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The production of Novel Sustainable Lightweight Mortar from the electronic plastic waste

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Abstract:

Electronic plastic waste (EPW) like Compact Discs, also known as CDs or Digital Video Disc DVDs, is considered a massive challenge because of the low biodegradability of the material and exists in large quantities. Thus, using friendly alternative disposal methods for waste is becoming a significant research issue. This paper aims to explore producing lightweight mortar with fine EPW as fine aggregate to produce sustainable lightweight mortar (SLWM). To address the aim, the effect of a high percentage (50%, 75%) of electronic plastic waste EPW as a replacement material with sand (by weight of the sand) is compared with standard mortar (NM). Physical and mechanical characteristics such as water absorption, ultrasonic pulse velocity, bulk density, and compressive strength were measured on all specimens at 7, 28, and 90 days. The results show that there is a possibility of producing SLWM from EPW, and the 50% replacement of sand by weight gives better results than 75% and has a mechanical strength adequate for lightweight materials.

Keywords: *electronic plastic waste; Sustainable mortar; lightweight mortar; recycled sand; plastic waste.*

1. Introduction and background

The volume of concrete is typically consistent from 70–80 % aggregates; for example, normal concrete contains fine aggregate and coarse aggregate in different sizes and shapes. One of the methods adopted to reduce waste materials is using them as alternative aggregate in the concrete mix. Various recycled materials, including blast furnace slag, coal ash, fibreglass, rubber, plastics, and sintered sludge pellets, are being studied as aggregate substitutes. [1]. Concrete production costs can be reduced by repurposing waste. Such a disposal approach can reduce waste materials' environmental impact and address the lack of aggregate in various construction sites. Because of the enormous volumes disposed of and the low biodegradability of plastic trash (e.g. CDs and DVDs), it is hazardous to the environment[2]. All the waste materials must be evaluating their properties before using as recycled aggregate. Plastic waste is one of the different recycled materials utilised as a recycled aggregate like bottle polyethene terephthalate PET, pipe polyvinyl chloride PVC and boxes. Polyethene PE [3].

The reuse the plastic waste in concrete production has many benefits as it is widely used, and usually, concrete structures have a long life span. Furthermore, plastic waste reuse in the concrete might improve some properties such as chemical resistance, tensile strength, short- and long-term creep, and drying shrinkage. Choi et al. [4] looked at the influence of repurposing plastic bottles on concrete properties as an aggregate replacement. According to the findings, the concrete weight was lowered by 2–6%, and the concrete compressive strength was reduced by 33%. On the other hand, Batayneh et al. [5] established that the plastic content increase causes a decrease in concrete compressive strength. The results showed that for a sand substitution of 20%, the concrete compressive strength was decreased by 70%. Likewise, other studies [6-9] have investigated plastic bottle waste as a sand replacement to produce composite materials that can be used for construction applications. The outcomes indicate that when the compressive strength and density of concrete were reduced by more than half of the sand volume, the concrete's compressive strength and density decreased. Furthermore, due to insufficient adhesion between the plastic and the cement, plastic detachment from the concrete mixture may result in compressive strength reduction.

On the other hand, there are many benefits to using plastic waste and decreasing the pollution of plastic waste in the environment; plastic material has suitable properties like lightweight, and it cannot provide thermal conduct and sound insulation. This study proposed to look into the possibility of using electronic plastic waste EPW to produce lightweight, low-cost mortar. At the same time,it maintains good physical and mechanical properties that could be employed in various applications, for instance, the internal insulating walls and roofs as a replacement layer for an insulation layer. The mortar's physical and mechanical characteristics were evaluated using cube and prism samples. This research examined the viability of using CDs and DVDs as a sand substitute to create sustainable lightweight mortar (SLWM). It then evaluated the innovative material's mechanical and physical attributes.

2. Experiment Programme

2.1. Materials used in this work

The material used in this work for Sustainable Lightweight Mortar SLWM were:

2.1.1. The cement binder used in the study

The cement employed is ordinary Portland cement manufactured in Iraq in compliance with the ASTM C150 – Type 1 [10]. Table 1 illustrates the physical and chemical properties of the cement used.

Table 1: Cement Properties

Oxides composition Cement	Content%	Limits of Iraqi specification No.5/1984
CaO	61.12	---
SiO_2	20.18	---
Al_2O_3	5.00	---
Fe_2O_3	3.30	---
MgO	3.80	<5.00
SO_3	2.34	<2.80
LOI.	3.16	<4.00
Insoluble residue	0.14	<1.5
Lime Saturation Factor, LSF.	0.96	0.66-1.02
C_3S	54.40	---
C_2S	16.89	---
C_3A	7.16	---
C_4AF	10.94	---
Physical Properties	Results	Limits of Iraqi specification No.5/1984
Specific surface area (Blaine Method), m^2/kg	330	≥230
Setting time (Vicat Apparatus),		
The initial setting, hr: min	3.00	≥00:45
The final setting, hr: min	5.30	≤10:00
Compressive strength, MPa		
3 days	19.63	≥15.00
7 days	28.93	≥23.00
Soundness (Autoclave Method), %	0.09	≤0.8

2.1.2. Aggregate used in the study

Natural sand (NS) from Al-Ekhaider is employed in this study as fine aggregate. Table (2) lists the griding of NS and EPW. The physical and chemical characteristics of the sand used are specific gravity 2.62 kg/m^3, sulfate content SO_3 0.22, absorption 1.85% and dry loose-unit weight $kg/m^3$1562, all the properties are in line with standards of Iraqi Specification No. 45/1984, zone 3.[11].

Table (2): Grading NS and EPW used in the study.

Sieve size (mm)	Passing NS,%	Passing EPW,%	Iraqi specification (IS) No.45/1984
4.75	95	95	90-100
2.36	90	85	85-100
1.18	83	75	75-100
0.600	65	60	60-79
0.300	26	8	12-40
0.150	8	2	0-10

2.1.3. Recycled sand content and preparation

The SLWM mix was designed to explore the effect of replacing the sand with the grounded electronic plastic waste obtained from the plastic of a Compact Disc known as 'CD', and a Digital Video Disc known as 'DVD'.

Generally, CDs and DVDs can be defined as digital optical disc data storage formats. The CD and DVDs were first co-created and released in the early 1980s by Philips and Sony. This type of waste contains polycarbonate, durable material with high resistance, low scratch and chemical resistance, and good fatigue.Fig.1 shows the diagram of CD and DVD layers [12]:

A. A polycarbonate disc layer.
B. A shiny reflective layer primarily reflects the laser.
C. A layer of lacquer with the primary purpose is to protect the shiny layer.
D. The top layer is an artwork screen which is printed on the top.

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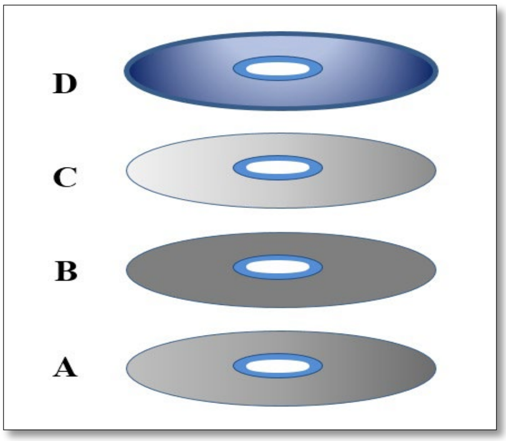

Fig. 1: The sequence of layers of CD and DVD.

2.1.1. Water

Both mixing and curing mortar have been done with tap water.

2.2. Preparation of recycled sand

Fig. 2 shows the stages of recycled sand preparation; all the CD and DVD waste was crashed for the small part, then crashed as recycled sand by a crash machine then sieved to the required size.

Fig.2. Preparation of recycled sand.

2.3. Samples Preparation and Test Methods

The moulds have been oiled properly for easy de-moulding. The moulds were filled carefully in two layers and checked to be filled. The hardened samples were de-moulded and cured in a storage tank at a temperature of 232 Co for 7, 28, and 90 days after being left in the concrete for 48 hours. The hardened cubes were tested aged 7, 28, and 90 days.

3. Test methods

3.1. Samples preparation

To conduct the study, cubes of (50×50×50mm) and prism specimens of (40×40×160mm) were made for each mixture. The mix design (1:2.5:0.5) is shown in Table (3). After casting, the specimens were kept in water under 22 ± 1ºC. The water absorption, density, and Ultrasonic Pulse Velocity tests measured physical and mechanical properties.

Table (3): Mix the proportion.

Mix ID	electronic plastic waste EPW,%	Cement, kg/m^3	natural sand NS, kg/m^3	electronic plastic waste EPW, kg/m^3	Water/Cement
M0	0%	500	1250	-	0.5
M50	50%	500	625	625	0.5
M75	75%	500	257.5	937.5	0.5

3.2 physical test

The water absorption test and the bulk density were carried out on the cub samples corresponding to ASTM C642 standards [13]. The oven-dried mass sample was measured for this test, and the samples were then submerged in water at 20ºC until they reached a consistent mass. After that, the saturated mass of the sample was calculated using the constant mass. By dividing the water absorbed on the oven-dried mass, the absorption % was calculated.

Prism specimens 40×40×160 mm were used for the ultrasonic pulse velocity test following ASTM C597-97[14]. The UPV test evaluates mortar homogeneity and discovers any voids or cracks. It can also be used to track the progress of the mortar component's compressive strength. The UPV used direct transmission to determine the velocity of an ultrasonic wave travelling across its longitudinal axis.

3.3. Mechanical properties

In compliance with ASTM C109/ C109M -05 requirements, compressive strength tests were performed on cube samples with dimensions of (50×50×50mm) using a digital compression testing machine with a capacity of 2000kN and a loading rate of 1.5 kN/sec. [15]. The results presented in this paper are based on an average of three cubes being tested for each age group (7, 28 and 90 days).

4. Results and discussion

The EPW (electronic plastic waste) utilised in this study is lighter and has a larger particle size than the natural sand 'NS', as shown in Fig.3.

The large surface area of EPW particles reduces the water demand in the mixture because the plastic waste material, such as Compact Disc CDs and Digital Video Disc DVDs, does not absorb the water [16,17]. The followability and the workability of the mixture increased with a higher replacement EPW percentage in the mix. This can be due to the smooth surface area and not absorbing the water.

Fig.4 shows the density test results for all mixtures (SLWM) at 7,28, and 90 days and with (0%,50% and 75%) EPW as a replacement. The results showed a decrease in the density for the sand when the EPW percentage increased for M50 (21.39, 20.82 and 20.96 %) respectively at 7, 28 and 90 days. For M75 (38.85, 32.84, and 33.43%) at 7,28 and 90 days compared to M0. This could be attributed to EPW's particles' smooth surface area and lightweight; the smooth surface resulted in decreased attachment between the cement paste, sand, and EPW and weakened the interfacial transition zone (ITZ) among the mix's components. [1,18]. Therefore, the cracks and porosity appear in the microstructure of the SLWM, as shown in Fig.5. On the other hand, Fig.4 shows increased density with age due to the development of the hydration process of cement.

Fig.6 shows the water absorption test results, which show decreased water absorption with age due to the hydration process that improves the ITZ with age [1]. Furthermore, the data reveal that as the amount of EPW replaced increases, so does the absorption percentage. Fig.7. show the effect of the distribution of the particles, particles size and EPW shapes, which formed a void between the particles. All these factors affect the density of the M0, M50 and M75 mixes.

Fig.8 shows the ultrasonic pulse velocity test results for M0, M50 and M75. It is clear from Fig.8 that the M50 and M75 at 7 days had the lowest value than other mixes, which means that many factors affect the value of velocity pulses like porosity and cracks the low density. In this study, the UPV indicates the compressive strength and the effect of EPW as a replacement percentage.

Fig.9 shows the compressive strength result for all mixtures (SLWM) for 7,28, and 90 days, with (0%,50% and 75%) EPW as a replacement with NS. The results show that the cement hydration raised the age of the entire combination. This formed an interfacial transition zone (ITZ) between the cement matrix and the EPW [2]. The compressive strength of M50 decreased (82.75%,80.91% and 75.55%) for (7, 28 and 90 days) compared with M0. Then M75 showed a decrease of (86.89%, 86.64% and 90.45%) for (7,28 and 90 days) compared with M0. The smooth surface of EPW particles causes the (deboning) between the EPW and matrix as the micro-cracks propagate in the mortar due to the poor physicochemical bonding strength with cement. The M50 has the highest value (7.5, 10.63 and 14.08) MPa for (7,28 and 90 days) respectively; all the values have the limit required to produce the sustainable lightweight mortar SLWM.

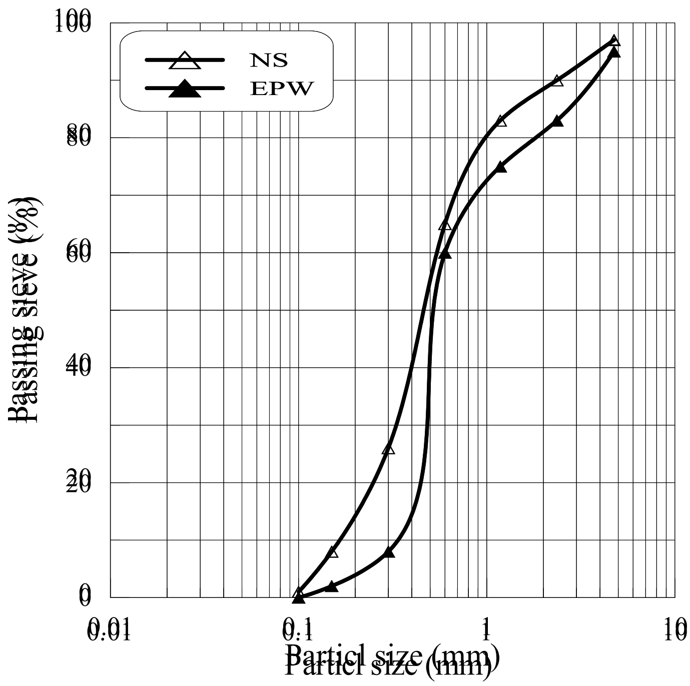

Fig.3. The distribution of particles for NS and EPW.

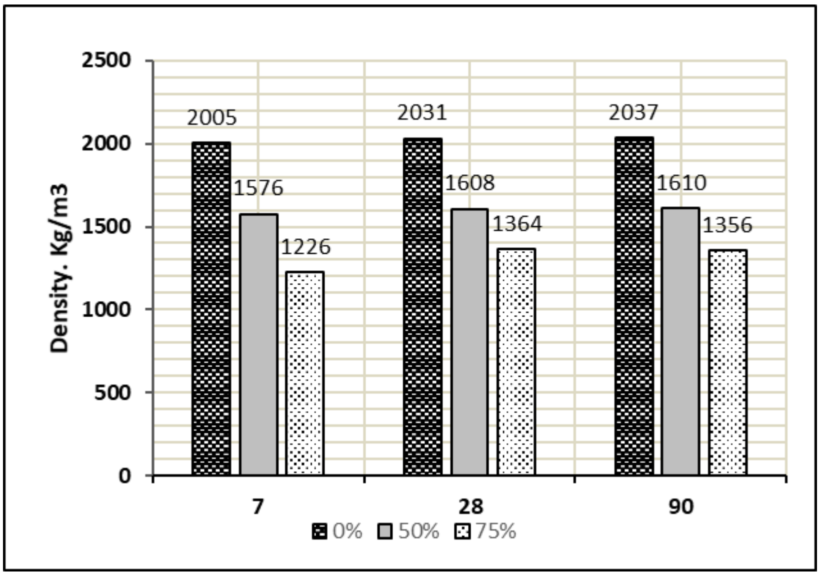

Fig.4.The density for different mixes with age.

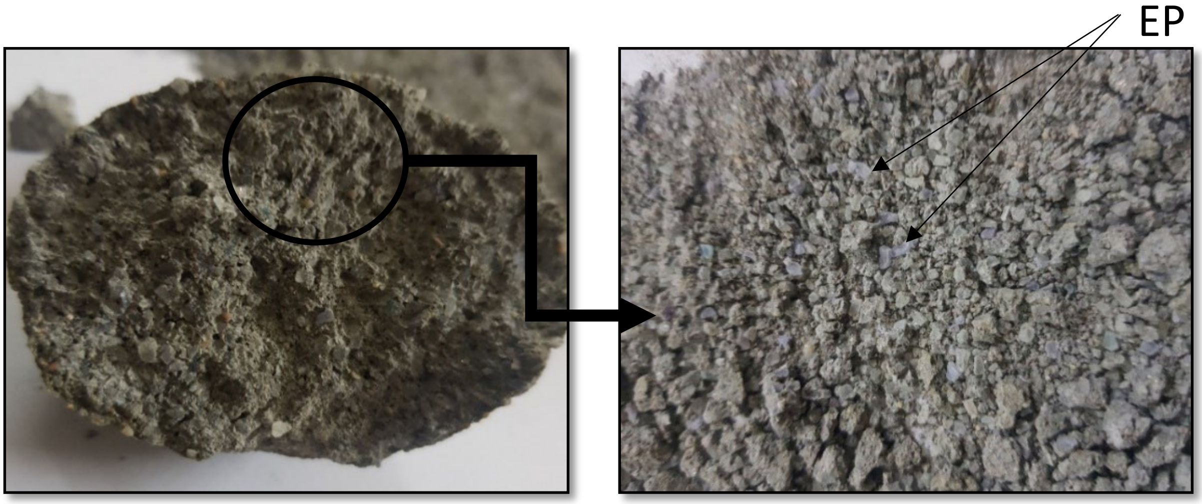

Fig.5. Sample of M50.

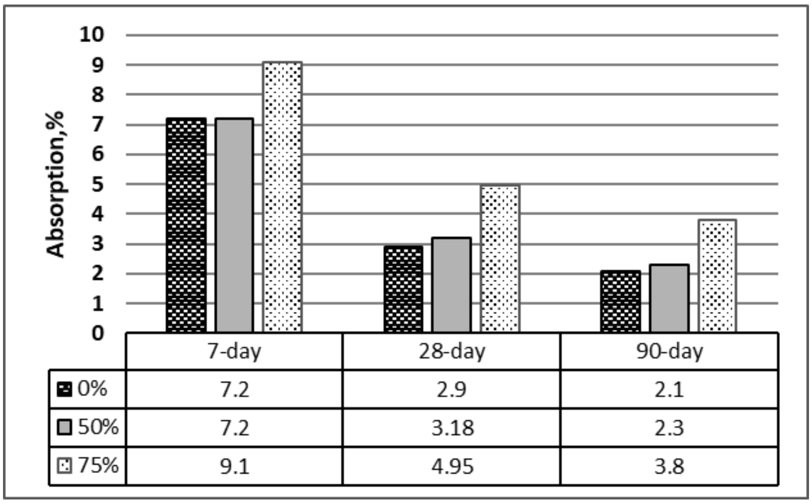

Fig.6.The water absorption% for different mixes with age.

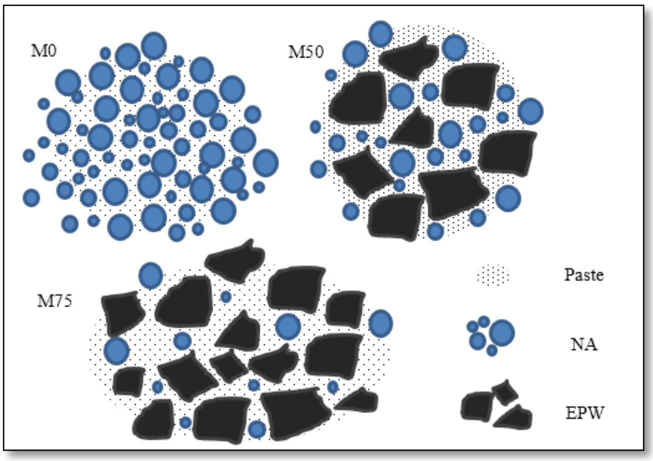

Fig.7. The distribution of composite of all mixes.

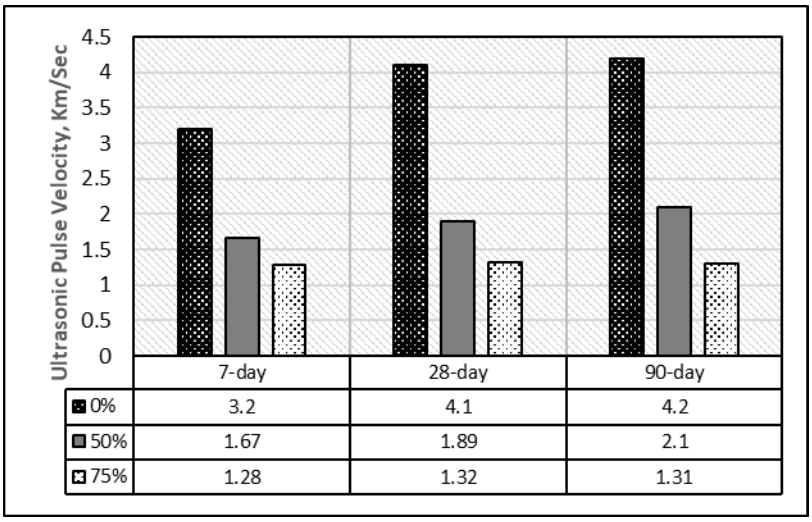

Fig.8.The Ultrasonic Pulse Velocity tests for different mixes with age.

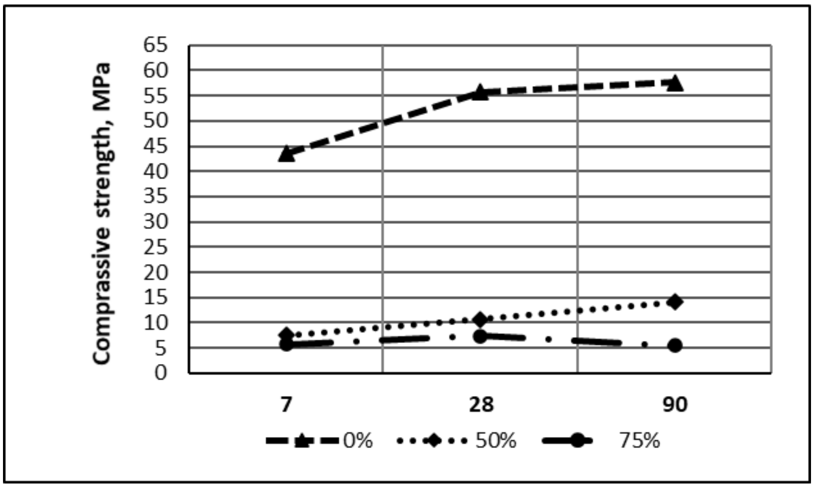

Fig.9.The compressive strength for all mixes with age.

5. Conclusions

This research investigated the ability to produce sustainable lightweight mortar SLWM from CDs and DVDs as a sand replacement. It then assessed the physical and mechanical properties of the novel material. The main findings of the study were:

1. The electronic plastic waste EPW produced from grounded Disc CD or Digital Video Disc DVD can be utilised as a fine aggregate to generate a lightweight, sustainable mortar.
2. The SLWM is a product with good physical properties as a lightweight mortar; the results of density at 90-day for M50 and M75 are (1610 and 1356) the two mixes within the specific requirements, and the water absorption test results for M50 and M75 at 90-day is (2.3 and 2.8) which are within the specific requirements.
3. The M50 have the highest compressive strength of SLWM, 14.08 MPa at 90-day, and the compressive strength reduction is 75.55%.

Acknowledgements

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