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Thermal insulation enhancement in concretes by adding waste PET and rubber pieces

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ABSTRACT

The relative change in insulation property of the ordinary concrete due to adding polymeric based waste material is experimentally investigated here. The polyethylene (PET) bottle and automobile tire pieces, which can easily be obtained from the environment with almost no cost, are shredded and added into ordinary concrete to examine heat insulation behaviors of specimens. Five different concrete samples (one ordinary concrete, one concrete with scrap rubber pieces and three concretes with waste PET bottle pieces of various geometries) are considered. The adiabatic hot-box technique is used for comparing effective thermal transmittances of these concrete samples. The results reveal that proper addition of selected waste materials into concrete can significantly reduce heat loss or improve thermal insulation performance. The degree of improvement in thermal insulation is found to vary with the added waste material and geometry of shredded-pieces.

1. Introduction

Polyethylene terephthalate (PET) bottles and scrap automobile tires have been extensively recycled and reused polymeric products [1–3]. Scrap-tires have been used in a variety of rubber and plastic products, burning for production of electricity, or as fuel for cement kilns, as modifiers in asphalt concrete [4,5]. Products made from recycled PET bottles include carpeting, concrete, insulation and automobile parts. Recycled PET bottles are also used in drainage filtration systems, asphalt concrete-mixes and road stabilizations [6,7].

Recycling rate of such polymeric products is however still low comparing to that of paper, glass and metals [1,2]. Currently only 3.5% of generated polymeric products is recycled whereas these percentages for paper, glass and metals are, respectively, 34%, 22% and 30%. The recycling rate for all PET bottles, which represent 44% of total plastic bottle production, dropped to 25% in year of 2000. As a result of this, PET bottle recycling rate has remained much behind of virgin resin PET sales, which increased dramatically in recent years [3]. Reutilization rate of scrap-tires is similarly much below than annually generated tires [4]. In order to prevent polymeric wastes, in particular discarded PET bottles and automobile tires, from damaging the environment, finding alternative routes for increasing their reutilization is highly necessary [8–16].

Reutilization of such wastes in building industry appears to be a viable route for contributing to both preventing environmental pollution and designing economical buildings. The increase in the popularity of using environmentally friendly, low cost and lightweight construction materials in building industry brings the need for searching more innovative, flexible and versatile composites [17]. The most important aspects of innovation might be in the development of integrated insulation products; such as waste polymer added mortars, concretes and bricks [15–17]. As a part of this interest, establishment of an appropriate thermal test technique is also a challenge for guiding product development and manufacturing [18].

The use of scrap-tires in building components, particularly in Portland cement concrete, has become popular application in the last few decades. Excellent overviews of such studies can be found in [4,5]. The use of waste PET bottles in concretes is not as common as scrap rubbers since slitting, shredding and retreating processes are relatively more complex and costly. Waste PET bottles have earlier been used in making lightweight aggregates to improve concrete mechanical properties [8]. Glycolysis of PET bottles for preparation of polymeric concrete has also been studied because of its economical and environmental benefits [9–12]. PET recycling for forming thermal-insulating materials for the building industry has been another feasible application [13,14]. The effects of waste PET and rubber addition on thermal transmission (or insulation) property of ordinary concrete have not been reported due to difficulties encountered in thermal testing of such heterogeneous structures [18].

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The work presented here is related with both developments of integrated building products using waste polymeric materials and thermal performance measurements of such alternative products. The shredded PET bottle and automobile tire pieces are added into ordinary concrete-mix to enhance its thermal insulation performance. Five different concrete samples (one ordinary concrete, one concrete with scrap rubber pieces and three concretes with waste PET bottle pieces) are considered. Thermal insulation performances of these samples are examined by the adiabatic hot-box technique, recently proposed by the authors [18].

2. Experimental frame

2.1. Concrete samples

The concrete samples used here are the ordinary concrete and the concretes with waste polymeric materials. PET bottles were shredded into strip, square and irregular shapes for settling into fresh concrete. From the rubber, only square shaped rubber pieces were cut, since experiments were planned to mainly investigate effect of waste PET addition on thermal transmittance of ordinary concrete. Geometric specifications of the specimens are given in Fig. 1.

Ordinary Portland cement (Type I, with density of 315 kg/m^3), natural sand and water were used for preparation of fresh concrete. The mixture proportions by weight were 1:2.75:0.5, and the largest diameter of fine-aggregate was 5 mm, well within the corresponding ASTM standard. The densities of PET and rubber settled into fresh concrete were 0.2 g/cm^3 and 0.84 g/cm^3, respectively. The thicknesses of all PET pieces are 1 mm and those of rubber pieces are 2 mm since thinner rubber sheets could not be obtained from scrap market. The volumetric amount of PET pieces in each specimen, regardless of the shape used, is nearly same (40 cm^3) within the uncertainty of ±1.5 cm^3. The rubber amount in the specimen with square shaped rubber is 80 ± 1.5 cm^3. A hand-scissor is used obtaining strip, square and irregular shaped pieces at desired dimensions. These pieces were settled into and lined up center surface of fresh concrete before pouring the rest of it to form the specimens illustrated in Fig. 1. Due to heterogeneous future of specimens, three samples for each specimen were prepared. All specimens were cured for 10 days in a controlled environment before thermal tests were done. The required basic tests of fresh and hardened concretes with and without waste polymeric material were accordingly performed.

2.2. Thermal test apparatus

The dynamic adiabatic-box technique [18], which is a secondary but simple and inexpensive technique, is used here for the thermal tests. The technique can be used for pre-estimation purpose for materials developed in a laboratory before taking absolute measurements with one of the standardized techniques, if necessary. The apparatus is schematically illustrated in Fig. 2a. The main component of the apparatus is the adiabatic-box, whose outer and bottom walls are heavily insulated to minimize heat losses to its surroundings. The test specimen with much higher thermal conductivity and thinner in size forms the top wall of the box to provide one-dimensional axial heat flow. The dimensions of the box are shown in Fig. 2b.

A heater controlled by a thermostat is installed close to the bottom wall for heating small depth of water to a certain temperature (ranges between 35 and 55 °C). Using water in the box helps to obtain more homogenous temperature distribution in lateral direction during heating and transient cooling. The box is placed in a cold chamber operating at controlled fixed temperatures, humidity and air flow conditions. Temperature and relative humidity sensors are positioned at several points to measure the corresponding air conditions. A highly sensitive immersible temperature sensor integrated with internal data-logger is put into water to monitor its temperature. The specimen is tightly installed as soon as water is heated to a desired temperature. The heater is then turned off letting water to loss its heat from the top wall of the box. The data-recording in transient state starts at this time of $t = 0$. Cooling rate of water can be considered a measure of specimen thermal transmittance since major part of the heat is transferred through the specimen surface. The analysis of time–temperature curve indeed allows estimation of overall heat transfer coefficient (between water and cold air). Measurements can be extended a variety of hot and cold space conditions, including effects of convection which could be a significant component of heat transfer particularly for roof specimens.

This new thermal testing technique has been proven to be more utilizable and free of many concerns when different inhomogeneous specimens are tested at purely identical hot and cold space conditions [18]. Simple analysis of time–temperature curves for the specimens allows fair comparison of their thermal transmittances under specified conditions [17,18].

3. Results and discussion

Thermal insulation performances of the five different concrete samples (one ordinary concrete, one concrete with scrap rubber pieces and three concretes with waste PET bottle pieces) are investigated by using the adiabatic-box technique. Thermal measurements at transient state for the ordinary concrete (without PET

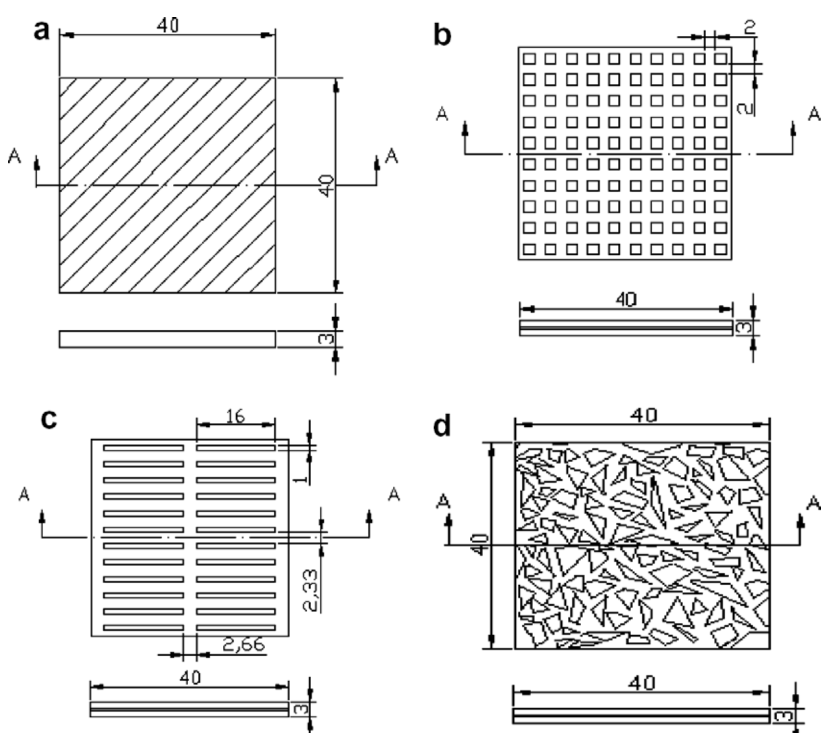

Fig. 1. Geometric specifications of the specimens; (a) ordinary concrete, (b) concrete with strip PET pieces, (c) concrete with square PET pieces, (d) concrete with irregular PET pieces.

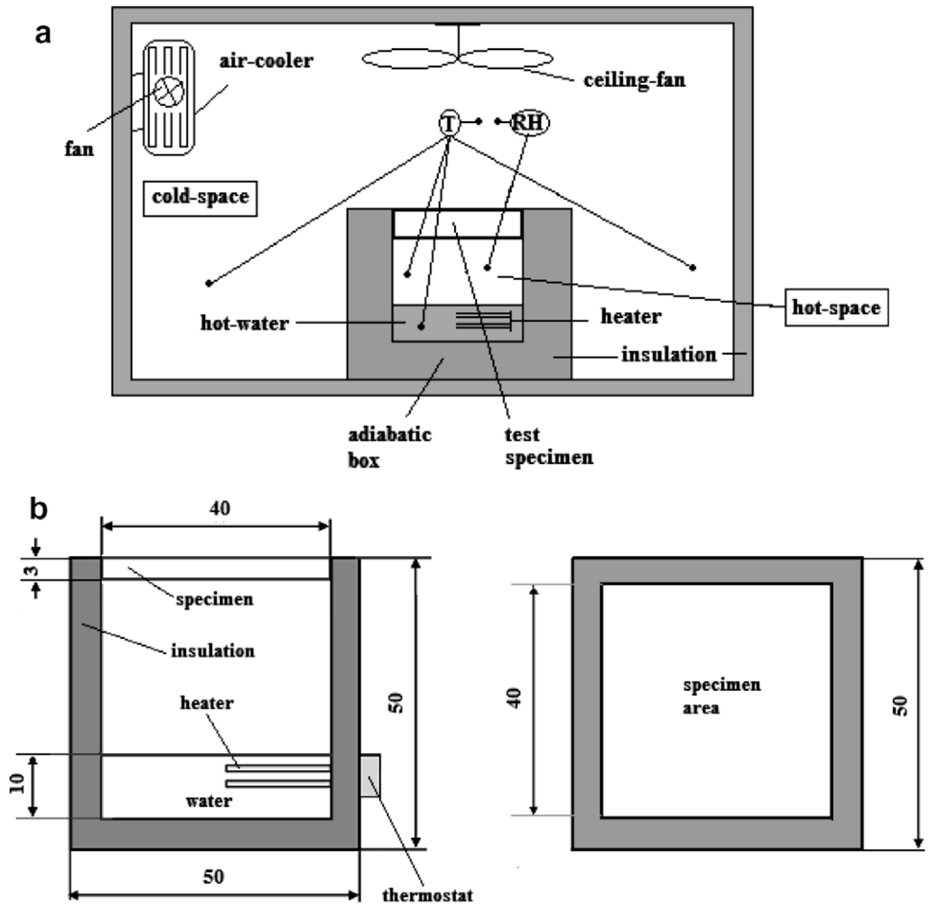

Fig. 2. (a) Schematic of the dynamic adiabatic-box apparatus (T: temperature sensor, RH: relative humidity sensor) and (b) dimensions of the adiabatic-box (in cm).

addition) and the concrete with square PET pieces are first presented, in Fig. 3a. The instantaneous temperatures in the graph represent temperature of water in the box, whose top surface is covered by the corresponding specimens. The cooling rate of water is directly related with thermal transmittance of the specimen in question since major heat loss pass through from the specimen surface. Some heat losses at insignificant level could be possible from the other surfaces of the box; however, this does not affect comparison since all specimens are subject to the same internal and external conditions. Temperature curve for each specimen is the average of temperatures obtained from the three identical samples. Reproducibility of the experiments with identical specimens was fairly good (deviations within 3%). The instant value of cold room temperature was obtained by averaging instant temperatures taken at three different points in the room. The local variations in cold-air temperatures were all remained within ±2 °C. The time-averaged constant value of instant temperatures in cold room (shown with dashed line) is used in comparisons.

The time–temperature curves for specimens show similar behaviors at the beginning of the experiments. The temperatures sharply decrease first and then slow down. Significant differences exist in cooling rates of the specimens at intermediate times. The larger heat loss rate occurs for the ordinary concrete, including no PET pieces. The addition of square PET lowers the thermal transmittance of the concrete, or improves its insulation property, since the instant temperatures remain higher during the experimental time.

The equilibrium temperature could not be obtained although experiments last about 40 h. The dimensionless temperatures (θ^*) for the specimens are thus defined as

$$\theta^* = \frac{T(t) - T_0}{T(t=0) - T_0} = \frac{\theta}{\theta_i}, \tag{1}$$

where $T(t)$ and $T(t=0) = T_i$ indicate, respectively, water temperatures at the beginning and at any instant time of the experiments, and T_0 represents the time-averaged temperature of the cold space. This definition is useful even for the specimens tested at different internal and external temperatures, with the condition of preserving the same heat transfer mechanism. The variations of θ^* with time are shown in Fig. 3b for the specimens tested. The differences in thermal behaviors can now be observed more clearly. The experimental time can be considered long enough to make fair comparison since the decrease rate of the curves get nearly constant at the end of experiments.

The physical meaning of the dimensionless temperature parameter is that the ratio of hot water exergy at any time to that at the beginning of the experiment (available exergy). The corresponding meaning can be expressed for the hot water with known mass (m) and specific heat (c_p) as

$$\theta^* = \frac{Q}{Q_i} = \frac{mc_p(T - T_0)}{mc_p(T_i - T_0)} = \frac{\theta}{\theta_i}. \tag{2}$$

Sum of the differences in θ^* values allows comparing thermal transmittances of two different specimens. The percentage-wise difference can be calculated by the following equation:

$$X = \left[\frac{\left(\sum_{t=0}^{t=t_e} \theta_t^*\right)_1}{\left(\sum_{t=0}^{t=t_e} \theta_t^*\right)_2} - 1\right] \cdot 100, \tag{3}$$

where t_e indicates the total experimental time, and the subscripts 1 and 2 correspond, respectively, concrete with square PET pieces and

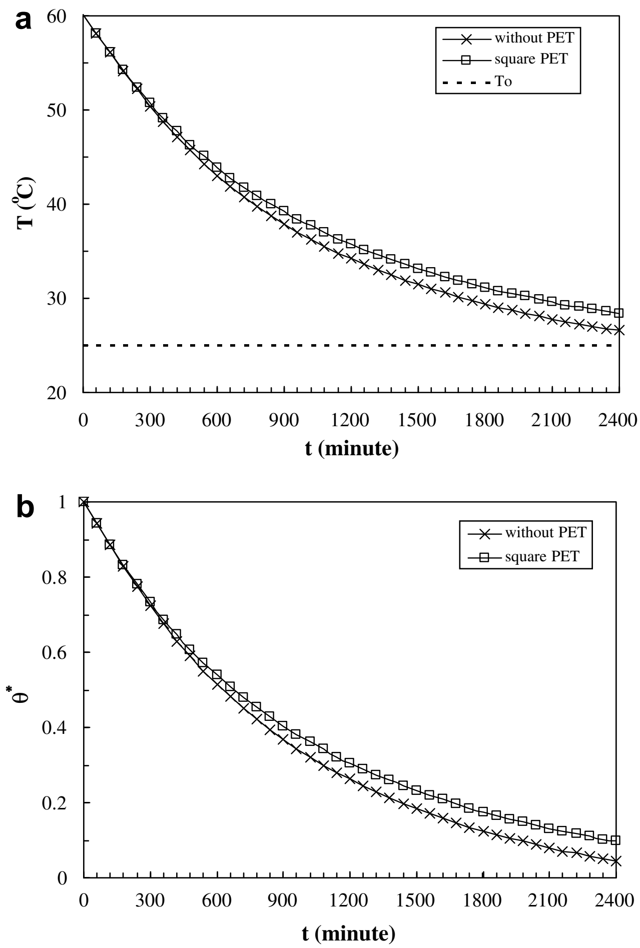

Fig. 3. The transient temperatures for specimens of ordinary concrete and concrete with square PET pieces: (a) in dimensional form and (b) in dimensionless form.

ordinary concrete (without PET pieces). This selection is useful for determining effect of waste material addition on the thermal transmittance of the ordinary concrete. The values of X for square PET added concrete is found to be 10.27%, meaning that the insulation property of ordinary concrete is improved as much as 10.27% by addition of square PET pieces.

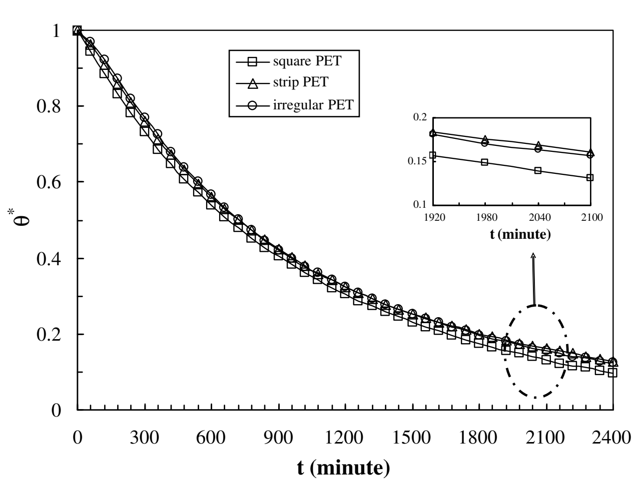

Fig. 4. Dimensionless transient temperatures for specimens of concretes with PET pieces of various shapes.

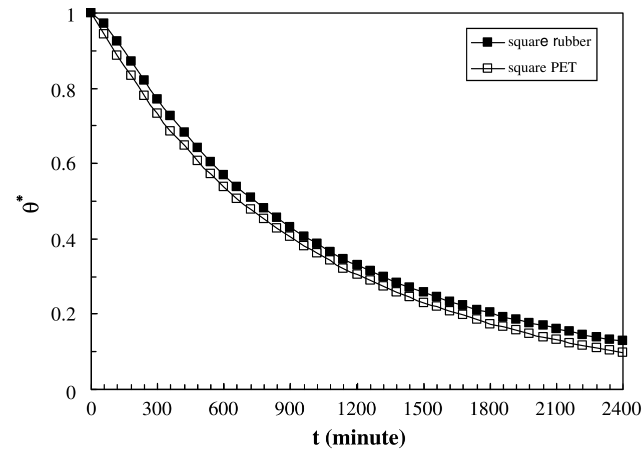

Fig. 5. Dimensionless transient temperatures for specimens of concretes with PET and rubber pieces of square shapes.

Table 1
Percentages of insulation improvement in concrete by addition of waste polymeric materials.

Shape and type of waste material	Square-PET pieces	Strip-PET pieces	Irregular-PET pieces	Square-rubber pieces[a]
X (%)	10.27	17.11	17.16	18.52

[a] Thicknesses of rubber pieces (2 mm) are twice of PET pieces.

The effect of the geometrical shapes of PET pieces added into ordinary concrete on thermal behavior is shown in Fig. 4. The variations of dimensionless temperature (θ^*) with time are similar for all three specimens containing square, strip and irregular shaped PET pieces. The differences can be realized only from inset given in the figure. The specimens with strip and irregular shaped PET pieces show better insulation behavior when equilibrium temperature with cold room is approached. The reason for this difference is not clear since the amount of PET pieces in all specimens are the same. However, the adherences of strip PET pieces with concrete were observed to be much better than those of square PET pieces. The worse adherence is known to cause in higher thermal transmittance and this could be the case for the specimen with square PET pieces. The specimen with irregular shaped PET pieces has an advantage of being closer each other and may create a better thermal barrier than the other arrangement of PET pieces. More thermal experiments along with micro-structural tests seem to be necessary to resolve this issue.

The effect of waste material type is investigated for specimens with square shaped PET and rubber pieces. The results are given in Fig. 5. The thickness of rubber pieces was 2 mm, twice of PET pieces as explained in Section 2. The thermal behaviors are correspondingly different. The effect of rubber addition on thermal insulation improvement is more obvious although shapes and arrangements of pieces are the same and their thermal conductivities are even close to each other. This result accordingly indicates that type and amount of waste material used in concrete affect its insulation behavior.

4. Concluding remarks

The effect of waste polymeric material addition on thermal transmission (or insulation) property of ordinary concrete is studied here. Waste PET bottle and tire rubber pieces are used for this purpose. These materials are shredded into small pieces of different shapes (strip, square and irregular) and lined into fresh concrete before hardening. Thermal test are performed with the dynamic adiabatic-box technique. The results show that waste PET and rubber pieces remarkably lower thermal transmittance (or improve insulation property) of ordinary concrete. The percentage-wise improvements, calculated by Eq. (3), due to adding waste materials are given in Table 1. It is found that the insulation performance is improved as much as 18.52% by addition of square rubber matrix into the ordinary concrete. The corresponding percentages for PET bottle pieces vary between 10.27% and 18.16%, depending on the geometries of added pieces.

Both of the waste materials, PET bottles and tire rubber, used here abundantly exist in environment and can be obtained with almost no cost. The reuse of these materials in concretes seems to be good choice for contributing to cleaner environment and lower insulation cost. The effect of waste material addition on mechanical properties of concrete is also a critical issue to increase its utilization. We hope to report this in a future work.

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