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Effect on Thermal Conductivity of Concrete Containing Recycled Polyethylene Terephthalate (PET)

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Abstract

The production of plastic solid waste rising annually with the current habit of consumption nowadays prevalent in society. Improper handling of plastic was a significant environmental issue, because it is not readily degradable. There has been considerable debate on the topic of environmental contamination caused by polyethylene terephthalates (PET), and recycling is the best option proposed. Therefore, recycling PET as fiber concrete (FC) in the building industry is one of the viable solutions. A composite material called FC is created by adding fibers to normal concrete. The objective is to define the optimum percentages of PET fiber in concrete and the relationship between the thermal conductivity value (k-value) with density fibers and water absorption of concrete containing PET. The fibers were easily cut from 1.5L mineral water bottles made of PET plastic. Recycled PET fibers have fixed dimensions of 25 mm and 5 mm, respectively. A total of 15 concrete cube samples were tested for 7 and 28 days with measuring 100 mm x 100 mm x 100 mm and with a separate percentage of 0%, 0.5%, 1.0%, 1.5% and 2.0% PET fibers as concrete admixture. The curing process was performed for 7 and 28 days. Using a heat transfer equipment, the samples' thermal conductivity was evaluated. PET fiber content in concrete gets higher with percentage, which lowers the conductivity of thermal (k value). From the tests conducted, the optimum percentage of PET fibre to produce concrete with lowest thermal conductivity value was 1.0% from concrete weight. Thus, by decreasing heat transfer, building structures may utilize less energy.

1. Introduction

Concrete is frequently utilized as the main building material because it has several benefits, including durability., resilience, easy of manufacturing, long service life, low cost, and non-combustility [1]. Moreover, concrete is commonly used to making super structure in building construction such as beam, column, slab and foundation and has greater demand compared to steel. Although it has weak tensile strength, concrete has good compressive strength. This situation occurs due to the emergence of micro and macro cracks caused by concrete shrinking during the cooling process [2]. Therefore, the invention of concrete on this study is required to enhance the qualities of concrete.

PET, short for polyethylene terephthalate is among the most used contaminants in fibers, which are extremely detrimental to the environment and can take hundreds of years to degrade. PET fibers is the chemical family of thermoplastic polymer resins. PET is colourless and semi-crystalline resin in its natural state and it can be semi-rigid to and very lightweight. To protect the environment from pollution, the amount of waste plastic fibers must be controlled. Hence, a more effective and cheaper solutions are needed to reduce the waste of these PET bottles. One of the methods required is utilizing chopped plastic trash for recycling as an aggregate replacement or additive to produce of recycled concrete [3]. PET fibers are added at different percentages can increase the absorption of energy and the ductility of concrete [1].

Malaysia is near the equator and has almost uniform temperatures with high humidity and abundant rainfall. The minimum temperature in this area fluctuates depending on the time of day. Building interiors, building openings, the outside environment, the temperature inside, and other factors all affect indoor thermal comfort. Additionally, using heat-extinguishing electronics like laptops can disrupt the equilibrium of the interior temperature. High demand for the installation of air conditioners (HVAC) in the building as it ensures better ventilation and thermal comfort in the building [4]. However, an analysis of the concrete-related characteristics of PET fibers is very important to ensure the thermal comfort achieve in building. Waste materials such as recycled plastic can exhibit extreme flexibility, lightness, durability, durability of chemicals, and have high thermal insulation properties and are excellent when added to concrete. This can be leveraged to create an innovative and sustainable use of composite materials [5].

Previous research by [29] revealed that using 30 mm-long PET fibers can increase the tensile strength of concrete for a volume replacement of up to 1.5% compared to 20 mm-long PET fibers. The results show that long fibers can be inserted between aggregates and create stronger structure.

It is also important to consider the ratio of applied materials to concrete, as numerous studies have shown that these materials can significantly impact the technical properties of concrete [6]. A shredded plastic waste was used as an addition of aggregate in the concrete mix can create the production of recycled concrete and to save the environment against pollution [3]. Using PET fibers by 1.5% of the mixing volume enhanced the mechanical properties of specimens 28 days old [1]. In addition, longer PET fibers have been shown to enhance the tensile strength of concrete when used as a replacement for volume [7]. Unfortunately, only some percentages are allowed in concrete mixtures due to the weak bonding strength between the PET surfaces during fibers bridge stress [3]. Therefore, this research use waste PET fibers with different percentage (0%, 0.5%, 1.0%, 1.5% and 2.0%) in concrete and fixed length and width were 25 mm and 5 mm respectively. Testing was done to identify the optimum PET fibers percentage in concrete.

2. Methodology, Materials and Procedure

2.1 Methodology

Fig. 1 displays the flowchart of this research. It consists of the phases, that is material preparation, followed by concrete mix design, relevant laboratory testing and data analysis. The purpose of the flowchart act as a deadline of the process involved in this research from the beginning of the research until the result of the research.

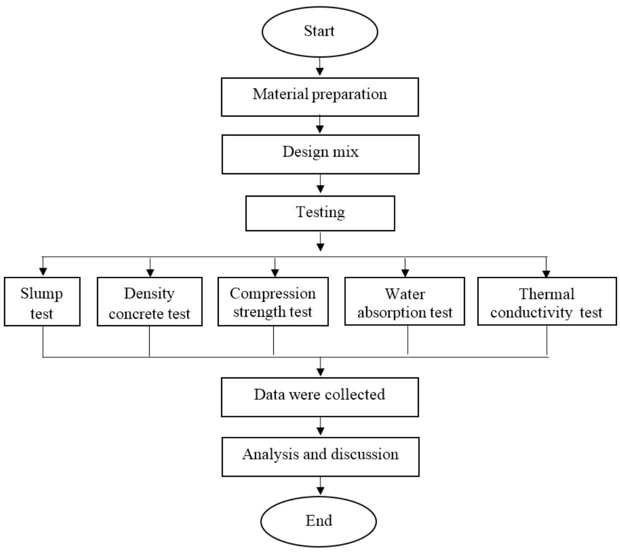

Fig. 1 *Flowchart of research methodology*

2.2 Materials Preparation

The process of choosing and preparing of materials is essential, the preparation of materials is according to [8] and serves as suggestions for specific materials used in Malaysia's construction industry. All the necessary information needed to obtain the results of the study was defined. This study utilized fine aggregates with a maximum size of 4.7 mm, as well as for coarse aggregates sized was used 4.7 mm to 20 mm. Therefore, it will go through the sieving process according to [8], Ordinary Portland Cement Type 1, water, superplasticizer and 5 mm wide by 25 mm long of recycled PET fibers.

In order to conduct this research, recycled PET bottles were acquired and cleaned. Once this recycled PET bottle is collected, it was cleaned first and then dried before it is cut. Next the recycled PET bottle was cut using scissors according to the size set 25 mm long and 5 mm wide. Fig. 2 below shows the recycled PET bottle collection process until the bottle is cut to the specified size.

(a) (b)

Fig. 2 *PET Fiber preparation (a) Collected the recycled PET plastic bottles; (b) Cut the recycled PET bottles*

2.3 Design Mix Proportion

Design mix of concrete is used to evaluate relative quality and select the ingredients that will produce the appropriate strength. In this research, the proportion of concrete mixing material to be used is in accordance with mix design in Table 1.

Table 1 *Concrete mix design*

Quantities (kg)	Per m^3	Total (kg)
Cement	500.00	30.0
Water	225.00	13.5
Fine Aggregates	505.00	30.3
Coarse Aggregates	1175.00	70.5
PET fiber	420.00	0.26
Superplasticizers	6.00	0.35

Relative amounts of fine and coarse aggregate are obtained by multiplying the absolute volume of all aggregates by the percentage of each aggregate used in the mix. Percentages of aggregate are dependent on the properties of the aggregate (size, shape, porosity, texture, etc).

To batch concrete accurately, the theoretical batch weights were adjusted to account for the weight of free water in the fine aggregate. Free water is measured as a percentage of the weight of the fine aggregate and is referred to as "moisture content" which is 0.45 in design mix calculation. While the quantities for PET is made by container of 100ml cylinder full loaded with PET fibers which is 0.042 kg.

It is necessary to perform the process of mixing PET fibers into concrete in an orderly manner so that PET fibers can be uniformly distributed. The first step is mixing materials such as fine aggregate, coarse aggregate, cement, superplasticizers, fibers and water grouped together. Further, the surface of the mixture needs to be washed first before mixing to produce a uniform mixture. Then, fine aggregates and coarse aggregates were added to the mixer followed by cement, water, and finally fibers.

2.4 Specimens Testing

2.4.1 Slump Test

A slump test was conducted to assess whether the mixture received the appropriate quantity of water. The test was conducted in accordance with [9], which is a procedure for slump test. The slump test is conducted as follows:

On a strong, level base that is impermeable, a steel slump cone has been set, and three equal layers of new concrete have been added on top. For compaction, each layer was rodded 25 times. The peak of the cone was at similar level to the third tier. The cone was gently lifted after that, leaving a small amount of settled concrete behind.

Fig. 3 *Real observation concrete slump value*

As shown at the Fig. 3 the slump cone was turned upside down and set on the base to serve as a reference. The height discrepancies between the top of the slump cone and the top of the concrete heap were measured and recorded.

2.4.2 Density of Concrete

According to the [10] provides that normal concrete consists only of normal concrete which is the density of cement, fine aggregates, coarse aggregates and water should be between 2300 kg/m^3 and 2400 kg/m^3. The density of each cube sample was also determined and recorded. The average value was then determined as a result. The density value will be determined using density equation (1).

$$Density = \frac{\text{Mass of concrete}}{\text{Volume of concrete}} \left(\frac{\text{kg}}{m^3}\right) \tag{1}$$

2.4.3 Compressive Strength Test

According to the [11], the compression testing was conducted using a compressive test machine to ascertain the compressive strength of concrete cubes. Before the specimen could fail under the maximum compressive stress, increasing compressive load was applied on it. The sample dimensions were measured before to the experimentation. Compressive strength testing was done on the concrete cube at 7 and 28 days following curing.

2.4.4 Water Absorption

After the 28-day curing process, three samples were put into a drying oven so that each sample would be at least 25 mm away from any heat source. Three samples had been oven-dried for 72 ± 2 hours. Other samples should not be placed in the same oven while it is drying., and every sample surface must have unrestricted access to air. Each sample was allowed to cool after being taken out of the oven for 24 +/- 0.5 hours. The weight of each sample follows. The samples were then submerged in water at a depth of 25 5 mm, according to the alignment, horizontality, and length of the longitudinal axis. Each sample was submerged in water for 30 +/- 0.5 minutes. After removing each sample from the water, it was shaken and quickly dried with a piece of cloth until no water was left on the surface. After that, each sample was weighed. The entire process described in [12].

2.4.5 Thermal Conductivity Test

The test in this study involves using a lab tool called a heat transfer device to ascertain the thermal characteristics of concrete fibers.

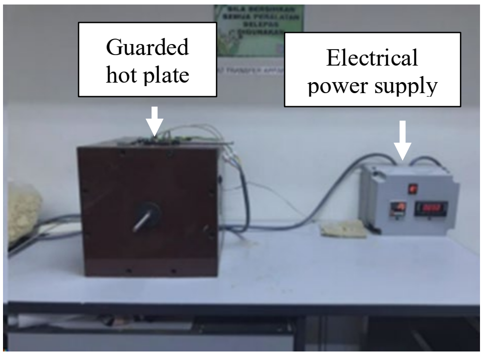

Fig. 4 *Heat transfer apparatus (Guarded hot plate test)*

As shown in the Fig. 4, a test was conducted in accordance with [13]. The concrete is examined using a thermal conductivity test, with 15 samples being checked for 28 days. Depending on the surface area, thermal conductivity, which is measured in watts per square meter with a temperature gradient of 1 k per unit of 1 m, defines a material's capacity to absorb and transmit heat. There are five distinct PET fiber content levels in the concrete used in this test, ranging from 0% to 0.5%, 1.0% to 1.5%, and 2.0%. Following a 28-day curing period, the concrete cube has undergone testing.

3. Results and Discussions

3.1 Workability

The test results may however review appropriate knowledge about the uniformity of the components. The results of normal concrete and recycled PET concrete slump tests are shown in Fig. 5.

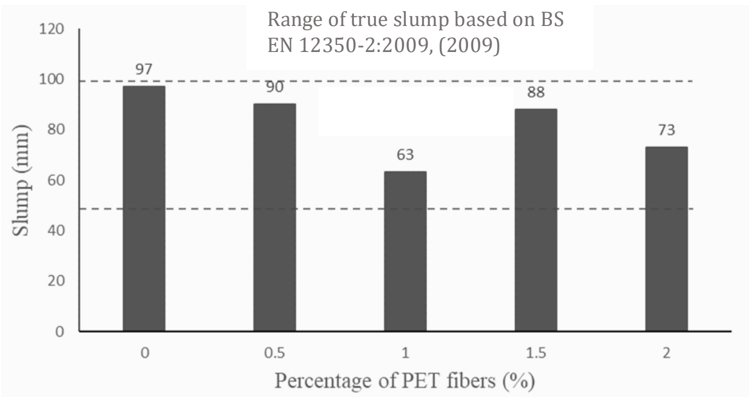

Fig. 5 *Slump versus the percentage of PET fibers (%)*

The slump test was used in this analysis to measure the workability of concrete. The actual slump ranged from 75 ± 25 mm or from 50 mm to 100 mm, according to [9]. The results of Fig. 5 show that the addition of PET fiber to concrete contributes to a reduction in the rate of corrosion from normal concrete, thus decreasing the workability of fresh concrete.

The normal concrete in the experiment showed that the concrete slump was 97 mm that lied between 50 and 100 mm of the target range. The concrete with PET fiber decreased to 90 mm, which was 7% less than the value of concrete control by adding 0.5% of PET fiber to the concrete while the 1.0% PET was far decrease to 35% difference by 63 mm. The remaining layers of fiber concrete displayed diminishing slump values of 88 mm (9% difference), and 73 mm (25% difference) for 1,5% PET and 2,0% PET, respectively.

Fiber in the concrete matrix may be used to shape a network structure and avoid separation and flow mixtures. Adding PET fibers to the concrete creates more friction between the particles, which ensures that mixtures are less workable. In addition, due to their mercenary form, PET particles have a more unique area than natural sand. In addition, the cement paste can easily be absorbed with high content and wide surface area by increasing the viscosity of the concrete mixture [14]. With the rise in PET content, plasticity and fresh concrete quality are decreased.

According to [15], had made two suggestions for improving the working of fiber concrete, reducing the volumetrical content of fibers to 0.1% to 1% and adding more water. However, water applied can adversely affect the strength of concrete. Thus, plasticizers or water reduction admixtures in fiber concrete are often used to increase the working efficiency without increasing their water content. According to [29], the PET fiber content did not decrease substantially when the traditional concrete slump was reached by 0.5%. Unfortunately, the fresh concrete slump value only amounted to about 25% when fibre content was raised to 1,0%. However, some groups have noticed that the functionality only improved if the cement had a lower fiber material.

3.2 Density of Concrete

According to the [10], it provides that normal concrete consists only of normal concrete which is the density of cement, fine aggregates, coarse aggregates and water should be between 2300 kg/m³ and 2400 kg/m³. Lightweight concrete is defined as having a density less than 2300 kg/m³.

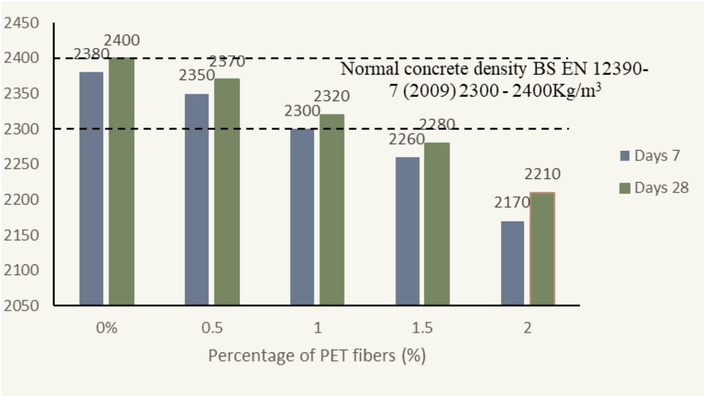

Fig. 6 *Density of concrete versus the percentage of PET fibers (%)*

This study found a decreasing trend regarding density values. The higher percentage of PET as additional materials, the lower density is achieved. Besides that, the density difference was less than 2.0% from 7 days to 28 days. These results are almost the same as previous study, which indicates a density increase of less than 2% from 7 days to 28 days [16]. More synthesis fiber fractions in cement are mixed into the more permeable voids of fiber-reinforced concrete have been found, leading to a decrease to the density of the concrete [5].

3.3 Density of Concrete

Fig. 7 shown the results of compressive strength test value pattern. Concrete's target strength was 35 N/mm2. However, the results indicate a change in the value of the compressive strength of concrete fibers by increasing the percentage of PET fibers.

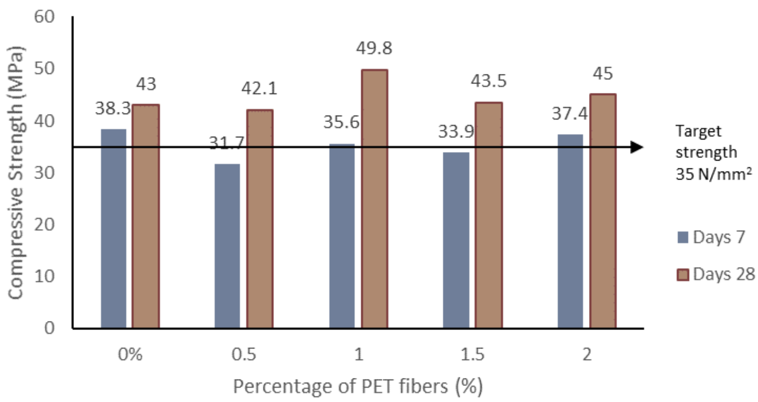

Fig. 7 *Compressive strength versus percentages of PET fibers*

During day 7, 38.3 MPa was the average concrete compressive strength test results, 31.7 MPa for concrete containing 0.5% PET, 35.6 MPa for concrete containing 1.0% PET, 33.9 MPa for concrete containing 1.5% PET, and 37.4 MPa for concrete containing 2.0% PET. While for concrete that is cured for 28 days shows the normal concrete and the fiber concrete was achieves at 35 N / mm². The results showed 43 MPa for normal concrete while concrete with PET (0.5%, 1.5% and 2.0%) recorded values of 42.1 MPa, 43.5 MPa and 45 MPa respectively. However, 49.8 MPa were the highest value for concrete with PET fibers.

Variation was apparent in the compressive strength graph with various recycled PET fiber content percentages. The graph showed that 0.5% PET fiber concrete scored the lowest strength value. Meanwhile 1.0% PET fiber concrete scored the highest strength value. This is because fibers were added, and this contributed to uncontrolled concrete dispersion.

During the analysis stage, among various fiber concretes, 1.0% PET fiber concrete showed the best potential fiber distribution. Therefore, the maximum value for the compressive strength was obtained by 1.0% PET fiber concrete. According to [17], tested the effect of PET bottle fiber binary binders, and findings indicate a stronger compressive resistance at all ages. 144,1 MPa for 1% shredding of plastic fibers was the maximum compression strength achieved.

The fibers were estimated to be 30 mm long in this study. The length was chosen because of previous studies [18], which demonstrated an increase in plastic measurement of 30 mm in length compared to 10 and 20 mm respectively in terms of compressive strength. The compressive strength decreased longer fiber to a given fraction more than the short fibers. Short fibers are thoroughly mixed with other components and a mesh-like structure was therefore not developed, as with long fibers [19].

3.4 Water Absorptions

One method of determining concrete's performance is to evaluate its water absorption. According to [20], water absorption is the movement of water through porous solids as a result of surface tension acting in capillaries. Concrete water absorption cannot be utilized as a concrete performance metric [21]. It also claimed that good concrete absorbs less than 10% of its weight in water. Testing for water absorption in accordance with [12]. Results of the water absorption test for concrete with a 28-day age are shown in Fig. 8.

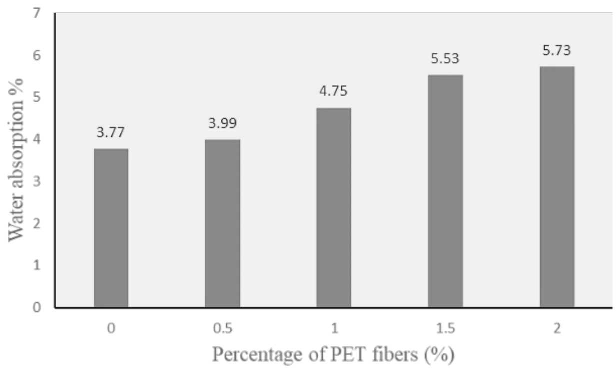

Fig. 8 *Water absorption results*

Fig. 8 shows that the results of 0% to 2.0% water absorption at age 28 days for PET indicate respective values of 3.77%, 3.99%, 4.75%, 5.53%, and 5.73%. The graphic demonstrates that concrete absorbs water more quickly the greater the PET amount. According to [22], there are two ways aggregate can influence the effect of porosity: by first producing the appropriate porosity and then changing the paste. To put it another way, because PET has a flat and long shape, it generates a suitable and distinct porosity for the replacement component of the natural fine aggregate.

3.5 Thermal Conductivity

The thermal conductivity of concrete materials determines how much heat can be transferred through them. A test was conducted in accordance with [13]. Fig. 9 displays the concrete with PET fibers and normal concrete thermal conductivity values. Based on standard precast wall panels, the sample's thickness was 100 mm [23].

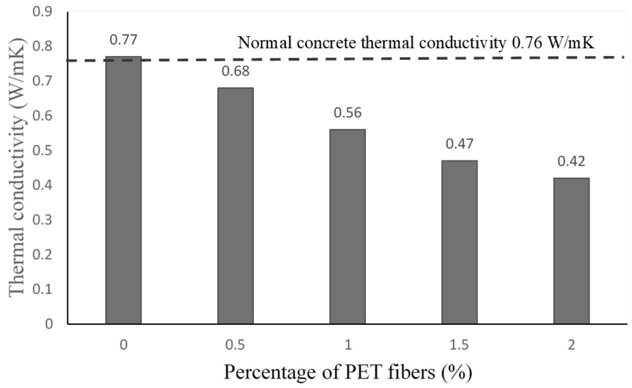

Fig. 9 *Thermal conductivity at age 28 days*

Fig. 9 shows, it can be seen that after 28 days of maturation, the thermal conductivity of the concrete decreased from normal concrete which is of 0% PET to 2.0% PET, with values of 0.77 W/mK on normal concrete falling off to the lowest values of 0.42 W/mK on 2.0% PET. According to [13], the lower the thermal conductivity, the less heat will travel from the outside to the inside of the concrete wall. Thermal resistance and thermal conductivity have an inverse relationship. In steady state, thermal conductivity is influenced by material characteristics, surface area, thickness of the space, and temperature gradient [24].

Lower thermal conductivity is also influenced by concrete's density. The lower the concrete density, the lower the thermal conductivity [25]. If the concrete particles are packaged, the heat can immediately infiltrate the material and raise the temperature. However, heat cannot directly enter the concrete if the particles are lost since there are many voids in between the particles. Therefore, the absence of voids and pores is crucial in lowering the density and heat conductivity of concrete.

One of the crucial factors to consider in modified concrete is density. Concrete that has been altered during production in order to make it safer to use as a building material is referred to as modified concrete. One of the criteria that reflects the concrete's porosity is density. Higher voids and porosity, higher concrete lightness.

3.6 Relationship Between Density and Thermal Conductivity

It has been investigated how thermal conductivity and density relate. Since thermal conductance functions best in lightness, the two factors are reliant on one another which is more pores and voids in the concrete. As a result, less dense concrete would be required because its thermal conductivity decreases with decreasing density. The relationship between normal and PET concrete on density and thermal conductivity is depicted in Fig. 10.

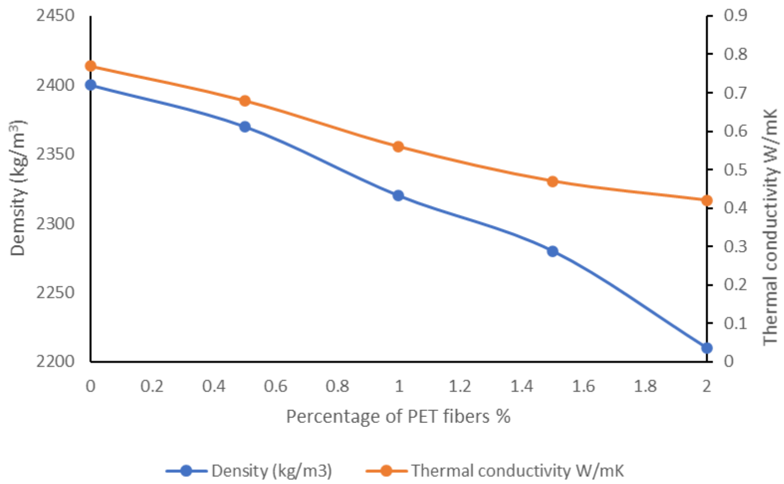

Fig. 10 *Relationship between density and thermal conductivity of normal and PET concrete*

As shown in Table 4, a pattern of diminishing density has been noticed. The values for normal concrete ranged from 0% to 2.0% PET, and they were 2400 kg/m³, 2370 kg/m³, 2320 kg/m³, 2280 kg/m³, and 2210 kg/m³, respectively. In terms of thermal conductivity, a declining trend was seen at 28 days for thermal conductivity with the highest values of 0.77 W/mK for normal concrete and to the lowest values of 0.42 W/mK for 2.0% PET concrete. Concrete that is lighter has more pores and voids. As was already said, it is true that pores and holes in concrete walls trap air, preventing heat from entering the walls directly.

Concrete decreasing density may be connected to the percentage of PET fibers being used. Because less of the typical concrete mixture, such as aggregate, is present when PET fiber content is higher, less weight is lost by the concrete. Concrete's weight can be decreased thanks to PET fibers' light weight. Accordance from [26], the PET aggregate produces high-quality mixes with a lower volumetric weight but similar mechanical behavior to that of normal concrete. Furthermore, two lightweight concrete formulations using PET as an aggregate-one made entirely of PET aggregates and the other combining PET and sand aggregates—have been studied.

Additionally, the thermal conductivity (k-value) of concrete decreases as PET fiber content increases. In particular, high-density polyethylene (HDPE), low density polyethylene (LDPE), polypropylene (PP), and polyethylene (PET) were shown to have lower thermal conductivity than plain concrete [27]. The thermal conductivity values of the made concrete reduced by roughly 2-31% in comparison to plain concrete as the volume percentages of plastic fibers increased [18]. Therefore, the use of this composite material can contribute to reducing thermal bridging, improving overall energy efficiency in buildings and reducing cooling and heating costs.

3.7 Relationship Between Thermal Conductivity and Water Absorption

Thermal conductivity and water absorption of concrete are interdependent since they both depend on pores and spaces. In order to prevent direct heat penetration, pores and voids are essential for thermal conductivity. Regarding water absorption, the voids and pores in concrete's capillaries allow water to pass through. However, based on [12], water absorption cannot be more than 10% of the mass; otherwise, concrete will become wet and weak. In order to produce the suitable concrete fibers, it is crucial to carefully consider a range of PET fiber percentages. The relationship between thermal conductivity and water absorption is depicted in Fig. 11.

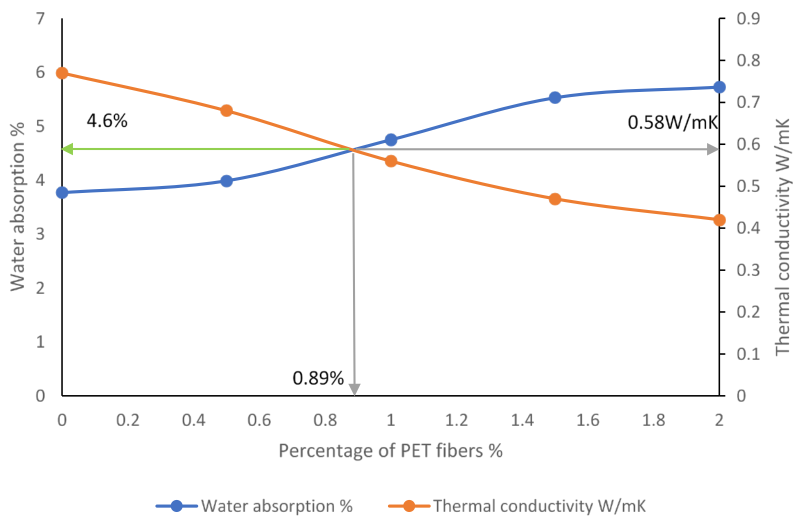

Fig. 11 *Relationship between thermal conductivity and water absorption*

Fig. 11 demonstrates that 0.89% of PET satisfies the requirements for thermal conductivity and water absorption. Thermal conductivity for PET with a thermal conductivity of 0.89% was 0.58 W/mK, while water absorption was 4.6%.

Concrete absorbs more water and has a lower thermal conductivity (k value) value when there is a higher proportion of PET fibers in the mix. The irregular shapes and sharp edges of PET particles in concrete contribute to increased voids and pores, resulting in improved thermal conductivity [28]. Hence, to produce the best concrete fibers, the size, form, and amount of PET fibers employed can be thought of as 0.8% to 1.0%.

4. Conclusions

The compressive strength of the concrete varies with increasing proportions of recycled PET fiber added to the mix. However, the results of the tests show that for all percentages of fiber concrete, there is little variance from normal concrete. In particular, the compression test results indicate that the objective concrete strength was 35 N/mm^2, which was passed by every batch of concrete mix. The optimum percentage of PET fibers concrete was 1.0 % based on the results of the tests performed. When 1.0% of pet fibers are applied to concrete relative to normal concrete at age 28 days, their compressive strength increases by about 14%. The test results is 49.8 MPa compared to the normal concrete which recorded values of 43 MPa. Furthermore, the findings of slump tests revealed the highest strength performance with concrete that contains 1.0% PET fiber. According to the thermal conductivity measurement, the amount of thermal conductivity (k value) decreases as more PET fibers are added to the mixture. Less weight loss would result from using more concrete PET fibers than the normal concrete-like mixture. One characteristic that illustrates the emptiness and porosity of concrete is density. For concrete to have less density and thermal conductivity, pores and voids must not exist. At a percentage of 2.0% PET fiber. The thermal conductivity (k-value) with the lowest value is 0.42 W/mK; however, this is not the ideal percentage of PET fiber because concrete strength must also be considered. For the best concrete fibers with a thermal conductivity value of 0.58 W/mK, a PET fiber percentage of 0.8% to 1.0% can be used.

Relationship tests must be carried out after collecting all data appropriate for thermal performance. This consisted of the relationship between thermal conductivity related to the density of fiber concrete and water absorption. The high percentage of PET fibers in the concrete mix results in a decrease in the value of thermal conductivity and an increase in water absorption in the fiber concrete. This is because, the lightweight of PET fibers has changed the properties of concrete. Therefore, a number of percentage PET fibers need to be carefully considered in order to obtain all optimum concrete fibers.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***Data collection:*** *Adib Fikri Abdul Manaf;* ***analysis and discussion:*** *Adib Fikri Abdul Manaf, Mohamad Azim Mohammad Azmi;* ***interpretation of results:*** *Shahiron Shahidan; reviewed final version and validation from industry: Norbazlan Mohd Yusof.*

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