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Effects of Modified Waste Polystyrene Aggregate (MEPS) on the Physical Properties of Light Weight concrete

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ABSTRACT

With growing population, industrialization, urbanization and globalization it is clear that there will be a corresponding growth in the air, water and land pollution. Because increasing wealth and population mean increasing of the number of the consumer and demand of the buying more products and ultimately creating more waste. To meet the demand bring about new lifestyle, such as eating fast food, and new packaging and technological products, much of these contain materials that are not biodegradable. Recycling of these materials is one of the best ways to overcome the pollution problem and have a positive impact on the world in which we live. Production of concrete from raw materials are more expensive and both non-environmentally friendly and sustainable. Shortly, we can no longer continue to ignore the pollution problems on the one hand and the unrestricted depletion of natural resources on the other hand.

Because of the above reasons waste expanded polystyrene was studied. Expanded polystyrene (EPS) is a polymeric material that can be used as artificial aggregates after thermally modification process. Thermally modified waste EPS is abbreviated as MEPS. The study covers the use of MEPS as lightweight aggregate in concrete. MEPS were used instead of natural aggregate at 0%, 25%, 50%, 75%, and 100% on the volume basis. Studied parameters are thermal conductivity (TC) and drying shrinkage. The TC of MEPS concrete decreased with increasing of MEPS aggregate in the mixes. Maximum reduction in the TC observed at 100% MEPS replacement of natural aggregate and the reduction value was 275%. The average drying shrinkage after 210-d of exposure to the ambient condition was 2.59×10^{-3} for mix contained 25% natural aggregate, samples (type C6); while it was 5.08×10^{-3} for 100% MEPS concrete samples (C1).

INTRODUCTION

Expanded polystyrene (EPS) is made from expandable polystyrene, which is a rigid cellular plastic containing an expansion agent. EPS is a type of insulation materials that is molded or expanded to produce coarse, closed cells containing air. The rigid cellular structure provides thermal and acoustical insulation, strength with low weight, and coverage with few heat loss paths. There are many application areas of EPS. The range of applications for expanded polystyrene is very wide. They can be classified into three main categories. These categories are: Packaging**,** Construction and other applications

In the study will focus on waste EPS that are used for packaging. It is conservatively estimated that well over 300,000 tons of waste EPS are produced on an annual basis in the UK. In Europe, these products are being totally banned from landfills, with the originating manufacturer being responsible for their collection, recycling, or disposal because the items are not biodegradable. In the USA according to the EPA [1] over 377.579 tons of Polystyrene are produced in California alone. Although some companies have a recycling policy for this material if they use large amounts, unfortunately, most EPS are found its way into landfill sites around the world. Because EPS is so light, the volume of landfill space it takes up compared to its weight is considerable. To put this in perspective 300.000 tons equates to approximately 37.5 million cubic meters. In addition this waste is not biodegradable. It is estimated that on a volume basis, post consumer and post manufacturer expanded and extruded polystyrene, constitute 7% of the waste being placed in landfills in the US [2].

On the other hand because of their desirability as a lightweight protective packaging material and their insulation qualities, EPS use continues to grow. That in turn results in a continuing increase in the availability of EPS waste. EPS manufacturers, aware of the jaundiced eye cast by landfills, and the public, on the litter problem of EPS in particular, have established an industry organization to alleviate the problem.

Recycling of these materials is one of the best ways to overcome the pollution problem and have a positive impact on the world in which we live. On the other hand the digging of the surface of the earth treats the ecological balance and decreasing raw sources. Production of concrete from raw materials are more expensive and both non-environmentally friendly and sustainable. Shortly, we can no longer continue to ignore the pollution problems on the one hand and the unrestricted depletion of natural resources on the other hand.

Shrinkage is an important parameter among others such as ductility, self-compacting ability, strength, high modulus or wear resistance. Shrinkage is a time-dependant decrease in concrete volume compared with the original placement volume of concrete. Shrinkage results from physical and chemical changes that occur in the paste fraction of concrete. The two principal types of shrinkage are plastic and drying shrinkage. Plastic shrinkage occurs while concrete is in plastic state. Drying shrinkage occurs after concrete has reached initial set. Technically, drying shrinkage will continue through the life of the concrete, but most shrinkage will occur within the first 90 days after placement. The duration of shrinkage is dependent on the size and shape of concrete since they control the rate of moisture loss. In addition, Wittmann [3] reported that] drying shrinkage reaches critical values after some 100 days depending on the dimensions of the drying specimen. The size and shape are often considered together as the volume-to-surface area ratio. Larger specimens will shrink after longer periods but the ultimate magnitude may be lower. When a hardened concrete, cured in water, is allowed to dry, it first loses water from its voids and capillary pores and only starts to shrink during further drying when water is drawn out of its cement gel. This known as drying shrinkage and in some concretes it can be greater than 1500 $x10^{-6}$, but a value in excess of 800 $x10^{-6}$ is usually considered undesirable for most structural applications [4].

A review of earlier studies reveals that Mineralogical character of the aggregate would greatly influence the TC of concrete [5]. Aggregate with less TC produce the less conductive concrete whereas the more conductive aggregates produce more conductive concrete [6, 7]. Thus, aggregate type can cause nearly twice an increase in TC of concrete and this is depend on not only aggregate composition but also depend on its degree of crystallization. Aggregate with crystalline structure shows higher heat conduction than amorphous and vitreous aggregate of the same composition [8, 9].

There has been little published work concerning the utilisation of expanded polystyrene wastes as aggregate. This paper reports on the second stage of research on physical properties of concrete produced from a modified expanded polystyrene (MEPS). In the previous stage of this study [10] modification of MEPS as concrete aggregate was studied. After that mechanical properties of concrete made up of combination of both MEPS and normal aggregate were studied and published [11]. The last stage of the study is the physical properties of the concrete made up of the different percent of the MEPS and normal aggregate.

MATERIALS and METHODS

Properties of MEPS aggregate were given in Table 1. Maximum aggregate size of MEPS and natural aggregates were 16 mm. The modification process of the MEPS was detailed elsewhere [10] (see Fig.1). ASTM Type I Portland cement was used in the study. The cement contents for the concrete mixtures were 500 kg/m^3 and constant throughout the study. A polycarboxylate-based super plasticizer was used to produce to improve workability of the concretes. Consolidation of concrete was done by hand compaction. The details of the MEPS aggregate concrete mix proportions were given in Table 2. MEPS aggregate was used as 0, 25, 50, 75, 100% of natural aggregate and three concrete prism specimens were produced for each mixture proportions (Table 2).

Table 1 Properties of MEPS aggregate

MEPS AGGREGATE			
Origin of aggregate	Crushed waste Expanded Polystyrene foams (EPS)		
Method of recycling	At 130^{o}C for 15 minute, thermal treatment method		
Density (kg/m^3)		Loose	Dense
	Fine	191	220
	Coarse	138	162
	Mixed	181	196
Water absorption	By weight	4.1%	
	By volume	0.58%	
Compressive strength at 10% deformation (MPa)	1.76- 8.22 MPa		
Thermal conductivity (W/mK)	0.0521, 0.0415, 0.0366		
Weight loss of Freezing-thawing (10 cycling)	0.31%		
Specific gravity factor (SGF)	Coarse	0.22-0.24	
	Fine	0.31-0.34	

Table 2 Details of MEPS concrete mixes containing natural aggregate

Mix Type	MEPS / NA* (%) (F+CA) / (F+CA*)	cement (kg)	MEPS (kg)		NA* (kg)		SP* (kg)	w/c	Fresh density (kg/m^3)	Slump values (mm)
			F	CA	F	CA				
C 1	50%+50% /0%	500	108	77	-	-	2.5	0.38	876	25
C 2	25%+50% /25%+ 0%	500	53	75	402	-	2.5	0.39	1229	30
C 3	0%+50% /50%+ 0%	500	-	74	786	-	2.5	0.42	1572	30
C 4	50%+ 0% / 0%+50%	500	104	-	-	804	2.5	0.42	1621	30
C 5	25%+25% /25%+25%	500	52	37	393	402	2.5	0.42	1596	40
C 6	25%+ 0% /25%+50%	500	52	-	390	797	2.5	0.43	1956	50

*NA : natural aggregate, *F+CA : fine and coarse aggregates, *SP : super plasticizer

Mix preparation is particularly important when using very lightweight aggregates. For the anticipated testing exactly six various mixtures of component materials are produced (they are labeled as series from C1–C6).

All the concretes were mixed in a planetary mixer of 50 *l* capacity in the laboratory. Prisms of 40x110x160 mm and 70x70x240 mm were cast for the determination of TC and drying shrinkage of MEPS concretes, respectively. For each test, three specimens were cast. The mixing of materials was done in a specific sequence, by placing a part of the water with super plasticizer in the mixture and adding the dry MEPS aggregates, which was thoroughly mixed for about 5 min to get the aggregates wetted with water and plasticizer similar to the mixes designed for previous studies [12,13]. Then the remaining materials were added to the mixer and the remaining water was gradually added while the mixing was in progress. The mixing continued until a mix of uniform and flowing nature was achieved. The fresh concrete densities and flow values were measured immediately after mixing for all the concretes. The test specimens were consolidated with hand compaction. The curing of concrete adopted for TC has been described earlier [14-16]. The specimens were covered with wet gunny bags 10 h after casting, remolded after 24 h and stored in water for curing until testing. A quick thermal conductivity meter (QTM 500) based on ASTM C 1113-90 [17] was used. Measurement range is 0.0116–6 W/mK. The QTM 500 system is a rapid, non-destructive easy to use thermal conductivity system. Based on the modified hot-wire technique, users can expect accurate and repeatable results. The effects of different volume contents of MEPS on the shrinkage were investigated as well. Mitutoyo Digimatic Calipers trademarked was used to determine drying shrinkage. (Measuring range: 0-300mm (0-12"), accuracy: 0.03mm (0.001"), (>100-200mm)). Drying shrinkage specimens were exposed to ambient air conditions (t = 20°C and RH 40%) alongside the thermal conductivity specimens. After the water on the surface of each specimen was wiped off with a damp cloth, the length change was measured and the shrinkage strain was calculated along the 210 days following setting according to ASTM C490–93a [18].

DISCUSSION

Thermal conductivity

TC of aggregate are strongly influenced by porosity and moisture contents. Mindess et al [19] reported that the TC of granite, basalt, lime stone, dolomite, sandstone, quartzite and marble are 3.1, 1.4, 3.1, 3.6, 3.9, 4.3 and 2.7 W/(mK), respectively. TC of most rocks is approximately 3.0 W/(mK). Notable exceptions are quartz and dolomite that are higher, basalt that is very lower. Some authors [9, 20] reported that TC of rocks, commonly used as aggregates in concrete, ranges from 1.163 to 8.6 W/mK. Quartzite, sandstone and other quartzite rocks have the highest thermal conductivity; granite, gneiss, limestone and dolomite have intermediate, whilst basalt and dolerite demonstrate lowest conductivities [20]. Aggregate with less thermal conductivity produce the less conductive concrete whereas the more conductive aggregates produce more conductive concrete [8, 21, and 22]. Aggregate type can result in nearly twice an increase in TC of concrete [21]. Rocks with crystalline structure show higher TC than amorphous and vitreous rocks of the same composition [8]. Demirboga [22] reported that when sand added to the neat cement paste the TC of the paste increased 56%. Chen et al [23] find out that when they increased volume fractions of nature sand from 30 to 50% the TC of mixtures increased approximately 16 percent.

By differentiating fine aggregate fractions from the total amount of aggregates, measurement of TC was measured for four sets of specimens by Kim [24]. It was concluded that there seems to be a little, yet increasing, change of the values with respect to the fine aggregate fractions. Kim [24] also reported that this uprising trend may be due to the fact TC of fine aggregate is greater than that of coarse aggregate or the fact that aggregates are uniformly distributed in the mix with the addition of fine aggregate.

The TC values of MEPS concretes was found to be directly proportional to the concrete dry density, the saturated surface dry density (SSD) and MEPS aggregate contents as shown in the Fig. 2. By increasing dry density of MEPS concrete from 980 to 2025 kg/m^3, thermal conductivity coefficients have vary from 0.530 to 1.99 W/mK. Natural aggregate in MEPS concrete mixture, increased the thermal conductivity of group samples (C2 to C6). The TC values of EPS concrete marginally increased as the natural aggregate ratio increased, and decreased as the MEPS aggregate ratio increased. This increase in TC was more in leaner mixes compared to the richer mixes. The TC values of MEPS concretes at dry conditions, according to MEPS aggregate ratio, as minimum 0.530W/mK and maximum 1.990 W/mK has been measured. MEPS concrete that was produced with artificial MEPS aggregate has lower thermal conductivity than normal concrete.

The natural sand increases the thermal conductivity of concrete from that produced by outright MEPS aggregate (from C2 to C6 type concretes). There was a good relationship between thermal conductivity (λ) and density (γ) in experimental results (R^2=0.92 and 0.98). For the moderate thermal conductivity of MEPS concrete, the following equations can be proposed:

$$\lambda = 0.193e^{1.146\gamma} \quad (1)$$

$$\lambda = 0.303e^{1..965\gamma} \quad (2)$$

TC of concrete is influenced by the mineralogical characteristics of aggregate, and by the moisture content, density, and temperature of concrete. TC of concrete depends also on curing and compacting condition.

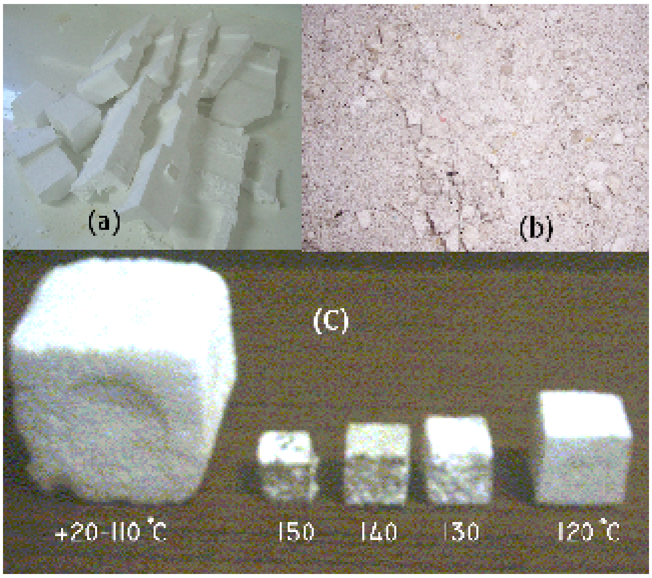

Figure 1 (a) Collected waste EPS foams, (b) MEPS aggregate, and (c) Waste EPS cube samples exposed to the different temperatures

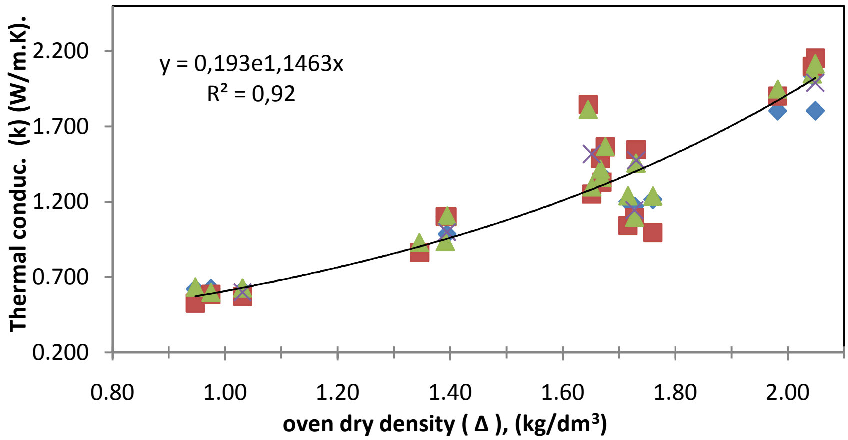

Figure 2 Relationship between TC and dry density

Shrinkage

Fig. 3 show the substitution effect of natural aggregates by MEPS aggregates on drying shrinkage. It can be clearly observed that natural aggregate concrete (C6) presents up to 30 days a delayed shrinkage compared to MEPS aggregates concrete; this is followed by an abrupt increase of up to 0.30% at 90 days of age. For the MEPS concrete (C1 and C2), shrinkage at early age is almost higher than for the natural aggregates concrete (C6) and continues with the same rate of increase up to 210 days. This is likely to be due to the fact that there will be some water movement in the fine MEPS aggregates arising from changes in moisture content as drying proceeds. On the other hand, when both coarse and fine MEPS are used together as aggregates, the shrinkage of the MEPS concrete (C1) is stabilized at early age (up to 7 days) and becomes comparable with that of the C6 concrete. At later age, shrinkage of MEPS aggregates concrete is again higher than that of partially replaced natural aggregate concrete (C3 to C5). The incorporation of MEPS aggregates significantly increases the shrinkage and the use of plasticizer admixture is very beneficial.

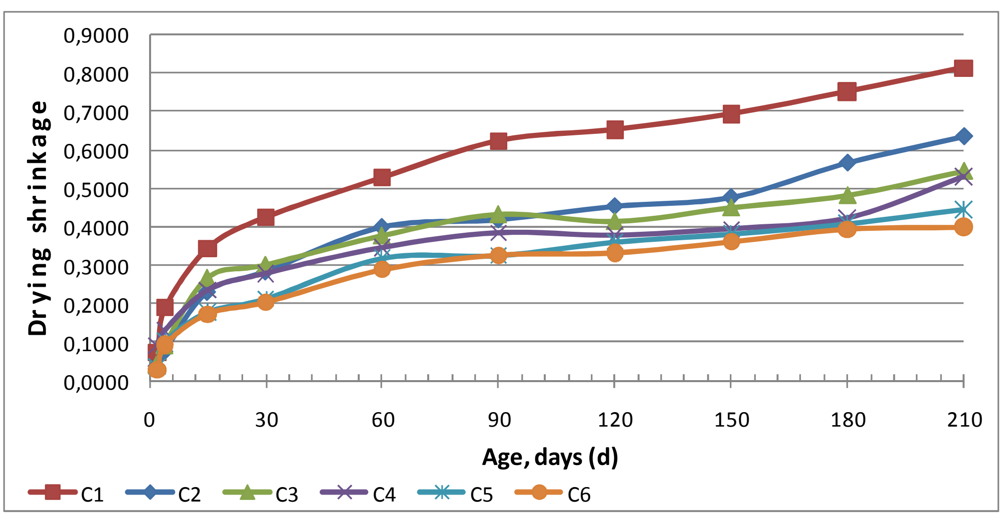

Figure 3 Relationship between drying shrinkage and curing duration

CONCLUSION

-Dry densities decreased from 2025 to 980 kg/m^3 with the increase of MEPS aggregate ratio.

-Drying shrinkage is significantly increased when the MEPS aggregate content is significantly increased. For example, when the MEPS aggregate content was 25% (C6 type) drying shrinkage was 2.35 times less than that of the C1 type (having 100% MEPS aggregate) after 210 days.

-The rate of shrinkage for the MEPS aggregate concrete with the density of about 1600 kg/m3 is significant even after 90 days of drying.

-Partial replacement of normal aggregate with MEPS aggregate changed the concrete properties in the following ways: density, TC and shrinkage were reduced depending on the level of replacement.

-TC is more sensitive to change in the density than the shrinkage.

It was observed that drying shrinkage and TC change according to MEPS aggregate ratio used. The TC values of MEPS concretes was found to be directly proportional to the concrete density. The research findings showed that the higher the amount of MEPS aggregates in the mixture, the lesser the TC of the MEPS aggregate concrete.

As a result, the artificial MEPS aggregate can be offered as a potential construction material and simultaneously solving the environmental problem by using solid waste.

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