 EAJSE

Utilization of Waste Plastic and Waste Glass Together as Fine and Coarse Aggregate in Concrete

Ilham I. Mohammed[1] & Nazim Abdul Nariman[2] & Kaywan Othman[3] & Sarhad Ali[4] & Peshwaz Mohammed[5] & Sirwan Samad[6]

[1,2,3,4,5&6]Civil Engineering Department, Faculty of Engineering, Tishk International University, Sulaimani, Iraq
Correspondence: Ilham I. Mohammed, Tishk International University, Sulaimani, Iraq.
Email: ilham.ibrahim@ishik.edu.iq

Doi: 10.23918/eajse.v6i2p1

Abstract: Concrete is one of the common materials for producing different construction-related structures around the world, mainly due to its low cost, availability, long period of durability, and ability to withstand very bad weather conditions. Glass and plastics have become an inseparable and integral part of our lives. The amount of glass and plastics consumed annually has been growing steadily. Its low density, strength, user-friendly designs, fabrication capabilities, long life, lightweight, and low cost are the factors behind such phenomenal growth. Glass and plastic are found in municipal solid waste (MSW), and they are of the most used daily materials; they can be used as a construction material in buildings or primarily in the form of containers, etc. This paper focuses on replacing some fine and coarse aggregates in concrete with waste plastic and waste glass. To evaluate the effects of including these wastes, mechanical tests like compressive strength, splitting tensile strength, and flexural tests conducted on samples prepared with four different percentages of fine and coarse aggregate replaced with fine and coarse plastic and glass waste together. From the results obtained, it was seen that waste plastic and waste glass together reduces compressive strength, flexural strength, and density, while in some proportions of replacement increased splitting tensile strength and water absorption percentage; however, the results are in a manner that even though the concrete produced with such aggregates can be used for structural applications.

Keywords: Waste Plastic Aggregate, Waste Glass Aggregates, Mechanical Properties of Concrete

1. Introduction

Kurdistan has experienced a rapid boom in the construction sector, especially during 2005-2014, which has caused a high economic growth rate. A material that is the theme of the construction sector is concrete. Concrete is known as one of the oldest and most used construction materials around the world due to its low cost, availability of its constituent material, long-running durability, and ability to sustain extreme weather environments. The worldwide production of concrete is ten times that of steel by tonnage (Li, 2011). However, other construction materials such as steel and polymers, due to their price and less availability, are less common.

The concrete production among the five countries responsible for producing 80% of the total world's concrete was estimated as of 2014 by 3.013 billion tons annually (Mehta, 2001). It can be said that this number under normal conditions increases annually by increasing the number of the population due to the demand for different structures.

Received: October 10, 2020
Accepted: November 26, 2020
Mohammed, I. I., & Nariman, N.A., & Othman, K., & Ali, S., & Mohammed, P., & Samad, S. (2020). Utilization of waste plastic and waste glass together as fine and coarse aggregate in concrete. *Eurasian Journal of Science & Engineering*, 6(2), 1-10.

Polyethylene (PET) plastic is one type of thermoplastic polymers and a universal polymer currently in use for penetrating many aspects of life for global trends, including household and industrial applications. This material is made by several methods by addition polymerization of ethene, which is principally produced by the cracking of ethane and propane, naphtha and gas oil; nevertheless, it can be processed into either short life products, such as for packaging food, medical devices, drinking bottles or long-life products such as Polyethylene sheeting (film) which has a big role in offering plastic protection. The global wide use of (PET) usually accompanied by wastes as the material approach to the end of their useful economic life. These wastes are in progress day by day and have been disposed of in the form of landfilling (Mohammed, Mohammed, & Mohammed, 2019).

With such large and varying applications, plastics contribute to an ever-increasing volume in the solid waste stream (Siddique, Khatib, & Kaur, 2008). Globally, it can be seen as a very dramatic increase in plastics from the time when it was first developed for industrial use. The disposal of such waste causes poor soil fertility, emission of toxic gases, poor drainage due to landfill, pollution of groundwater due to leaching of chemicals from these waste products, etc. There are many recycling plastics; using plastic in concrete is also a popular way of recycling plastic wastes. Utilizing plastic waste in the construction industry has two advantages, namely: (I) resolve the environmental problem due to disposal of the waste and (II) reduction in construction costs as these wastes are available in large quantities at low costs (Sadiq & Khattak, 2015).

There are numerous research works on reusing plastic in concrete production. Amula et al. (2016) studied the behavior of concrete which was made of recycled plastic materials along with related physical properties. In the concrete mix they replaced the fine aggregate with plastic in the ranges 0%, 10%, 15%, 20% & 25% and investigated the compressive strength of the product. It was concluded that the compressive strength would be reduced by increasing the plastic content up to 70%. Also, Ashwini (2016) studied the flexural strength of concrete specimens made of E-waste particles as fine and coarse aggregates with a percentage replacement ranging from 0%, 20% to 30%. It was seen that for a given w/c, the use of plastics in the mix lowers the density, compressive strength, and tensile strength of concrete and also tends to make concrete ductile, hence increasing the ability of concrete to significantly deform before failure. This characteristic makes the concrete useful when subjected to harsh weather such as expansion and contraction or freeze and thaw (Ashwini, 2016).

On the other hand, it can be said, glass which is made from liquid sand (which is mostly made of silicon dioxide) is found in municipal solid waste (MSW) and is one of the most used daily materials. Glass can be used as a construction material in buildings or primarily in the form of containers such as beer bottles, soft drink bottles, etc. The reuse of waste glass is also one of the most important issues worldwide due to the increase of solid wastes in the landfill and the non-degradable nature of its disposal (Shao, Lefort, Moras, & Rodriguez, 2000). A huge amount of natural aggregates, fuel, sand, and water, are being consumed in cement and concrete production. Consequently, to minimize these constituent materials, to reduce their environmental consequences, researches have concentrated on the use of waste materials as potential alternatives in the construction industry, especially in concrete construction. The use of recycled waste glass in concrete has attracted much interest worldwide, and numerous researches have been carried out, showing the possibility of use of waste glass as building materials by partially replacing in concrete mixtures (Kataria, 2010; Mohammadinia, Wong, Arulrajah, & Horpibulsuk, 2019; Topcu & Canbaz, 2004).

As stated before, plastic and glass waste can attack the environment, and there is a need for managing and reducing the risks due to this waste. There is a good chance for recycling these types of wastes and incorporating in concrete production. The present research investigates the fundamental properties of concrete partially replaced with plastic and glass aggregate together. Since from the literature review, it is seen that adding plastic to concrete reduces the mechanical properties of concrete to an extent; however, by combining with glass, and these reductions can be compensated while a sustainable mix is provided. Details of experimental tests for assessing workability, density, absorption, strength, and durability are presented and discussed in this paper.

2. Methodology

The study was carried out by using Ordinary Portland Cement, river sand (fine aggregate), natural gravel (coarse aggregate). And replacing the natural aggregates with waste glass (drinking bottles) and waste plastic (polyethylene plastic), the percentage ratios for replacing aggregates were obtained from the literature review in which we used (%5 - %10– %15 - %25) respectively for fine and coarse aggregate. The replacement was done using volume percentage for plastic waste, and through weight percentage for glass waste (the same ratio), due to the huge variance in the density of glass and plastic. The concrete mix was prepared using tap water and a superplasticizer (Gantre 99) to increase the workability. A typical mix design was used to prepare the concrete mixture.

3. Materials Used

The materials used in this study were (fine natural aggregates, natural coarse aggregate, waste plastic (polyethylene terephthalate), waste glass both from drinking bottles, and ordinary Portland cement from Tasluja plant and water). Ordinary Portland cement (OPC) complies with the Iraqi Standard IQ. S 5:1984 Type I and EN 197-1:2011. The waste glasses and waste plastic were obtained from the waste dumping site in Tanjaro site near Sulaimani.

3.1 Waste Plastic as Coarse and Fine Aggregates

Plastic bottles (PET) were cut into small pieces, as shown in Figure 1. After cutting, plastics were washed off to remove the dust and dirt on the surface so that they are ready for the recycling and reusing process. The density of the plastic used was (925 Kg/m^3). Sieve analysis for the coarse and fine plastic aggregate was done. The maximum aggregate size of 6 mm & 16 mm was used for both fine and coarse aggregate, respectively.

Figure 1: Plastic waste as fine and coarse aggregate

3.2 Waste Glass as Coarse and Fine Aggregates

Glass bottles were broken down into small pieces, as shown in Figure 2, by using loss angles abrasion machine. The glass bottles were drinking bottles that are daily used and are sources of landfill contamination with a density of (2400 Kg/m^3). The sieve analysis for the fine and coarse glass also was done, and the maximum aggregate size of 6 mm & 16 mm was used for both fine and coarse aggregate, respectively.

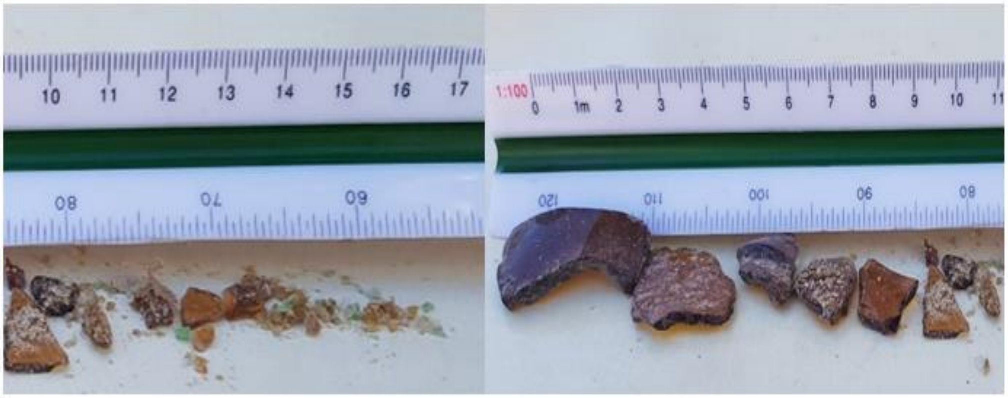

Figure 2: Glass waste as fine and coarse aggregate

3.3 Design of Concrete Mixture

Concrete is a mixture which contains a different amount of constituent materials to produce a fresh mix. A typical concrete mix is adopted to prepare the fresh concrete samples, with the proportions for one-meter cubic given in Table 1. Different percentages (%5, %10, %15, %25) by weight and volume for plastic and glass were chosen based on the literature review, and samples were prepared by replacing normal aggregate with the recycled plastic and glass at each percentage.

For example, 0% is the control sample, which means the concrete sample is prepared with conventional constituent materials. 5% is the ratio in which 2.5% plastic by volume and 2.5% glass by weight from both fine and coarse aggregate is replaced with natural fine and coarse aggregate to prepare the fresh concrete samples. The rest of the samples are like this one. To compare the effect of glass and plastic in concrete, a control sample is prepared, and the rest of the samples were compared with this one.

Table 1: Detail of Constituent materials for the concrete samples for 1-meter cubic based on the mix design

Sample No.	Percent of Replacement	Water for $1m^3$	Cement for $1m^3$	Fine Aggregate for $1m^3$	Coarse Aggregate for $1m^3$	Fine Plastic for $1m^3$	Coarse Plastic for $1m^3$	Fine Glass for $1m^3$	Coarse Glass for $1m^3$
1	0%	151.78 l/m^3	475 kg/m^3	648.9 kg/m^3	1037.2 kg/m^3				
2	5%	151.78 l/m^3	475 kg/m^3	632.677 kg/m^3	1011.27 kg/m^3	5.066 kg/m^3	5.383 kg/m^3	8.106 kg/m^3	12.666 kg/m^3
3	10%	151.78 l/m^3	475 kg/m^3	616.455 kg/m^3	985.34 kg/m^3	10.132 kg/m^3	10.766 kg/m^3	16.21 kg/m^3	25.332 kg/m^3
4	15%	151.78 l/m^3	475 kg/m^3	600.232 kg/m^3	959.41 kg/m^3	15.198 kg/m^3	16.149 kg/m^3	24.31 kg/m^3	37.998 kg/m^3
5	25%	151.78 l/m^3	475 kg/m^3	567.787 kg/m^3	907.55 kg/m^3	25.33 kg/m^3	26.915 kg/m^3	32.42 kg/m^3	63.33 kg/m^3

3.4 Preparation of Concrete Mixtures

To prepare the mixture, cement, fine aggregate, coarse aggregate, fine plastic, coarse plastic, fine glass, and coarse glass were added to the mixer. Superplasticizer (Gantre 99) was mixed with some portion of water that is designed for the mix (to have a workable mix). Materials were mixed for 2 minutes after the mixing completed water and the superplasticizer was added to the mixture in three stages, first some water was added to make the materials wet, and then mixed for 2 minutes. A mixture of superplasticizer and water was added to the mixture and mixed for 1 minute. After that, retained water was added to the mixture, and the fresh concrete was prepared.

The slump test was done to evaluate the workability of the fresh concrete of all the mixtures at all different ratios of aggregate replacements, and it was noticed that for all of the samples, the slump was flow, and there was no specific change in the workability of a particular replacement. This result was due to the amount of superplasticizer was used equally for all the samples. The concrete mixture was cast into different molds, and each sample was left in the mold for one day, and the concrete specimens were removed from the mold without damage. After demolding, it was kept in the water tank to be cured at 20° C for 28 days.

4. Results and Discussion

4.1 Compressive Strength Test Results and Discussion

To study the effects on compressive strength fine and coarse aggregates were replaced with plastic and glass together. Cube samples of concrete were used for each replacement ratios (0%, 5%, 10%, 15%, 25%). The test was conducted as per (ASTM – C39) (Annual Book of ASTM Standard, 2013). The different percentages of plastic and glass waste are shown in Table 2 and Figure 3.

From the data, it can be seen that by increasing the amount of waste aggregate, compressive strength will reduce, however as compared to the results obtained by (Mohammed, 2019) and (Kılıçoğlu, 2017), it can be said that the results are reasonable, since even up to 25% replacement of both aggregate types there is only maximum 20% reduction from the compressive strength for the designated mix.

Table 2: Results of compressive strength test for 28 days

Sample No.	Compressive Strength MPa	Percentage of Reduction %
0%	50.14	0.00
5%	45.92	-8.42
10%	45.75	-8.75
15%	42.21	-15.81
25%	39.70	-20.82

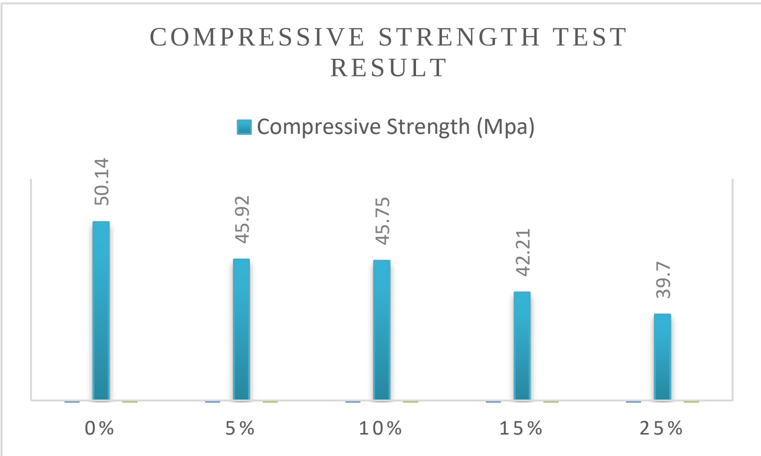

Figure 3: Compressive strength of concrete at different percentages of waste glass and plastic aggregate

For finding the effects of replacing fine and coarse aggregates with plastic and glass waste aggregate on splitting tensile strength, the cylindrical specimens were prepared for each replacement ratio (0%, 5%, 10%, 15%, 25%). The test was conducted as per (ASTM – C496). The test results are shown in Table 3 and Figure 4. From the test data, it can be seen that by increasing the percentage of replacing plastic and glass as fine and coarse aggregates, the splitting tensile strength decreases. Tensile splitting strength of concrete mixtures decreased with the increase in glass aggregate as stated by (Kılıçoğlu & Coruh, 2017). However, combining these two waste materials in a smaller range is promising; from these results, it can be seen that the reduction curve correlates with the compressive strength test.

Table 3: Results of splitting tensile strength test for 28 days

Sample No.	Splitting Tensile load KN	Splitting Tensile Strength Mpa (2P/πDL)
0%	104	3.31
5%	97	3.09
10%	80	2.55
15%	74	2.36
25%	70	2.23

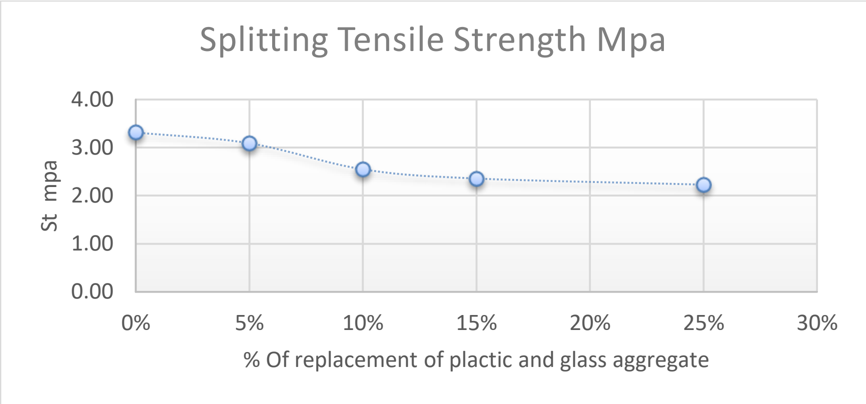

Figure 4: Splitting tensile strength of concrete at different percentages of waste glass and plastic aggregate

4.2 Flexural Strength (Modulus of Rupture) Results and Discussion

The effects of fine and coarse aggregates that are replaced with plastic and glass wastes were observed on flexural strength. In this case, for each percentage ratio (0%, 5%, 10%, 15%, 25%), two prisms (beams) of 15x15x60 cm were cast and tested after 28 days. The results were compared with those from the control samples.

In general, there is a reduction in modulus of rupture as the amount of replacing waste materials both plastic and glass increase. As can be seen from the data, the reduction in modulus of rupture is more than the reduction in compressive strength. This issue can be attributed to the inclusion of the glass aggregate content since glass has a better resistance against compression and weak in tension. It can be useful to compare this reduction in flexure with the past test data on different concretes with plastic and glass waste. Tests on self-compacting concrete with PVC powder indicate that there is a 20% reduction in flexural stress when 25% of plastic by cement weight is added. According to Kataria (2010) the optimum replacement level of glass is nearly 20% by cement weight. The test was conducted as per ASTM C78 for a four-point load test. The test result of flexural strength is shown in Table 4 and Figure 5.

Table 4: Results of flexural strength test for 28 days

Sample No	Ultimate Load Up to Failure (F) KN	Flexural Strength Mpa (FL/bd^2)
0%	62.18	11.1
5%	60.81	10.8
10%	53.31	9.5
15%	42.81	7.6
25%	47.51	8.4

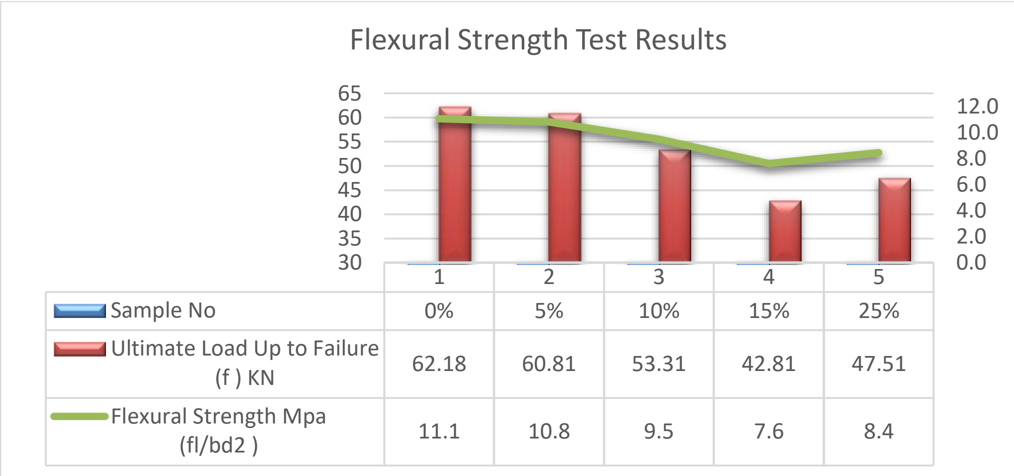

Figure 5: flexural test results at 28 days

4.3 Density

The density of each trial sample was calculated after 28 days of curing. The purpose of the test is to find out the effects of replacing fine and coarse aggregates with waste glass and waste plastics on densities at each % of replacement. For each percentage, an average of 3 samples was used. It can be seen that the density decreases as the ratio of replacement increases; this is mostly due to the density of plastic, which is about 925kg/m^{3,} while the density of normal weight aggregate is between 2300-2600 kg/m3.

4.4 Water Absorption

Water absorption is one of the parameters that can be used to evaluate good quality concrete. If the concrete has low permeability, it means low water absorption; then, it is labeled as resistant to freezing and thawing. Concrete with low permeability resists the ingress of water and is not susceptible to freezing and thawing and hence it can be termed as a durable concrete. The water absorption was done using the samples prepared at the age of 28 days using cubic specimens.

From the results of the absorption, it can be seen that as the waste plastic and glass increases, the absorption increases. This can be attributed to the weak bond or transition zone between plastic and natural aggregate or cement paste due to the surface texture of plastic and the matrix.

Table 5: Density and water absorption test results of the samples at each percentage of replacements

Sample No.	Density (Kg/m^3)	Water Absorption (%)	The difference in Percentage %
0%	2370.52	3.335	0
5%	2368	3.34	1.1
10%	2321.04	3.397	1.8
15%	2311.85	3.524	5.6
25%	2296.3	3.619	8.5

5. Conclusion

To investigate the effects of waste plastic and waste glass on plain concrete properties, five trial mixes were designed. Each sample was tested with a compression test. Splitting tensile strength test, flexural test, density, and water absorption. The following conclusions are drawn from the present work.

- By increasing the amount of waste plastic and waste glass, the compressive strength gradually decreases from (50.14 MPa) to (39.7 MPa) at (25%) replacement ratio. This strength can be used for different structural applications.
- At (10%) replacement, compressive strength is (45.75), compared to (5%) sample; the compressive strength is slightly deceased, this means (10%) replacement could be the proper mixture depending on the compressive strength.
- Splitting tensile strength values of the samples decreases to (32.72%) at a 25% replacement ratio, compared to the control sample.
- For the flexural strength, the modulus of rupture decreases up to (31.15%) at a 25% replacement ratio. However, at a 10% ratio, there is only a 15% reduction from the modulus of rupture, which means replacing the aggregates with waste plastic and waste glass, the value of the modulus of rupture decreases.
- The density of the trail mix samples is gradually decreasing by increasing the replacement of fine and coarse aggregates with waste plastic and waste glass.
- From the results of the absorption, it can be seen that as the waste plastic and glass increase in the samples, the absorption increase. This can be attributed to the weak bond or transition zone between plastic and natural aggregate or cement paste due to the surface texture of plastic and the matrix.
- At a 25% replacement ratio, even though there was a reduction for all the tests except the density, as a conclusion, it can be said, utilizing plastic and glass as fine and coarse aggregate together creates a concrete that is sustainable environmentally, and samples can be used for structural applications.

References

Amula, R.G., Ashraf, A., Hashim, M., Rejith, K.U., & Vijitha.V. (2016). Use of waste plastic as fine aggregate substitute in concrete. *International Journal of Scientific & Engineering Research*, 7(4), 172-177.

Ashwini, M. (2016). Partial replacement of E-plastic waste as coarse-aggregate in concrete. *Procedia Environmental Sciences*, 35, 731 – 739.

ASTM Designation C143 (2013). Standard Test Method for Slump of Hydraulic- Cement Concrete, Annual Book of ASTM Standard.

ASTM Designation C39 (2013). Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, Annual Book of ASTM Standard.

ASTM Designation C496 (2013). Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens, Annual Book of ASTM Standard.

ASTM Designation C78 (2013). Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Four-Point Loading), Annual Book of ASTM Standard.

Kataria, A. (2010). *Studies on mechanical properties of concrete containing waste glass powder and post-consumer waste plastic*. MSc Thesis, Department of Civil Engineering. Thapar University, India.

Kılıçoğlu, C., & Çoruh, S. (2017). Recycling of waste glass in a concrete plant as aggregate and pozzolan replacement. *Int. J. Global Warming,* 11(3), 250–262.

Li, Z. (2011). *Advanced concrete technology*. John Wiley & Sons, Inc.

Mehta, P. (2001). Reducing the environmental impact of concrete. *Concrete International–American Concrete Institute*, pp. 61–66.

Mohammadinia, A., Wong, Y., Arulrajah, A., & Horpibulsuk, S. (2019). Strength evaluation of utilizing recycled plastic waste and recycled crushed glass in concrete footpaths. *Construction and Building Materials*, 197, 489-496.

Mohammed, A.A., Mohammed, I.I., & Mohammed, S.A. (2019). Some properties of concrete with plastic aggregate derived from shredded PVC sheets. *Construction and Building Materials,* 201, 232-245.

Sadiq, M.M., & Khattak, M.R. (2015). Literature review on different plastic waste materials use in concrete. *Journal of Emerging Technologies and Innovative Research*, 2(6).

Shao, Y., Lefort, T., Moras, S., & Rodriguez, D. (2000). Studies on concrete containing ground waste glass. *Cement and Concrete Research*, 91-100.

Siddique, R., Khatib, J., & Kaur, I. (2008). Use of recycled plastic in concrete: A review. *Waste Management*, 28(10), 1835-1852.

Topcu, I.B., & Canbaz, M. (2004). Properties of concrete containing waste glass. *Cem. Concr. Res*. 34 (2), 267–274.