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Thermal Properties of Lead-Acid Battery Plastic Lightweight Concrete

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ABSTRACT

This study investigates the possibility of using waste plastic as one of the components of expired lead-acid batteries to produce lightweight concrete. Different percentages of lead-acid battery plastic were used in the production of lightweight concrete. The replacements were (70, 80 and 100%) by volume of the fine and coarse aggregate. Results demonstrated that a reduction of approximately 23.6% to 35% in the wet density was observed when replacement of 70% to 100% of the natural aggregate by lead-acid battery plastic. Also, the compressive strength decreased slightly with the increase in plastic content at different curing ages of 7, 28, 60, 90, 120 days. The lowest value of compressive strength was (20.7 MPa) for (waste plastic =100%) at (120) days test age. The results also revealed that the thermal conductivity decreased by the addition of waste plastic compared to plain concrete and this property is decreased due to an increase in waste proportion.

Key Words: lightweight concrete; acid-lead battery plastic; strength properties; thermal conductivity; wet density.

الخصائص الحرارية لبلاستك بطاريات الرصاص الحامضية في أنتاج الخرسانة خفيفة الوزن

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الخلاصة

تتناول هذه الدراسة إمكانية استخدام البلاستيك المستهلك في بطارية الرصاص الحامضية المنتهية الصلاحية لإنتاج الخرسانة خفيفة الوزن وقد تم استخدام نسب مختلفة من بلاستيك البطاريات في إنتاج الخرسانة خفيفة الوزن وكانت نسب الاستعاضة (70و 80 و 100٪) من حيث الحجم الكلي للركام الناعم والخشن. أظهرت النتائج انخفاضا بنسبة 23.6٪ إلى 35٪ في الكثافة الرطبة عند معدل استبدال 70٪ إلى 100٪ من الركام الطبيعي بواسطة بلاستك بطارية الرصاص الحامضية كما انخفضت قوة الانضغاط بشكل طفيف مع زيادة محتوى البلاستيك في نسبة نفايات البلاستك المختلفة (7و28و60و90و120) يوم. وكانت اقل قيمة لمقاومة الانضغاط (20.7 ميجا باسكال) لنسبة (100٪) في عمر الاختبار (120) يوما. وأظهرت النتائج أيضا أن التوصيل الحراري انخفض من خلال إضافة النفايات البلاستيكية مقارنة بالخرسانة العادية مع زيادة نسبة نفايات البلاستك.

الكلمات الرئيسية: الخرسانةخفيفة الوزن، بلاستك البطاريات ، مقاومة الخرسانة، الموصلية الحرارية،الكثافة الرطبة.

1. INTRODUCTION

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Due to the socio-economic characteristics, a variety of consumption and differences in waste management programs are different in each country. Plastics rank first in the total amount of global waste. Since natural resources have decreased and environmental pollution has reached to threatening size for humanity, then using recycled or waste materials which do not damage the ecological balance is one of the basic elements of sustainable building design, **Akçaözoğlu, 2015**.

Each year, approximately 800.000 ton of automotive batteries, 190.000 ton of industrial batteries and 160.000 ton of portable batteries are placed on the community market. Batteries and accumulators pose not particular environmental concerns when they are in use or kept at home. However, sooner or later those batteries will become waste and risk of contributing to the final disposal of waste in the community, **COM, 2003.**

The lead and sulfuric may contaminate soil and ground-water potentially affecting the quality of our drinking water supply if lead-acid batteries are dumped off in a solid waste landfill, **Uddin, et al., 2013.**

The disposal of waste plastic, with the municipal solid wastes in a sanitary landfill, has many problems due to its non-biodegradability. So, these items cause loss of landfill space and springiness of the land for landfill which cannot be reclaimed for load-bearing uses.

The lack of landfill sites and the high cost of landfills operations has resulted in a move to recover solid wastes components as a beneficial source of materials and values, if recovering of batteries is not chosen, disposal in a protected landfill is the next preferred option. Empty battery cases must be disposed of carefully because they can still contain significant amounts of lead. Batteries should then be covered in heavy-duty plastic or encapsulated with concrete**, Jasim, 2009**.

The use of waste plastic in construction applications to substitute the natural aggregate is well known, the construction industry is one of the areas in which plastic wastes can be used in large quantities in order to reduce the use of large amounts of natural resources such as aggregate and timber. Utilization of waste plastics in the construction industry may also be helpful in reducing environmental problems such as reduction of landfill disposal and preservation of non-renewable raw materials and prevention of environmental pollution**, Akçaözoğlu, 2015**.

Plastic is applied in concrete, either in shredded form or combined with aggregate to form an artificial aggregate. Since plastics have a lower density than most natural materials, they can be readily used to form a lightweight aggregate which may replace naturally-existing aggregate of similar density.

Concrete produced with a conventional lightweight aggregate has been shown to exhibit excessive shrinkage and high water absorption, **Alqahtani, et al., 2015.**

Lightweight concrete can be well-defined as a type of concrete which contains an expanding agent in which it increases the volume of the mixture while giving additional qualities such as decreasing the dead weight. It is lighter than the conventional concrete. The use of lightweight concrete has been widely spread through countries such as USA, United Kingdom, and Sweden. Lightweight concrete has great importance to the construction industry. Most of the current concrete study focuses on high-performance concrete, by which is meant a cost-effective material that satisfies demanding performance requirements, including durability, **Kamsiah, et al., 2003**.

A number of researchers have used waste plastic in concrete as a direct replacement for natural aggregates.

Elzafraney, et al., 2005, investigated the possibility of using recycled plastic aggregate as partial replacement of coarse aggregate in the concrete mix and concluded that the recycled plastic concrete having good insulation used 8% less energy in comparison of normal concrete.

Ismail and AL-Hashmi, 2008, investigated the efficiency of reusing waste plastic in fibriform shapes in the production of concrete as a partial replacement for sand by 0%, 10%, 15%, and 20% and concluded that a sharp decrease in slump, dry density and compressive and flexural strength with increasing the percentage of waste plastic also the results proved the arrest of the propagation of microcracks by introducing waste plastic of fibriform shapes to concrete mixtures.

Ahmed, 2013, used the recycled plastics as a partial replacement of coarse aggregate in concrete and concluded that the use of plastic solid waste in concrete results in the formation of lightweight concrete. The properties such as compressive, tensile strength as well as thermal conductivity are reduced with the addition of plastic in concrete.

Alqahtani, et al., 2015, investigated the feasibility to produce recycled plastic aggregate (RPA) using waste plastic and red sand as a filler. It was observed that 100% replacement showed about 13% reduction in chloride penetration also a reduction ranges between 12 and 15 MPa in compressive strength, the achieved strength was useful for non-structural elements such as low side building, cementitious backfill, pavements, and others.

This study focuses on the utilization of waste plastic released from the expired lead-acid batteries as a lightweight aggregate in the concrete mix.

2. MATERIALS AND MIX DESIGN

2.1 Materials

All the materials used in this study are locally available except the admixture.

- Cement; Ordinary Portland cement conforming to IQS No. 5/1984 was used. **Tables 1 and 2** illustrate the chemical characteristics and physical properties of cement.
- Aggregate: Natural sand of zone (1) conforming to IS No.45/1980 was used as a fine aggregate with a grading complied with the limit of IQS No.45\1984, zone (2). Crushed river gravel with 20 mm maximum size and properties conforming to Iraqi standards No.45/1984 and grading complied with the limit of IQS No.45\1984, zone(2).
- High range water reducing admixture (HRWR) super-plasticizer, known as (Flocrete SP42) complies with ASTM C 494 type G was used. **Table 3** shows the properties of HRWR

Waste plastic: a scrap of lead-acid batteries casings collected from the (General Company for the Manufacture of Batteries and Equipment / Ministry of Industry and Minerals) after removing and recycling the discarded lead plate into lead product, then lead-acid battery plastic (LABP) was shredded by a mechanical shredder machine as given in **Fig.1,** then sieved to the desired particle size complied with the limit of IQ.S. No. 45-1980 Zone (1) for fine waste plastic and the limit of Iraqi standards No. (45\1984) for coarse waste plastic, the chemical and physical properties of LABP are shown in **Table 4.**

2.2 Concrete Mix Proportions

Two types of concrete mixes were prepared in this study; (1) reference concrete mix free of LABP and was denoted as (R) and (2) LABP- concrete mixes. Three categories of LABP - concrete mixes were prepared by the addition of LABP to replace the aggregate by 70%, 80% and 100% by weight and these mixtures were denoted as LABP 70, LABP 80 and LABP 100, respectively. **Table 5** presents the details of the mixes proportion.

According to a typical mixing procedure, a mixer of capacity 20 kg was used to prepare the concrete mix; initially, fine aggregates and coarse aggregates mixed together and then

followed by cement. Firstly, dry materials were mixed for 1.5 min, and then of HRWR and 30% of water were added together. After 1.5 min of mixing, the remaining water was added. Then all the batches were mixed for about 2 min. The water was adjusted to maintain a slump within the range (80-90) mm. The mixing period was kept as low as possible, to prevent fresh concrete from segregation. For the testing, specimens of the hardened properties were prepared by the direct pouring of concrete into molds with compaction on a vibrating table, and it was designed to achieve compressive strengths of 50 MPa at 28 days.
LABP aggregate was mixed in a similar procedure to reference concrete except that the required quantity of waste LABP was mixed with dry sand and gravel very well, then mixed with other ingredients in the same manner as for reference concrete to achieve compressive strength of 17.24 MPa at 28 days.

2.3 Specimen and Tests

Concrete cubes of size 150 × 150 × 150 mm were prepared for compressive strength, where they were cast, compacted and cured for 7, 28, 60, 90 and 120 days according to B.S.1881, part 116:1989 then testing was accomplished using (CONTROLS) model of 2000 KN capacity compression machine with a digital indicator. The average compression strength of 3 cubes was recorded for each testing age. Thermal conductivity (k) for slab specimens of (100×100×200) mm at age of 90 days was measured using Linseis HFM 300 machine (Linseis HFM 300) and thermal conductivity factor (U) in the range of (0.005-0.5 W/m.K). Wet density for specimens (150×300×100) mm was calculated by dividing the net weight of fresh concrete on the volume of mold.

3. RESULTS AND DISCUSSION

3.1 Fresh Density

As given in **Fig.2**, the density of the specimens was decreased with increasing of LABP content. The replacement of 70% to 100% of the natural aggregate by LABP caused a reduction of approximately 23.6% to 35% which is in agreement with the finding of many previous studies such as **Marzouk, et al., 2007, Akçaözoğlu, et al., 2013, Fraternali, et al., 2011 and Yesilata, et al., 2009**.

3.2 Compressive Strength

The compressive strength results for specimens of plain concrete and LWAC replacing the aggregate with LABP tested at various ages (7, 28, 60, 90 and 120) days were plotted in **Fig.3**. As shown in this figure, increasing level of LABP replacement resulted in the reduction of compressive strength at all curing ages but all of the compressive strength values were greater than the minimum compressive strength required for lightweight structural concrete which is 17.24 MPa. Also, this figure indicates that the compressive strength for LABP - concrete mixtures reduced slightly in comparison with the reference mortar. This tendency can be attributed to the decrease in adhesive strength between the surface of the waste plastic and the cement paste, as well as the particles size of the waste plastic increase, **Ismail, and AL-Hashmi, 2008.** Furthermore, plastic is considered to be a hydrophobic material, so this property may restrict the water essentially for cement hydration from entering through the structure of the concrete samples during the curing period, **Pezzi, et al., 2006 and Marzouk, et al., 2007.**
The compressive strength increased through increasing ages from 7 to 120 days can be attributed to the fact of progress in cement hydration with time, at different percentage of increments as can be seen in **Fig.3**. The maximum value in compressive strength was (34.5) MPa for 80% LABP at 120 days.

3.3 Thermal Conductivity

Fig.4 shows that increasing the LABP has a positive effect in reducing the amount of transmitted heat through the thickness of the specimens at 90 days curing age on the matrices and composites in both dry and saturated states. It can be observed that each LABP- concrete specimen exhibited high level of thermal insulating power, it decreased with the addition of LABP as compared to the reference concrete and continue to decrease with increasing LABP, the heat resistance falls considerably compared to the reference concrete with an approximate reduction of 33% and 63% for 70 and 100% replacement respectively.
These results were agreement with the findings reported by **Akçaözoğlu, et al., 2013 and Fraternali, et al., 2011 and Yesilata, et al., 2009,** unified on the determination that plastic has a significant effect on the concrete characteristics under the additional influence of high temperature.

4. CONCLUSIONS

This study assessed the feasibility of using batteries plastic waste as partial replacement of aggregate, the results showed that:

1. The compressive strength of the concrete decreased with increasing the content of the LABP at all curing ages but all of the compressive strength values were greater than the minimum compressive strength required for lightweight structural concrete which is 17.24 MPa. The compressive strength increased through increasing ages from 7 to 120 days, the maximum value in compressive strength was (34.5) MPa for 80% LABP at 120 days.
2. The fresh density of the specimens was decreased with increasing of LABP content from (70 to 100%) at a rate ranges between (23.6 to 35% w) replacement of the natural aggregate. This type of concrete can, therefore, be classified as a lightweight concrete.
3. The transmitted heat through the thickness of the specimens decreased with increasing the LABP content in both dry and saturated states by a reduction rate of 33% and 63% in thermal conductivity for 70 and 100% replacement respectively at 90 day curing ages.

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SYMBOLS:

LABP = light aggregate batteries plastic.
LWAC = light weight aggregate concrete.
HRWR = high range water reducing admixture

Figure 1. Waste plastic.

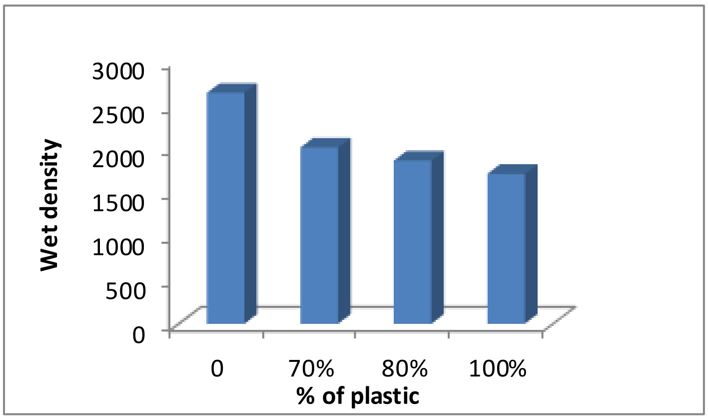

Figure 2. Wet density.

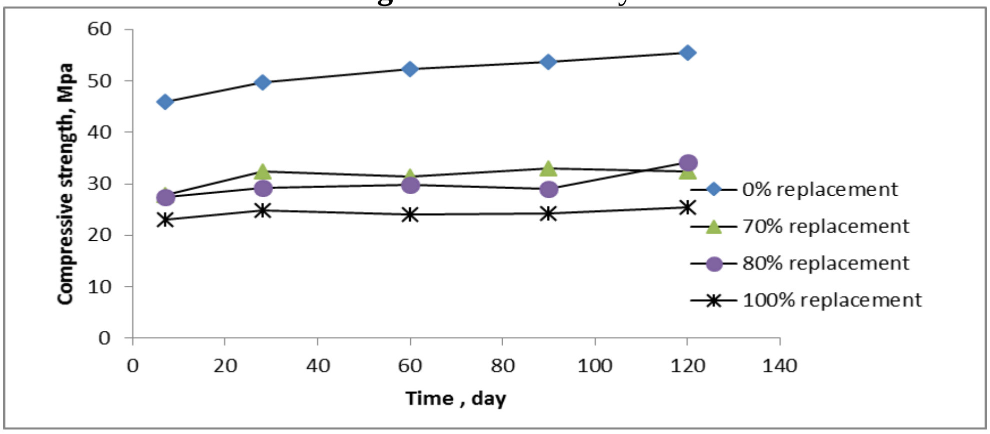

Figure 3. Effect of LABP on compressive strength of lightweight concrete.

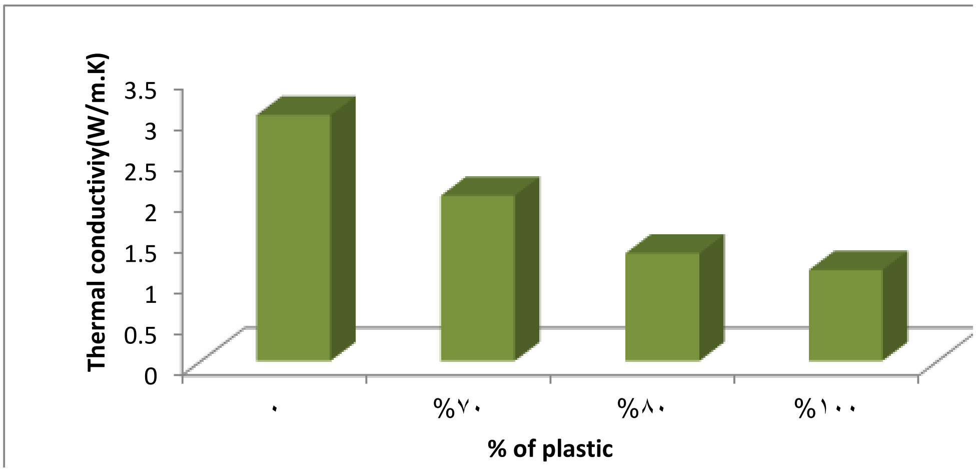

Figure 4. Thermal conductivity.

Table1. Chemical properties of cement.

Compound composition	Abbreviation	Percent by weight	Limit of IQS No.5/1984
Lime	CaO	62.78	-
Silica	SiO_2	20.66	-
Alumina	Al_2O_3	4.88	-
Iron oxide	Fe_2O_3	3.43	-
Magnesia	MgO	4.37	$\leq 2.85\%$
Sulfate	SO_3	2.50	$\leq 5\%$
Loss on ignition	L.O.I	1.36	$\leq 4\%$
Insoluble residue	I.R	0.73	≤ 1.5
Lime saturation factor	L.S.F	0.92	0.66-1.02
Main compounds % by weight			
Name of compounds	Abbreviation	Percent by weight	
Tri calcium silicate	C_3S	49.07	
Di calcium silicate	C_2S	22.46	
Tricalicium luminate	C_3A	7.13	
Tetra calcium aluminoferrite	C_4AF	10.42	
Free lime	-	1.12	

Table 2. Physical properties of cement.

Physical properties	Limits of cement	Limits of IQS No. 5/1984
Fineness Blaine cm^2/kg	3500	≥ 2300
Initial setting time (h:min)	2:40	≥ 00:45
Final setting time (h:min)	4:30	≤ 10:00
Compressive strength(MPa) 3 days 7 days	16 29	≥ 15 ≥ 23

Table 3. Properties of HRWR.

Color, appearance	Brown liquid
Freezing point	≈ -2 ◦C
Specific gravity	1.21 ± 0.02 g/cm^3
Chloride content (%)	Nil

Table 4. Physical and chemical properties of polypropylene waste plastic

Material Name	Polypropylene Copolymer
Color	White
Usage	To produce Batteries cases
Melt Flow Index at 230 C◦	3.0 ± 0.6 g / 10 min
Specific Gravity	0.91± 0.005
Hardness(Shore) D	73 ± 5
Heat Distribution	102 ± 2 C◦
Flammability	1.6 ± 0.2 m / min
Tensile Strength at Yield	4200 ± 420 psi 295 ± 29 Kg / cm
Elongation	7 ± 13 % Lb
Izod Impact Strength at 23 C◦	3.0 ± 0.3 ft .ibs / in – notch 16.2 ± 1.6 Kg.cm / cm- notch
Vicat Softening Point	144 ± 3 C◦

Table 9. Concrete proportion mix.

Concrete mix	Cement kg/m^3	Waste added kg/m^3		Percentage of waste, %	Fine aggregate kg/m^3	Coarse aggregate kg/m^3	w/c ratio	HRWR adm.%
		Fine WP	Coarse WP					
R	400	0	0	0	750	1035	0.41	1.20%
LABP 70	400	305	667	70	487.5	672.75	0.41	1.25%
LABP 80	400	325	759	80	450	621	0.41	1.32%
LABP 100	400	354	890	100	375	517.5	0.41	1.30%