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To cite this article: N F A Halim *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **452** 012108

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The performance of thermal property in concrete containing waste pet (polyethylene terephthalate) as an alternative sustainable building material

N F A Halim¹, N Taib¹ and Z A Aziz¹

¹ School of Housing, Building and Planning, Universiti Sains Malaysia, 11800 USM, Pulau Pinang Malaysia

Email: nooriati@usm.my

Abstract. Polyethylene Terephthalate (PET), known as plastic, is the most widely used product in the world today. However, the increase in the amount of imperishable plastic waste is a concern today. Repurposing of plastic waste in useful products such as concrete appears as an alternative in the construction industry. This paper's main objective is to explore the performance of thermal properties in concrete by incorporating waste Polyethylene Terephthalate (PET) as an aggregate in a concrete mix. Other than reducing energy usage in buildings, reusing waste PET should introduce an improvement in friendly waste management. Laboratory experimental analysis was done by measuring the parameters of thermal conductivity on four types of concrete design mix which includes 0% PET, PET 5%, PET 15% and 25% PET in concrete block. Finally, an implementation of a sustainable approach to these new concrete materials; the obtained results highlight their mechanical properties of enhancement in thermal property, which reduces heat gain and achieve better thermal insulation compared to a traditional concrete mixture with a similar application of test type. This implementation has been proved to optimize efficient thermal performance towards sustainable building material.

1. Introduction

After half a decade of manufacturing and its use, the lasting amount of plastic waste has risen to date. Since 2013, a total of 299 million tons of plastics have been produced and disposed of, that is a 4 percent growth over the previous year. [6], thereby increasing the trend of its use in preceding years. In 2015, a total of 6300 million tons of plastic waste was estimated worldwide [5]. Moreover, it is reported that by the end of 2050, the estimated amount of plastic waste is expected to reach 12,000 million tons [5]. The use of plastic materials in our daily consumption affects us in thinking that plastic is the essentials of our lives, which indicate excessive use. This behavior has severely degraded the planet.

With the implementation of building construction, re-use substance of PET waste in cement media, such as concrete mix likewise cement mix, should be an acceptable option for possible means of eliminating waste of plastic due to the economic and ecological benefits [12]. These implementations could also be a reasonable choice for sustainable building material.

Concrete is widely used in all climate areas and for all types of structures. Its foremost features are thermo-conductivity, specific heat, thermal fatigue, and thermal expansion coefficients; the first two



are only significant in mass concrete construction where it requires tight temperature control [9]. The thermal properties of a material are associated with its heat conductivity. These properties are presented by a substance when the heat passes through it. Thermal conductivity reflects the heat conduction capacity of a matter. It is measured in joules per second for one square meter of body area when the temperature difference is 1°C per meter of body thickness [7]. Concrete conductivity depends on the aggregate, density, moisture content, and temperature [14]. This study focuses on the investigation of the use of plastic waste as an aggregate in concrete and to achieve the effects of the usage in terms of thermal conductivity. By lowering the thermal conductivity means improving the thermal insulation. Hence, enhanced thermal insulation will achieve a better thermal comfort for the users. Along with that, by integrating plastic waste into construction material will also contribute a cleaner environment. These contributions eventually promote a sustainable built environment.

Buildings exist as a big part of all countries. Most of the energy goes to the heat and cooling of the building, especially to a hot and humid country like Malaysia. There are many ways to reduce the use of heating and air conditioning through the design and selection of the building's envelope and its appropriate material. Not only does the building insulation help reduce the energy required for the cooling system, but it also assists in the annual cost of energy [13]. Additionally, it extends the duration of thermal comfort without relying on mechanical systems, such as air conditioning, especially during hot weather. The amount of energy conservation due to the use of heat insulation varies by design of building, the climate condition in which the location of the building and the type of insulation material used [8]. Therefore, this study is much suitable to experiment in a hot climate in Malaysia.

Energy conservation is necessary because of the growing population and the lack of natural resources. In many countries, buildings account for more than 30% of greenhouse gas emissions and one-third of total energy consumption [10]. The fact that about 90% of most people consume their lives indoor has made thermal comfort and energy conservation in buildings a controversial issue [11]. The amount of energy required for the cooling, heating, and thermal comfort of the building depends mainly on the thermophysical properties of the building materials. Heat gain in fabric and ventilation are two main reasons that cause heat gain in buildings. Heat gain through ventilation involves heat transfer by air replacement through heating, ventilation, and air conditioning systems (HVAC). Gaining heat from the fabric, on the other hand, relates to the gain of conductive heat through floors, walls, windows, and roofs. Heat transfer is a vector quantity produced by conduction, convection, and radiation. Conductive heat transfer in solids is caused by a mixture of molecular vibrations and energy transport by free electrons [16]. Thermal enclosure (k value) is the material property that indicates its ability to carry out heat. Thermal conductivity (k-value), such as concrete, a cement-based material reflects the amount of heat transfer through conduction. The amount of heat gain through the roof and walls directly affects the use of building energy. The energy use of a building is based on the value of the thermal conductivity of building materials [1]. The value of thermal conductivity affects the insulation property of a material.

More than ten trillion pounds of concrete is produced annually, making it a universal material around the world, and its demand is expected to increase to 18 trillion pounds by 2050 [4]. Concrete has broad applications in buildings, bridges, parking lots, industrial walkways, and other structures. Researchers have considered its engineering properties due to its extensive use. Thermal conductivity, specific heat, and thermal diffusivity are deemed thermo-physical properties of concrete [2]. The most significant thermal terms affecting heat transfer through concrete are thermal conductivity [15]. Concrete with low thermal conductivity reduces heat transfer and reduces energy consumption in buildings. A study reports that, compared to usual weight concrete, 30% of the thermal insulation in concrete can be achieved by the use of 60% of thermosetting plastic waste as a sand replacement in concrete [3]. Therefore, a lower thermal conductivity of building material gives better thermal insulation, which reduces heat gain to the building and therefore, lowers the building energy usage.

2. Experimental Method

Laboratory tests are used in this methodology. This study was carried out by combining waste plastic from the environment into a concrete mix. In this experiment, concrete block samples will be constructed and developed by re-using PET bottles and empty containers, shredded them to be used as aggregates in concrete blocks. Plastic waste will be collected and classified according to various components and will be grouped particularly to PET bottles and containers. When the bottle is gathered, the lid is removed, and the body of the bottle is crushed into an irregular piece. After that, it is inserted into a conventional concrete mixture. The percentage of PETs is the manipulated variable in the study of this experiment.

Manipulated variable: Percentage of PET in concrete.

Fixed variable: Dimension and thickness of the concrete block.

Responding variables: Thermal conductivity of concrete block.

Many test methods can be used to test concrete samples. In this study, experimental methods were used to study the effect of concrete's properties of thermal conductivity with PET additives in the mixture. Grade 20 concrete samples measure heat conductivity test with four types of mixes that includes PET 0% PET, 15% PET, and 25% PET in concrete.

2.1. Materials Preparation

Continuing with the idea of experimentation, an action strategy for this study is done, and it was shown in the following way:



Figure 1. Collection of PET waste.

Figure 1 shows the collection of PET waste containers and bottles, and the waste is shredded into smaller pieces. The point here is to change the plastic waste as aggregate in the concrete mix. Containers and bottles were collected in the compound of Universiti Sains Malaysia and were shredded at a nearby recycling plant.

2.2. Concrete production

The experimental program included a test of 100 x 100 x 100 mm concrete samples standardized a curing age of 28 days and different percentages of PET aggregates (0% PET, PET 5%, PET 15%, and PET 25%). The mixed design used is based on a ratio of 1: 1: 2 with cement type, ordinary Portland cement (OPC). The sample model details are shown in table 1.

Table 1. Details of Specimens Cast.

Sample Number	Type of Concrete Mix	Addition of PET %	Volume/Cube	Cost	No of Cubes
1	OPC	0% of PET	1000cm ³	None	2
2	OPC	5% of PET	1000cm ³	None	2
3	OPC	15% of PET	1000cm ³	None	2
4	OPC	25% of PET	1000cm ³	None	2
Total Specimen Cast					8

**Figure 2.** The making of PET concrete block.

In figure 2, the shredded PET waste is added to the standard concrete mixture according to the calculated percentage. An ordinary block of concrete mix (0% PET) is also set to differentiate the concrete blocks of PET. The mixture is left dry in one day. The concrete blocks are separated from molds and cured by water curing methods by submerging the sample in a tank filled with water for 28 days.

2.3. Experiment apparatus

This test is done with 28 days of curing age by using the Transient plane source (TPS) technique to analyze the thermal conductivity of concrete samples.

Thermal conductivity is the property of the material associated with pertaining to heat conduction. The amount of thermal conductivity (k-value) through heat transfer is a key factor in determining the thermal properties of cement-based materials such as concrete. Total heat gain through walls and ceilings directly affects the use of building energy. The building will use less energy by reducing heat exchange with low thermal conductivity of the concrete. Thermal conductivity tests were performed on day 28 of concrete samples curing age.

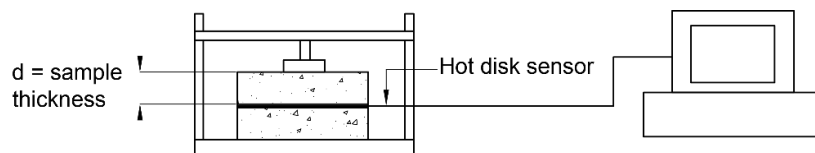
**Figure 3.** Schematic view of the test arrangement.



Figure 4. Overview of the test configuration.



Figure 5. Overview of the test configuration.

Thermal conductivity is assessed by using Transient plane source (TPS) method, which is based on the power input and time-dependent source. Through transient plane source method, it measures the in-plane and through-plane thermal conductivity of materials. Figure 3 showing a flat sensor is sandwiched between the concrete samples. When initiated, the electrical current passes through the sensor where it increases temperature. Figure 4 and figure 5 shows an overview of the test that has been set up in the laboratory. By taking account of the temperature against the time, it is possible to determine the thermal properties of the concrete. Finally, the results measured by the sensor are sent and recorded to the computer. Concrete samples for each amount of PET percentage in the sample is tested with the same two cubes to get the best average among the result of the test conducted.

3. Results and discussion

In previous years, most researchers have paid more attention to the study of concrete's mechanical properties. Recently, more studies evaluate thermal conductivity in the mechanical properties of concrete due to the importance of building energy efficiency in construction. In general, materials with low-value k are considered as an acceptable choice to save energy in the building construction industry.

The performance of four different concrete in heat insulation property (ordinary 0% PET concrete, 5% PET content concrete, 15% PET concrete and 25% PET concrete) was investigated by the test of thermal conductivity of concrete samples. Low thermal conductivity of the material will cause better thermal insulation.

Table 2. Thermal Conductivity of Concrete Specimens (W/mK).

Cube	28 days	
0% of PET	2.288	2.858
	2.573	
5% of PET	2.08	2.10
	2.09	
15% of PET	0.873	0.708
	0.7905	
25% of PET	0.1322	0.1198
	0.126	

According to table 2, the thermal conductivity test in concrete achieved gradually decreases with the number of PET in concrete used. The specimen with the highest thermal conductivity after 28 days of curing was concrete with PET 0% and followed concrete with 5% PET, 15% PET and the lowest was concrete with 25% PET.

Concrete with 0% PET specimen shows the highest with 2,573 W / mK at 28 days. Also, concrete with 5% PET samples showed the highest thermal conductivity of 2.09 W / mK at 28 days. It is followed by the concrete sample with 15% PET sample at 0.7905 W / mK at 28 days. The last specimen is concrete with 25% PET, having the lowest heat conductivity of 0.126 at 28 days.

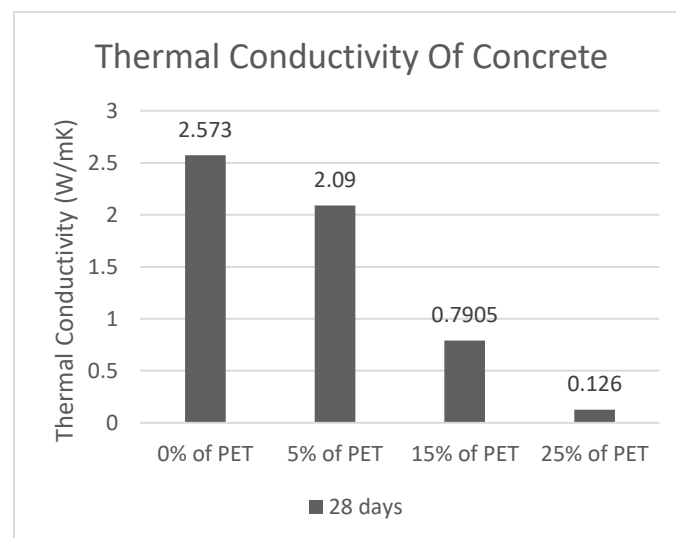


Figure 6. Thermal Conductivity of Concrete Specimens (W/mK).

The transient thermal conductivity measurements for all different concrete samples are shown in figure 6. Concrete heat conductivity is reduced inversely with higher PET content in concrete. Specimens with the highest thermal conductivity after 28 days of curing were concrete with 0% PET and then concrete with 5% PET, 15% PET and lowest concrete with PET 25%. Thus, we can conclude that thermal conductivity reductions are observed with higher PET percentages in concrete. It is agreed that for concrete samples with 25% PET with the lowest thermal conductivity value, the performance capacity or heat transfer ability is lower than others. This result suggests that insulation properties in concrete increase up to 95% by including 25% PET additives. Hence, the sample has a better heat insulation capability. These findings relate to the previous study of plastic waste incorporated concrete, where there was a reduction of temperature of 30% in concrete by incorporating 60% of plastic waste.

Conclusion

Growing concerns for waste management and environmental issues have led to a search for an important way in the use of waste products such as plastics. It shows a different perspective on plastics and its implementation, which can be summarized and concluded as follows:

This research investigates the effect of PET plastic waste on thermal conductivity (or insulation) in ordinary concrete. Thermal conductivity tests are performed by hot-wire techniques. The findings have shown that plastic waste reduces thermal conductivity (or better insulation properties) than ordinary concrete. It has been proven that the insulator is fixed up to 95% with the inclusion of PET aggregates in standard concrete. Each percentage for PET aggregates varies between 18% and 94%, depending on the amount of supplemental PET content. These findings concur with the previous study where the

researcher investigates the thermal insulation of concrete incorporation with plastic admixtures [3]. It can be concluded that concrete with PET is suitable for the use of low insulation walls where the thermal gain in the building will be less than the use of ordinary concrete.

The reuse of PET plastic materials in concrete is, according to all accounts, excellent results in the initiative towards a cleaner environment, efficient building energy, and lower construction costs. Therefore, concrete blocks containing plastic waste as aggregates are suitable for use as sustainable building materials.

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