9, and 10.1%) for groups B, C and D respectively with respect to the shrinkage of the reference bricks (group A).

This increase in longitudinal shrinkage might be because the burned polymeric waste materials form voids in the microstructure of bricks causing reduction in volume.

Results also show that addition coarser chopped bottle wastes (passed through sieve size 2.36 mm) to the soil mix caused longitudinal shrinkage of bricks more than those with chopped plastic wastes passed through sieve size 1.18 mm. This might be because finer chopped bottle wastes result in relatively finer pores when fired, so the longitudinal shrinkage become lower.

Table 5: Effects of Polymer Wastes on Properties of Fired Bricks

Group symbol	Raw materials	% Waste addition	Firing Shrinkage %	Bulk density g/cm^3	Comp. Strength N/mm^2	Water absorption %	Thermal conductivity W/m.K
A	Soil Reference	----	1.58	1.67	12.4	21.66	0.47
B1	Soil+ chopped bottles passing through sieve size 2.36mm	2	1.62	1.59	11.03	23.71	0.44
B2		4	1.66	1.51	10.15	24.89	0.42
B3		6	1.73	1.42	9.01	25.91	0.39
B4		8	1.81	1.33	8.29	28.65	0.36
B5		10	1.90	1.25	7.41	31.1	0.32
C1	Soil+chopped bottles passing through sieve size 1.18mm	2	1.61	1.60	11.66	23.09	0.44
C2		4	1.63	1.51	10.52	24.11	0.43
C3		6	1.67	1.43	9.12	25.17	0.41
C4		8	1.74	1.35	8.71	27.01	0.38
C5		10	1.82	1.26	7.84	29.12	0.35
D1	Soil+ chopped rubber tires passing through sieve size 0.6 mm	2	1.59	1.61	11.88	22.32	0.46
D2		4	1.62	1.52	11.03	22.73	0.44
D3		6	1.65	1.43	10.23	23.41	0.41
D4		8	1.69	1.34	9.49	24.42	0.39
D5		10	1.74	1.28	8.71	25.51	0.37

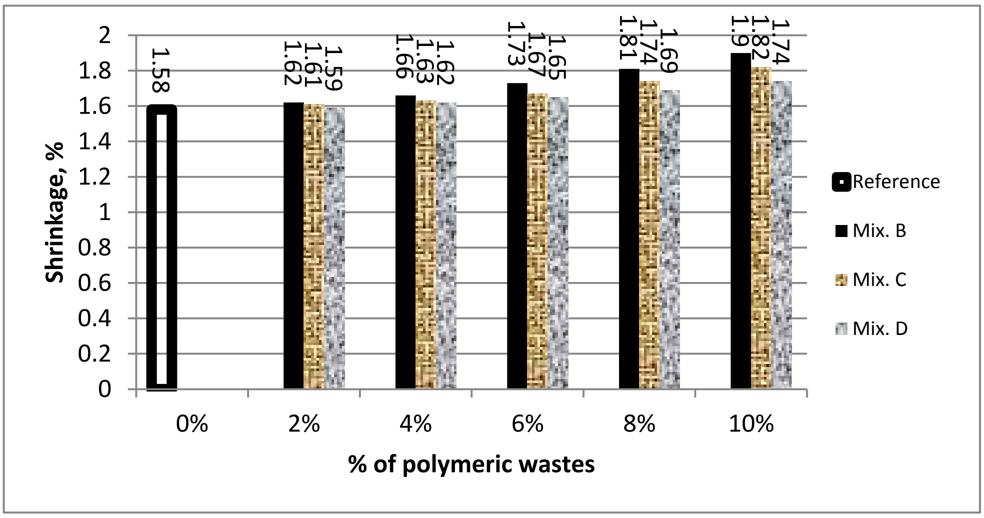

Figure 1: Effect of Polymeric Wastes on the Firing Shrinkage

II. Bulk Density

The average bulk density of ten samples, carried out according to method reported by Beech [4], recorded for each test in Table 5 and Figure 2, using the following equation:

Bulk density (g / cm^3) = Wf / V f (2)

Where:

W f = Sample weight after firing (g)

Vf = Sample size after firing (cm^3)

Results show that the incorporation of (2,4,6,8, and 10%) of plastic wastes with 2.36 mm max. size, and plastic wastes with 1.18 mm max. size, in addition to incorporation rubber wastes with 0.6 mm max. size cause decrease in the bulk density of the reference samples by (4.7, 9.5, 14.9, 20.3, and 25.1%), (4.1, 9.5, 14.3, 19.1, and 24.5%), and (3.5, 8.9, 14.3, 19.7, and 23.3 %) respectively. This decrease in the bulk density might be due to several reasons, including reduction the percentage of clay in the mixture, which were replaced by polymeric wastes have less density of clay. In addition, those wastes burned during firing process leaving pores that lower the clay brick density. Figure 3 /a, b, c, and d show the cross-section of the fracture surface of fired clay bricks samples without and with different polymeric wastes content. From Figures 3/ c and d, it could be observed that chopped bottle wastes passed through sieve size 2.36 mm caused larger pores in the fired clay body as compared with samples using chopped bottle wastes passed through sieve size 1.18 mm, so mixtures with chopped bottle waste passed through sieve size 2.36 mm have less density than that with passed through sieve size 1.18 mm has been indicated in Table 5 and Figure 6. Figures (3/ b, c and d) show that addition of chopped rubber tires, having smaller particles size and more sphericity particles shape, produce fired clay bricks with more homogeneous pores distribution and smaller size compared with clay brick incorporating chopped plastic wastes having flaky shape and larger particles size.

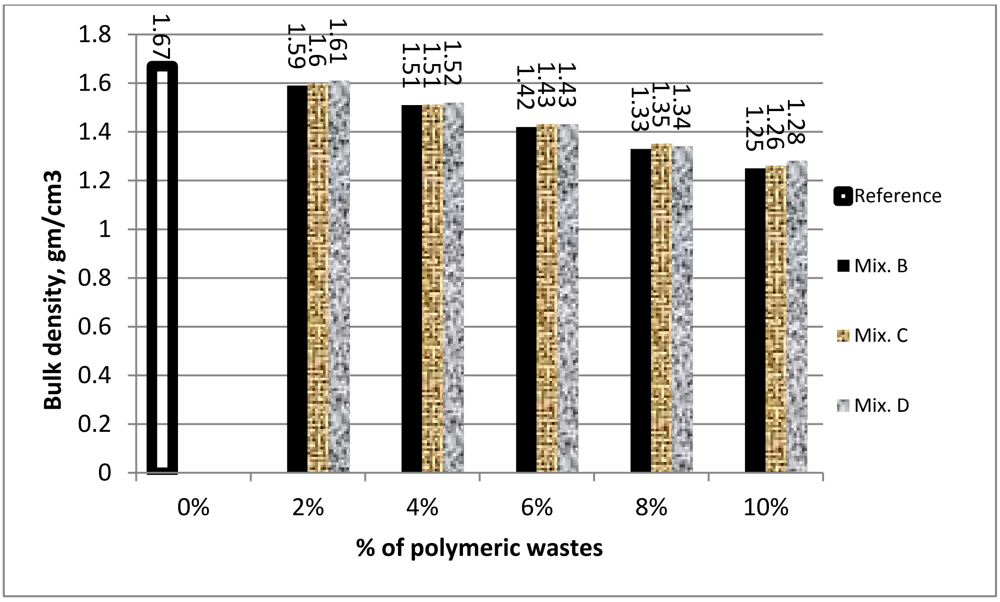

Figure 2: Effect of Polymeric Wastes on the Bulk Density of Fired Bricks

(a) Reference Sample (Without Additives)

(b)10 wt% Chopped Rubber Addition

(c) 10wt% Chopped Plastic Addition
(max size 1.18mm)

(d) 10wt% Chopped Plastic Addition
(max size 2.36 mm)

Figure 3: Surface Texture of Samples with Different Contents and Types of Polymeric Wastes

III. Water Absorption

The average water absorption of ten samples, carried out according to Iraqi specification IQS 24/1988 [6], recorded for each test, are shown in Table 5 and Figure 4. Results show that there are increase in the values of water absorption with increase in the polymeric wastes content (2, 4, 6, 8, and 10%).The percentages of increase are (9.4, 14.9, 19.6, 32.2, and 43.5%), (6.6, 11.3, 16.2, 24.7, and 34.4%) and (3, 4.9, 8, 12.7, and 17.7%) for groups B, C and D respectively with respect to reference group A. This correlation might be due to the increased amount of liberated gases resulting from the burning of polymeric wastes inside the bricks. Liberated gases cause pores and capillary channels and lead to increase the open pores in the bricks. In addition, partial replacement of the soil by the polymeric wastes reduces the products of mineralogical phases that fills the pores. Results also show that incorporating chopped bottle wastes passed through sieve size 2.36 mm in the clay bricks mix caused water absorption more than those incorporating chopped bottle wastes passed through sieve size 1.18 mm, since porous material will absorb more water as its porosity increases. This is due to the increase in voids fraction that are readily filled by water as the material soaked in water. Results from Table 5 indicate that the fired clay bricks with all the percentages of incorporated chopped rubber tires addition (2, 4, 6, 8, and 10%) satisfied the water absorption requirements of the Iraqi specification IQS 25/1988 [7] of 26% (max limit), for clay bricks class C, used for non-structural partitions. Also can be used with not more than 6% addition to satisfy the requirements of class B load-bearing bricks that need the water absorption to be not more than 24%. For samples incorporating chopped bottles, the Iraqi specification requirements for clay bricks class C did not satisfied for those with more than 6% waste addition.

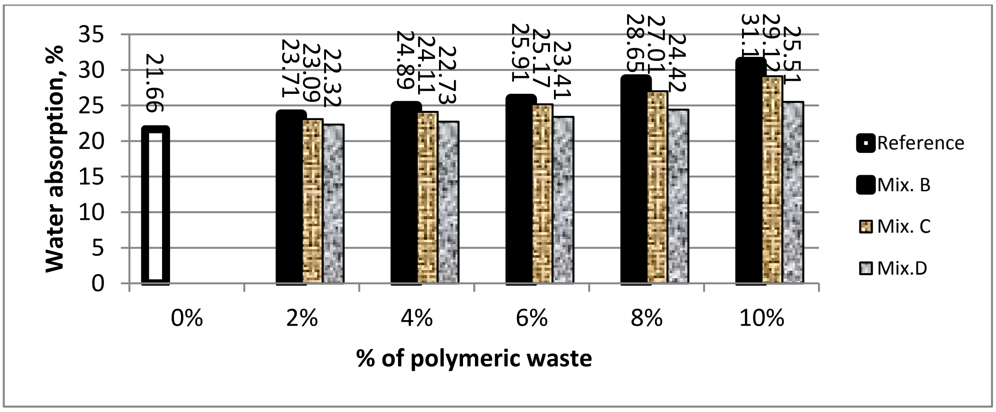

Figure 4: Effect of Polymeric Wastes on the Water Absorption of Fired Bricks

IV. Compressive strength

The average compressive strength of ten samples, carried out according to Iraqi specification IQS [6], recorded for each test (Table 5 and Figure 5). Results show clearly that the compressive strength decrease with the increase in the percentage of polymeric wastes for all mixes. The percentages of reduction in the compressive strength of the reference samples are (11, 18.1, 27.3, 33.1, and 40.2%), (5.9, 15.1, 26.4, 29.7, and 36.7%), and (4.1, 11, 17.5, 23.4, and 29.7%) for groups B, C and D when the polymeric wastes incorporated in the soil mixes are (2, 4, 6, 8, and 10%) respectively. Decreasing in the compressive strength might be due to voids resulted from burning of polymeric wastes inside the bricks. Liberated gases causes pores and capillary channels, which reduce the compressive strength. In addition, partial replacement of clay by polymeric wastes reduces the percentage of clay in the mass. This reduces crystalline minerals, which is responsible for the increased compressive strength. Chopped bottle waste addition (passed through sieve size 2.36mm) reduce the compressive more than that passed through sieve size 1.18mm, since it causes larger pores and continuity. According to Iraqi standard No.25/1988 [6], the minimum compressive strength (average for 10 bricks) for grade C equal to 9 Mpa, this grade intended for use in partitions. Table 5 and Figure 5 indicate that it is possible to incorporate not more than 8% of chopped rubber tires (group D) or not more than 6% of chopped bottles (group B and C) to the clay soil to produce clay bricks satisfying the requirements of grade C of bricks according to the Iraqi specification IQS [7]. Polymeric waste can contribute to reducing the environmental problems producing from their disposal, in addition to product lightweight building material.

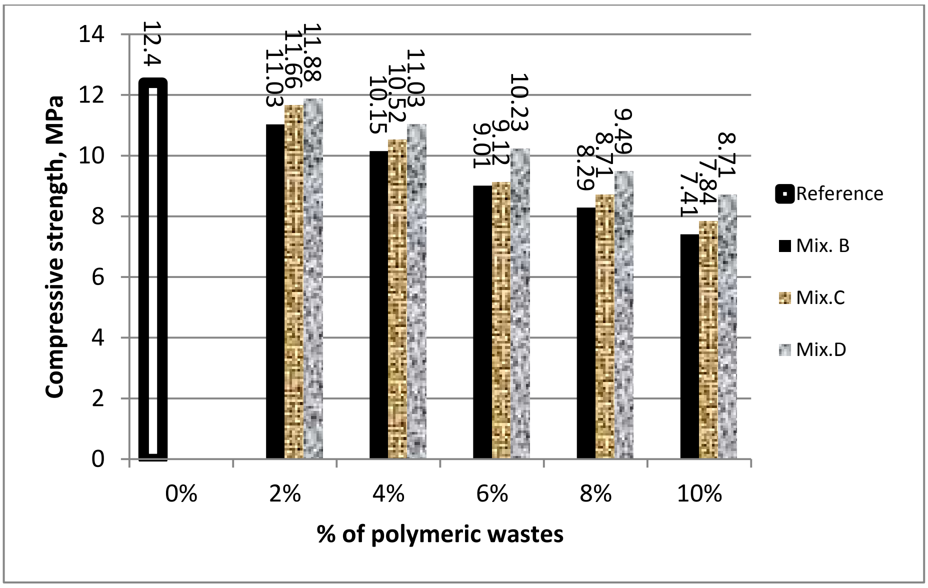

Figure 5: Effect of Polymeric Wastes on the Compressive Strength of Fired Bricks

V. Thermal Conductivity

The average thermal conductivity of two samples carried out using hot disk thermal constants analyzer apparatus. Hot Disk TPS 500 thermal constants analyser instrument used for determining the thermal conductivity [8], recorded for each test in Table 5. The samples tested were composite disks with a diameter, D of (1.5-8) cm and a thickness of (0.5-3) cm. The sensor had a constant electrical current (variable by sample from 0.03W – 1.25W) over a short period (variable by sample from 2.5s – 40s) passed through it. The generated heat dissipated within the double spiral was conducted through the Kapton insulating layer and into the surrounding sample, causing a rise in the temperature of the sensor and the sample, then shows the number represents the value of the thermal conductivity in units of (W/m.K). The results show that higher percentages of polymeric wastes incorporation induce lower thermal conductivity of the samples relative to reference bricks. This is because of the increase of air voids volume obtained by burning of the polymeric

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wastes, a process that leads to pores forming within the samples to make them poor thermal conductors. From the results, it can be concluded that thermal conductivity decreases with decrease in density and increase in fired clay bricks porosity. The percentages of reduction in thermal conductivity of the reference samples were (6.4, 10.6, 17, 23.4 and 31.9%), (6.4, 8.5, 12.8, 19.1, and 25.5%), and (2.1, 6.4, 12.8, 17, and 21.3%) for groups B, C and D respectively. Lower thermal conductivity is desirable, as it will reduce the energy required for heating and cooling.

7. Conclusions

Based on the experimental work results, the following conclusions can be drawn:

1-It is possible to incorporate not more than 8% of chopped rubber tires or not more than 6% of chopped bottles to the clay soil to produce lightweight fired clay bricks satisfying the compressive strength and water absorption requirements for grade C of bricks (used for partitions) according to the Iraqi specification IQS 25/1988.

2- Addition of chopped rubber tires, having smaller particles size and more sphere particles shape, produce fired clay bricks with more homogeneous pores distribution and smaller size compared with clay brick incorporating chopped plastic wastes having flaky shape and larger particles size, leading to produce clay brick with higher density and strength, with lower water absorption.

3- There is an increase in the value of longitudinal firing shrinkage with increase in the polymeric waste content addition (2, 4, 6, 8, and 10%) to the clay brick mixture. The percentages of increase are (2.5, 5, 9.5, 14.5, and 20.2%), (1.8, 3.1, 5.7, 10.1, and 15.2%), and (0.6, 2.5, 4.4, 6.9, and 10.1%) for groups B (incorporating chopped bottles passing through sieve size 2.36 mm), C (incorporating chopped bottles passing through sieve size 1.18 mm) and D (incorporating chopped rubber tires passing through sieve 0.6 mm) respectively with respect to the shrinkage of the reference bricks (group A).

4- The incorporation of (2, 4, 6, 8, and 10%) of plastic wastes with 2.36 mm max. size, and plastic wastes with 1.18 mm max. size, in addition to incorporation rubber wastes with 0.6 mm max. size cause decrease in the bulk density of the reference samples by (4.7, 9.5, 14.9, 20.3, and 25.1%), (4.1, 9.5, 14.3, 19.1, and 24.5%), and (3.5, 8.9, 14.3, 19.7, and 23.3 %) respectively.

5- There are increase in the values of water absorption with increase in the polymeric wastes content (2, 4, 6, 8, and 10%).The percentages of increase are (9.4, 14.9, 19.6, 32.2, and 43.5%), (6.6, 11.3, 16.2, 24.7, and 34.4%) and (3, 4.9, 8, 12.7, and 17.7%) for groups B, C and D respectively with respect to reference group A.

6-The compressive strength decreases with the increase in the percentage of polymeric wastes for all mixes. The percentages of reduction in the compressive strength of the reference samples were (11, 18.1, 27.3, 33.1, and 40.2%), (5.9, 15.1, 26.4, 29.7, and 36.7%), and (4.1, 11, 17.5, 23.4, and 29.7%) for groups B, C and D when the polymeric wastes incorporated in the soil mixes are (2, 4, 6, 8, and 10%) respectively.

7-Thermal conductivity of clay bricks reduced when polymeric wastes were used, and reduction value depends on type and incorporation percentage by clay weight for polymeric wastes. The percentages of reduction were (6.4, 10.6, 17, 23.4 and 31.9%), (6.4, 8.5, 12.8, 19.1, and 25.5%), and (2.1, 6.4, 12.8, 17, and 21.3%) for groups B, C and D respectively.

Lower thermal conductivity is desirable, as it will reduce the energy required for heating and cooling.

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