Al-Nahrain Journal for Engineering Sciences **NJES** 25(4)159-164, 2022
http://doi.org/10.29194/NJES.25040159

Physical and Mechanical Properties of Cementitious PVC Composites

Ghassan Subhi Jameel [1], Bashar Abdulazeez Mahmood[2], Maher Zuhair Mohammed[3], Abdulkader Ismail Al-Hadithi[4]

Authors affiliations:
1*) Department of Dams and Water Resources Engineering, College of Engineering, University of Anbar, Ramadi-Iraq.
ghassan.alkubaisi@uoanbar.edu.iq

2) Department of Chemistry, Education for pure sciences, University of Anbar, Ramadi-Iraq.
esp.bashar.abdulaziz@uoanbar.edu.iq
3) Civil Engineering Department, College of Engineering, University of Anbar, Ramadi-Iraq.
maher.zuhair@uoanbar.edu.iq
4) Civil Engineering Department, College of Engineering, University of Anbar, Ramadi-Iraq.
abdulkader.alhadithi@uoanbar.edu.iq

Paper History:

Received: 8nd Nov. 2022

Revised: 3th Dec. 2022

Accepted: 16th Dec. 2022

Abstract

This research studies the physical and mechanical properties of mortar composed of PVC plastic waste particles used as fine aggregate replacement material. PVC particles in quantities of 5%, 10%, 15%, 20%, 25%, and 30% by volume were used for sand fraction substitution. At 7 and 28 days, the compressive and splitting tensile strengths to represent the mortar's mechanical characteristics were evaluated. Additionally, the physical characteristics of density and absorption were investigated. The findings demonstrated that the mechanical properties and density of mortar containing PVC particles were minimized compared with reference mixture.

Keywords: PVC particles, Compressive Strength, cementitious PVC composites, Splitting Tensile Strength, Waste Materials.

الخواص الفيزيائية والميكانيكية لمركبات الـ PVC الأسمنتية

غسان صبحي جميل، بشار عبد العزيز، ماهر زهير محمد, عبد القادر اسماعيل الحديثي

الخلاصة:

تناول هذا البحث تقييم الخصائص الفيزيائية والميكانيكية للملاط المحتوي على النفايات البلاستيكية PVC المستخدمة كمواد بديلة للركام الناعم حيث استخدمت فضلات ال PVC بكميات ٥٪ ، ١٠٪ ، ١٥٪ ، ٢٠٪ ، ٢٥٪ و ٣٠٪ كبديل جزئي عن الرمل. تم فحص مقاومة الانضغاط والشد كخصائص ميكانيكية للملاط بعمر ٧ و ٢٨ يوم. بالإضافة إلى ذلك، تم فحص الخصائص الفيزيائية (الكثافة والامتصاص). أظهرت النتائج أن الخواص الميكانيكية وكثافة الملاط المحتوي على مسحوق PVC قد انخفضت مقارنتا مع الخلطة المرجعية.

1. Introduction

Waste plastic is a significant environmental concern and comprises 15-20% of waste materials[1]. Using plastic waste in concrete is considered a viable solution to lower its negative impact on the environment [2]. Disposing of waste plastic without treatment creates an environmental problem because of the 450 years required to dissolve it in landfills [3]. Consequently, recycling waste plastic and its utilization in construction manufacturing are considered an important methods to reduce the negative effect of plastic disposal. As a result, it is important to look at the impact of waste on concrete characteristics because some waste materials are unsuitable for concrete incorporation [4]. The fine aggregate (FA) or coarse aggregate (CA) in concrete can be partially replaced by plastic trash. Generally, waste plastic aggregate has less bulk density than the normal aggregate. Subsequently, they were selected for manufacturing lightweight concrete [5]. Moreover, it has been reported in several studies that waste plastic has a significant effect on the characteristics of concrete, such as fluidity, mechanical, physical, and thermal [6-9].

Many researchers have reported on the effect of waste PVC in concrete. Merlo et al. [10] state the impact of recycled PVC waste on mortar properties was investigated. The diminishment of compressive and flexural strength with increasing PVC were the principal outcomes.

Ruiz. et al.[11] investigated the effects of plastic trash on the mechanical and thermal properties of concrete and mortar cellular materials. Density, compressive strength, and tensile strength were all shown to decrease. The impact of curing conditions on the characteristics of concrete with PVC waste as an aggregate is the primary topic of the study by Haghighatnejad et al. [12]. They mixes the discarded PVC pipes in place of natural sand at various percentages. Various methods of curing were employed. Results demonstrate that the mechanical characteristics of concrete are negatively impacted by PVC incorporation independent of the curing state.

Further, ductility, impact load resistance, and energy absorption can be significantly increased due to waste plastic inclusion [13][14].

The use of PVC waste with concrete led to reduce the environmental impact of plastic waste and decrease the density of concrete to get or near of lightweight concrete.

This study aims to analyze how replacing sand with PVC particles derived from recycled plastic pipes effect on mortar's physical and mechanical properties. Reference mixtures (0PVC) and six other mixtures were created with plastic particles substitution ratios of 5%, 10%, 15%, 20%, 25%, and 30% by volume of fine aggregate. Compressive strength, splitting tensile strength, density, and absorption were among the physical and mechanical characteristics tested.

2. The Program of the Experimental

2-1. The Materials

Portland cement was utilized in the reference mixture and mixture containing PVC particles. All mixtures were made using natural sand with a maximum particle size of 4.75 mm. The sieve analysis and determination of physical parameters followed protocols established by ASTM C128 [15]. With a specific gravity of (1.4), PVC particles used as a sand alternative by volume. Compare the physical characteristics of sand and PVC particles by a sieve examination, as shown in Table 1.

Table (1): Physical properties and sieve analysis of sand and PVC particles

Sieve size mm	Fine aggregate %	PVC particles %
4.75	94	95
2.6	80	83
1.18	68	70
0.6	52	53
0.3	18	21
0.15	2	3
Fineness modulus	3.77	-
Water Absorption %	2.37	0

2.2-Mixtures Design and Casting

Seven mortar mixtures were designed and cast to conduct physical and mechanical properties. The first mix, reference mixtures (0PVC), consists of cement, sand, and water while the other six mixtures involve PVC particles and materials in the reference mixture. Powdered PVC is a volumetric alternative for fine aggregate. The ratio of sand replacement with PVC was 5%, 10%, 15%, 20%, 25%, and 30%, corresponding to mixtures 2, 3, 4, 5, 6, and 7, respectively. As shown in table 2, mixtures were coded according to the ratio of incorporated PVC particles. For example, the mix coded 15PVC indicates the mixture contains 15% PVC particles instead of fine aggregate.

Table 2. The mortar mix ratios (kg/m^3).

Mix ID	Cement	FA	PVC	w/c
0PVC	525	1557	0	0.45
5PVC	525	1500.8	41.73	0.45
10PVC	525	1421.8	83.3	0.45
15PVC	525	1342.3	125.25	0.45
20PVC	525	1200.6	166.9	0.45
25PVC	525	1184.5	208.97	0.45
30PVC	525	1011.7	251.04	0.45

Concrete molding began with mixing sand with PVC particles and cement for one minute to achieve homogeneity. Then, to avoid segregation, the water has been added into two parts, and the mortar was blended for 3 minutes. Finally, the mortar was left to stand for two minutes and re-mixed for two minutes to complete the mixing sequence. Conduct the mechanical examinations, 50×50×50 mm cubic samples were used for compressive strength, density, and absorption tests. Also, 100×200 mm cylindrical samples were utilized for splitting tensile strength tests [16]. All samples were molded and placed in water for curing until the testing ages of 7 and 28 days.

3. Test Procedure

Mechanical and physical characteristics were examined to evaluate the impact of the PVC waste ratio level and the viability of using this material as an acceptable aggregate replacement in mortar.

3.1. Mechanical Characteristics

The compression tests were performed by EN BS 12300 – PART 3[17]. Three cube samples (50 mm on a side) were taken for each mixture and then examined at 7 and 28 days to determine the results. As with the compressive strength, a mean of three cylinder (100×200 mm^2) results was used to determine splitting tensile strength evaluated under ASTM C496[18].

The following is how the splitting tensile strength was calculated:

$$F_t=2P/\pi dl \quad ......(1)$$

Where:

Ft is the tensile splitting strength (N mm^{-2}), maximum applied load (N) is P, the length (mm) is L, and d is the diameter (mm).

3.2. Physical Properties

Density was measured under the standard BS 1881: part 114 [19]. The same samples used in the density tests were also used to determine the water absorption test. The samples were dried until no change in the succeeded reading of weight was observed. The density was calculated geometrically; the specimen was refined to acquire flat and regular surfaces. The caliper measured the lengths of the sides, and the scale was used to weigh the object. Mortar samples were tested for water absorption. The characteristic of absorption relates the ratio of water weight (the change in weight for saturated and dried status) to the weight of the dry samples.

4. Results and Discussions:

4.1. The Compressive Strength

Figure 1 illustrate the results of compressive strength tests conducted on mortar after 7 and 28 days, respectively. The use of PVC particles as a partial substitution for sand adversely impacted mortar compressive strength in the samples containing PVC particles.

The reduction in compressive strength results from the low adhesion of cement paste to PVC particles and may be due to the weakness of the PVC particles [5][20].

However, the greatest reduction in the strength of mixtures was about 49% and 41% for 7 and 28 days, respectively. Hence, the variation of concrete compressive strength ranged between 13.68 - 26.8 and 21.5- 36.34 MPa for seven days and twenty-eight days, respectively.

The decrease in compressive strength of mortar conforms with many studies which find that incorporating PVC reduced the compressive strength [5][21][22][23][24]. The reduction of workability and loss of bond between the surface of plastic and cement paste leads to that behavior, in addition to the hydrophobic nature of PVC aggregate.

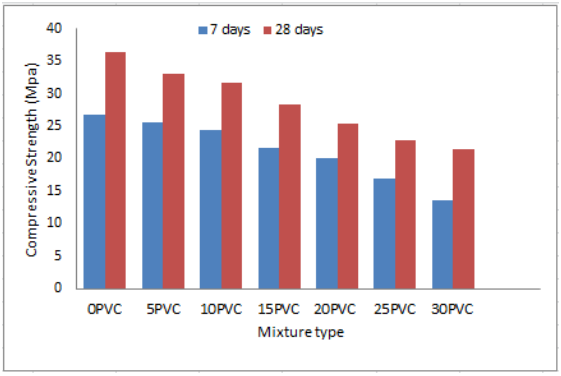

Figure (1): Compressive strength for mortar

4.2 Splitting Tensile Strength

The results of the seven days and twenty-eight days for the strength tensile tests of PVC mortar are shown in figure 2. Similar to the outcomes reported in the compressive strength results, adding PVC particles reduces the splitting tensile strength. However, it was apparent that as the PVC ratio rose, the tension strength of concrete significantly decreased. For seven and twenty-eight days, the highest drop in splitting tensile strength was 34% and 63%.

As described in the previous paragraph, the same reasons that affected the compressive strength may be responsible for the decrease in splitting tensile strength. Additionally, the decreased splitting tensile strength results from microcracks developing under the applied load, resulting in a lower splitting tensile strength compared to the reference mixture.

Additionally, adding PVC particles makes concrete more porous, which lowers the splitting tensile strength. The findings regarding tensile strength were consistent with several of researches that demonstrated how using any PVC negatively affects the mechanical properties of concrete [9][22][23].

Kou et al. [25] reported that PVC waste decrease the 28 days strength of lightweight concrete. The plastic particles have a smooth surface, which minimizes the ITZ's strength and results in bonding between cement paste and PVC particles. Finally, PVC particles will form weak regions inside mixtures.

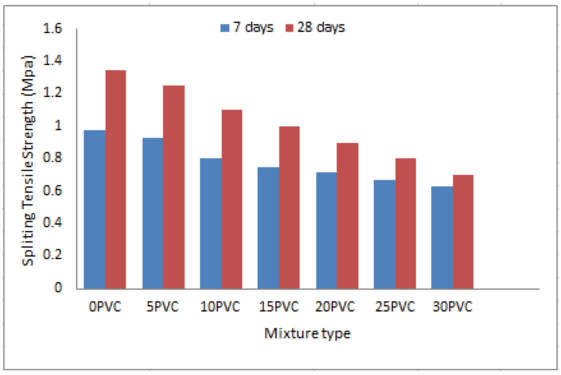

Figure (2): Splitting tensile strength for mortar

4.3 The Relationship Between Splitting Tensile Strengths and Compressive

Compressive and splitting tensile strengths are shown in Figures 3 and 4, respectively. As seen in the figures, PVC concrete's compressive and tensile strengths were found to correlate quite well. The correlation factor (R^2) of 0.99 shows that the mortar compressive strength strongly correlated with mortar slitting tensile strength regardless of several substitution levels of PVC powder. Kou et al. [25] reported the same relationship for this parameter. The linear relationship between compressive and tensile strengths is also expressed using regression analysis and written out in equation 2.

$$f_{st} = 0.0789f_c + 1.021 \quad \ldots(2)$$

f_{st} and f_c represent PVC concrete's tensile and compressive strength, respectively.

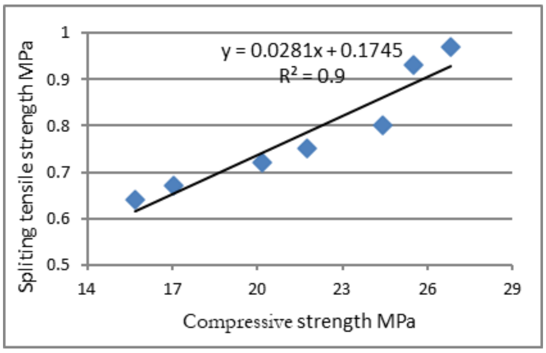

Figure (3): Relationship between compressive and splitting tensile strength at 7 day

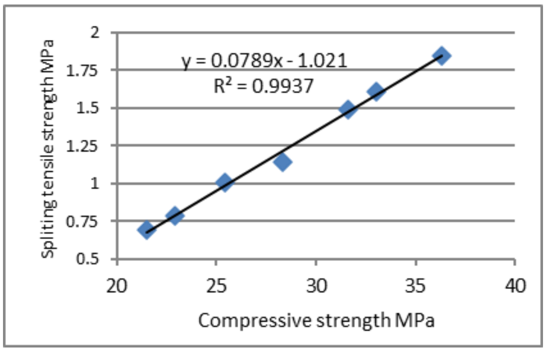

Figure (4): Relationship between compressive and splitting tensile strength at 28 day

4.4- Density and Absorption

Figure 5 and figure 6 explain the density results of all mixtures. It is clear that the lower density of mortar comes from the higher content of PVC particles. As expected, there is a strong correlation between PVC powder content and density. The decrease in density can be due to PVC's lower density than sand.

Figure 7 displays the absorption of the reference mixture and those containing PVC particles. Water absorption is an essential characteristic because of its effect on the corrosion of reinforcement. Concrete absorption was examined at twenty-eight days of age.

The results of absorption tests revealed that the incorporation of PVC waste led to an increase in absorption. As apparent, the lower absorption was in the reference mixture, and the highest absorption was in the mixture containing 30% PVC waste. The absorption results conform with the findings of Ruiz-Herrero et al. [11].

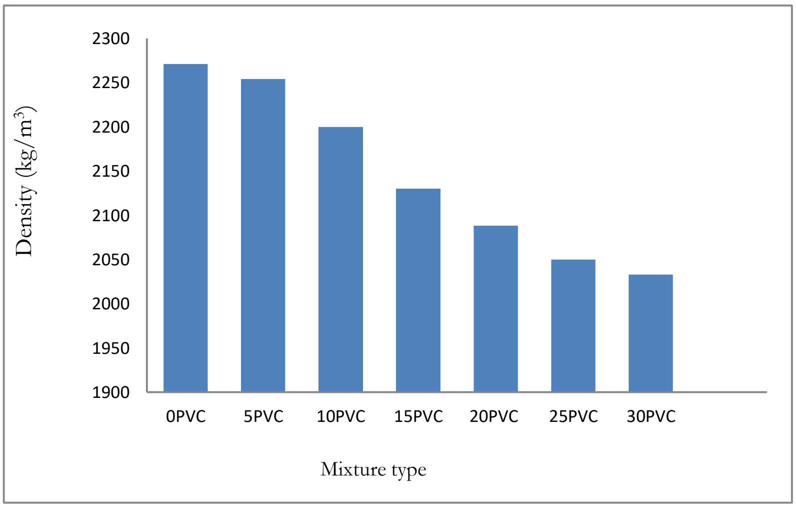

Figure-5 Density

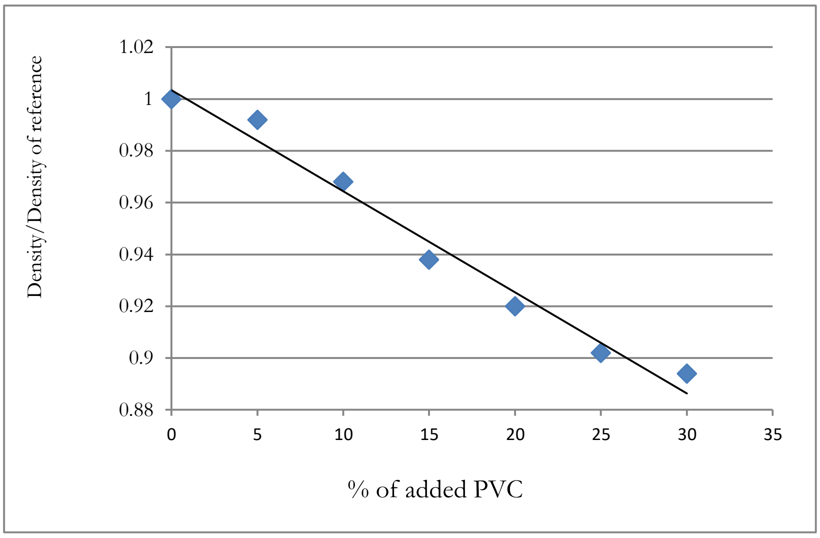

Figure-6 Percent of density decrease

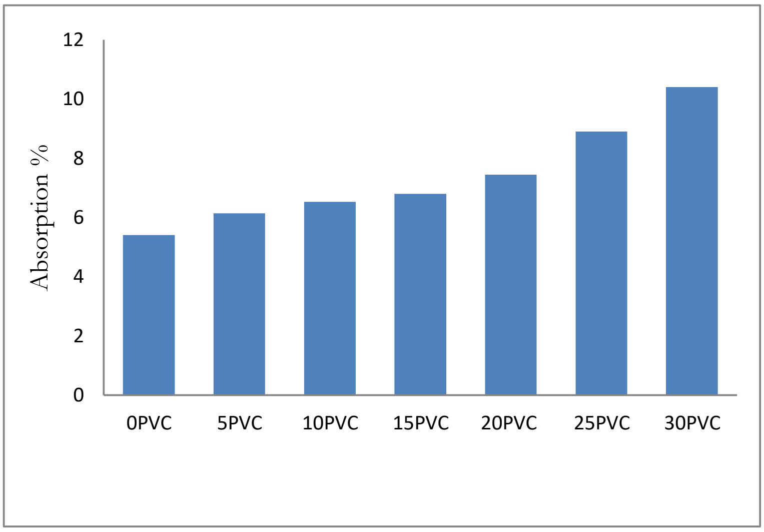

Figure-7 Absorption

5- Conclusions

The present study's experimental results indicate the following conclusions:

1- Utilizing PVC waste as particles harmed the compressive strength of concrete. This outcome gets increasingly evident as PVC content increases.

2- The splitting tensile strength followed the same pattern as its compressive strength. Increasing PVC content reduces the mortar's splitting tensile strength.

3- The introduction of PVC particles changed the density. With increasing PVC particles content, density was seen to decrease.

4- The absorption of concrete was found to increase with the PVC waste dosage increase.

References

[1] H. O. Kose, S. Ayaz, and B. Koroglu, "Waste management in Turkey national regulations and evaluation of implementation results," *Perform. Audit Rep.*, p. 82, 2007.

[2] A. Hassani, H. Ganjidoust, and A. A. Maghanaki, "Use of plastic waste (poly-ethylene terephthalate) in asphalt concrete mixture as aggregate replacement," *Waste Manag. \& Res.*, vol. 23, no. 4, pp. 322–327, 2005.

[3] F. U.S. National Park Service; Mote Marina Lab, Sarasota, "Garbage In, Garbage Out," *Audubon magazine*, 1998.

[4] A. of waste Azo. Build, "beneficial use of industrial by-products as constituents of concrete," 37, 2003.

[5] B. Safi, M. Saidi, D. Aboutaleb, and M. Maallem, "The use of plastic waste as fine aggregate in the self-compacting mortars: Effect on physical and mechanical properties," *Constr. Build. Mater.*, vol. 43, pp. 436–442, 2013.

[6] S. Akçaözo\uglu, K. Akçaözo\uglu, and C. D. Ati\cs, "Thermal conductivity, compressive strength and ultrasonic wave velocity of cementitious composite containing waste PET lightweight aggregate (WPLA)," *Compos. Part B Eng.*, vol. 45, no. 1, pp. 721–726, 2013.

[7] F. Pelisser, O. R. K. Montedo, P. J. P. Gleize, and H. R. Roman, "Mechanical properties of recycled PET fibers in concrete," *Mater. Res.*, vol. 15, pp. 679–686, 2012.

[8] K. Hannawi, W. Prince, and S. Kamali-Bernard, "Effect of thermoplastic aggregates incorporation on physical, mechanical and transfer behaviour of cementitious materials," *Waste and Biomass Valorization*, vol. 1, no. 2, pp. 251–259, 2010.

[9] Z. Z. Ismail and E. A. Al-Hashmi, "Use of waste plastic in concrete mixture as aggregate replacement," *Waste Manag.*, vol. 28, no. 11, pp. 2041–2047, 2008.

[10] A. Merlo, L. Lavagna, D. Suarez-Riera, and M. Pavese, "Mechanical properties of mortar containing waste plastic (PVC) as aggregate partial replacement," *Case Stud. Constr. Mater.*, vol. 13, p. e00467, 2020.

[11] J. L. Ruiz-Herrero *et al.*, "Mechanical and thermal performance of concrete and mortar cellular materials containing plastic waste," *Constr. Build. Mater.*, vol. 104, pp. 298–310, 2016.

[12] N. Haghighatnejad, S. Y. Mousavi, S. J. Khaleghi, A. Tabarsa, and S. Yousefi, "Properties of recycled PVC aggregate concrete under different curing conditions," *Constr. Build. Mater.*, vol. 126, pp. 943–950, 2016.

[13] A. Sadrmomtazi, S. Dolati-Milehsara, O. Lotfi-Omran, and A. Sadeghi-Nik, "The combined effects of waste Polyethylene Terephthalate (PET) particles and pozzolanic materials on the properties of self-compacting concrete," *J. Clean. Prod.*, vol. 112, pp. 2363–2373, 2016.

[14] R. H. Faraj, H. F. H. Ali, A. F. H. Sherwani, B. R. Hassan, and H. Karim, "Use of recycled plastic in self-compacting concrete: A comprehensive review on fresh and mechanical properties," *J. Build. Eng.*, vol. 30, p. 101283, 2020.

[15] A. Standard, "C128-12, Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate," *ASTM Int. West Conshohocken, PA*, 2012.

[16] C. ASTM, "192. 2004. Standard Practice for Making and Curing Concrete Test Specimens in

the Laboratory," *Annu. B. ASTM Stand.*, vol. 4, 2006.

[17] B. S. En and others, "12390-3, Testing hardened concrete-Part 3: Compressive strength of test specimens," *Br. Stand. Inst.*, 2002.

[18] A. S. for Testing, M. C. C.-9 on Concrete, and C. Aggregates, *Standard test method for splitting tensile strength of cylindrical concrete specimens*. ASTM International, 2011.

[19] BS, "Method for determination of density of hardened concrete." London, p. part114, 1983.

[20] B. Rai, S. T. Rushad, B. Kr, and S. K. Duggal, "Study of waste plastic mix concrete with plasticizer," *Int. Sch. Res. Not.*, vol. 2012, 2012.

[21] Ö. B. Ceran, B. \cSim\csek, T. Uyguno\uglu, and O. N. \cSara, "PVC concrete composites: comparative study with other polymer concrete in terms of mechanical, thermal and electrical properties," *J. Mater. Cycles Waste Manag.*, vol. 21, no. 4, pp. 818–828, 2019.

[22] S. Bahij, S. Omary, F. Feugeas, and A. Faqiri, "Fresh and hardened properties of concrete containing different forms of plastic waste--A review," *Waste Manag.*, vol. 113, pp. 157–175, 2020.

[23] M. Batayneh, I. Marie, and I. Asi, "Use of selected waste materials in concrete mixes," *Waste Manag.*, vol. 27, no. 12, pp. 1870–1876, 2007.

[24] A. A. Mohammed, I. I. Mohammed, and S. A. Mohammed, "Some properties of concrete with plastic aggregate derived from shredded PVC sheets," *Constr. Build. Mater.*, vol. 201, pp. 232–245, 2019.

[25] S. C. Kou, G. Lee, C. S. Poon, and W. L. Lai, "Properties of lightweight aggregate concrete prepared with PVC granules derived from scraped PVC pipes," *Waste Manag.*, vol. 29, no. 2, pp. 621–628, 2009.