THERMAL PERFORMANCE OF POLYMERIC LIGHTWEIGHT CONCRETE

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Abstract. *Variations in temperature tend to cause heat transfer. When there is a difference in temperature in a way or means of heat transfer occurs, this flow may occur in the form of conduction, convection or radiation. When it comes to materials, the thermal conductivity (on the drive) is a major thermal insulating properties of that combined with other characteristics such as density, porosity and specific heat can assess their thermal performance such as change their mechanical properties. This work proposes the analysis of thermal performance of a polymeric lightweight concrete with a view on obtaining a building block used in the masonry fence. The polymeric lightweight concrete, already patented and used in this study, consists of a composite that adds industrial waste unsaturated thermosetting polymer (UTP) to the composition of the conventional cellular lightweight concrete. The waste UTP is not recyclable but can be well used as an artificial aggregation in a mixture for the production of concrete polymeric concrete in a composition of non-structured elements. The cellular lightweight concrete is known as an excellent thermal insulator with many practical applications as the envelope of pipelines carrying fluids at high temperatures, the manufacture of solar collectors, construction of social housing when moulded in the form of panels, blocks or plates for thermal comfort can be used even as the fire element. To experiment the thermal performances compared with other ceramic materials such as brick, concrete conventional foam cells, block of cement block and plaster were obtained using the thermal properties of conductive meter model Quickline-ABX99 of polymer concrete cell. The analysis of these results promotes the possibility of finding the efficiency of cellular polymer concrete as thermal insulation.*

Key-words: *lightweight concrete, unsaturated thermoset polyester (UTP), light artificial aggregate, waste, thermal insulation.*

1. INTRODUCTION

In Brazil, as in the rest of the world, the amount of solid waste is growing at an accelerated rate. It is estimated that this amount doubles every 10 years, owing to the rapid population growth and ever-expanding industrial sector. Of this total, around 20% are polymers (Plastivida, 2008).

Plastics can be separated into two types. The first is thermoplastic, which can be melted and recycled. Examples of these are polyethylene, polypropylene, polyamide, polyoxymethylene, polytetrafluorethylene, and terephthalate. The second is thermoset, which cannot be melted or molten by heat because their adjacent molecule chains are formed by covalent cross-links that bind the chains together, impeding vibrational movement and high temperatures. This type of polymer is generally harder than the thermoplastics and exhibits better dimensional stability. The most well known thermoset plastics are: vulcanized rubber, epoxies, silicone, phenolic resins, polyurethane and UTP. Thermoset plastic waste is normally burned, buried or deposited in sanitary landfills. All of these methods are tedious and harmful to ecosystems. However, if the UTP waste is reused, these negative effects may be minimized.

The aim of the present study was to seek alternatives for recycling UTP waste, incorporating it into construction materials, particularly for the production of parts or plates as filler in pre-molded cement slabs, and in the erecting of interior building walls, or in walls molded in loco with an inner iron framework.

In the Brazilian civil construction market, in processes such as filling in pre-molded slabs, ceramic blocks or expanded polystyrene blocks (EPB) are used, as shown in Fig. 1. Despite their widespread use, both cause inconveniences in the construction process. Ceramic blocks have the disadvantage of elevated weight, requiring added strength throughout the entire building, including the foundation, thereby raising final costs. Expanded polystyrene blocks, in turn, incur high costs, nearly double those of ceramic blocks, and offer very low mechanical strength. Both cause considerable environmental damage during the manufacturing process, whether by the firing of the ceramic, a process that contributes to deforestation and the release of carbon gas into the atmosphere, or by the use of non-renewable resources in the composition of the expanded polystyrene.

Non-structural PCC blocks can be produced with a density between 400 and 600 kg/m^3, weighing only one-third of the normal weight of a common ceramic brick. An important factor to be considered in this application is the characteristic of FCC as good thermal and acoustic insulation (Ohama, 1988). Compressive strength is in the 2.5 to 3.5 MPa range, an 8 to 10-fold increase over FCC without waste, at a density of 400 and 600 kg/m^3 and within the specifications of Brazilian Association of Technical Norm (ABNT) NBR 12.646. This compressive strength of 2.5 MPa is the same required by the ABNT for ceramic bricks used in non-structural walls in Brazil.

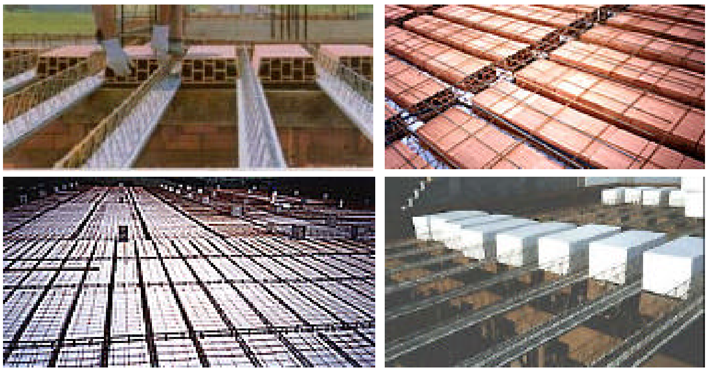

Figure 1. Pre-molded slabs made with ceramic brick and expanded polystyrene (EPB).

The manufacturing technology of FCC can be separated into three main types. The first is called light concrete with no fine aggregate, where the sand is removed from the mixture, resulting in voids between the parts of the thick aggregate (EPB-expanded polystyrene), a situation that leads to lower density concrete. The second is called aerated concrete, which forms voids within the concrete mass with the use of agents, such as aluminum powder, that generate and incorporate micro air bubbles. The third is made of light aggregates, such as pumice stone. A new material was created in the present study. This material combined the second and third types of FCC, using an air entraining agent denominated Neopor® 600, and a light artificial aggregate from pulverulent polyester industrial waste. The density of UTP is lower than that of the aggregates normally used in the mixture for FCC production, resulting in lower final density in the PCC product.

During the last decade, many studies have investigated the use of solid residues in concrete and construction materials. Rebeiz (1996) researched the compressive strength properties of concrete, using a non-saturated polyester resin with a recycled polyethylene terephthalate (PET) plastic base. The results showed that recycled PET-based resin can be used in the production of good-quality prefabricated concrete parts. However, Naik *et al.* (1996) reported that compressive strength decreases with an increased proportion of plastic in the concrete mixture, especially above 0.5% of plastic beyond the total weight of the mixture. Sikalidis *et al.* (2002) investigated the use of urban solid waste (USW) in mortar production. These wastes consist of two parts: one is a heavy component, composed mainly of materials such as stone, broken ceramic and glass, and the other is made up of light materials such as paper, wood, plastics, pieces of leather and cloth, fibers and several other similar combustible materials. It was observed that the USW is economically feasible in mortar production. Choi *et al.* (2005) investigated the effects of PET bottle waste on the properties of concrete. Plastic waste could reduce weight by 2% to 6% of the normal weight of concrete. However, compressive strength was reduced by up to 33% compared to normal concrete. Similarly, the results obtained by Batayneh *et al.* (2006) showed reduced compressive strength with an increase of plastic in the concrete mixture. For a proportion of plastic of 20% in relation to sand, compressive strength was reduced by up to 70% compared to normal concrete. Recently, Marzouk *et al.* (2007) also studied the effects of PET waste on the density and compressive strength of concrete. It was found that density and compressive strength decreased when the PET aggregate exceeded the volume of sand by 50%. The density and compressive strength of concrete was between 1000 and 2000 kg/m^3 and 5 and 60 MPa, respectively. However, PET bottles are made of thermoplastic polymer, a valuable material, given that it can be recycled by fusion. In many Brazilian cities, plastic material is collected separately for recycling. However, thermoset plastic is seldom reused because it does not reassume its original properties when submitted to the fusion process a second time. Accordingly, investigating the use of thermoset plastics as a component of concrete, in particular cellular concrete, becomes quite relevant.

2. MATERIALS

This article investigates the use of thermoset polymer waste as a component in the mixture of foam cellular concrete, specifically unsaturated polyester, for final analysis of thermal performance of new material for other products available in the area of civil construction. The method used to entrain air in concrete is done by a foam generating machine, using the Neopor® 600 foaming agent.

The cement used in the experiments of the product developed in this research is the CP II-Z-32 RS type, cement that meets NBR norms 11578/1991 and 5737/1992. Sulphate-resistant Portland cement is the most common type found in the region.

The fine aggregate used is mineral in nature and originates in the river of the region. The sand used meets ABNT-NBR norm 7211/83.

Hydrated lime is one of the main elements of mortar because it promotes a series of construction benefits. When its very fine grains are mixed with water, they function as a lubricant, reducing attrition between sand grains. The result is better workability (or bonding), good adherence and greater labor output. But the advantages do not end there: the hydrated lime has extraordinary capacity for retaining water around its grains, forming in the mortar a perfect combination with cement.

The addition of polypropylene synthetic fibers to the PCC aims at reducing the phenomena of wall, part or plate cracking, provoked by traction stresses resulting from concrete retraction, mainly when it is cured. Its use increases volumetric stability, resistance to impact and final product durability. This type of fiber is chemically inert, not putrefiable, does not absorb water and does not rust. The fiber is also alkali resistant, with a high content of zircon oxide, conferring high resistance to alkalinity during the hydration reaction and concrete curing.

The polymer used in the PCC mixture developed in the present study is unsaturated thermoset polyester (UTP), widely applied in the plastic industry. This waste originates specifically in one of the largest button manufacturing factories in the world, located in the region. More than 50% of the raw material is lost during the shaping, modeling and finishing process, resulting in a large volume of waste. The photos of UTP waste are shown in Fig. 2.

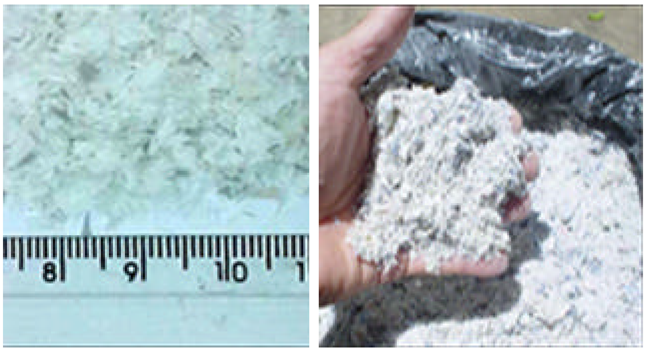

Figure 2. Photos of UTP waste.

The foaming agent used was Neopor® 600. The solution used and transformed into stable and homogeneous is composed of 40 parts water to 1 part Neopor® 600 concentrate. This organic element is a biodegradable liquid agent with a hydrolyzed keratin protein base of animal origin. The size of the air bubbles ranges from 0.1 to 0.5 mm. They have high surface stress and do not rupture during the mixing of PCC. These small air bubbles mixed into the PCC formula cause an expansion in the mass of concrete paste, reducing its density.

3. EXPERIMENTAL PROGRAM

3.1. Determination of polymeric lightweight concrete mixture

To determine the ideal amount of each material (sand, lime and UTP), 2^3 factorial planning was used, varying aggregate amounts to assess their influence on the compressive strength of the PCC.

The proportions of the mixtures were tested in laboratory and are shown in Tab. 2 In this study, the experimental planning matrix to obtain the ideal mixture was divided into two different densities (400 and 600 Kg/m^3). For both groups, the cement, the Neopor® 600 and the water/cement factor were specified as a constant in the mixtures. The PCCs were formulated from the addition of UTP waste, lime and fine sand, at different percentages relative to the cement mass. Table 2 depicts the 18 formulations.

The mixtures of the materials in the PCC formula were tested based on the following Brazilian norms: NBR 12.5739/1993 – concrete cylinder test specimen compression test, NBR 12.646/1992 – compressive strength of test specimens, where after 28 days the concrete must have compressive strength of 2.5 MPa and NBR 5738/1993 – molding and curing of concrete cylindrical test specimens.

For the mixing process, the sand, cement, lime, UTP and polypropylene fiber were added to the standard mixer according to the required density. Water is then added and the solution is mixed until a homogeneous mixture is obtained. Finally, the Neopor® 600 foam made in the foam generator is added for 3 to 5 minutes, after which time the PCC is ready.

Table 2. Formulations to obtain the ideal PCC formula.

Proportions of the mixture (by weight)								
Nº	Density (kg/m^3)	Cement	Polypropylene fiber kg/m^3	Neopor® 600 (% water)	Factor w/c	Sand	Lime	Polyester (UTP)
1						0,0	0,0	0,0
2						0,2	0,0	0,0
3						0,0	0,2	0,0
4						0,0	0,0	0,2
5	PCC 400			28,2	0,57	0,1	0,1	0,1
6						0,2	0,2	0,0
7						0,0	0,2	0,2
8						0,2	0,0	0,2
9						0,2	0,2	0,2
10		1,0	1,0			1,0	0,0	0,0
11						1,0	0,2	0,0
12						1,0	0,0	0,2
13						1,0	0,2	0,2
14	PCC 600			24,6	0,53	0,8	0,1	0,1
15						0,6	0,0	0,0
16						0,6	0,2	0,0
17						0,6	0,0	0,2
18						0,6	0,2	0,2

Figure 3 shows the thermal properties of the PCC were determinated using a thermal properties analyzer Quick Line TM–30/Anter Corp., that provided the thermal conductivity (k), the thermal diffusivity (α) and the calorific capacity.

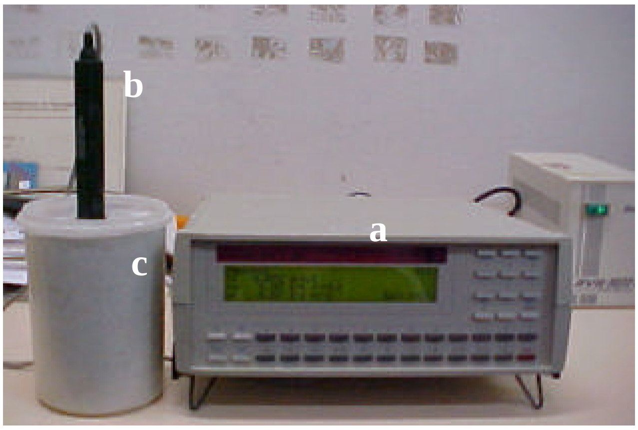

Figure 3. Thermal properties analyzer: (a) TM–30; (b) probe; (c) COF sample

4. RESULTS AND DISCUSSION

4.1. Materials

The results presented in Tab. 5 show that UTP waste has a lower specific and unit mass than that of the agglomerants (cement and lime) and of the fine aggregate (sand) used in this study.

According to Petrucci (1993), the influence of fine aggregates on resistance is owing to their grain size, while coarse aggregates influence as a function of their shape and grain texture. In the case of fine aggregates, the finer the grain size, the more specific surfaces they will have, requiring thus, a larger amount of water to wet the grains and, consequently, decreasing resistance.

Tommy *et al.* (2007) report that the resistance of concrete with light aggregate is more related to aggregate density than to grain size. Accordingly, UTP waste significantly increases the resistance of PCC and may even cause the opposite effect. In contrast, UTP waste favors the maintenance of low PCC density, essential for confining the waste and achieving the objectives of the final product.

Table 5 – Specific and unit mass of the material.

Test	Method	Result
Cement		
Specific mass (g/cm^3)	NBR NM52/2003	3,48
Unit mass (g/cm^3)	NBR NM45/2006	0.98
Lime		
Specific mass (g/cm^3)	NBR NM52/2003	3,28
Unit mass (g/cm^3)	NBR NM45/2006	1.05
Fine aggregate – sand		
Specific mass (g/cm^3)	NBR NM52/2003	2,57
Unit mass (g/cm^3)	NBR NM45/2006	1,41
Unsaturated thermoset polyester – UTP		
Specific mass (g/cm^3)	NBR NM52/2003	1,42
Unit mass (g/cm^3)	NBR NM45/2006	0,06

Grain size and the fineness modulus are important elements in the performance of concretes and mortars. River quartz sand was the fine aggregate used to produce the PCC, whose grain size distribution, fineness modulus, specific mass and natural moisture are shown in Tab. 6.

Table 6 – Grain size distribution analyses of the sand.

Sieve (#) (mm)	Mass retained (g)	% Retained	% Accumulated retained
4.8	0,0	0,0	0,0
2.4	1,0	0,1	0,1
1.2	49,0	4,9	5,0
0.6	180,0	18,0	23,0
0.3	400,0	40,0	63,0
0.15	267,0	26,7	89,7
bottom	103,0	10,3	100,0
total	1000,00	100,00	100,00
Modulus of fineness	-	1,80	NBR NM248/2003
Maximum diameter	mm	4,8	NBR NM52/2003
Moisture content	%	0,50	-
Classification	Fine sand		NBR 7211/2005

Figure 4 shows the grain size curve of the sand used in the mixtures. The curve is located between the lower and upper range of zone 1, classifying it as fine sand.

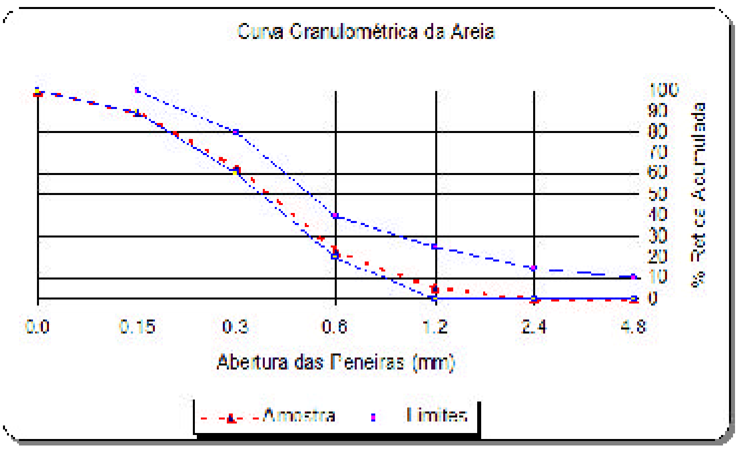

Figure 4. Curve size of sand used.

An analysis of the grain size of the waste was performed to obtain the accumulative percentage of the waste in each of the sieves, as shown in Tab. 7. UTP waste particles are shaped like thin flakes with a pulverulent aspect.

Table 7. Grain size analysis of the UTP waste.

Sieve (#) (mm)	Percentage (%)	
	Retained	Accumulated
4,8	0,35	0,35
2,4	8,05	8,40
1,2	25,70	34,10
0,6	26,50	60,60
0.3	21,35	81,95
0,15	11,50	93,45
< 0.15	6,55	100

4.2. Behavior of thermal properties of materials at the PCC

Table 8 shows the PCCs properties present lower values than those obtained from other materials. The addition of particles of the UTP in the FCC, transforming it into PCC, caused the decrease of values of properties: thermal conductivity (k), heat capacity (Cp) and thermal diffusivity (a) when compared to the properties of the FCC.

The decreasing values of thermal conductivity and heat capacity result, respectively, in the reduction and increase in thermal diffusivity. It is believed that the decrease in thermal diffusivity of the PCC, due to the increase in density (?). The Eq. (1) shows the thermal behavior of materials, where the increase in density causes a decrease in thermal diffusivity.

$$a = k / C_p * ? \quad (1)$$

Based on these results we can state that, if compared two identical constructions, one composed of CCP have more resistance to heat flow than the FCC.

The thermal conductivity of PCC 400 is 84,6% lower than the ceramic brick and 88,3% lower than the block of concrete. The thermal conductivity of PCC 600 with UTP is 81,3% lower than the ceramic brick and 85.8% lower than the block of concrete. The heat capacity of the PCC 400 with UTP is 32,8% higher than that of ceramic brick and 29,6% higher than the block of concrete. The heat capacity of the PCC 600 with UTP is 30,5% higher than that of ceramic brick and 37,3% higher than the block of concrete. Therefore, as the thermal diffusivity of PCCc are much lower than those of conventional elements, the use of the PCCs will result in a resistance to heat flow of much larger and, consequently, to a greater thermal stability within a building. It would be possible to obtain thermal comfort with reduced energy expenditure.

Table 8. Thermal properties of the PCC.

Materials	Thermal conductivity - k W/m.k	calorific capacity - C_p J/m^3.k	thermal diffusivity - a m^2/s
FCC 400	0,153	1,43	0,104
PCC 400	0,106	1,25	0,086
FCC 600	0,162	1,48	0,121
PCC 600	0,129	1,21	0,105
Ceramic brick	0,690	0,84	0,520
Concrete block	0,910	0,82	0,820
Plaster wallboard	0,550	0,80	0,670

5. CONCLUSIONS

The study of the interaction between the PCC materials showed no physical-chemical incompatibility with the joint use of Portland CP II-Z - 32 RS cement, lime, unsaturated thermoset polyester (UTP) waste and the Neopor® 600 air entraining agent.

The use of UTP waste did not reduce the water/cement factor in the PCCs or alter the consistence index.

The conductivity and diffusivity thermal in CCPs are lower than those of conventional materials such as ceramic bricks, concrete blocks and plaster wallboards used in construction and even lower in CCPs with residue compared to those without. Its heat capacity indicated that CCPs require a smaller amount of heat to warm up than conventional materials. The CCPs, with their porous structure, have better insulation properties than conventional materials (ceramic brick, concrete block and plaster wallboard), can maintain the temperature inside the building more stable, reducing energy consumption and providing greater thermal comfort.

The use of waste, once a pollutant, is viable in the formulation of an aerated light concrete, substituting natural raw materials and contributing to preserve the ecosystem.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Batayneh, M., Iqbal, M., Ibrahim, A., 2006. "Use of selected waste materials in concrete mixes". Waste Management, doi:10.1016/j.wasman. 2006.07.026.

Choi, Y. W., Moon, D.J., Chung, J.S., Cho, S.K., 2005. "Effects of waste PET bottles aggregate on the properties of concrete". Cement and Concrete Research 35, 776-781.

Marzouk, O.Y., Dheilly, R.M., Queneudec, M., 2007. "Valorization of post-consumer waste plastic in cementitious concrete composites". Waste Management 27, 310-318.

Naik, T. R., Singh, S.S., Huber, C.O., Brodersen, B.S., 1996. "Use of postconsumer waste plastics in cement-based composites". Cement and Concrete Research 26 (10), 1489-1492.

Ohama, Y., "Polymer-Based Admixtures". Nikon University of Japan. Cement and Concrete Composites 20 (1988) 189-212.

Petrucci, E. G. R.. "Concreto de Cimento Portland". 12ª Edição. Editora Globo, 1993.

Phaiboon Panyakapo, Mallika Panyakapo, Reuse of thermosetting plastic waste for lightweight concrete, Waste Management, 2007.

Plastivida. "Instituto sócio-ambiental dos plásticos" <http://www.plastivida.org.br/.htm> Acessado 20 Agosto 2008.

Rebeiz, K. S., 1996. "Precast use of polymer concrete using unsaturated polyester resin based on recycled PET waste". Construction and Building Materials 10 (3), 215–220.

Sikalidis, C. A., Zabaniotou, A. A., Famellos, S.P., 2002. "Utilization of municipal solid wastes for mortar production". Resources, Conservation and Recycling 36, 155-167.

Tommy Y. Lo, W. C. Tang, H. Z. Cui. "The effects of aggregate properties on lightweight concrete". Building and Environment 42 (2007) 3025-3029.

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