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Investigation of X-ray Shielding Properties of Concrete Containing Different Percentages of Recycled Lead Shots

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study investigated the recycled lead in shot form with maximum radius of 1.18 mm that added to concrete constituents in different percentages of lead-to-cement ratio (20% to 140%) by weight.
Several tests on fresh and hardened concrete were carried out. The fresh concrete was tested for slump and workability. The tests of hardened concrete included compressive strength at 7 days, 14 days, and 28 days. The penetration of x-ray to concrete after 14 days from casting date was done using a basic x-ray machine as source at 100KeV and 120KeV energies.
An X-Ray Dosimeter STEP OD-01 used as detector to measure the radiation dose rate (µsv/h) that penetrated the concrete samples.
It is observed that the lead-to-cement ratio of 80% gives the best results, where the compressive strength is the max at this value as well as the shielding properties improved.

Keywords: Recycle lead; X-ray; lead shots; concrete; compressive strength.

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1. INTRODUCTION

The radiation dosimetry is an important subject in physics, as the radiation started to be used in various fields with the development of technology. Regardless of the many benefits that come from the application of radiation, it is hazardous for human cells, which should be protected. This can be made possible by applying three main methods namely time, distance and shielding in a proper way. The latter is the most used method especially for critical buildings such as Radio-Diagnostic Centers. Heavy elements such as lead or tungsten are ideal materials for use in radiation shielding. However, these materials cannot be used directly in building construction due to durability and economic considerations. Concrete is one of the main materials used in building construction, even though it is a less effective shielding material than, e.g. lead. Alternatively, production of concrete with different types of aggregates or material used becomes important for this purpose [1,2,3,4,5,6].

To produce more effective resistant-concrete to radiation than normal concrete needs the use of additives which have high atomic number and heavy density, where proportional relation exists between atomic number, density and ability of material to shield radiation [7,8].

Many researchers [1,2,9,10,11] have studied the properties of shielding material from radiation. Therefore, the objective of the present work is to improve X-ray radiation of concrete used in Radio-Diagnostic centers by increasing attenuation properties of normal concrete. This would satisfy the properties of a shielding material through adding recycled lead shots in different percentages to concrete mixes in order to decrease their transmittance of x-rays radiation. Linear attenuation coefficients of material used will be measured. In addition, the half value layer of material thickness will be determined.

Recycled lead collected from disposed car batteries was used in this study. This waste lead was recycled, treated and added to the constituents of concrete in shot form with maximum size of 1.18 mm at different percentages of lead to cement ratios (0% to 140%) with 20% increments and mixed together to produce a homogenous new concrete.

The recycled lead that used in this study has environmental and economic advantages. Environmentally, disposed car batteries that contain lead sheets are to be used safely in producing a new concrete which is more effective in shielding than normal concrete. Economically, recycled lead is less expensive than raw lead and room wall thickness will be decreased.

2. MATERIALS OF CONCRETE AND METHODS

The materials which were used in the testing program included ordinary Portland cement, three types of aggregates which had different gradations with three sizes, clean sand, recycled lead shots and drinking water.

All physical tests were carried out on aggregates, sand and cement to ensure conformity to international standards (ASTM). The results of physical tests will be used in the design of concrete job mix.

The testing program will include studying the effect of recycled lead shots (RLS) in different ratios on concrete resistant to x-ray radiation and the mechanical properties of fresh and hardened concrete. From basic tests, the optimal percent for recycled lead shots (RLS) material can be defined. These tests included penetration x-ray and compressive strength for hardened concrete and slump test for fresh concrete.

The necessary tests are conducted in the soil and material laboratory at the Islamic University and at the Radiology department in Al Shifa Medical Complex, Gaza Strip.

Recycled lead (RL) used in this study was obtained from lead sheets obtained from disposed car batteries collected from Khanyounis City. Several steps performed to obtain recycled lead shots with a maximum size of 1.18 mm added to concrete constituents in different percentages.

2.1 Steps of Obtaining Recycled Lead

Step 1: Collecting the damaged car batteries to get the lead sheets.
Step 2: Cleaning lead sheets from impurities.
Step 3: Melting the lead sheets at a temperature of about 327℃, which is lead melting temperature.
Step 4: Disposing the slag formed during the melting process.

Step 5: Pouring the lead liquid into molds after ensuring all the slag was taken out.
Step 6: Grinding the solid lead manually to shot form with a maximum size of 1.18 mm.

Several tests and sieve analysis were carried out on recycled lead. The physical and chemical properties in addition to sieve analysis results are shown in Table 1.

2.2 Casting and Curing Procedures

The fresh concrete was cast in timber moulds (200 x 200x 40, 60, 80, 100 mm) to measure penetration of x-rays radiation but steel cubes (100 x 100 x 100 mm) are used for compression strength tests as shown in Fig. 1.

Table 1. Physical and chemical properties of recycled lead shots

Property	Recycled lead
Specific gravity	11.2
Maximum size (mm)	1.18
Color	Lead- gray
Lead percentage (%)	83.60

After 20-40 hours, the hardened concrete was carefully removed from the molds to prevent any damage to the samples. After that, the compression test samples are placed in a curing water tank at a temperature of 21-25℃ until testing, but the penetration test samples were cured by spraying water five times daily for a week period, see Fig. 2.

Fig. 1. (a) Timber moulds (b) Steel cubes

(a) **(b)**

Fig. 2. Curing process for (a) Samples of penetration test (b) Samples of compression strength test

2.3 Experimental Programs

Three tests are carried out on concrete; the first is slump test on fresh concrete, the second is compressive strength test on hardened concrete where concrete specimens experimentally investigated after 7 days, 14 days, and 28 days. The third test is penetration of x-ray to concrete samples where all samples are tested in the radiology department in Al Shifa Medical Complex at room no. 6, using a basic x-ray machine as source. In addition, an X-Ray Dosimeter STEP OD-01 used as a detector to measure the radiation dose rate (µsv/h) which penetrated the concrete samples.

2.4 Procedures to Perform Penetration Test

- After 14 days the concrete samples exposed to radiation of basic x-ray machine.
- Different sample thicknesses 200 x 200 x (40, 60, 80 and 100) mm for each batch are used.
- Recycled lead shots to cement ratio changed for each batch. Ratios used are (20%, 40%, 60%, 80%, 100%, 120%, 140%).
- The test was performed at different energy 100 KeV and 120 KeV of the source to detect the energy effect for shielding parameters.
- Source object detector distance (SOD) is 70 cm, which is the distance from source x-ray radiation to concrete sample. Source dosimeter detector distance (SDD) is 81 cm, which is the distance from source x-ray radiation to detector, see Fig. 3.
- Using steel holder to carry samples surrounding by lead plates with a thickness of 3 mm in order to reduce background radiation effects, see Fig. 4.
- The linear attenuation coefficients (µ,cm^{-1}) will be determined by Lambert law's:

$$I = I_0 e^{-\mu x}$$

Where x is concrete thickness, I_0 is the incident x-ray and I is the photon intensity recorded in detector after it passed the concrete material, where X-Ray Dosimeter STEP OD-01 is used to measure absorb dose (µsv/h) through concrete samples.

- The intensity of radiation in (µsv/h) versus the concrete thickness (cm) values for each recycled lead percentage are investigated and discussed thought different figures. Then linear attenuation coefficient (LAC) and half value layer (HVL) were determined.

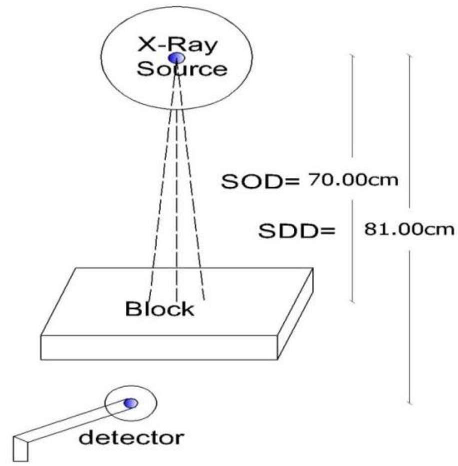

Fig. 3. Penetration X-Ray test chart for concrete sample

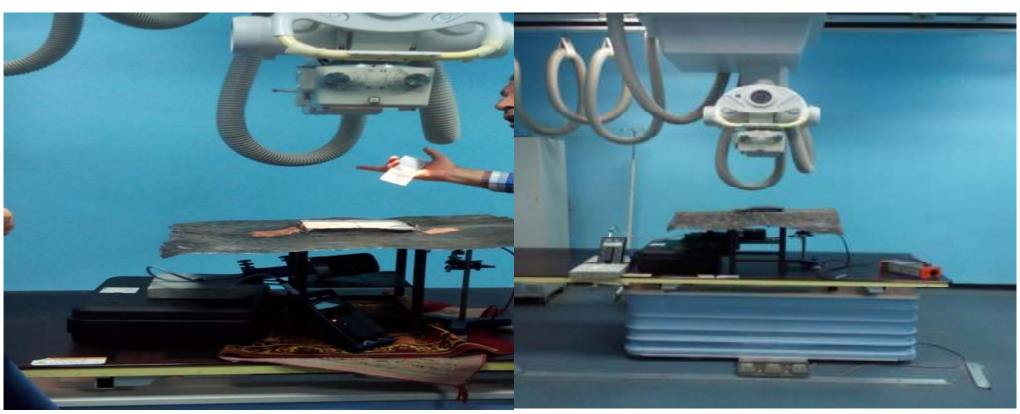

Fig. 4. Conducted penetration test

3. RESULTS AND DISCUSSION

The present work investigated the effect of recycled lead shots (RLS) on the mechanical and shielding properties of fresh and hardened concrete. This investigation was done by adding seven different percentages of (RLS) material to normal concrete. The mechanical property of fresh concrete made by conducting slump test for every mix. The primary mechanical property of hardened concrete "compressive strength" was done by crushing 4 cubic molds for each age of concrete (7, 14 and 28 days) and ability of concrete sample of absorbing radiation was also detected. Then, the optimum ratio of RLS to enhance the shielding and the compressive strength can be defined.

Test results showed an increment of RLS would reduce slump of concrete. This reduction ranged from 110 mm for normal concrete without RLS to 45 mm for 140% of additive RLS.

It is also noticed that, the density of concrete increased from 2361 Kg/m^3 at 0% of RLS to 2762.0 Kg/m^3 at 140% of RLS. This means that adding 140% of RLS to cement would increase concrete density by about 17.0%.

The compressive strength increased from 37.1 MPa at 0% of RLS to 47.6 MPa at 80% of RLS. This illustrates that adding 80% of RLS would also increase the compressive strength by about 28.4%. In addition, when the RLS to cement ratio was increased from 80% to 140%, concrete compressive strength decreased to 35.3 MPa at 140% of RLS.

Improvement in compressive strength of concrete might be attributed to two reasons; first, the density of concrete was improved because the lead shots have filled up the pores in concrete, where sieve analysis of the mix design was improved. Second, the lead causes the formation of Pb(OH)2 and enhanced the formation of a larger amounts of calcium silicate hydrates (C–S–H) and calcium aluminate hydrates (C–A–H) as discussed by [3]. This is an important bound on concrete hydration. Thus, an extra lead shots play a negative role in decreasing cohesion between concrete constituents, where the compressive strength would decreased. Table 2 shows mechanical properties of concrete at 28 days of age with different ratios of RLS.

3.1 Penetration X-Ray Test Results

The penetration of x-ray radiation to concrete after 14 days from casting date at100KeV and 120KeV at different concrete sample thicknesses (4, 6, 8, 10 cm) and different recycled lead percentages (0% to 140%) is evaluated.

The linear attenuation coefficient (LAC), and half value layer (HVL) as a function of radiation intensity and concrete thickness were obtained and illustrated in Figures.

The results show that LAC of concrete increased by increasing the lead shot percentage for both x-ray energy at 100 Kev and 120 Kev. It is found that LAC in the absence of lead is 0.31 cm^{-1}, whereas the ratio of RLS 140%, the LAC is 0.48 cm^{-1} at 100 Kev.

Half value layer (HVL) thickness is the other parameter that evaluated or x-ray shielding. This variation of HVL against an increasing lead percentage in concrete at 100 Kev is reduced by increasing from 2.24 cm for normal concrete without RLS to 1.41 cm for 140% of RLS. Table3. shows shielding parameters for concrete at two energies;100 KeV and 120 KeV.

Also, test results exhibits when x-ray energy increases from 100 KeV to 120 KeV the LAC decreased from 0.31 $\mathbf{cm^{-1}}$ to 0.13 $\mathbf{cm^{-1}}$ and HVL was increased from 2.24 cm to 5.33 cm respectively. Figs. 5 and 6 show the relation between x-ray energy and shielding parameters such as LAC and HVL.

Table 2. Mechanical properties of concrete at 28 days of age with the ratio of RLS

RLS (%)	Slump test (mm)	Concrete density (Kg/m^3)	Compressive strength (MPa)
0	110.0	2361.0	37.1
20	105.0	2439.0	44.6
40	90.0	2491.0	45.1
60	80.0	2535.0	46.5
80	75.0	2595.0	47.6
100	65.0	2646.0	45.4
120	50.0	2698.0	37.6
140	45.0	2762.0	35.3

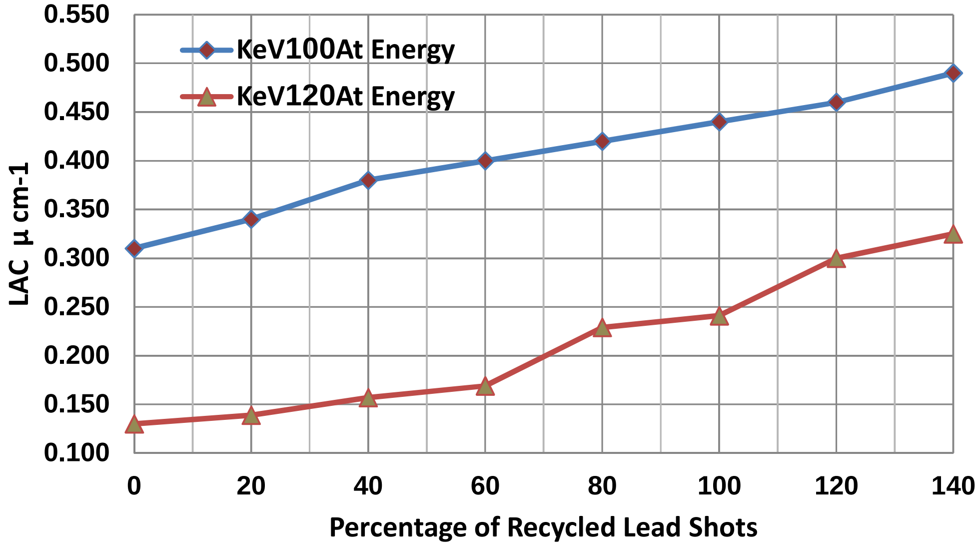

Fig. 5. Relation between RLS ratio and LAC values at 100 KeV and 120 KeV

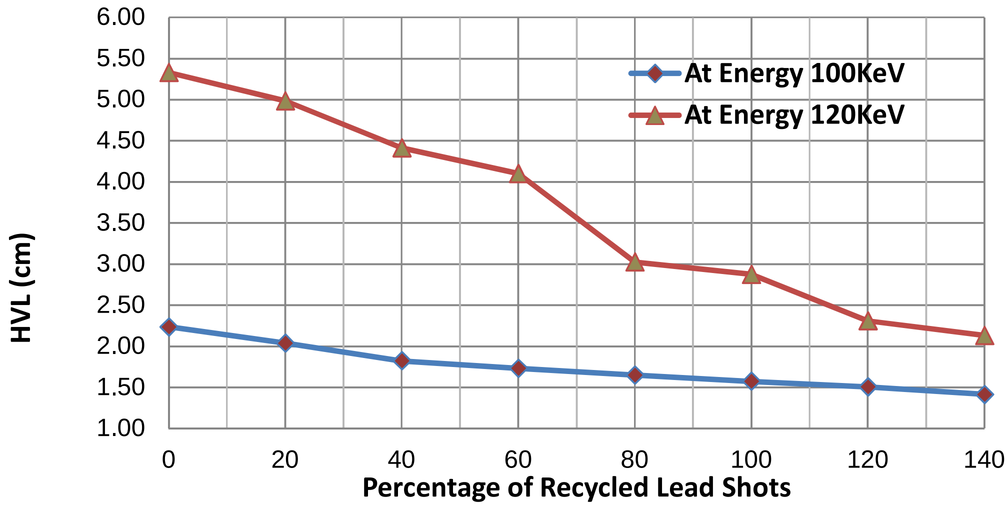

Fig. 6. Relation between RLS ratio and HVL values at 100 KeV and 120 KeV

Table 3. Average LAC, MAC, HVL, TVL and RLS ratio at energy 100 KeV and 120 KeV

RLS (%)	Density (Kg/m^3)	At Energy 100 KeV				At Energy 120 KeV			
		LAC µ(cm^{-1})	MAC $\mu_m(cm^2/g)$	HVL (cm)	TVL (cm)	LAC µ (cm^{-1})	MAC $\mu_m(cm^2/g)$	HVL (cm)	TVL (cm)
0%	2361.3	0.310	0.131	2.24	7.43	0.130	0.055	5.33	17.72
20%	2438.8	0.340	0.139	2.04	6.77	0.139	0.057	4.99	16.57
40%	2490.8	0.380	0.153	1.82	6.06	0.157	0.063	4.41	14.67
60%	2520.7	0.400	0.159	1.73	5.76	0.169	0.067	4.10	13.63
80%	2564.8	0.420	0.164	1.65	5.48	0.229	0.089	3.03	10.06
100%	2615.3	0.440	0.168	1.58	5.23	0.241	0.092	2.88	9.556
120%	2648.4	0.460	0.174	1.51	5.01	0.300	0.113	2.31	7.677
140%	2708.0	0.490	0.181	1.41	4.70	0.325	0.120	2.13	7.086

4. CONCLUSION

It is observed from this study that when the lead-to-cement ratio is increased from 0% to 80%, its compressive strength and x-ray shielding properties are improved with maximum values obtained at 80%. However, when the lead-to-cement ratio is increased from 80% to140%, the x-ray shielding properties of concrete are increased but the compressive strength is decreased. This indicates that higher values of RLS percentage in concrete are unsuitable for shielding, where compressive strength is reduced.

The LAC of concrete with 80% of lead, based on X-Ray emission at energy 100 KeV and 120 KeV, was about 1.35 and 1.76 times higher than that of the concrete without lead, respectively.

Also, the results have demonstrated that the density of concrete increases as the percentage of recycled lead shot increases, and the workability of concrete decreases when recycled lead shot ratio increases.

In addition, we have compared our results with Rezaei-Ochbelagh and Azimkhani [6]. They were displayed that when the lead-to-cement is increased from zero up to 90%, the compressive strength and x-ray shielding properties showed a good improvement. However, more increase in the percentage of lead to cement indicate unsuitable shielding. This agrees well with our results, where the optimum ratio is 80% in the present work.

It is concluded that the inclusion of additives of recycled lead shot to concrete is able to improve its resistant to x-ray radiation when used in radio-diagnostic centers. More research is needed and recommended in the area of "Improving Radiation Resistance of Concrete Used in Radio-Diagnostic and Therapeutic Centers". This is due to the importance of this field and lack of such studies in this field in our country.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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