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Experimental Research of Waste PET and Foundry Sand Recycling Into Bricks

Nigar Sezen BAL[1*], **Sevim YOLCULAR**[1]
[1]*Kimya Mühendisliği, Ege Üniversitesi, İzmir, Türkiye.*
**balsezen29@gmail.com*

Abstract

In this study, the aim is to produce Polyethylene terephthalate-sand bricks that are more durable, lighter, more economical, have less water absorption, and thermal conductivity compared to clay bricks by using waste Polyethylene terephthalate and waste foundry sand in different proportions. After the bricks were produced at different ratios; in three-point bending test, the brick with the highest percentage of Polyethylene terephthalate, S1, has the highest maximum stress (17.04 MPa), impact test result shows that S1 (1:2) and S2 (1:3) are impact-resistant bricks, in the water absorption test, S1 (1:2) has the lowest water absorption with 0.35%, lastly, in thermal conductivity test, the red brick had the lowest thermal conductivity with 0.713 W/mK. All bricks produced in different proportions weigh less than red bricks. Moreover, since the production of Polyethylene terephthalate-sand bricks does not require a long-term and high-temperature kiln, energy savings are provided, and the production of Polyethylene terephthalate-sand is more economical.

Keywords: Recycle, Polyethylene terephthalate, brick, foundry sand, sustainable construction material

Atık PET ve döküm kumunun tuğla olarak geri dönüştürülmesinin deneysel araştırması

Özet

Bu çalışmada, atık Polietilen tereftalat ve atık döküm kumunu farklı oranlarda kullanarak kil tuğlalara göre dayanıklı, hafif, ekonomik, daha az su emme ve ısı iletkenliğine sahip Polietilen tereftalat-kum tuğlaları üretmek amaçlanmıştır. Farklı kum/ Polietilen tereftalat karışım oranlarında tuğlalar üretildikten sonra fiziksel ve mekanik özellikleri kırmızı tuğlalarla kıyaslanmıştır. Sonuçta; üç nokta eğme deneyinde, en yüksek Polietilen tereftalat oranına sahip tuğla olan S1, maksimum gerilmeye (17.04 MPa) sahip olmuş, darbe testi sonucu S1 (1:2) ve S2 (1:3)'nin darbeye dayanıklı tuğlalar olduğunu, su emme deneyinde S1 (1:2)'in %0.35 ile en düşük su emme değerine sahip olduğunu, son olarak ısı iletkenlik deneyinde ise kırmızı tuğlanın 0.713 W/mK ile en düşük ısı iletkenliğine sahip olduğunu göstermiştir. Farklı karışım oranlarında üretilen tüm tuğlalar, kırmızı tuğlalardan daha az ağırlığa sahiptir. Ayrıca, Polietilen tereftalat-kum tuğlaların üretimi uzun süreli ve yüksek sıcaklıkta fırın gerektirmediğinden enerji tasarrufu sağlanmakta ve Polietilen tereftalat-kum üretimi daha ekonomik olmaktadır.

Anahtar Kelimeler: Geri dönüşüm, Polietilen tereftalat, tuğla, döküm kumu, sürdürülebilir inşaat malzemesi

1. INTRODUCTION

Plastics are one of the most useful inventions of the last century that make human life easier. They are cheap, durable, and lightweight materials that can be molded into a variety of products. They are used in many applications, including furniture, packaging, electronic materials, automotive, medical devices, industrial components, and so on. However, this situation becomes a disadvantage when these items are thrown away. The major problem is that plastics have non-biodegradable characteristics, and waste mismanagement leads to damage to the environment. In addition, since plastics cannot be broken down by bacteria, they do not decompose easily, and it takes between 20 and 600 years to decompose in nature. Therefore, as the use of plastics has increased over the years, there has been a dramatic increase in the volume of landfills. There have been many ways to overcome this problem, such as incineration, recycling, chemical, physical, and biological treatment, etc. In fact, recycling is one of the most important actions to take to solve this problem. Moreover, plastics can be blended with many materials. Recycling plastic items into new goods helps the environment, reduces plastic material production from petroleum, emissions of greenhouse gases, landfill volume, and creates new economic opportunities.

Among all plastic types, one of the most commonly used materials is polyethylene terephthalate. Polyethylene terephthalate, also known as PET, is a type of plastic that is strong, lightweight, recyclable, and has transparent, amorphous thermoplastic characteristics. PET is formed as a result of the polycondensation of ethylene glycol and terephthalic acids [1]. Blow molding, extrusion, and injection molding methods are used to produce products containing PET. PET is widely manufactured for packaging foods, beverages, water, cooking oils, shampoo, liquid hand soap, shopping bags, textiles, containers, etc. [2].

As mentioned before, PET is a recyclable material and can be recycled in many ways. New products are manufactured by using either all of the recycled PET or by mixing some of it with virgin one. This recycled PET can also be mixed with other types of plastic or non-plastic materials as well. In order to reuse PET, there are physical and chemical recycling methods applied in many parts of the world. In the physical recycling of PET, items that are made of PET are collected and sent to sorting centers, where they are sorted and squashed into bales to make the transportation easy to be sent to recycling plants. When waste PET enters the recycling process, in the first step, it is separated from any metal parts inside by using a magnet. Then, they are washed to remove the labels and glue. In order to not let non-PET go further, optical and manual sorting are done. After that, the items are sent to a grinder and grinded into flakes. The flakes go through various sorting machines to be separated according to their colors. The flakes are then dried, melted, filtered, and cut into pellets, ready to be reused. On the other hand, in chemical recycling, PET can be converted to monomers by complete depolymerization or to oligomers and other products by partial depolymerization. The monomers are then repolymerized, and these polymers are formed into new products. These polymers, regenerated monomers, or both may be blended with virgin materials. There are some methods for chemical recycling of waste PET, and most of them consist of esterifying polyester with an excess of reactants such as alcohols, diamines, diols, or water.

Moreover, there are lots of benefits to recycling PET bottles. First of all, the use of PET bottles is growing as the population increases over the years. This causes accumulation in landfill areas, which is a significant problem for the environment. Sales of bottled water have been steadily increasing, from 8.76 billion gallons sold in 2010 to 15.3 billion gallons in 2021 [3]. As the consumption of these bottles increases, the volume of waste will increase; therefore, recycling is a good solution for accumulation. Secondly, recycling PET reduces the amount of energy and resources that are needed to create PET. According to Stanford University (2023), recycling one ton of plastics provides 16.3 barrels of oil and 5.774 kWh of energy savings, which is enough to run an average household for months [4]. Thirdly, PET accumulation and the manufacturing process of PET bottles are major threats to ecosystems in an environmentally harmful manner. 90 percent of the waste that is seriously harmful and found on the surface of the oceans consists of plastic, which makes about 46,000 parts of plastic per square mile [5]. Every year, thousands of marine animals and seabirds die due to plastic pollution [6]. Finally, recycled

PET can be used in many areas, such as construction, textiles, and toys. Recycling supports businesses in developing innovative products and creates job opportunities for people. The effort that people make and the developments in the recycling industry have made huge differences in decreasing the volume of landfills and, therefore, pollution in the soil and ocean.

In addition to the waste plastic concern, there has been another waste problem for years: used foundry sand (FS). Virgin sand is purchased by foundries in order to make molds for metal casting, and in the manufacturing process, sand is reused repeatedly. Approximately 1 ton of foundry sand is used for each ton of metal production [7]. Reusing the sand eventually renders it inconvenient for casting. The grains of the sand begin to break down due to heat and mechanical abrasion, and it loses its uniformity and cleanliness; therefore, new sand must be added to the unit to maintain proper casting. The waste sand has to be recycled; otherwise, it is sent to landfills. Foundry sand recycling reduces virgin material mining and saves energy. The waste foundry sand can be safely and economically recycled and used in many fields, such as manufacturing soil plants, in soilless mediums, and as an additive for roads.

Many studies have developed various methods for recycling waste. One of the literature suggestions is to recycle waste plastic and foundry sand for construction. In this field, the primary material is bricks that are made of clay. The procedures for making traditional bricks are mixing, molding, drying, and firing at a temperature between 1000 °C and 1100 °C [8]. However, the soil material usage puts stress on the soil and therefore causes soil erosion, which leads to high energy consumption in production. Moreover, the emission of greenhouse gases causes acid rain, climate change, and global warming. The bricks that are made of plastic and sand reduce waste, which is a sustainable and ecological development. The advantages of thermoplastic waste aggregates are lower production costs, a lighter product because of the recycled plastics' lower specific gravity, greater flexibility in design, a lower dead load on the structure, and enhanced thermal insulation, which is important for energy conservation. Nowadays, commercial-level applications have been made by entrepreneurs in brick-making. These bricks are expected to have better properties than commercial bricks. These features include being more durable, lighter, and cheaper, having less water absorption, and having less thermal conductivity. Several developing countries have established factories to produce bricks that are made of plastic in order to clean the environment and provide affordable alternative construction materials.

In Argentina, Ecoinclusion was founded to solve environmental problems. They work for the reduction of PET bottle waste through the production of bricks made of plastic residues for use in the construction sector [9]. They started to manufacture eco-friendly bricks that consist of waste PET, cement, and different additives. To produce one brick, 1 kilogram (20 bottles) of recycled plastic is needed. The bricks are lighter and have better insulating and sound-proofing properties than red bricks [10]. They have a technical certification that is granted by the UN-Habitat Secretariat and were patented by Ceve-Conicet. In 2017, Ecoinclusion won the Google.org challenge [9].

In India, the casting industry causes millions of metric tons of dumped waste, which is hazardous for the environment [11]. An Indian company called Rhino Machines makes silica plastic blocks from plastic waste and recycled sand. These bricks are made of 20% mixed plastic waste and 80% recycled sand waste/foundry dust. The conventional bricks that we use for daily construction activities fall apart when they are disintegrated into smaller sizes; however, silica plastic bricks keep their shape and strength even after you drill a hole in them [12]. The cost of production will be relatively low. The mixed plastic waste was used as a bonding agent. The bricks were 2.5 times stronger than the commercial red clay bricks, and 80% less natural resources were used. Moreover, the other best thing about Rhino bricks is that they are cheaper than commercial bricks [13].

Another example is Gjenge Makers Ltd, which produces plastic-sand bricks as well. In Kenya, they started designing machines for recycling plastic waste into bricks [14]. High-density polyethylene and low-density polyethylene are used for production. The result is a brick that is 5 to 7 times stronger than concrete, weighs half as much, and therefore reduces CO_2 emissions and logistics costs. The positive results of brick production include increased income for garbage collectors, a stronger construction industry due to more affordable materials, a contribution to the circular economy, and fewer CO_2 emissions during transportation.

In another study, single-use surgical masks were used to solve the plastic pollution problem. The recycled surgical masks were mixed with ground granulated blast furnace slag, ash, sand, rice husk, and sodium silicate. The bricks were then tested for water absorption, compressive strength, flexural strength, efflorescence, density, and drying shrinkage. The results show that the recycled surgical masks in the bricks improved compressive strength and flexural strength. Additionally, with the increase in recycled surgical masks, there was a decrease in the brick weight. The recycled surgical masks reduced the drying shrinkage of the bricks. However, there was no significant effect on the water absorption or properties of recycled surgical masks [15].

In this thesis study, the aim is to produce PET-sand bricks that are more durable, lighter, more economical, have less water absorption, and have less thermal conductivity compared to red bricks that are made of clay by using waste PET and FS in different proportions. Waste PET and foundry sand were chosen as ingredients since PET is one of the most wasted materials in the world, and waste foundry sand is a major problem for casting factories. The importance of the thesis is to reduce the volume of waste PET and foundry sand in landfills by recycling them into bricks and trying to reduce environmental pollution to some extent. In the experiments, the bricks were produced at different rates and subjected to three-point bending, impact, water absorption, and thermal conductivity tests. After the tests, the results are compared first among the PET bricks with different ratios and then with the red brick.

2. MATERIALS AND METHODS

2.1 Materials

In the production of the PET-sand bricks, PET and FS were mixed in different proportions. The ratio of sample 1 (S1) is 1:2, the ratio of sample 2 (S2) is 1:3, and the ratio of sample 3 (S3) is 1:4 according to the PET:FS. The reason behind taking different proportions is to find the optimum results while investigating various properties. After the experiments, the produced PET-sand bricks will be compared with red bricks. The size of the shredded pieces varied from 2–5 mm in length and 1–3 mm in width. The thickness of the shredded pieces was less than 1 mm. The components of foundry sand are 85% silica sand, 10% bentonite, and 5% coal dust. Its particle size distribution varies between 0.075 and 0.600 mm. The clay brick components are 75% SiO_2, 16% Al_2O_3, 5% K_2O, 1.25% Na_2O, 0.96% FeO, 0.25% CaO, 0.25% MgO, and 0.15% TiO_2. Their usage areas are pedestrian and light vehicle traffic floors. Its dimensions are 210 mm x 105 mm x 40 mm. The average weight of the brick is 1.900 kg.

2.2 Instruments

In the production of the PET-sand bricks, PET and FS are heated separately. A granite-covered container, a steel container, and a metal thermometer are used in the experiment. The granite-covered container is used as a drum to prevent the hot mixture from sticking to the container. The steel container is used for heating the sand. Both containers are heated on a gas stove and mixed with wooden mixers. Wooden material is used due to its low thermal conductivity. A metal thermometer that is capable of measuring up to 300 °C is used to measure the temperatures during the process. The molds for the bricks are made of medium-density fiberboard. Waxed paper is used inside the mold to avoid contact between the mixture and the mold surface. The size of the mold is 210 mm x 105 mm x 40 mm, which has the same dimensions as the red brick to give precise results. For the three-point flexural test, a 210 mm x 55 mm x 40 mm mold is used.

2.3 Methods

In the first step, PET powder and sand are weighed in certain proportions for the bricks that have different proportions. In the heating and mixing process, while the waste PET powder is heated in the granite-covered pan, the FS is heated in the steel container as well. PET is allowed to melt and is continuously mixed in the temperature range of 220-270 °C. After the PET is completely melted, the heated FS is gradually added to the container and mixed with the PET continuously. When the mixture becomes homogeneous, it will be ready to be filled into the molds. The mixture is filled into the molds, which are covered with waxed paper in order to avoid sticking to the mold itself. Lastly, the lid is placed on the mold, and a weight of 100 kg is placed on the lid, allowing the mixture to pass into each other with pressure, and it is left to cool for about 5 hours.

2.4 Tests

After the production of the bricks with different ratios, they will first be weighed to be able to compare them with the red brick's weight. Then, the products were tested for three-point flexural, impact, water absorption, and thermal conductivity. They will be compared among themselves and with the red brick. The three-point flexural tests will be done at the Central Research Test and Analysis Laboratory Application and Research Center at Ege University, and the thermal conductivity tests will be done at the Mechanical Engineering Laboratory at İzmir Katip Çelebi University.

2.4.1 The Three-point Flexural Test

The three-point flexural test is a standard test method for bricks and structural clay tiles. The purpose of the test is to find the resistance of the brick to bending through the internal stresses in the brick structures. The loading and support noses, which are cylindrical materials, have a diameter of 30 mm and a length of 60 mm. Since the size of the bricks should fit the testing machine, the size of both red brick and PET-sand was reduced to 210 mm x 5-6 mm x 4-5 mm. Therefore, a smaller mold for the PET-sand brick was made, and the red brick was cut in half for this test. In a three-point flexural test, the dimensions of the bricks are measured. The locations where the load will be applied under three-point bending are marked, and the length between the supports is noted. The servo controller device that is shown will be used for operating the tests. Loading is applied continuously until failure, and the maximum load is recorded. After the failure, a stress vs. stroke graph is drawn. Lastly, the results are compared first among the PET bricks with different ratios and then with the red brick. The aim is to test the samples for elastic modulus in bending, stress-strain behavior, and failure limits in bending.

2.4.2 The Impact Test

An impact test aims to certify the proper bonding of a brick so that it cannot be damaged easily. If the brick is damaged or broken, it means that its impact value is low. The impact test will be considered a failure and not acceptable for construction work. If it is not broken, it is considered a good-quality brick. In this test, each brick is forced to break by free falling from 1 meter. The bricks are checked for falling to pieces. If any, the number of pieces is noted. The results are compared first among the PET bricks with different ratios and then with the red brick. The aim of the test is to find the brick that does not break or is the least fragmented.

2.4.3 The Water Absorption Test

The water absorption test gives the quantity of water being absorbed by bricks. The aim of the test is to find out which brick has the lowest absorbed water because it decreases the durability of the brick. The results of this test show the bonding of the mortar to the brick. After cooling every brick to room temperature, they are weighed in total dry conditions (M_1). Then, they are immersed in fresh water in a container at room temperature for 24 hours. After 24 hours, they are removed, wiped out of any traces of water with a cloth, and weighed (M_2). The amount of absorbed water (by mass) is calculated by the formula below:

$$\text{Water Absorption} = (M_2 - M_1/M_1) * 100\% \quad (1)$$

Where,

M_1= dry weight of brick

M_2= wet weight of brick

Lastly, the results are compared first among the PET bricks with different ratios and then with the red brick.

2.4.4 The Thermal Conductivity Test

In a thermal conductivity test, the aim is to determine the thermal conductivity value of a poor conductor. It is often denoted as k with a unit of W/mK. A suitable probe that is connected to the thermal conductivity meter is placed on the sample. A C-therm thermal conductivity analyzer will be used for the test. The device is used for testing ceramics, polymers, composites, etc. Then, the heater's current value is selected to complete the measurement. After the measurement, the heat transfer coefficient of the sample is shown in tabular form. The results of this test show the thermal conductivity coefficients (k) of the bricks. Then, the results are compared first among the PET bricks with different ratios and then with the red brick. The aim of the test is to find the brick that is the least conductive.

3. RESULT AND DISCUSSION

After the production of the bricks, they were first weighed. The weight proportions of each brick are as follows:

Table 1. The weight proportions of each brick

	PET (gr)	Sand (gr)	Clay (gr)	Total (gr)
Ratio 1:2	537	1073	-	1610
Ratio 1:3	399	1196	-	1595
Ratio 1:4	295	1180	-	1475
Red brick	-	-	1900	1900

As seen in Table 1, S3 has the lightest mass among them, with a value of 1475 g. S2 and S1 are 1595 g and 1610 g, respectively. Red brick is the heaviest brick, with a mass of 1900 g. In this study, as in other studies, bricks with pet content were found to be lighter than red bricks. The weight of a 0.5-liter bottle that is made of PET is approximately 10.35 grams. Therefore, 295 grams of PET powder are used in the production of S3, which is equivalent to 28.5 bottles. For S1, it is 52, and for S2, it is 38,5 PET bottles. The material cost of the bricks was zero since waste PET and FS were provided free of charge by the factories. Only natural gas, which was used as fuel during production, could be shown as an expenditure. Red bricks are made of clay, and mining is required to obtain the material. Therefore, mining is an expenditure for red brick production. Moreover, red brick requires staying in a tunnel kiln at 1050 °C for 3.5 days during production, while in the production of PET-sand brick, two containers were used for sand and PET separately at 220-270 °C for 50 minutes. Therefore, the production of PET-sand bricks consumes less energy and is more economical. Energy savings were achieved as there was no need for a high-temperature ceramic furnace as in the production of red bricks. In addition, this production method could reduce the air pollution from brick kilns due to the long production time of red brick. To solve this problem, this study explored how the use of plastic bricks can be a cost-effective, beneficial, and sustainable solution, as well as an effective way to manage the country’s plastic waste and the environmental degradation caused by it. In the production of S1 and S2, the mixtures were blended very well. However, S3 fell apart due to having less PET than the other two PET-sand bricks. An insufficient situation in the production of PET-sand bricks was not working with higher pressures. During the production of the bricks, higher pressure was needed in the molding process. The advantage of working with high pressure is that the gaps formed in the bricks are as small as possible.

3.1 The Three-point Flexural Test Results

In a three-point flexural test, the brick's ability to resist deformation was examined. Before the test, the dimensions of the red and PET-sand bricks were measured. The locations where the load would be applied under three-point bending were marked, and the length of the support was noted. The brick was placed on the stage of the 3-point bending fixture of the device. The servo controller device was used for operating the tests. Loading was applied continuously until failure, and the maximum loads were recorded. After the failure, the stress vs. stroke (TD2) graph is drawn. Then, the results were compared first among the PET bricks with different ratios and then with the red brick. The aim was to test the samples for their strengths. (where length of brick: 210 mm, rate of loading = 0,5 mm/dk and T = 25 °C (room temperature)

The diameter of the support noses is 30 mm x 2 = 60 mm, (2)

Effective span= (210-60) mm = 150mm (3)

Table 2. Results of the three-point flexural test

Sample	Maximum Load (kN)	Maximum Stress (MPa)
Red Brick	4,63	13,02
Sample 1	8,52	17,04
Sample 2	4,76	10,58
Sample 3	2,70	6,67

As seen from Table 2, the highest maximum load was applied to S1. It had the highest maximum stress, which was 17.04 Mpa; red brick was the second one with 13.02 Mpa; S2 was the third one with 10.58 Mpa; and lastly, S3 had the lowest value, which was 6.67 Mpa. The broken bricks are shown in Figure 1. It was observed that the PET addition had increased the strength of the brick. It has been determined that S1 is a good composite as a construction material.

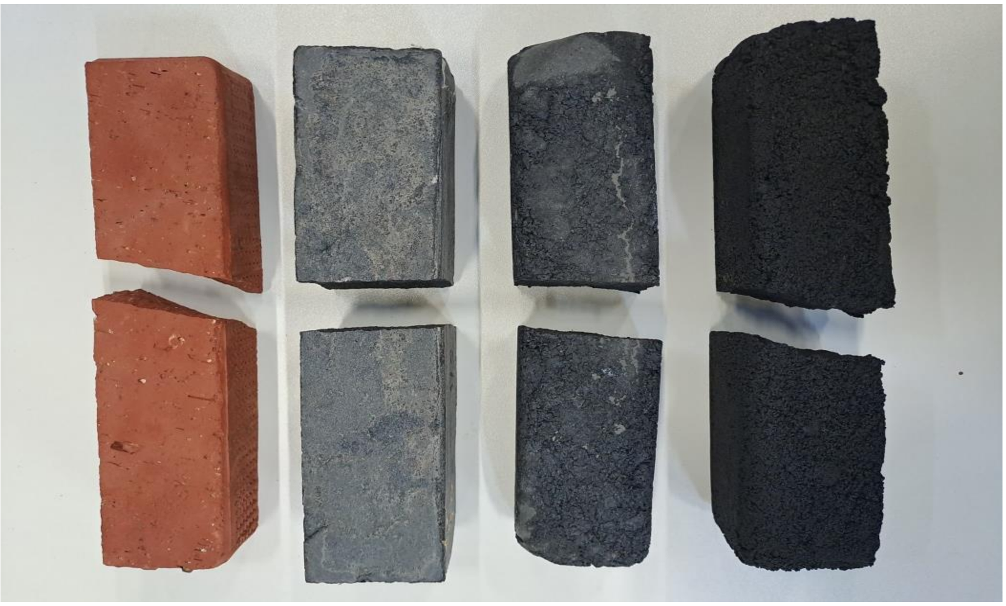

Figure 1. Broken sample bricks after three-point flexural test

Figure 2 shows the curves that are collected in a single stress vs. stroke (TD2) graph. It is understood that S1 has the highest maximum stress.

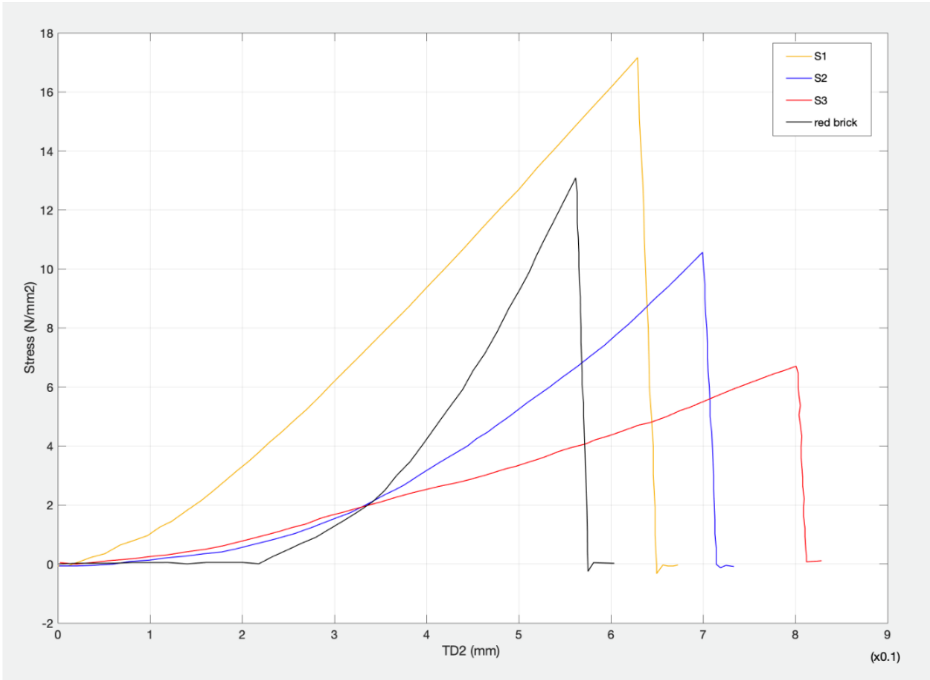

Figure 2. Stress vs stroke (TD2) graph of all bricks

3.2 The Impact Test Results

In the impact test, PET-sand bricks and the red brick were dropped from 1 meter. The red brick fell apart in two pieces (Figure 3.a). S1 (Figure 3.b) and S2 (Figure 3.c) were not broken; however, S3 (Figure 3.d) was already falling apart before freefall, and after the fall, while small pieces were separated from the edges, there was no complete breakage.

The aim of this test was to ensure the proper bond in a brick so that it would not break easily. S1 and S2 were not broken, the test results are considered passed, and the bricks are considered to be of good quality. However, small pieces were separated from the edges of S3, and the red brick was broken, which means their impact values are low, and they are not acceptable for construction work. Their impact tests were failures. This test result showed that S1 and S2 are impact-resistant and good-quality bricks.

Figure 3. a) Impact test result of red brick b) Impact test result of S1 c) Impact test result of S2 d) Impact test result of S3

3.3 The Water Absorption Test Results

In the water absorption test, the quantity of water being absorbed was determined. After cooling each brick to room temperature, they were weighed in total dry conditions (M1). Then, they were immersed in fresh water in a container at room temperature for 24 hours. After 24 hours, they were taken out of the water, wiped out of any traces of water with a cloth, and weighed (M2). The water absorption percentages (by mass) were calculated as follows:

Table 3. Results of the Water Absorption Test

	M1(dry)	M2(wet)	%water(gr/gr)
Red Brick	1900	1966,5	3,20
S1	1610	1666	0,35
S2	1595	1616	1,31
S3	1475	1497	1,46

In the water absorption test, Table 3 shows that S1 has the lowest water absorption with 0.35%. S2 is the second one, with the lowest value of 1,31%. S3 is the third one, with a value of 1,46%. The red brick has the highest percentage, with a value of 3,2% when compared to S1, S2, and S3.

Absorbed water decreases the durability of the brick. For clay bricks, to increase the density and decrease the water absorption, the firing temperature must be increased. According to the results, S1 has the lowest value and is more durable than the other bricks.

3.4 The Thermal Conductivity Test Results

In the thermal conductivity test, the aim was to determine the thermal conductivity, k value, of a poor conductor since the brick would be used as pavers. The results of the experiment were taken from the computer. Each k value was found by averaging the highest five data in the tables. According to the results, S3 has the lowest conductivity with 0.165 W/mK; followed by Red Brick with 0.713 W/mK; S2 with 0.955 W/mK; and lastly, S1 with the highest conductivity with 1.009 W/mK.

A high thermal conductivity is a sign of a good heat conductor. It seems that S3 is the one that is suitable for the purpose; however, the reason behind the lowest value is the air gaps inside the brick. Since the thermal conductivity of the air is 0.025 W/mK when we compare the PET sand bricks, there is a huge difference between S3 and other PET-sand bricks with different ratios [16]. The reason for the large air gaps is due to the low PET ratio, which was used as a bonding agent between the sand particles. The test showed that, as far as thermal conductivity is concerned, the red brick is the most suitable among the other bricks.

$$\text{Conductivity of a brick} = k_b = \frac{k_{b1}+k_{b2}+k_{b3}+k_{b4}+k_{b5}}{5} \quad (4)$$

$$\text{Conductivity of red brick} = k_{rb} = \frac{0{,}717+0{,}714+0{,}713+0{,}711+0{,}710}{5} = 0.713\text{W/mK}$$

$$\text{Conductivity of S1} = k_{S1} = \frac{1{,}012+1{,}009+1{,}008+1{,}008+1{,}008}{5} = 1.009 \text{ W/mK}$$

$$\text{Conductivity of S2} = k_{S2} = \frac{0{,}981+0{,}972+0{,}967+0{,}932+0{,}925}{5} = 0{,}955 \text{ W/mK}$$

$$\text{Conductivity of S3} = k_{S3} = \frac{0{,}167+0{,}166+0{,}165+0{,}164+0{,}163}{5} = 0{,}165 \text{ W/mK}$$

4. CONCLUSION

This research has investigated the possibility of using sustainable and affordable alternative bricks that are made of waste PET and foundry sand as a substitute for red bricks. The main goal of this study was to produce bricks that are stronger, lighter, cheaper, have less water absorption, and have less thermal conductivity than red bricks by doing experiments with different ratios of the materials.

After the production of the bricks, they were weighed. S3 is the lightest sample, with a weight of 1475 grams. During the production of S1 and S2, the PET and sand blended very well. However, S3 fell apart due to having less PET than the other two PET-sand bricks. For this reason, although the lightest brick was S3, it was not suitable as an image because there were some scatterings of the brick. Furthermore, when production times and temperatures are considered, red bricks need to stay in a tunnel kiln at 1050℃ for 3.5 days during production; however, two containers were used for sand and PET, and they were heated on a gas cooker at 220-270℃ in 50 minutes. Energy savings were achieved as there was no need for a high-temperature ceramic furnace as in the production of red bricks. Since less energy is consumed, the production of PET-sand bricks is more economical than the production of red bricks.

Moreover, the PET-sand bricks and red bricks were tested for three-point flexural, impact, water absorption, and thermal conductivity. The result of the tests showed that in the three-point flexural test, PET addition increased the strength of the brick. S1 is a good composite. The flexural strength of S1 showed some fair results in its structural efficiency when compared to the red brick. In the impact test, S1 and S2 did not break, which shows high impact values. However, the red brick and S3 bricks were broken, so the impact test failed. These test results showed that S1 and S2 are impact-resistant, good-quality bricks, and acceptable for construction work. In the water absorption test, the PET-sand bricks have an advantage over clay bricks. In the water absorption test, the least amount of water was absorbed by S1 at 0.35%. Absorbed water decreases the durability of the brick. Therefore, S1 performed well in the water absorption test. Lastly, in the thermal conductivity test, the red brick has the lowest conductivity with 0.713 W/mK. The test showed that, as far as thermal conductivity is concerned, the red brick is the most suitable among the other bricks.

With this study, it was proven that a good-quality PET-sand brick, S1, could be produced. When it is compared to commercial red brick, a brick that is lighter, more durable, more economical, absorbs less water, and consumes less energy due to its shorter production time and lower working temperature has been produced. However, the desired result could not be obtained in terms of thermal conductivity.

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