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REUSE PLASTIC AND GLASS WASTES AS A PARTIAL REPLACEMENT OF CONCRETE COMPONENTS

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Abstract

The current paper investigates the possibility of replacing part of the fine aggregates, part of the cement, or both with crushed glass and plastic wastes and evaluate the change in its compressive strength. In this work, crushed glass and plastic aggregates were substituted at different percentages. The compressive strength of the developed concrete was measured after 7 and 28 days and compared with that of traditional concrete (mix ratio of 1:1.5:3). The results showed that the crushed glass wastes could be utilized in concrete as a good substitution of cement and sand. However, the results indicated that the use of plastic wastes decreases compressive strength. Such findings will significantly contribute to reducing the cost of the produced concrete by reducing the amount of used aggregates and this consequently reduces the aggregates demands/ manufacturing. Less consumption of aggregates will reduce the depletion of natural resources.

Keywords: Compressive strength, Concrete, Glass powder, Plastic powder.

1. Introduction

Solid waste is a substance that should be thrown away, which comes from the different activities of humans [1, 2]. Solid wastes normally include medical wastes, domestic wastes, and industrial wastes [3, 4]. These wastes comprise sand, stone, gravel, tiles, ceramics, marbles, glass, wood, aluminium, plastic, papers, paint, plumbing pipes, asbestos, electrical parts and other substances [5-9].

Hashim et al. [10] mentioned that a significant quantity of the non-degradable wastes lasts in the environment for many decades or centuries before it decomposed. Non- degradable wastes cause many significant environmental problems and waste disposal crisis [1, 11-16]. Moreover, the accumulation of such wastes, on a global scale, reached a dangerous level nowadays [17-19]. The current possible solution for this problem is the abandoning of many of these wastes as stockpile or landfill or dumped illegally in a chosen area, which still has many potential negative environmental impacts, such as leaching of dangerous materials to the groundwater [10, 20]. Furthermore, an immense quantity of these wastes cannot be gotten rid of. Thus, the sustainable recycling of these wastes could significantly decrease the negative environmental impacts of these types of wastes [1, 21]. According to Batayneh et al. [22], the hierarchy of the solutions 'waste hierarchy', which ranks the solutions in three levels, the recycling process is the preferred method of waste disposal.

Researches into innovative and new uses of waste materials are frequently reported [23-27]. This researching effort tries to fulfil the need for safer economic disposal of waste materials. For example, carpet wastes have been used, as lightweight aggregates, to develop a new type of concrete [28]. The new concrete was subjected to a series of tests, such as absorption and compressive and flexural strengths. The results of this study indicated that carpet waste decreases the compressive and flexural strengths of concrete, however, it still very comparable to the quality of polymer fibres-based concrete. Therefore, this new type of concrete could be an eco-friendly alternative for the polymer fibres-based concrete. Corncob ash wastes were applied, as a binding material, to produce lightweight concrete [29].

In this study, the corncob ash has been used as cement replacements at different ratios (5 to 35 %). Both compressive strength and weight of the new concrete was measured at 7 and 28 days. The outcomes of this investigation indicated that increasing the ratio of corncob ash is beneficial in terms of concrete weight, but it decreases the compressive strength. However, it has been found that replacing 15 % of cement by corncob ash did not cause a noteworthy reduction in the compressive strength, but it decreases the density of concrete from 2209.38 kg/ m^3 to 1835.06 kg/m^3.

A similar study was conducted by Wardhono [30] to check the feasibility of using seashell wastes to develop a geopolymer concrete. In this study, 10 % of seashell wastes was added, along with fly ash, to the concrete mixture. The obtained results indicated that the application of seashell wastes did not decrease the compressive strength of concrete, and it eliminates the need for thermal curing of concrete, the latter is an essential process for traditional fly ash-based concrete. Coal bottom-ash was also investigated as a possible cementitious material [31]. In this study, coal bottom-ash was used at ratios of 10 %, 20 % and 30 % (weight of cement). The mechanical properties of the developed concrete were assessed after

28 days. The results indicated that the workability of the developed concrete decreased at high ratios of coal bottom-ash, however, there is no significant decrease in the compressive strength. Table 1 lists other studies about the recycling of different waste materials in the concrete industry.

Table 1. Previous studies about recycling of waste materials in concrete.

No.	Recycled material	Main results
1	Oil palm shell and ash [32]	The authors found that compressive strength at early ages was low, but it increased during the late ages to reach a comparable level to that of ordinary Portland cement
2	Construction wastes (ceramic) [33]	The outcomes of this study proved that waste ceramic could be used as efficient, cost-effective, and eco-friendly alternative to natural coarse aggregates in concrete industry. It has been found that the complete replacement of the natural coarse aggregates (100 %) by wastes ceramic could cause very minor reduction in the mechanical properties of the produced concrete
3	Tire rubbers [34]	The findings of this study demonstrated that the penetration of chloride in the rubber-concrete was lower than its penetration in the traditional concrete, the compressive strength of the rubber-concrete (after the acidic attack) was better than it of traditional concrete. Additionally, it was noticed that both compressive strength and flexural strengths of traditional and rubber concrete were very comparable
4	Marble and granite waste dust [35]	The results proved that the resistance for corrosion of the developed cement is better than that of traditional concrete. Nevertheless, the developed concrete showed lower compressive strength in comparison with the traditional concrete
5	Silica fume and marble [36]	The outcomes of this study indicated that adding low percentages (less than 10 %) of marble waste is beneficial for both durability and strength and of the developed concrete. However, high percentages of marble waste decrease the compressive strength. While the silica fume has enhanced, to a certain limit, both compressive strength and durability of the developed concrete. Better results were obtained by mixing marble waste and silica fume, where it has been found that adding 20 % of marble wastes and 10 % of silica fume enhanced the properties of the developed concrete
6	Sandstone slurry [37]	The results obtained from this investigation indicated that the application of sandstone slurry as filler materials in concrete did not significantly decrease the compressive and flexural strengths, in comparison with traditional concrete. Additionally, it has been found that new concrete has good resistance for chemical attacks, and good permeability
7	GGBS and PFA [9]	After 28 days of curing, the results indicated that the mixture incorporated 80% GGBS and PFA has higher compressive strength relative to the control mixture
8	Waste glass [38]	The obtained results confirmed that the compressive strength was decreased with the increase of the glass ratio

In this context, the objective of the current work is to investigate the possibility of recycling glass and plastic wastes in concrete. These materials will be used as a partial replacement for aggregate and ordinary Portland cement. This recycling method saves dumping spaces and natural resources and helps to keep environments clean.

The objective of this work has been validated via experiments and tests in laboratories; by substituting fine glass and plastic aggregate for certain percentages of the fine aggregate (sand) and check the mechanical properties of the developed concrete. Additionally, the mechanical properties of the developed concrete will be compared with those of traditional concrete.

2. Materials and Methods

Concrete is defined as a structural material that has certain simple components, which forms very solid material when mixed with water. Generally, concrete mixtures consist of coarse and fine aggregates, cement, and water [39].

Additionally, in some cases, essential additives could be added to enhance some properties of concrete. For example, some additives are used to delay or accelerate the hardening process. Concrete is a favourable material in the construction process due to many attractive features, such as its good compressive strength and resistance for fire.

Because of its nature, recipes of concrete could be changed to meet the circumstantial need. For example, its strength, weight, or resistance for chemicals and weather could be controlled by changing the mixing ratios and/ or using some additives. However, like any other construction material, concrete has some disadvantages, such as the high weight, and the negative environmental impacts of concrete industry [40, 41].

Generally, as it was mentioned above, concrete consists of cement, aggregate, and water. The importance of these materials will be explained in the following section of this study.

2.1. Water

Water is a substantial element in the production of concrete. It is required for the initiation of the hydration process through its reaction with the cement, which results in the formation of concrete. Thus, the availability of water is essential to develop concrete. However, an excessive amount of water could give undesirable results, such as the reduction in the compressive strength. Therefore, the scientists studied the optimum water/cement ratio for each type of concrete [1].

2.2. Cement

Cement is a substantial element in the concrete industry as it is responsible for the binding of concrete components. Ordinary Portland cement (OPC), which is responsible for many environmental problems, is the most widely used type of cement in the concrete industry. OPC general chemical and physical properties are listed in Tables 2 and 3 [1, 9, 42, 43].

Table 2. OPC general chemical properties.

Oxide chemical composition	Content %
SiO_2	20.2
CaO	62.63
Al_2O_3	4.9
Fe_2O_3	2.802
MgO	1.05
Na_2O	0.1
K_2O	0.9
SO_3	3.17
TiO_2	0.23
Chloride	0.018
LOI	2.1
IR	1.9

Table 3. OPC general physical properties.

Test name	Result
Initial settling time (min)	110
Final settling time (min)	205
Fines (Blaine) in m^2/kg	307

2.3. Aggregates

Aggregates, which are a main component of concrete, are classified, according to their physical properties, into two types: fine and coarse aggregates. Generally, aggregates with a diameter ≤ 0.2 cm are classified as fine aggregates, while the rest (> 0.2 cm) are classified as coarse aggregates.

The economic parts of concrete utilize the minimum amount of cement to develop the required strengths. Therefore, the coarse aggregate with its larger size will create large portions of the concrete, while the fine aggregate will act as a filler the voids between the coarse aggregates.

Additionally, fine aggregates decrease the consumption of cement as if only coarse aggregates are used in the concrete industry; there will be huge void spaces between the coarse aggregates that must be filled with cement. Therefore, fine aggregates are used to fill these void spaces. Hence, the aim of the concrete industry is to produce concrete mixtures with as few as possible of voids, which significantly decreases the consumption of cement.

Another important factor related to the aggregates is their moisture content (water content). For example, using fresh aggregates decreases water consumption as fresh aggregates contain moisture [44]. Thus, it will not significantly influence the water/cement ratio, and thereby the hydration process will not be influenced.

In the case of using air-dry aggregates, the surfaces will look dry and so some water is taken in, decreasing the water/cement ratio, and consequently, the concrete strength will be slightly decreased. In the case of using oven-dry aggregates, a huge amount of water will be absorbed to fill the internal void spaces, which significantly decreases the water/cement ratio.

As a result, the hydration process is terminated, and the concrete strength is significantly decreased. The saturated dry-surface aggregate has internal void spaces filled with water and so cannot absorb more water. Those aggregates will maintain the water/cement ratio, and the concrete will keep its complete strength [45]. In contrary, over-saturated aggregates (their internal void spaces and surfaces drenched with water) will add water to the mix that increases the water: cement ratio, which results in a reduction in concrete strength.

Therefore, in the current work, the saturated surface dried (SSD) aggregates will be used to guarantee the actual efficiencies of the varied water/cement ratio utilized to prepare the concrete mixture [22].

2.4. Glass wastes

The glass waste material utilized in this experimental work was obtained from reconstruction disposal and building demolition projects in the city of Hilla, Iraq. This material mainly came from clear and pure window glass. The whole quantities were separated from dirt material and impurities, and then it was crushed to a size fine enough to achieve pozzolanic behaviour. The crushed glass was used as a substitution for sand and cement at ratios of 5 %, 10 %, 15 % and 20 %. Table 4 shows the chemical composition of glass waste.

Table 4. Chemical properties of used glass wastes.

Oxides	Content %
SiO_2	71
Al_2O_3	2.25
Fe_2O_3	0.42
CaO	0.9
MgO	3
Na_2O	12

2.5. Plastic wastes

Plastic waste was utilized, in this work, by grinding the collected sample of plastic waste into small particles. Different amounts of this plastic waste (5 %, 10 %, 15 % and 20 %) were used to substitute sand and cement. Then, the development of compressive strength was measured at different ages and compared with that of ordinary concrete. Tables 5 and 6 show the mix design for both glass and plastic wastes.

Table 5. Mix design for glass wastes.

Mix ID	Substitution for aggregates (%)		Substitution for cement (%)	
	Natural aggregate	Glass wastes	OPC	Glass wastes
Mix 1	100	0	100	0
Mix 2	95	5	95	5
Mix 3	90	10	90	10
Mix 4	85	15	85	15
Mix 5	80	20	80	20

Table 6. Mix design for plastic wastes.

Mix ID	Substitution for aggregates (%)		Substitution for cement (%)	
	Natural aggregate	Plastic wastes	OPC	Plastic wastes
Mix 1	100	0	100	0
Mix 2	95	5	95	5
Mix 3	90	10	90	10
Mix 4	85	15	85	15
Mix 5	80	20	80	20

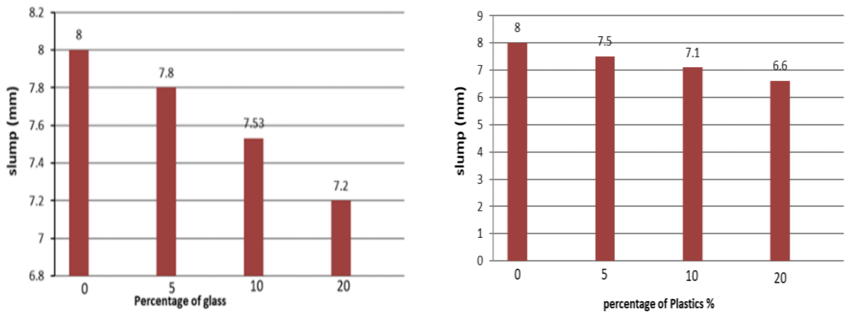
3. Experimental work and solid waste test

In this study, the required amounts of ordinary Portland cement (OPC) and natural aggregates (fine and coarse ones) were secured from a local market at Hilla city. The concrete samples were prepared using a mixing ratio of 1:1.5:3 (cement: sand: gravels), while the water/cement ratio was 0:5. Three cubes (15 cm^3) were prepared for each test. The compressive strength of these cubes was measured at 1.0, 2.0, and 4.0 weeks, and the average of these measurements was taken. Tests and curing process were commenced according to the British Standards, 1981. (Part 5:1983).

4. Results and Discussion

4.1. Slump test

The relationship between workability and the added percentages of glass and plastic wastes in the concrete mixes are shown in Fig. 1. The effect glass wastes (at ratios from 0 to 20%) on slumps and on the strengths of concrete is shown in Fig. 1(a). The results demonstrated that the workability of the developed concrete is very comparable with that of controls. On the contrary, the results indicated that the slump increases with the increase of the plastic ratio, Fig. 1(b). This change in the slump could be explained to the physical properties of the plastic particles, which have a sharper edge than the fine aggregates [1, 23-27].



(a) Using glass wastes. **(b) Using of plastic wastes.**

Fig. 1. Concrete workability verses percentages of glass and plastic wastes.

4.2. Compressive strength test

4.2.1. Ordinary concrete (controls)

Compressive strength of ordinary concrete (without waste materials) is shown in Fig. 2, which will be used for comparison purposes.

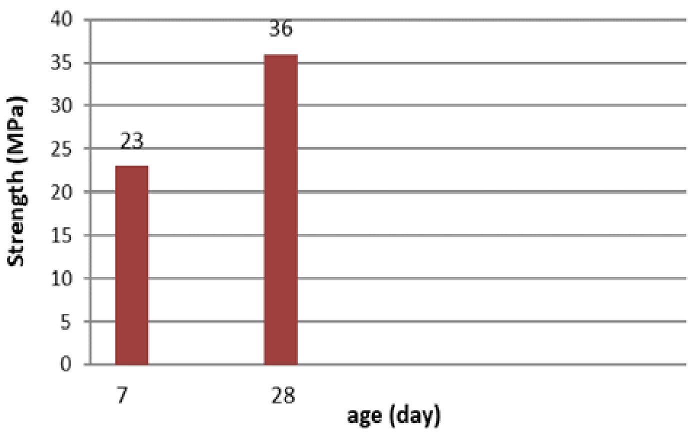


Fig. 2. Compressive strength of ordinary concrete.

4.2.2. Glass waste contain concrete

- **Replacing sand by glass wastes**

As it was mentioned above, the glass wastes were initially crushed in the laboratory and then sieved to a maximum size of 1.18 mm. Different ratios (5 %, 10 %, 15 %, and 20 %) of these wastes were applied as sand replacement in concrete. Figure 3 shows the development of the compressive strength during the experimental work for each mixing ratio. This trend in the compressive strength could be explained by the silica content of the glass wastes that enhanced, which in turn enhanced the strength development of concrete [1, 23-27].

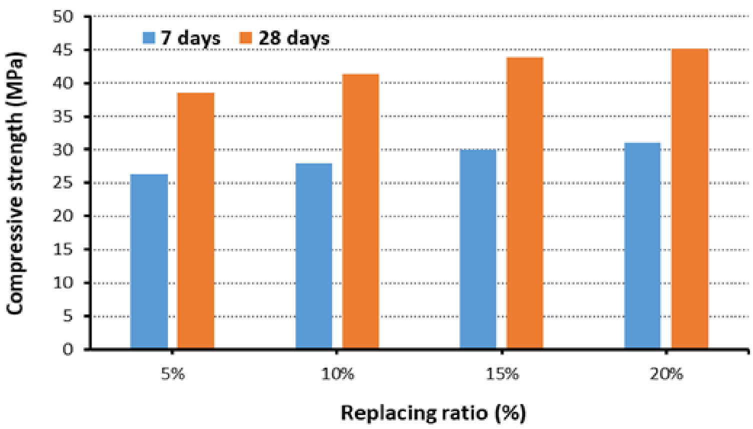


Fig. 3. Compressive strength for sand replacement by glass wastes.

- **Replacing cement by glass wastes**

In this experiment, the crashed glass wastes were sieved to a maximum size of 300µm before it was applied in concrete. Figure 4 shows the progress of the compressive strength, for each mixing ratio, during the test. This decrease in the compressive strength, at late ages, is explained by the fact that decreasing the amount of cement in the concrete decreases the binding between the components of concrete, which in turn decreases the compressive strength [1, 23-27].

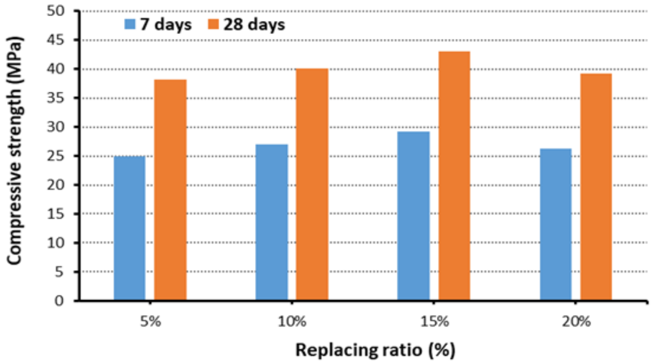


Fig. 4. Compressive strength for cement replacement by glass wastes.

- **Replacing both sand and cement by glass wastes**

In this stage of work, both cement and sand were replaced, at different ratios, by glass wastes. The obtained results, Fig. 5, indicated that the best compressive strength was obtained by adding 20 % and 15 % of glass wastes as a replacement for sand and cement, respectively. Where, it has been found that the compressive strength of the developed concrete, at this replacing ratio, was better than the normal concrete. This behaviour of the new concrete could be attributed to the physical properties of glass particles (such as the surface texture and load resistance). Therefore, according to these results, it could reasonable to recommend using glass wastes as a substitution for sand (up to a certain limit).

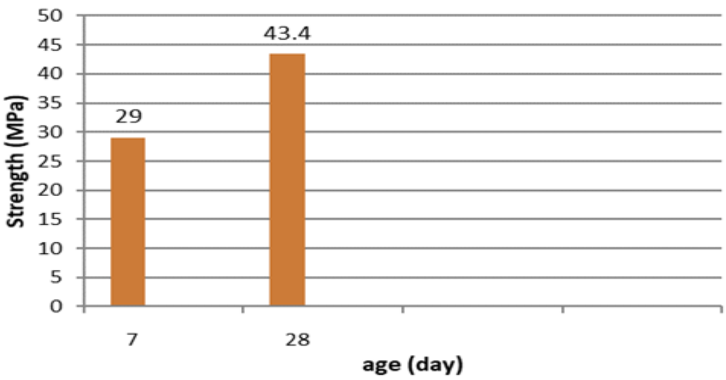


Fig. 5. Compressive strength verses time (20 % of sand and 15 % of cement was replaced by glass waste).

4.2.3. Plastic waste contain concrete

- **Replacing sand by plastic wastes**

Plastic waste was reutilized in this work by grinding it into small particles and then sieved to a maximum size of 1.18mm. Figure 6 shows the measured compressive strength at different ages for each mixing ratio. This decrease in the compressive strength is explained by the fact that plastic wastes do not contain a remarkable amount of binding materials or silica. Thus, increasing the percentage of plastic wastes decrease the binding between the components of concrete, which in turn decreases the compressive strength [1, 23-27].

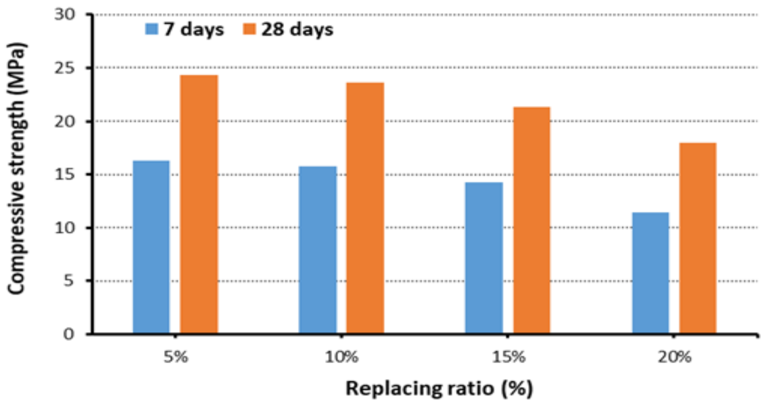


Fig. 6. Relationship between compressive strengths and age (days) when using 5% plastic as a substitute for sand.

- **Replacing cement by plastic wastes**

Waste plastic was utilized, in this study, by grinding them into smaller particles, and then sieved to the maximum size of 300 µm. Figure 7 shows the measured compressive strength at different ages for each mixing ratio. An inverse relationship has been noticed between the compressive strength and age (days) when utilizing 5, 10, 15 and 20% plastic as a replacement for sand and cement. These reductions in strength are due to the strength of the plastic particles, which are smaller than that of the aggregates. Therefore, both the use of concrete with plastic particles and the percentages of replacements should be managed, in accordance with the permitted strengths of the structural elements to be built. This decrease in the compressive strength, at late ages, is explained by the fact that decreasing the amount of cement in the concrete decreases the binding between the components of concrete, which in turn decreases the compressive strength [1, 23-27]. The obtained results showed good agreement with some of the previous studies. For example, it has been reported by Mohammadinia et al. [46] and Siddique et al. [47] that increasing the ratio of waste glass in concrete (as a partial replacement for fine aggregates) decreases the compressive strength.

Finally, due to the recent development in sensing and prediction technologies in the concrete industry and other industries [16, 48-50], the author recommends using these techniques to monitor the behaviour of such new types of concrete. This helps to have a better understanding of the nature and progress of chemical reactions.

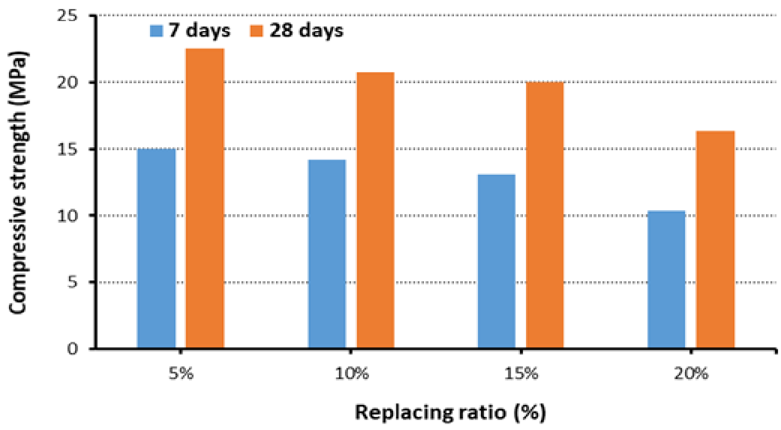


Fig. 7. Relationship between compressive strengths and age (days) when using 5% plastic as a substitution.

5. Conclusions

The results of the current research highlight the following:

- Mechanical properties of concrete, compressive strength and slumps, increases with the increase of waste glass ration and decreases with the increase of waste plastic ratio.
- Sand and cement could both be replaced with powdered waste glass (20% sand and 15% cement) without any noticeable difference in compressive strength. Thus, these ratios could be recommended as it ensures effective and eco-friendly recycling of waste glass.
- Addition of 20% of glass wastes to concrete enhanced the compressive strength of the concrete, which reached a comparable level to that of ordinary concrete. Contrary, the addition of 20% of plastic wastes to the concrete remarkably decreased the compressive strength in comparison with ordinary concrete. As a result, it is advised that concrete with plastic wastes to be used in civil engineering applications that require low compressive strengths (≤ 25 MPa), such as insulation walls, unloaded walls, and foundations for fences. This would contribute to minimising the constriction cost of such structures and enhances the environment by decreasing the need for cement and sands.

References

1. Shubbar, A.A.; Jafer, H.; Dulaimi, A.; Hashim, K.; Atherton, W.; and Sadique, M. (2018). The development of a low carbon binder produced from the ternary blending of cement, ground granulated blast furnace slag and high calcium fly ash: An experimental and statistical approach. *Construction and Building Materials,* 187, 1051-1060.
2. Al-Jumeily, D.; Hashim, K.; Alkaddar, R.; Al-Tufaily, M.; and Lunn, J. (2018). Sustainable and environmental friendly ancient reed houses (inspired by the past to motivate the future). *Proceeding of the 11th International Conference*

on Developments in eSystems Engineering (DeSE). Cambridge, United Kingdom, 214-219.

3. Abdulredha, M.; Al Khaddar, R.; Jordan, D.; Kot, P.; Abdulridha, A.; and Hashim, K. (2018). Estimating solid waste generation by hospitality industry during major festivals: A quantification model based on multiple regression. *Waste Management,* 77, 388-400.
4. Alattabi, A.W.; Harris, C.B.; Alkhaddar, R.M.; Hashim, K.S.; Ortoneda-Pedrola, M.; and Phipps, D. (2017). Improving sludge settleability by introducing an innovative, two-stage settling sequencing batch reactor. *Journal of Water Process Engineering,* 20, 207-216.
5. Siam, A.A. (2011). *Properties of concrete mixes with waste glass.* Ph.D. Thesis. Faculty of Engineering Department, Islamic University of Gaza, Gaza, Palestine.
6. Abdulredha, M.; Alkhaddar, R.; Jordan, D.; and Hashim, K. (2017). The development of a waste management system in Kerbala during major pilgrimage events: determination of solid waste composition. *Procedia Engineering,* 196, 779-784.
7. Alattabi, A.W.; Harris, C.; Alkhaddar, R.; Alzeyadi, A.; and Hashim, K. (2017). Treatment of residential complexes' wastewater using environmentally friendly technology. *Procedia Engineering,* 196, 792-799.
8. Idowu, I.A.; Atherton, W.; Hashim, K.; Kot, P.; Alkhaddar, R.; Alo, B.I.; and Shaw, A. (2019). An analyses of the status of landfill classification systems in developing countries: Sub Saharan Africa landfill experiences. *Waste Management,* 87, 761-771.
9. Shubbar, A.A.; Al-Shaer, A.; AlKizwini, R.S.; Hashim, K.; Hawesah, H.A.; and Sadique, M. (2019). Investigating the influence of cement replacement by high volume of GGBS and PFA on the mechanical performance of cement mortar. *Proceedings of the International Conference on Civil and Environmental Engineering Technologies*. Najaf, Iraq, 31-38.
10. Hashim, K.S.; Al-Saati, N.H.; Hussein, A.H.; and Al-Saati, Z.N. (2018). An Investigation into the level of heavy metals leaching from canal-dreged sediment: A case study metals leaching from dreged sediment. *Proceedings of the International Conference on Materials Engineering and Science*. Istanbul Aydın University, Turkey, 8 pages.
11. Al-Saati, N.H.; Hussein, T.K.; Abbas, M.H.; Hashim, K.; Al-Saati, Z.N.; Kot, P.; Sadique, M.; Aljefery, M.H.; and Carnacina, I. (2019). Statistical modelling of turbidity removal applied to non-toxic natural coagulants in water treatment: A case study. *Desalination and Water Treatment,* 150, 406-412.
12. Hashim, K.S.; AlKhaddar, R.; Shaw, A.; Kot, P.; Al-Jumeily, D.; Alwash, R.; and Aljefery, M.H. (2020). Electrocoagulation as an eco-friendly River water treatment method. *Advances in Water Resources Engineering and Management,* 219-235.
13. Abdulhadi, B.A.; Kot, P.; Hashim, K.S.; Shaw, A.; and Khaddar, R. (2019). Influence of current density and electrodes spacing on reactive red 120 dye removal from dyed water using electrocoagulation/electroflotation (EC/EF) process. *Proceedings of the International Conference on Civil and Environmental Engineering Technologies*. Najaf, Iraq, 12-22.

14. Hashim, K.S.; Al-Saati, N.H.; Alquzweeni, S.S.; Zubaidi, S.L.; Kot, P.; Kraidi, L.; Hussein, A.H.; Alkhaddar, R.; Shaw, A.; and Alwash, R. (2019). Decolourization of dye solutions by electrocoagulation: an investigation of the effect of operational parameters. *Proceedings of the International Conference on Civil and Environmental Engineering Technologies*. Najaf, Iraq, 8 pages.
15. Hashim, K.S.; Hussein, A.H.; Zubaidi, S.L.; Kot, P.; Kraidi, L.; Alkhaddar, R.; Shaw, A.; and Alwash, R. (2019). Effect of initial pH value on the removal of reactive black dye from water by electrocoagulation (EC) method. *Proceedings of the 2nd International Scientific Conference*. Al-Qadisiyah, Iraq, 6 pages.
16. Zubaidi, S.L.; Al-Bugharbee, H.; Muhsen, Y.R.; Hashim, K.; Alkhaddar, R.M.; Al-Jumeily, D.; and Aljaaf, A.J. (2020). A prediction of municipal water demand: Case study in Iraq. *Proceedings of the 12th International Conference on Developments in eSystems Engineering*. Kazan, Russia, 25-32.
17. Hashim, K.S.; Khaddar, R.A.; Jasim, N.; Shaw, A.; Phipps, D.; Kota, P.; Pedrola, M.O.; Alattabi, A.W.; Abdulredha, M.; and Alawsh, R. (2018). Electrocoagulation as a green technology for phosphate removal from River water. *Separation and Purification Technology,* 210, 135-144.
18. Hashim, K.S.; Shaw, A.; Al Khaddar, R.; Ortoneda Pedrola, M.; and Phipps, D. (2017). Defluoridation of drinking water using a new flow column-electrocoagulation reactor (FCER) - Experimental, statistical, and economic approach. *Journal of Environmental Management,* 197, 80-88.
19. Hashim, K.S.; Shaw, A.; Al Khaddar, R.; Pedrola, M.O.; and Phipps, D. (2017). Iron removal, energy consumption and operating cost of electrocoagulation of drinking water using a new flow column reactor. *Journal of Environmental Management,* 189, 98-108.
20. Hashim, K.S.; Shaw, A.; Al Khaddar, R.; Pedrola, M.O.; and Phipps, D. (2017). Energy efficient electrocoagulation using a new flow column reactor to remove nitrate from drinking water - Experimental, statistical, and economic approach. *Journal of Environmental Management,* 196, 224-233.
21. Hashim, K.S.; Idowu, I.A.; Jasim, N.; Al Khaddar, R.; Shaw, A.; Phipps, D.; Kot, P.; Pedrola, M.O.; Alattabi, A.W.; Abdulredha, M.; Alwash, R.; Teng, K.H.; Joshi, K.H.; and Aljefery, M.H. (2018). Removal of phosphate from River water using a new baffle plates electrochemical reactor. *MethodsX,* 5, 1413-1418.
22. Batayneh, M.; Marie, I.; and Asi, I. (2007). Use of selected waste materials in concrete mixes. *Waste Management,* 27(12), 1870-1876.
23. Perevozchikov, A.; Yakovlev, G.; and Kodolov, V. (2000). Polyethylene foam waste utilization for light-weight concrete production. *International Journal of Polymeric Materials,* 47(1), 7-17.
24. Dweik, H.S.; Ziara, M.M.; and Hadidoun, M.S. (2008). Enhancing concrete strength and thermal insulation using thermoset plastic waste. *International Journal of Polymeric Materials and Polymeric Biomaterials,* 57(7), 635-656.
25. Shubbar, A.A.; Sadique, M.; Shanbara, H.K.; and Hashim, K. (2020). The development of a new low carbon binder for construction as an alternative to cement. *Advances in sustainable construction materials and geotechnical engineering*, 205-213.

26. Murthi, P.; Awoyera, P.; Selvaraj, P.; Dharsana, D.; and Gobinath, R. (2018). Using silica mineral waste as aggregate in a green high strength concrete: workability, strength, failure mode, and morphology assessment. *Australian Journal of Civil Engineering,* 16(2), 122-128.
27. Karthika, V.; Awoyera, P.O.; Akinwumi, I.I.; Gobinath, R.; Gunasekaran, R.; and Lokesh, N. (2018). Structural properties of lightweight self-compacting concrete made with pumice stone and mineral admixtures. *Revista Romana de Materiale,* 48(2), 208-213.
28. Fashandi, H.; Pakravan, H.R.; and Latifi, M. (2019). Application of modified carpet waste cuttings for production of eco-efficient lightweight concrete. *Construction and Building Materials,* 198, 692-637.
29. Assefa, S.; and Dessalegn, M. (2019). Production of lightweight concrete using corncob ash as replacement of cement in concrete. *American Journal of Civil Engineering,* 7(1), 17-20.
30. Wardhono, A. (2018). The effect of seashell waste on setting and strength properties of class c fly ash geopolymer concrete cured at ambient temperature. *Journal of Engineering Science and Technology (JESTEC),* 14(3), 1220-1230.
31. Mangi, S.A.; Wan Ibrahim, M.H.; Jamaluddin, N.; Arshad, M.F.; and Ramadhansyah, J. (2019). Effects of ground coal bottom ash on the properties of concrete. *Journal of Engineering Science and Technology (JESTEC),* 14(1), 338-350.
32. Ul Islam, M.M.; Mo, K.H.; Alengaram, U.J.; and Jumaat, M.Z. (2016). Durability properties of sustainable concrete containing high volume palm oil waste materials. *Journal of Cleaner Production,* 137, 167-177.
33. Anderson, D.J.; Smith, S.T.; and Au, F.T.K. (2016). Mechanical properties of concrete utilising waste ceramic as coarseaggregate. *Construction and Building Materials,* 117, 20-28.
34. Thomas, B.S.; Gupta, R.C.; and Panicker, V.J. (2016). Recycling of waste tire rubber as aggregate in concrete: durability-related performance. *Journal of Cleaner Production,* 112(Part 1), 504-513.
35. Ghorbani, S.; Taji, I.; Tavakkolizadeh, M.; Davodi, A.; and de Brito, J. (2018). Improving corrosion resistance of steel rebars in concrete with marbleand granite waste dust as partial cement replacement. *Construction and Building Materials,* 185, 110-119.
36. Khodabakhshian, A.; Ghalehnovi, M.; de Brito, J.; and Shamsabadi, E.A. (2018). Durability performance of structural concrete containing silica fumeand marble industry waste powder. *Journal of Cleaner Production,* 170, 42-60.
37. Arif, M.; Gupta, V.; Choudhary, H.; Kumar, S.; and Basu, P. (2018). Performance evaluation of cement concrete containing sandstone slurry. *Construction and Building Materials,* 184, 432-439.
38. Ali, E.E.; and Al-Tersawy, S.H. (2012). Recycled glass as a partial replacement for fine aggregate in self compacting concrete. *Construction and Building Materials,* 35, 785-791.
39. Shi, C.; and Zheng, K. (2007). A review on the use of waste glasses in the production of cement and concrete. *Resources, Conservation and Recycling,* 52(2), 234-247.

40. George, A.; and Sofi, A. (2018). Torsional and cracking behaviours of normal weight and coconut shell lightweight concretes. *Journal of Engineering Science and Technology (JESTEC),* 13(12), 4104 - 4117.
41. Raut, M.V.; and Deo, S.V. (2018). Use of high volume fly ash on early age shrinkage in concrete for local hot and dry condition. *Journal of Engineering Science and Technology (JESTEC),* 13(7), 2036-2046.
42. Haga, K.; Sutou, S.; Hironaga, M.; Tanaka, S.; and Nagasaki, S. (2005). Effects of porosity on leaching of Ca from hardened ordinary Portland cement paste. *Cement and Concrete Research,* 35(9), 1764-1775.
43. Payá, J.; Monzó, J.; and Borrachero, M.V. (2001). Physical, chemical and mechanical properties of fluid catalytic cracking catalyst residue (FC3R) blended cements. *Cement and Concrete Research,* 31(1), 57-61.
44. Federico, L.M.; and Chidiac, S.E. (2009). Waste glass as a supplementary cementitious material in concrete-critical review of treatment methods. *Cement and Concrete Composites,* 31(8), 606-610.
45. Neville, A.M. (1995). *Properties of concrete* (1st ed). Harlow, Essex, United Kingdom: Longman
46. Mohammadinia, A.; Wong, Y.C.; Arulrajah, A.; and Horpibulsuk, S. (2019). Strength evaluation of utilizing recycled plastic waste and recycled crushed glass in concrete footpaths. *Construction and Building Materials,* 197, 489-496.
47. Siddique, R.; Khatib, J.; and Kaur, I. (2008). Use of recycled plastic in concrete: A review. *Waste Management,* 28(10), 1835-1852.
48. Teng, K.H.; Kot, P.; Muradov, M.; Shaw, A.; Hashim, K.; Gkantou, M.; and Al-Shamma'a, A. (2019). Embedded smart antenna for non-destructive testing and evaluation (NDT&E) of moisture content and deterioration in concrete. *Sensors,* 19(3), 12 pages.
49. Ryecroft, S.; Shaw, A.; Fergus, P.; Kot, P.; Hashim, K.; Moody, A.; and Conway, L. (2019). A first implementation of underwater communications in raw water using the 433 MHz frequency combined with a bowtie antenna. *Sensors,* 19(8), 1813.
50. Ryecroft, S.P.; Shaw, A.; Fergus, P.; Kot, P.; Hashim, K.; Conway, L.; and Moody, A. (2020). A novel gesomin detection method based on microwave spectroscopy. *Proceedings of the 12th International Conference on Developments in eSystems Engineering (DeSE)*. Kazan, Russia, 5 pages.