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Application of Waste Lead Acid Battery Plastic to Produce Lightweight Masonry Units

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ABSTRACT

The concrete industry consumes millions of tons of aggregate comprising of natural sands and gravels, each year. In recent years there has been an increasing trend towards using recycled aggregate to save natural resources and to produce lightweight concrete. This study investigates the possibility of using waste plastic as one of the components of lead-acid batteries to replace the fine aggregate by 50 and 70% by volume of concrete masonry units. Compared to the reference concrete mix, results demonstrated that a reduction of approximately 32.5% to 39.6% in the density for replacement of 50% to 70% respectively. At 28 days curing age, the compressive strength was decreased while the water absorption increased by increasing waste plastic percentage. The leaching test revealed that lead ion extracted from the WLABP-modified concrete was within the acceptable limits. The findings of this study indicated a sustainable alternative solution for reducing the effects on the environment posed by waste plastic from lead-acid batteries.

Keywords: lightweight masonry units; waste acid lead battery plastic; density; strength properties; water absorption; leaching tests.

أستخدام المخلفات البلاستيكية لبطاريات الرصاص الحامضية في أنتاج وحدات بناء خفيفة الوزن

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الخلاصة

تحتاج صناعة الخرسانة إلى ملايين الأطنان سنويا من الركام بما في ذلك الرمال الطبيعية والحصى.و في السنوات الأخيرة كان هناك اتجاه متزايد نحو استخدام الركام المعاد تدويره لحفظ الموارد الطبيعية وإنتاج الخرسانة خفيفة الوزن.تبحث هذه الدراسة في إمكانية استخدام نفايات البلاستيك كأحد مكونات بطاريات الرصاص الحامضية لتحل محل الركام الناعم بنسبة 50٪ و 70٪ من حجم وحدات البناء الخرسانية. مقارنةً بمزيج الخرسانة الاساسية ، أظهرت النتائج أن هناك انخفاض بنسبة 32.5٪و 39.6٪ في الكثافة عند استخدام 50٪ و 70٪ على التوالي. كما توصلت النتائج الى انه في عمر المعالجة 28 يومًا ، تنخفض قوة الانضغاط بينما يزداد امتصاص الماء بزيادة نسبة استبدال البلاستيك كما كشف اختبار النضوح أن أيون الرصاص المستخلص من الخرسانة المعززة WLABP كان ضمن الحدود المقبولة. وتمثل نتائج هذه الدراسة حل بديل مستدام للحد من الآثار التي تشكلها النفايات البلاستيكية المتخلفة من البطاريات على البيئة.

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الكلمات الرئيسية: وحدات البناء خفيفة الوزن ; بلاستك البطاريات ;الكثافة الرطب; مقاومة الخرسانة; امتصاص الماء; السمية

1. INTRODUCTION

Due to the socio-economic characteristics, waste management programs differs from country to another. Plastics rank first in the total amount of global waste. Since natural resources have decreased and environmental pollution has reached to threatening level 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**.

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.

Annually, about 800.000 tons of motorized batteries, 190.000 tons of industrial batteries and 160.000 tons of convenient batteries are placed on the public market. Batteries and accumulators do not pose specific environmental concerns when they are in use or kept at home. However, finally, those batteries will become a dangerous waste contributing to the final disposal of waste in the community, **COM, 2003.**

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, discarding in a protected landfill is the next preferred option. Empty battery cases must be disposed of carefully because they can still have significant amounts of lead. Batteries should then be covered in heavy-duty plastic or encapsulated with concrete, **Jasim, 2009.**

If reusing of batteries is not chosen, discarding in a secure landfill is the next favored choice. Empty battery cases should be disposed of carefully because they can still have significant amounts of lead. The acid should be removed from the casing and neutralized. Batteries should then be wrapped in heavy-duty plastic or encapsulated with concrete. The concrete and plastic serve the purpose of ensuring that lead will not be leached out and become mobile in landfill leachate, thus reducing the environmental risk, **Vest, 2002**.

Plastic and ebonite chips – polluted wastes: ebonite scraps removed from the crushing process may pose a problem since they are usually contaminated by levels as high as 5% (w/w) of lead. Therefore, it is essential that the final traces of lead are removed by many times of washing, preferably in an alkaline solution, followed by another rinse prior to further treatment or disposal, **Basel Convention series, 2003**.

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**.

Plastics are 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.**

A masonry structure is formed by combining masonry units, such as stone or brick, with mortar, **Mamlouk and Zaniewski, 1999.**

When Portland cement, water, and suitable aggregates are mixed and formed into individual pieces to be used in laying up walls and other structural details, the pieces thus formed are known as unit masonry, or units. Such units are also technically known as concrete masonry. However, most masons use the terms concrete block or block when they refer to such material. This type of masonry permits easy planning and quick erection and can be done by masons having little previous experience, **Dalzell, 1955.**

The hollow block according to ASTM C90 and C129 is one in which the net concrete cross-sectional area which is parallel to the bearing face is less than 75 percent of the cross-sectional area, while solid units have a net concrete cross-sectional area of 75 percent or more.

The hollow block according to IQS 1077 and IQD 1129, is one in which the hollow volume is between 25 to 50 percent of the total volume of the unit. The solid block has a hollow volume less than 25 percent of the total volume of the unit.

Lightweight units are the most common concrete units used in masonry construction because they are easy to handle and transport with reduced weight. Lightweight units have higher thermal and fire resistance properties and lower sound resistance than normal-weight units, **Mamlouk and Zaniewski, 1999.**

This research focuses on the feasibility of using waste plastic of lead acid battery (WLABP) locally available for establishing masonry units as a sustainable approach for WLABP management. Also, investigate the influence of incorporating (WLABP) as a hazardous waste material on the properties of the modified concrete mixes.

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 (2) 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. **Table 3** shows the gradation of fine aggregate
- High range water reducing admixture (HRWR) super-plasticizer, known as (Flocrete SP42) complies with ASTM C 494 type G was used. **Table 4** shows the properties of HRWR.
- Waste plastic: scrap of lead-acid batteries casings (WLABP) 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 shredding the (WLABP) by using 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 WLABP were shown in **Table 5**.

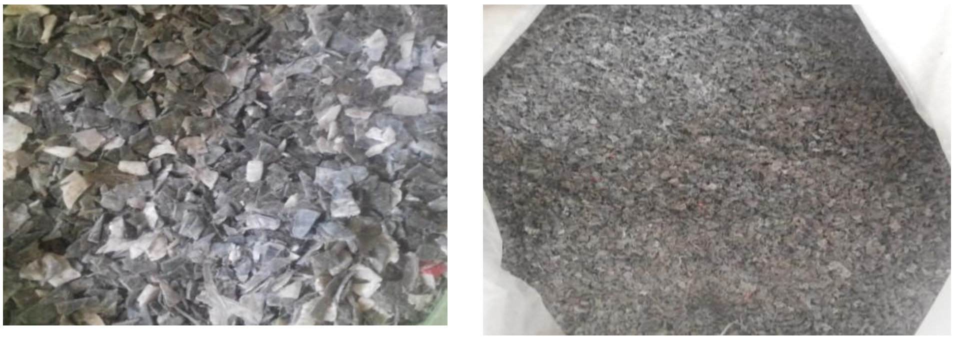

Figure 1. Waste plastic.

Table 1. 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	≤ 2.85%
Sulfate	SO_3	2.50	≤ 5%
Loss on ignition	L.O.I	1.36	≤ 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	16	≥ 15
7 days	29	≥ 23

Table 3. Gradation of fine aggregate.

Sieve size (mm)	Percentage passing %	Limit of IQS No.45\1984, zone(2)
10	100	100
4.75	96.6	90-100
2.36	84.8	60-90
1.18	68.2	30-70
0.6	46.2	20-55
0.3	15	5-20
0.15	2.3	0-10
Sulfite % (SO_3)	0.15	≤ 0.5%

Table 4. Properties of HRWR.

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

Table 5. Physical and chemical properties of waste plastic (*).

Material Name	Polypropylene Copolymer
Color	White
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◦

*These properties carried out in Ministry of Industry and Minerals / General Company for the manufacture of batteries and equipment.

2.2 Specimen Preparation and Tests

Two types of masonry mixes were prepared in this study reference mix and was denoted as (WLABP0) and masonry units with different percentage of waste lead-acid battery plastic (50 and 70%) by volume as partial replacement of fine aggregate and was denoted as (WLABP50 and WLABP70) respectively, mixes details were shown in **Table 6**.

Table 6. Mix details of the WLABP aggregate CMU.

Concrete mix	Cement kg/m^3	Waste added Kg/m^3	Percentage of waste, %	Fine aggregate kg/m^3	w/c ratio	HRWR adm.%
WLABP0	490.5	0	0	1327.7	0.41	1.20%
WLABP 50	490.5	234.5	50	663.85	0.41	1.25
WLABP 70	490.5	328.3	70	398.31	0.41	1.3%

2.3 Specimen and tests

The cement and sand were well mixed and then the waste plastic aggregate added and mixed. Finally, the water and HRWR was added gradually with continuous mixing of all the constituents and compacted at (540 KN) by apparatus used for compression strength as shown in **Fig. 2**, then molded into cubic specimens size of 15x15x15 cm, casting, compaction and curing for 7 and 28 days by wrapping them with a polyethylene sheet. Then they were tested for compressive strength, density and absorption to investigate the possibility of producing lightweight concrete blocks containing the WLABP of a certain shape, meets the requirements of compressive strength of the standard specifications for concrete masonry units (IQS 1077, IQD 1129, ASTM C90, and ASTM C129).

Figure 2. WLABP modified CMU specimens.

2.4 Toxicity Characteristics Leaching Test (TCLP)

Toxicity characteristics leaching procedure TCLP (EPA test Method 1311) was applied in this study to evaluate the leachability characteristics of the WLABP modified concrete. The test is done by using an extraction fluid of tap water acidified with HCL acid to obtain a pH of 4.9. This simulates what happens to waste materials inside landfills for a period of many years. The TCLP is the only leaching procedure specified by regulation for characterizing the hazardous waste Toxicity Characteristics, **Chih, 2001.**

After 28 days, the specimens curing period, the samples were crushed, sieved to pass 9.5 mm mesh. Then a weight of 100 g specimen for particles passing the 9.5 mm mesh and the other for the remaining particles, was mixed with the standard prepared 4.9 pH extraction fluid and left for top to bottom 18 h agitation at 30 rpm, then the tested tubes were left to settle, the solids were separated from the extraction fluids, and finally the extraction fluids were collected, filtered and taken for laboratory analysis, as shown in **Fig. 3.**

Figure 3. Toxicity Characteristics Leaching Test.

2.5 Semi-Dynamic Tank Leaching Test

Production of Semi-dynamic tank leaching or what is identified by (EPA test method 1315) is a mass transfer rate of constituents in a monolithic or compacted granular materials test.

This test was carried out for LABP100-concrete mix contain contaminated sand with lead ion concentration (1500 and 3000mg/kg) and with 25% ratio of OPC. The data picked up from this test gives material parameters for the release of inorganic species under mass transfer controlled leaching conditions. It additionally permits estimating the diffusivity of constituents and the physical retention parameters of the solid material.

The (5 cm diameter by 10 cm height) cylindrical cement based (S/S) specimens that have been previously cast and cured were submerged in a container holding a leaching fluid of (2 litters) of distilled water (DW). The specimens were hanged and submerged in such a way to get a liquid-surface area ratio (L/A) of (10ml/cm^2). Specimen suspension in the submerge extraction fluid insured a (100 %) exposure to the effluent (the extraction fluid) from all sides. The leaching solution (DW) was then exchanged with fresh (DW) at the pre-determined interval (28 days). The leaching solution (DW) was then exchanged with fresh (DW) at different intervals (0.08, 1, 2, 7, 14, 28, 42, 49, 63and 100 days), as shown in **Fig.4**.

Figure 4. Semi-dynamic tank leaching test

3. RESULTS AND DISCUSSION

3.1 Density Test

The density test results for the WLABP- CMU specimens at percentage (50 and 70%) aggregate is plotted in **Fig.5**. It can be seen from the figure that the density of the concrete decreased from 2177 to 1315 kg/m^3 with increasing the plastic aggregate content 70% as compared with reference concrete. It is obvious that the lowest dry density for WLABP70–modified concrete mixture reaches the dry density of lightweight concrete as shown in **Table 7**. The above results were in agreement with the study of **Rahman, et al., 2012** on recycled polymer materials as aggregates for concrete and blocks, where they stated that the density of the poly blocks decreases sharply with the polyurethane formaldehyde (PUF) and high-density polyethylene (HDPE) aggregate content. The reduction in the density of the poly blocks and the concrete was observed due to the lower unit weight property of the recycled plastic materials.

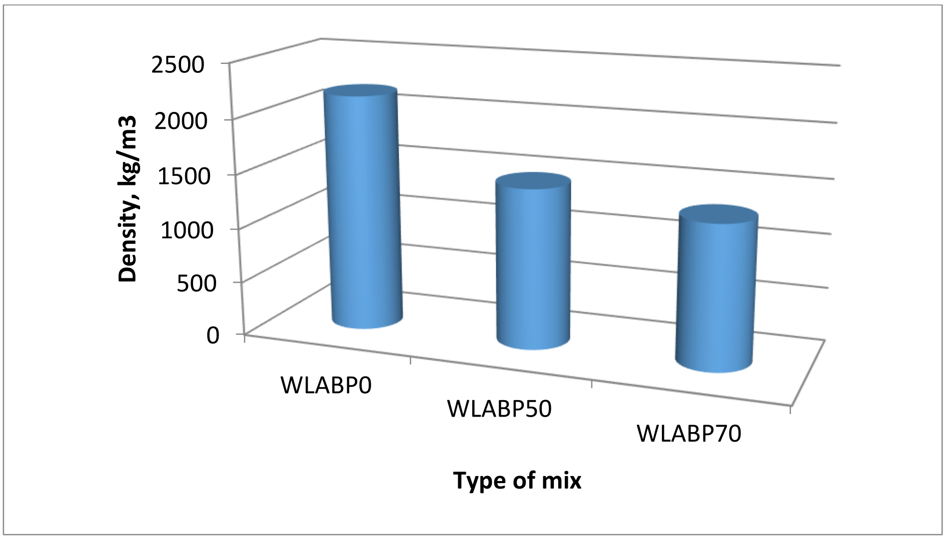

Figure 5. Density of WLABP- modified block masonry units.

Table 7. Weight Classification of Concrete Masonry Units (ASTM C90, ASTM C129, and IQD 1129).

Weight classification	Oven dry weight of concrete, Kg/m^3
Lightweight	Less than 1680
Medium-Weight	1680 to 2000
Normal-Weight	2000 or More

3.2. Compressive Strength Test

The results of the compressive strength test for the CMU specimens modified with (50 and 70% volume) aggregate of WLABP are presented in **Fig.6**. It can be seen from the figure that the compressive strength decreases as the plastic aggregate content increases, at a reduced rate in the strength of (28.1 and 37.4%) at 28 days as compared with reference concrete.

This decrease in compressive strength is may be due to the poor bond between the cement paste and the plastic CMU aggregate, and also the waste plastic aggregate undergoes to shape deformation under the compressive force, i.e. act as voids in the concrete mass. The results are in a good agreement with the findings of **Ismail and AL-Hashmi, 2008** which show that by increasing the waste plastic ratio, the results show a tendency for compressive strength values of waste plastic concrete mixtures to decrease below the plain mixtures at each curing age.

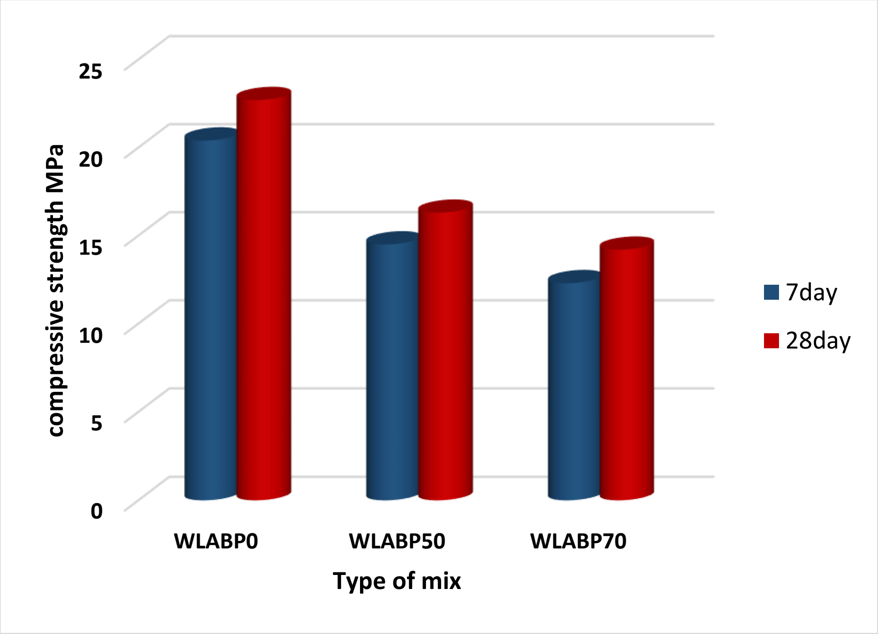

Figure 6. Compressive strength test of WLABP- modified CMU.

3.3. Water Absorption

The standard specification for concrete building brick or block limited the maximum water absorption. The ASTM C55 stated that the maximum water absorption required for lightweight concrete building block is 320 kg/m^3. Water absorption is an important factor due to the porous structure of the lightweight concrete to identify the capability of the concrete to absorb water.

The results of water absorption test for specimens with 0, 50 and 70% volume aggregate of WLABP at 28 days curing age are presented in **Fig.7.** The plots indicated that water absorption increased by increasing the percentage of plastic. This is because the higher percentage of plastic applied in each mixture increased the total voids distributed in the samples, resulted in higher water absorption capacity.

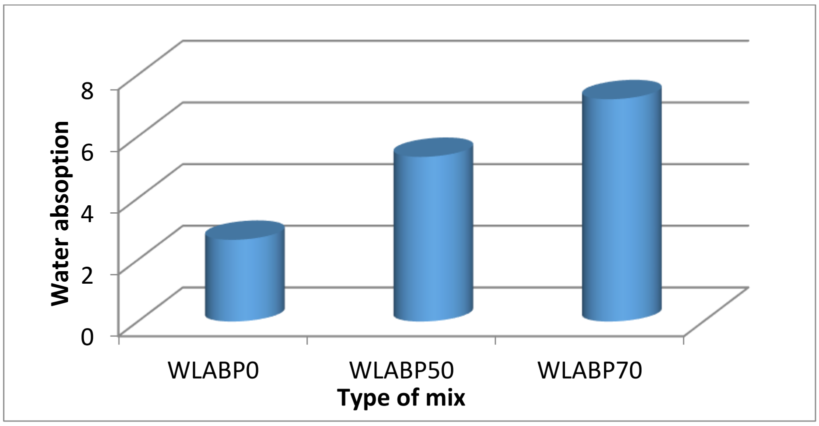

Figure 7. Water absorption of WLABP modified CMU.

3.4. Leaching Test

The results for TCLP lead ion extraction are plotted in **Fig. 8** and it can be seen from this figure that the toxicity of lead to the leachate was low and the TCLP lead for WLABP100 was higher than WLABP80 modified cement mixture. This indicated that the WLABP were free from lead residue and thus can be used in concrete production. The results of the casing and soil sampling concentrations were below 5.0 mg/l TCLP lead, then the excavated material may be disposed of at a permitted solid waste landfill accordance with the landfill’s Industrial Waste Management Plan, **Lafayette and Saint, 2004.**

Also, it can be seen in **Fig. 8** that increasing particle size > 9.5 mm the leachate decreased. Particle size increase positively effects on decreasing leaching characteristics of (S/S) materials. Larges particle size for crushed materials means lesser surface area exposure with the leaching solution and consequently resulting in lower leaching concentrations from the solidified matrixes. This comes compatible with other studies, **Olcay, et al., 2003, and Ebrahim, et al., 2017.**

The concentration of lead ions released from WLABP80 and WLABP100 at different time interval through Dynamic Monolithic Leaching Test (DMLT) are presented in **Table 8**. It can be seen from this table that the concentration of lead ion released in the leachate was within the accepted limit.

Fig. 9 shows that the pH value for the (TCLP) extraction solution specimens jumped from (4.9 ± 0.05) to values as high as (12.5) after 18 hours top to bottom agitation with (100 g) crushed particles of the WLABP-Modified concrete. Gradual dissolution of $Ca(OH)_2$ from cement results in pH adjustment of the extraction solution. Generally, the relatively high final extraction solution pH played an effective role in reducing the lead ion concentrations in the leached solution. High pH values are known to precipitate heavy metals in soils, sands, and clays by forming compounds such as hydroxides, sulphates, and chlorates species. This is an important consideration in the evaluation of the capability of a barrier to attenuate contaminants consisting of heavy metals, **Rymond and Yuwaree, 1993.**

Table 8. Lead ion leached concentration versus time for WLABP –modified CMU

Time(day)	Concentration, mg/L	
	WLABP80	WLABP100
0.08	ND*	ND
1	ND	0.001
2	0.001	0.001
7	0.001	0.002
14	0.003	0.004
28	0.005	0.006
42	0.006	0.007
49	0.006	0.007
63	0.008	0.009
100	0.009	0.011

* Not detected

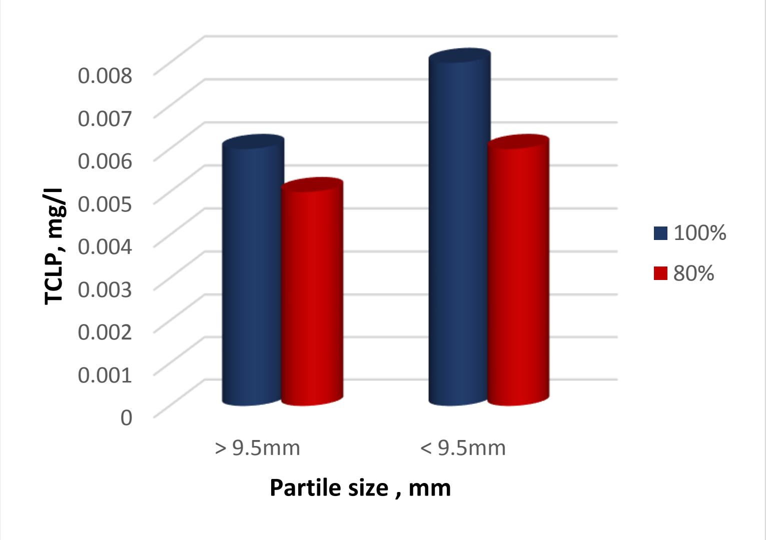

Figure 8. Toxicity test for WLABP- Modified concrete specimens.

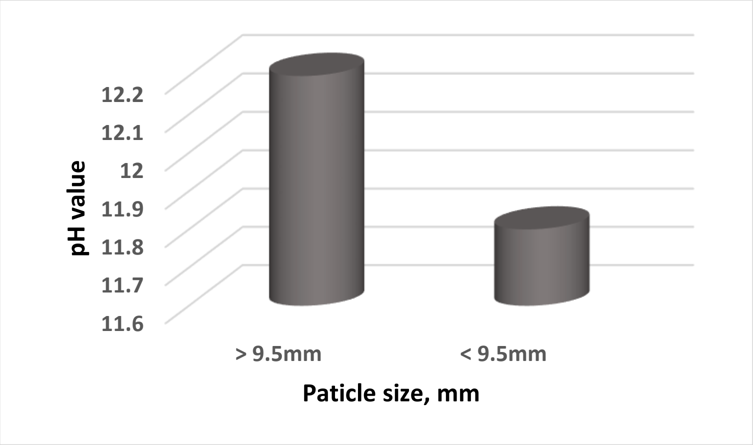

Figure 9. pH test of toxicity of Pb^{+2} ion for WLABP100- modified concrete mixture.

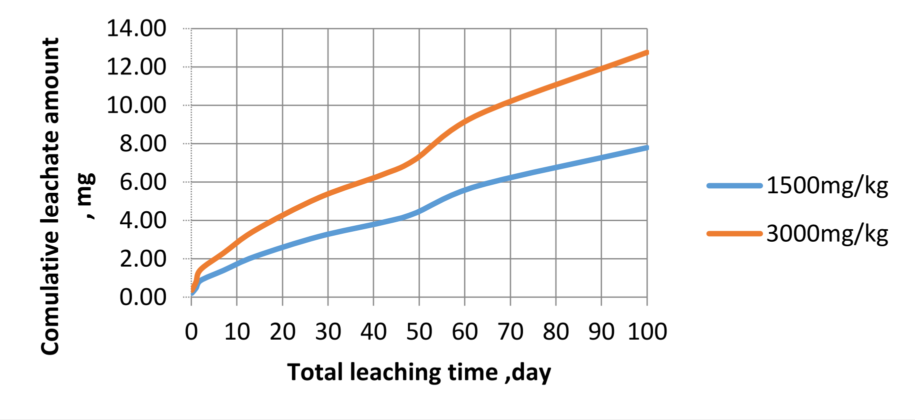

Figure 10. Lead ion Cumulative Leached Amounts (mg) versus time (days) for (S/S) LABP80 sample using 25% OPC.

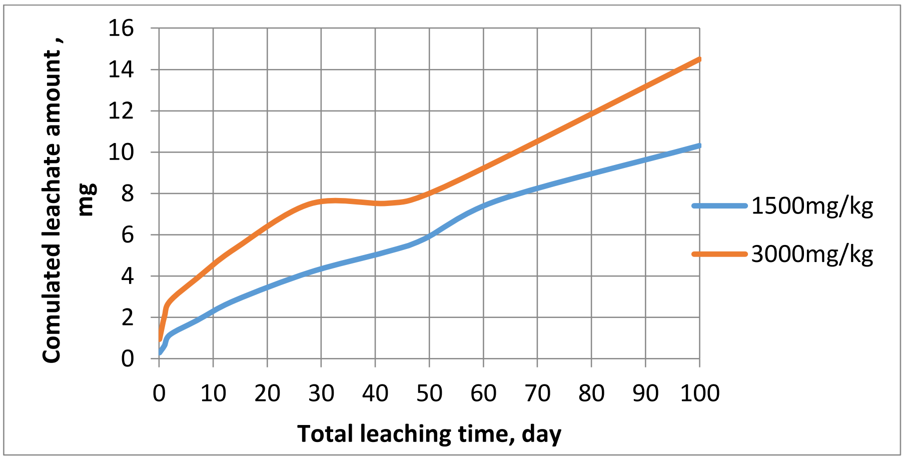

Figure 11. Lead ion Cumulative Leached Amounts (mg) versus time (days) for (S/S) LABP100 sample using 25% OPC.

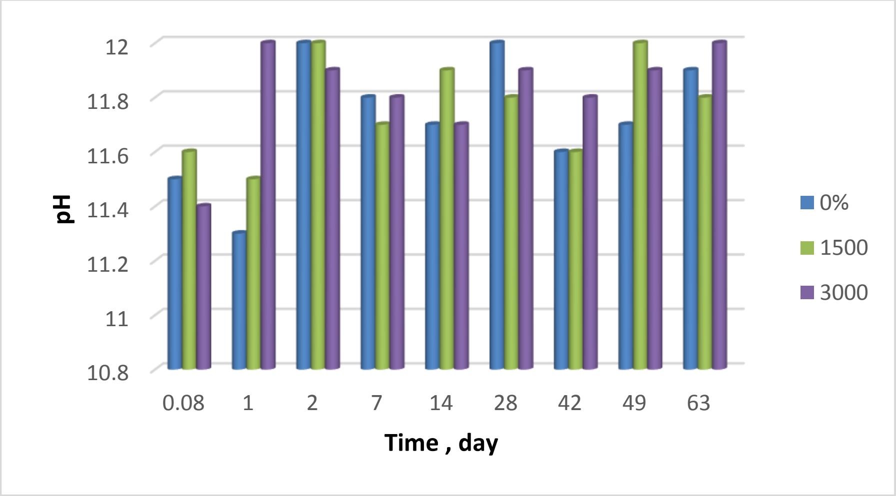

Figure 12. Average pH values after each semi-dynamic leaching intervals for LABP (25 %) OPC Mix design Solidification / Stabilization.

4. CONCLUSIONS

This study assessed the feasibility of using WLABP as partial replacement of aggregate for the production of lightweight masonry units, the results showed that:

1. The density of the specimens was decreased with increasing of WLABP content from (50 to 70%) at a rate ranges between (32.5 to 39.6% v) replacements of the natural aggregate. This type of concrete can, therefore, be classified as a lightweight concrete.
2. The compressive strength of the CMU decreased with increasing the content of the WLABP at all curing. The compressive strength increased through increasing ages from 7 to 28 days.
3. The absorption of the specimens increased with increasing the WLABP content in an increment rate of 50% and 63% for 50 and 70% replacement respectively at 28-day curing ages.
4. Leaching test revealed that using WLABP as partial replacement of aggregate for the production of lightweight masonry units is a non-hazardous approach and could meet the requirements of clean construction products. The disappearance of these constituents in the leachate could be attributed to the assumption that WLABP was washed with an alkaline solution.

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SYMBOLS:

WLABP = waste of lead-acid batteries plastic.

LWAC = light weight aggregate concrete.

HRWR = high range water reducing admixture.

CMU= concrete masonry units.

OPC= ordinary portland cement.

TCLP= toxicity characteristics leaching test.

CLA= accumulated leached amounts.

DMLT= dynamic monolithic leaching test.

S/S= solidification/stabilization process.