Available online at www.ejournals.uofk.edu

UofKEJ Vol. 9 Issue 1 pp. 37- 43 (Februry-2019)

UNIVERSITY OF KHARTOUM ENGINEERING JOURNAL (UofKEJ)

Use of Polypropylene Waste Plastic Pellets as Partial Replacement for Fine Aggregate in Concrete

Hind M. AbdelMoti, Mustafa A. Mustafa[a]
Materials and Nanotechnology Research Centre,
Faculty of Engineering, University of Khartoum, Khartoum,
Sudan ([a]Email: Dr.Mustafa.Abbas@gmail.com)

Abstract*:* This study aims to evaluate the effect of using polypropylene plastic pellets as partial replacement of fine aggregate with percentages of 5% and 10% by volume on the properties of fresh and hardened concrete. For this purpose, three mixes were prepared, 18 cubes were cast for compressive strength, fresh density and dry density, also 9 cylinders were cast for splitting tensile strength and 9 beams were cast to determine the flexural strength. The resulting slump of the mixes increases as the plastic percentage increases. The fresh density, dry density compressive strength and splitting tensile strength values decrease compared to the control. The flexural strength increases with the percentage increase.

Keywords: *waste PP pellets, concrete, mechanical properties, aggregates.*

1. INTRODUCTION

Plastic wastes are considered to be a serious environmental issue globally as the consumption is rapidly increasing for their favourable properties (Gu and Ozbakkaloglu, 2016). EPA reported in 2012 that the polypropylene (PP) accounts for large disposal rate in the Municipal Solid Waste (MSW) and comes third after Polyethylene Terephthalate (PET) and Low-density polyethylene (LDPE) and the high-density polyethylene (HDPE) together. In Sudan, no statistical data were reported regarding the disposal rate of PP plastic. However, the plastic waste accounts for 12.7% of the Municipal Solid Waste (MSW) produced annually in Khartoum and 80% of this waste is thermoplastic waste, which includes PP plastic (Abdelbagi, Ahmed and Mohmmed, 2018).

Post-consumer plastic can be recycled, incinerated or landfilled. The recycling process is considered somehow costly. The incineration process is mainly used because of the calorific value of the plastic polymer but is still considered a toxic solution since it releases a great amount to toxic chemicals and carbon dioxide. The landfilling should be highly avoided since the plastic is not biodegradable and can take years to degrade leading to long-term pollution problems (Gu and Ozbakkaloglu, 2016). The mentioned solutions account for 9.53%, 14.98% and 75.49% for the recycling, incineration and landfilling disposal ways for the plastic waste, respectively in the USA (EPA, 2014). Finding ways to incorporate plastic by means of reusing and incorporating it into the concrete matrix will greatly decrease the disposal rate. Plastic forms that are used in concrete are Plastic Aggregate (PA) and Plastic Fibres (PF) that can be used as fresh or Recycled materials to be Included in the concrete matrix. The PAs can be used as both Coarse Aggregate (CA) Replacement and Fine Aggregate (FA) Replacement. The use of plastic in concrete have been studied since the 1990s to evaluate the different types, sizes and addition and their effects on the properties of concrete (Gu and Ozbakkaloglu, 2016).

For Polyethylene Terephthalate (PET) bottles, several studies have been conducted to examine their effects on the properties of fresh and hardened concrete, since it is one of the most used plastics worldwide. For example Choi et al., (2005) studied the effect of granulated blast-furnace slag (GBFS) on PET plastic bottles waste surface on compressive strength, splitting tensile strength, slump and density of concrete, they used varying Water/Cement ratios (W/C) 0.45, 0.49, and 0.53 with the replacement ratio of the plastic aggregate by 0%, 25%, 50%, and 75% by volume, the bulk density of concrete were from 1940 - 2260 kg/m^3 which were lower compared to the control. There was a reduction in the compressive strength with the replacement ratio of 75% by 33% for the concrete with the W/C ratio of 0.45. It showed a great increase in the workability, their results concluded that the GBFS improved the surface properties of the (PET) plastic waste.

Marzouk et al., (2007) studied the concrete composites containing shredded PET aggregates without any modifications as sand replacement in different percentages (2%, 5%, 10%, 15%, 20%, 30%, 50%, 70%, and 100%) by volume, and varying the W/C ratio to have a constant workability. It showed that the reduction in density was small for the ratios between 0% - 30%. However, for the ratios that exceeded 50% the density decreased up to the value of 1000 kg/m^3. For the compressive strength, the substitution level below 50% showed a slight decrease in the compressive strength compared to the control, but when it exceeded 50%, there was a sharp decrease in the strength.

Another study by Saikia and De Brito, (2014) investigated the effect of different shapes and size of recycled PET aggregate on both fresh and hardened properties of concrete. They limited the substitution level of the plastic waste with the natural aggregate to 5%, 10%, and 15% by volume of the PET aggregate which was shaped as plastic pellets (Pp), plastic flakes which were coarse and fine of irregular size (Pc & Pf). The plastic pellets showed a slight decrease in the mechanical properties compared to the irregular shaped plastic flakes. This reduction in properties is related proportionally to the increase of the plastic content and the non-uniformity of the plastic shape in the concrete matrix.

For Low-density polyethylene (LDPE) plastic, Galvão et al., (2011) studied the effect of adding LDPE, PET and rubber to the concrete matrix on the mechanical properties along with some durability-related problems, using the substitution levels of 0.5%. 1%, 2.5%, 5% and 7.5% by weight, it was concluded that the LDPE gave the best performance and the optimum substitution was 2.5%. Table 1 summarizes the different types of plastic waste used as PA.

For Polystyrene (PS) plastic Babu et al., (2006) conducted a study in order to investigate the Polystyrene plastic type on the properties of lightweight concrete. They used Extended Polystyrene (EPS) and Un-Extended Polystyrene (UEPS) beads as partial fine aggregate replacement and fly ash was used as partial cement replacement. Two series of mixtures were prepared. The first series contained 30% fly ash, along with different replacements ratios by volume of EPS, the second series was for the UEPS, the resulting densities ranged from 200 to 2000 kg/m^3 varying significantly with replacement volume. The mixtures containing UEPS exhibited higher compressive strength than the ones with EPS aggregates.

For Polyvinyl chloride (PVC) plastic, Kou et al., (2009) investigated the effect of waste PVC crushed plastic on concrete as partially replacing the sand by 0%, 5%, 15%, 30%, and 45%. The resulting concrete was had lower density than the conventional concrete. However, the workability, compressive strength and splitting tensile strength tend to decrease compared to the conventional concrete.

Kumari and Srivastava, (2016) reported that the use of shredded PVC pipes affected the properties of concrete in which the resulting mixtures had lower workability, compressive strength, and flexural strength than the control mixture. They also investigated the using fly ash as partial cement replacement of 10% to compensate for the loss of strength. They suggested that treating plastic surface or addition of other waste pozzolanic materials can significantly improve the properties of concrete with the plastic waste.

For the Polypropylene (PP) plastic, only plastic fibers were extensively used, since they are easy to produce, has high tensile strength good durability performance (Yin et al., 2015). The PP was used as fresh or recycled fibers and was used in the applications of reinforced concrete, the addition was usually in small dosages, up to 3% by volume showed great results, increasing this percentage may decrease the effect of the fibres on the various properties.

The effect of the plastic fibers on the properties of concrete is reviewed by (Yin et al., 2015; Gu and Ozbakkaloglu, 2016) most of the studies they reviewed concluded that adding the plastic fibers improved the slump behaviour, compressive strength, splitting tensile strength, flexural strength, but did not affect the density of concrete since it was added in small percentages. Waste imposed by other PP forms such as plastic pellets or shredded plastic has not been studied, thus the aim of this study is to investigate the effect of PP waste pellets on the mechanical properties of the concrete.

Table 1. Summary of the previous studies on Plastic Aggregate (PA)

Reference	Plastic	Recycling method	Type & percentage replaced (by volume)	Remarks
Choi et al., (2005)	PET[1]	Melting of PET	FA: 0%, 25%, 50%, & 75%	Mixed with Ground Blast Furnace Slag
Marzouk et al., (2007)	PET	Shredding of PET bottles	FA: 2%, 5%, 10%, 15%, 20%, 30%, 50%, 70%, & 100%	
Ismail and AL-Hashmi, (2008)	80% PET & 20% PS[2]	Crushed waste Packages	FA: 0%, 5%, 15%, & 20%	
Choi et al., (2009)	PET	Shredding of PET bottles	FA: 0%, 25%, 50%, & 75%	Coated with River Sand
Albano et al., (2009)	PET	-	FA: 0%, 10%, & 20%	
Frigione, (2010)	PET	Grinding of PET bottles	FA: 5%	
Galvão et al., (2011)	PET bottles & LDPE[3] bags	Crushing after washing	FA: 0.5%, 1%, 2.5%, 5%, & 7.5%	
Saikia and De Brito, (2014)	PET bottles	Pf[4], Pc[5]: shredding Pp[6]: thermal treatment	Pc: CA & FA, 5%, 10% and 15% Pp and Pf: FA, 5%, 10% and 15%	
Kou et al., (2009)	PVC[7]	Grinding, irregular shape	FA: 10% & 20%	
Kumari and Srivastava, (2016)	PVC pipes	Shredded	FA: 2%, 4%, 6%, 8%	
Babu et al., (2006)	PS	Virgin form	CA: EPS: 20 – 50% UEPS: 30%	

[1] Polyethylene Terephthalate
[2] Polystyrene
[3] Low-density Polyethylene
[4] Fine plastic flakes
[5] Coarse plastic flakes
[6] Plastic pellets
[7] Polyvinyl chloride

2. Materials and Methods

2.1 Materials

The materials used in this study are as follow:

2.1.1 Cement

Ordinary Portland Cement (OPC) was used in this study. The cement conforming to the EN 197-1/2000 standard with strength class of 42.5 MPa branded as Sakhr El-Sudan and produced by Al-Takamol Cement Factory in Atbara in the north of Sudan. The cement was used in all the mixes, some of the physical properties of the cement are illustrated in Table 2.

2.2.2 Fine Aggregate

Natural sand with a maximum size of 5 mm was used as FA. The sand was collected from the runoff streams located at East Nile locality of Khartoum state. Its physical properties and gradation are presented in Table 3 and Table 4 respectively followed by the gradation curve in Figure 1.

2.1.3 Coarse Aggregate

For the coarse aggregate, natural well graded uncrushed gravel with the nominal maximum size of 20 mm and a bulk density of 1636.5 kg/m^3 was used. The gravel was collected from the natural gravel queries located at East Nile Locality in Khartoum State. The gradation of the CA is presented in Table 5 and gradation curve in Figure 1.

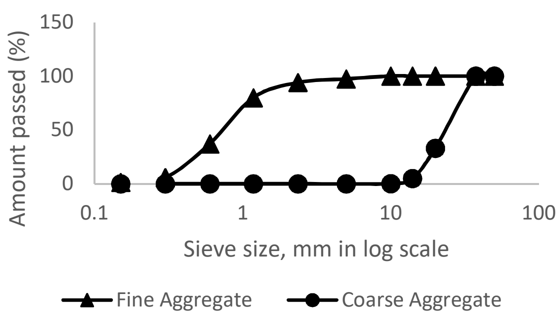

Fig.1. Fine and coarse aggregates gradation curve (4/40)

2.1.4 Plastic Waste

The polypropylene (PP) recycled plastic was obtained from the local market in Omdurman, the pellets were recycled only once by Tarig Elmahdi for Plastic Pellets Recycling. Table 4 shows the physical properties. The shape and size of plastic pellets are represented in Figure 2.

Figure 2: Recycled PP plastic pellets sample – Tarig Elmahdi for Plastic Pellets Recycling

2.1.5 Mixture Proportions

The control mixture (M1) was prepared according to the D.O.E method, the mixture proportions were 1:1.87:3.05 and a constant water/cement ratio (W/C) of 0.47. For the PP concrete mixes, the cement, CA and the (W/C) ratio were kept constant. The sand was partially replaced by the PP plastic pellets to form two other mixes (M2 and M3) containing (5% and 10%) by volume of plastic pellets, respectively. All the mixtures proportions are listed in Table 6.

2.2 Methods

2.2.1 Specimen Preparation

Six cubes 100 x 100 x 100 mm were cast for fresh density, dry density and compressive strength tests. Furthermore, three beams 100 x 100 x 500 mm were prepared for flexural strength test, and three cylinders 300 mm height and 150 mm diameter were cast for splitting tensile strength test for each mix. All the mixes were poured into the specified moulds in three layers and compacted after each layer using a vibrating table according to the BS EN 12390-2:2009.

2.2.2 Testing methods of specimen

The testing of specimens was completed according to standard methods which are presented in Table 7. The slump of all the concrete mixtures was determined using a slump cone having 300 mm height, 200 mm bottom diameter, and 100 mm top diameter, the concrete mixtures were poured into the cone immediately after mixing in three layers, with compacting each layer 25 times using a rod.

For the fresh density of concrete, the moulds were weighed empty and immediately after pouring the mixtures in the moulds and compaction, the weighing was the average of three cubes. For the dry density, the cubes were weighed prior to the compressive strength in SSD conditions test at each testing age.

The compressive strength was determined at the ages of 7 and 28 days of curing, with a compression machine of a maximum load of 2000 kN, model Cat C44D2 from CONTROLS in Milano, Italy. The splitting tensile strength test was carried out after 28 days of curing the cylinders, with a compression device of a maximum load of 3000 kN, model Cat C54L2 from CONTROLS in Milano, Italy.

The flexural strength test was determined with the compression device with the maximum capacity of 30 tons, machine type: A806/1474 from W&T AVERY Ltd. The test was carried out according to BS EN 12390-5/2009 using the two-point load method.

Table 2. Physical properties of Cement

Property	Value	Standard Limit (EN 197-1:2000)
Consistency (mm)	5	5 – 7 mm
Initial Setting Time (min)	174	≥ 45 minutes
Final Setting Time (min)	300	≤ 600 minutes
2-day Compressive Strength (MPa)	20.98	≥ 10
28-day Compressive Strength (MPa)	51.72	42.5 – 62.5

Table 3: Fine aggregate sieve analysis

Sieve Size (mm)	Accumulated percentage passing (%)	Standard Limit (BS EN 12620:2013) – 0/4
10	100	100
5	97.39	89 – 100
2.36	93.95	60 – 100
1.18	79.09	30 – 90
0.6	37.09	15 – 54
0.3	5.72	5 – 40
0.15	1.31	0 – 15

Table 4: Fine aggregate and plastic physical properties

Properties	Sand	Polypropylene
Bulk Density (kg/m^3)	1717	522.5
Specific gravity	2.53	-
Water absorption (24h %)	0.77	0
Colour	Brownish orange	Grey
Shape and size (mm)	Max. size 5 mm	Cylindrical Pellet shaped, 5 mm long, 3 mm diameter

Table 5: Coarse aggregate sieve analysis

Sieve size (mm)	*Accumulated Percentage passing (%)*	*Standard Limit (BS EN 12620:2013) – 4/40*
50	100	100
37.5	100	90 – 100
20	33.00	25 – 70
14	4.96	0 – 15
10	0.18	0 – 15
5	0	0

Table 6: Mix proportions of concrete mixtures

Mixtures(Symbols)	W/ C	Materials (kg/m^3)					Plastic (%)
		Cement	Water	Gravel	Sand	Plastic	
M1	0.47	375	180	1145	700	0	0
M2	0.47	375	180	1145	665	55	5
M3	0.47	375	180	1145	630	70	10

Table 7: Standard Methods used in the experiments

Property	Test
Aggregates analysis	
Fine aggregate sieve analysis	BS EN 933-1:2012
Fine aggregate water absorption	BS EN 1097-6: 2012
Fine aggregate bulk density	BS EN 1097-3: 1998
Fine aggregate specific gravity	BS EN 1097-6: 2012
Coarse aggregate sieve analysis	BS EN 933-1: 2012
Coarse aggregate bulk density	BS EN 1097-3: 1998
Fresh properties	
Slump test	BS EN 12350-2:2009
Density	BS EN 12350-6:2009
Hardened Properties	
Compressive strength	BS EN 12390-3:2009
Flexural strength	BS EN 12390-5:2009
Splitting Tensile strength	BS EN 12390- 6:2009

3 Results and Discussion

3.2 Fresh Properties

3.2.1 Consistency

The consistency of the tested concrete mixes is expressed in Figure 3.

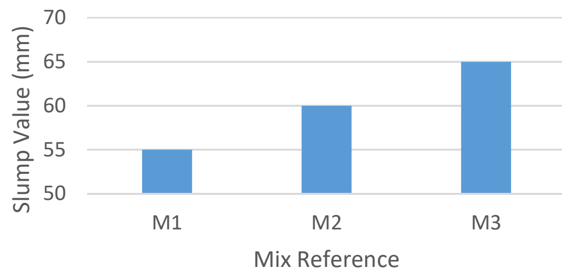

Fig. 3. Slump vs PP percentage Replacement with mix reference

For the mixes designed, the chosen slump value was between 30-60 mm. The resulting slump values increased slightly than the control's slump value which was 55 mm. the percentages for the increase in the slump for the concrete with PP plastic were: 9.09% and 18.18% for 5% (M2) and 10% (M3) replacements compared to the control, respectively. This increment in the workability may be due to the hydrophobic plastic nature, leaving some water free in the mixture. During conducting the test, no segregation was observed for all the mixes, with and without the PP.

3.2.2 Fresh Density

The results for the fresh density of the mixes are presented in Figure 4.

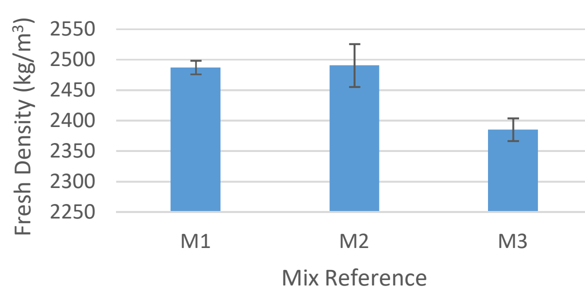

Fig. 4. The influence of adding PP waste pellets on the fresh density of concrete

The resulting concrete containing PP plastic aggregate was found to be lighter than the control (M1). In the case of the 10% replacement percentage (M3), there was a noticeable decrease in weight. This is due to the large density difference between the sand and PP plastic, but unlikely for the 5% replacement percentage (M2) there was a slight increase in weight. However, many factors may have caused this increase, whether it was in the mixing conditions or the uneven plastic distribution in the mixture.

3.3 Hardened Properties

3.3.1 *Dry Density*

The dry density was measured after 7 days & 28 days of curing. The results are presented in Figure 5.

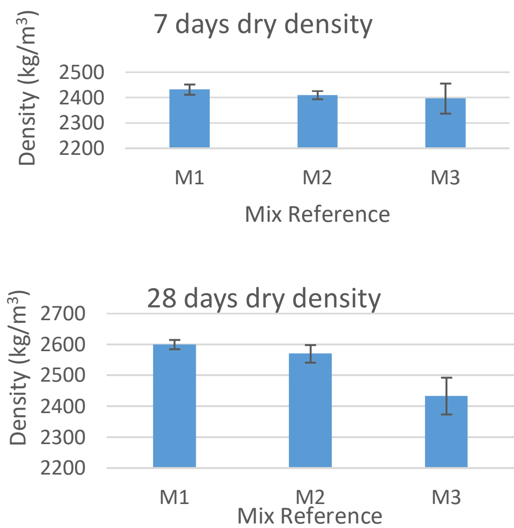

Fig. 5. Effect of adding PP waste pellets on the dry density of concrete for 7 days and 28 days

It was observed from the results, the 7 days' samples weight tend to slightly decrease with increasing plastic percentages, for both 5% (M2) and 10% (M3), the concrete still has a considerable amount of water which also accounts in the total volume. For the 28 days, the density decreases as well for M2 and M3 compared to the control. The large density difference between the PP pellets and the sand reduces the density as the percentage increases. Generally, the density increases with respect to age in all mixes, this may be attributed to the decrease of voids with the progress of hydration.

3.3.2 *Compressive Strength*

The results of the 7 days' compressive strength and 28 days' compressive strength are shown in Figure 6.

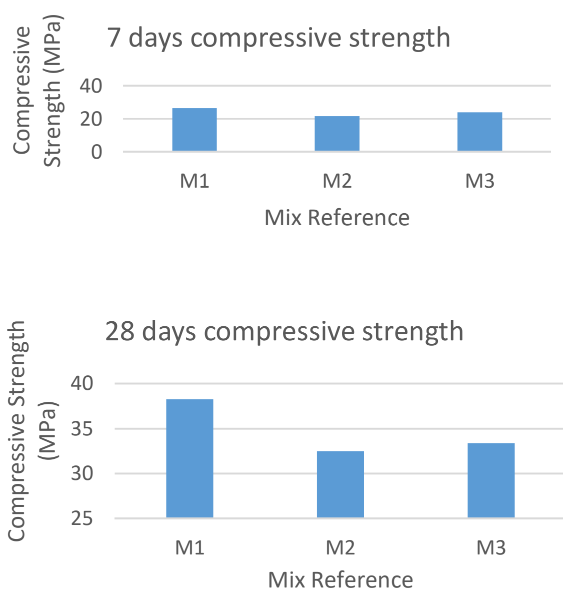

Fig. 6. 7 days and 28 days compressive strength of concrete with two different percentages of PP plastic

The decrease in the 5% (M2) was by 18.51% and 15.08% for 7 curing days and 28 curing days respectively, compared to the control, but for the 10% (M3) percentage replacement, the decrease was of 9.42% and 12.72% for 7 and 28 days of curing, respectively compared to the control. In general, the decrease in the compressive strength is attributed to the weak adhesive bond between the PP surface and the cement paste. However, the M2 mix may have exhibited uneven distribution of the PP pellets while mixing, hence giving lower values than M3.

3.3.3 *Splitting Tensile Strength*

For the splitting tensile strength, the results are shown in Figure 7.

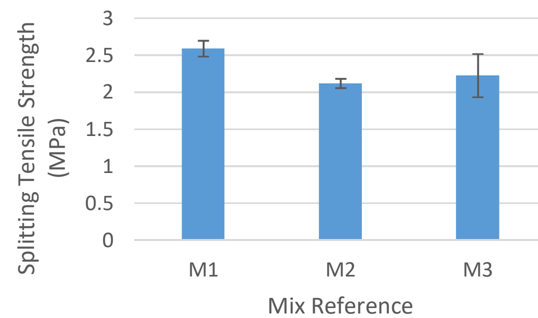

Fig.7. Splitting tensile strength for the concrete with the different PP waste pellets percentages

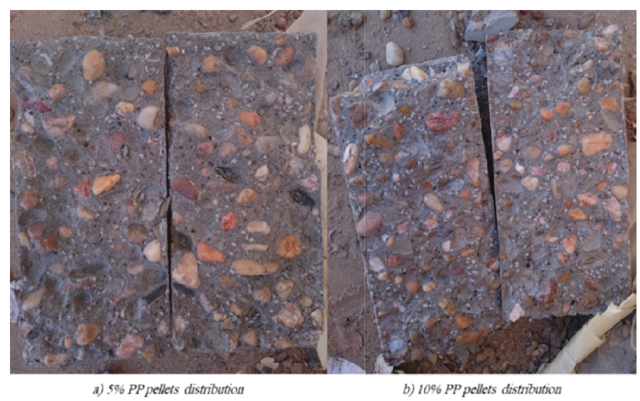

Fig. 8. Cylinders after the splitting tensile strength

It shows that the splitting tensile strength decrease by 18.15% for the 5% (M2) compared to the control (M1). The 10% (M3) increased by 4.78% from the 5% (M2) replacement percentage and decreased by 14.03% compared to the control (M1). Similarly, the same explanation can be valid for the decrease of the tensile strength compared to the control (M1) and the difference between pellets distribution of M2 and M3 mixes as shown in Figure 8 above.

3.3.4 Flexural Strength

The flexural strength results are expressed in Figure 9.

Unlike the other studies by Ismail and AL-Hashmi (2008) and Saikia and De Brito (2014), the flexural strength of the resulting concrete mixtures tend to slightly increase than the control mixture, this increase may be due to the relatively high bending resistance of the PP pellets compared to the sand.

The 5% (M2) was observed to be brittle and failed easily, in particular, one of the beams failed at the beginning of the test this resulted in an odd value which was excluded from the calculations. The behaviour was different for the 10% (M3), it was tougher than the 5% (M2) replacement and did not fail drastically, this behavior can be assumed that the random distribution of the waste plastic in the mixture.

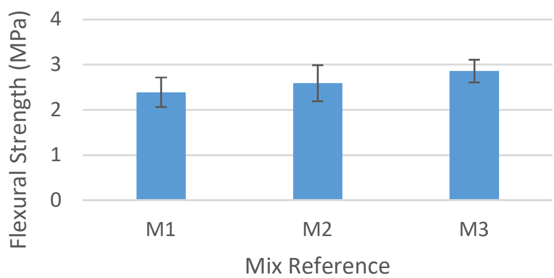

Figure 9: Flexural strength of concrete containing different PP waste pellets percentages

4 CONCLUSUION

From this study of some of the mechanical properties of fresh and hardened concrete with polypropylene (PP) pellets as sand replacement, the following conclusion can be extracted:

- The slump values for the percentages replaced tend to increase by 9.09% and 18.18% for 5% and 10% replacements (by volume of sand) compared to the control, respectively. The hydrophobic nature of the small cylindrical plastic pellets which leaves the water to move freely in the mixture.
- For the fresh density, the 5% showed a 0.134% increment compared to the control which is considered a very slight increase, the uneven distribution might be the reason for this result. The 10% decreased by 4.095% compared to the control. The difference between the sand and the plastic aggregate is the main contributor to this reduction.
- The dry density for both 7 and 28 days of cured specimen tend to decrease compared to the control. The percentage difference between the sand and the plastic pellets density is 69.5% which explains the decrease in the weight of the concrete mixes containing the 5% and 10% of PP pellets.
- The compressive strength for 7 days cured specimen decrease by 18.51% and 9.42% for the 5% and 10% replacement respectively. The 5% might have encountered some unnoticeable problems while mixing the PP pellets in the concrete mix. The 28 days compressive strength decreased by 15.08% and 12.72% for the 5% and 10%, respectively.
- The splitting tensile decreases for both the 5% and 10% mixtures than the control mixture. This may be due to the weak bond between the cement paste and the PP surface.
- The flexural strength increase by 8.33% and 19.44% for the 5% and 10% replacements, respectively, compared to the control since the PP pellets have higher bending resistance than the sand.

REFERENCES

[1] Abdelbagi, H., Ahmed, M. and Mohmmed, R 2018 'Thermal Degradation of Four Types of Plastic Solid Waste HDPE , LDPE , PP and PS', (July). doi: 10.13140/RG.2.2.17900.26245.

[2] Albano, C. Camacho, N., Hernandez, M., Matheus, A., and Gutierrez, A 2009, 'Influence of content and particle size of waste pet bottles on concrete behavior at different w/c ratios', *Waste Management*. Elsevier Ltd, Vol. 29, No. 10, pp. 2707–2716. doi: 10.1016/j.wasman.2009.05.007.

[3] Babu, D. S., Ganesh Babu, K. and Tiong-Huan, W 2006, 'Effect of polystyrene aggregate size on strength and moisture migration characteristics of lightweight concrete', *Cement and Concrete Composites*, Vol. 28, No. 6, pp. 520–527. doi: 10.1016/j.cemconcomp.2006.02.018.

[4] British Standard Institution 1998, *BS EN 1097-3: Tests for mechanical and physical properties of aggregates Part 3: Determination of loose bulk density and voids*.

[5] European Standard 2000, *EN 197-1: Cement - Part 1: Composition, specifications and conformitycriteria for common cements*.

[6] British Standard Institution 2009, *BS EN 12350-2: Testing fresh concrete Part 2: Slump-test*.

[7] British Standard Institution 2009, *BS EN 12350-6: Testing fresh concrete Part 6: Density*.

[8] British Standard Institution 2009, *BS EN 12390-3: Testing hardened concrete Part 3. Compressive strength of test specimens*.

[9] British Standard Institution 2009, *BS EN 12390-5: Testing hardened concrete Part 5. Flexural strength of test specimens*.

[10] British Standard Institution 2009, *BS EN 12390-6: Testing hardened concrete Part 6. Tensile splitting strength of test specimens*.

[11] British Standard Institution 2012, *BS EN 933-1: Tests for geometrical properties of aggregates. Determination of particle size distribution Part 1: Sieving method*.

[12] ritish Standard Institution 2013, *BS EN 1097-6: Tests for mechanical and physical properties of aggregates Part 6: Determination of particle density and water absorption*.

[13] British Standard Institution 2013, *BS EN 12620: Aggregates for concrete*.

[14] Choi, Y. W., Moon, D. J., Chung, J. S., and Cho, S. K 2005, 'Effects of waste PET bottles aggregate on the properties of concrete', *Cement and Concrete Research*, Vol. 35, No. 4, pp. 776–781. doi: 10.1016/j.cemconres.2004.05.014.

[15] Choi, Y. W., Moon, D. J., Kim, Y. J., and Lachemi, M 2009, 'Characteristics of mortar and concrete

containing fine aggregate manufactured from recycled waste polyethylene terephthalate bottles', *Construction and Building Materials*. Elsevier Ltd, Vol. 23, No. 8, pp. 2829–2835. doi: 10.1016/j.conbuildmat.2009.02.036.

[16] Environmental Protection Agency (EPA), 2014, *Facts and Figures about Materials, Waste and Recycling - Plastics: Material-Specific Data* [Online] Available at: https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/plastics-material-specific-data [Accessed 2018].

[17] Frigione, M 2010, 'Recycling of PET bottles as fine aggregate in concrete', *Waste Management*. Elsevier Ltd, Vol. 30, No. 6, pp. 1101–1106. doi: 10.1016/j.wasman.2010.01.030.

[18] Galvão, J. C. A., Portella, K. F., Joukoski, A., Mendes, R., and Ferreira, E. S 2011, 'Use of waste polymers in concrete for repair of dam hydraulic surfaces', *Construction and Building Materials*, Vol. 25, No. 2, pp. 1049–1055. doi: 10.1016/j.conbuildmat.2010.06.073.

[19] Gu, L. and Ozbakkaloglu, T 2016, 'Use of recycled plastics in concrete: A critical review', *Waste Management*. Elsevier Ltd, Vol. 51, pp. 19–42. doi: 10.1016/j.wasman.2016.03.005.

[20] Ismail, Z. Z. and AL-Hashmi, E. A 2008, 'Use of waste plastic in concrete mixture as aggregate replacement', *Waste Management*, Vol. 28, No. 11, pp. 2041–2047. doi: 10.1016/j.wasman.2007.08.023.

[21] Kou, S. C., Lee, G. Poon, C. S., and Lai, W. L 2009, 'Properties of lightweight aggregate concrete prepared with PVC granules derived from scraped PVC pipes', *Waste Management*. Elsevier Ltd, Vol. 29, No. 2, pp. 621–628. doi: 10.1016/j.wasman.2008.06.014.

[22] Kumari, B. and Srivastava, V 2016, 'Effect of waste plastic and fly ash on mechanical properties of rigid pavement', *International Journal of Civil Engineering and Technology*, Vol. 7, No. 5, pp. 247–256.

[23] Marzouk, O. Y., Dheilly, R. M. and Queneudec, M 2007, 'Valorization of post-consumer waste plastic in cementitious concrete composites', *Waste Management*, Vol. 27, No. 2, pp. 310–318. doi: 10.1016/j.wasman.2006.03.012.

[24] Saikia, N. and De Brito, J 2014, 'Mechanical properties and abrasion behaviour of concrete containing shredded PET bottle waste as a partial substitution of natural aggregate', *Construction and Building Materials*. Elsevier Ltd, Vol. 52, pp. 236–244. doi: 10.1016/j.conbuildmat.2013.11.049.

[25] Yin, S., Tuladhar, R., Shi, F., Combe, M., Collister, T., and Sivakugan, N 2015, 'Use of macro plastic fibres in concrete: A review', *Construction and Building Materials*. Elsevier Ltd, Vol.93, pp. 180–188. doi: 10.1016/j.conbuildmat.2015.05.105.