Mechanical Properties of Lightweight Concrete Made with Shredded Waste Polypropylene Yogurt Containers

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Abstract. The partial replacement of natural coarse (gravel) aggregate by waste plastic aggregate to produce lightweight concrete has become one of the major challenges in recent years and stresses on the need for a constant and authoritative development for the betterment of the environment. This work was carried out to investigation the possibilities of using waste polypropylene yogurt containers as polymer aggregate in concrete application. The concrete samples with 0%, 5%, 10%, 15%, 20% and 25% recycled plastic aggregate as partial replacement by mass of natural coarse aggregate are prepared after a curing period of 28 days. The effect of recycled plastic aggregate on compressive strength, density and water absorption of natural concrete are studied and compared with the results of specimen without plastic aggregate. Both compressive strength and density decreased with increasing the amount of plastic aggregate. The highest reduction in compressive strength and density were 50% and 19% respectively of concrete cubes containing 25% wt polypropylene waste aggregate in comparison of traditional concrete. It was found that water absorption increased as the plastic aggregate content increased up to 15% wt and then decreased when replaced coarse aggregate by 20% wt and 25% wt by recycled polypropylene aggregate. This study is recommended to use recycled polypropylene yogurt containers as a partial substance of traditional coarse (gravel) concrete mix.
up to 15% wt for applications include those where low compressive strengths and low cost production are desirable.

**Keywords:** waste plastic, lightweight concrete, compressive strength, physical properties.

1. **Introduction**

All over the world, plastic materials have become an essential and integral part of our modern lives by the variety of its features have been conducted to its recurrent use in wide range sectors. The year by year the rate of global plastic production has increased drastically during the few past years from 300 million tons in 2011 to 335 million tons in 2016 (Richard, P et al 2018 and Ossi Martikka et al 2019). A quantity of plastic materials is used in food industry (containers, bottles, packaging etc.). The success of plastics as packaging material has been substantial, they has offer many features over metals and ceramics such as light weight, ease of design, good weight to strength ratio, good chemical resistance, tough and low cost (M., Sulyman et al 2016 and M. B. Hossain et al 2016). Unfortunately, these plastics have serious drawbacks. They non – degradable and increasing the amount of solid waste have been making significant contribution to the increase in environmental pollution (Mohd Syahrul Hisyam Mohd Sani et al 2019).

One of the feasible application of waste plastics as shredded aggregate is in construction fields for produce lightweight concrete in order to reduce the total weight of concrete. Various types of the common waste thermoplastics are used as lightweight aggregate in the preparation of lightweight concrete such as ethylene vinyl acetate EVA E. Q. R. Santiago et al 2009, low-density polyethylene LDPE (A. O. Sojobi et al 2014 Manish Chaudhary et al 2014), high- density polyethylene HDPE (Deividas Rumšysa et al 2017 and Gopal Swarup Sangal 2018), polypropylene PP Martina Záleská et al 2018, polyvinylchloride PVC (S.C. Kou et al 2009, Y. Senhadji et al 2015, N. Haghighatnejad et al 2016 and H. H. Hussein et al 2017) and polystyrene PS Andrea Petrella et al 2020.

Polypropylene PP is one the most conventional widely thermoplastics used in the field of dairy milk packaging due to its good barrier properties, poor gas barriers, tough, inert, clear, good surface finish and low cost Fahad K. Alqahtani et al 2015. The lowest value of density making the polypropylene the lightest plastic materials known and this feature makes it the best candidate for lightweight concrete. In this present work, we are aimed the study the effectiveness of waste polypropylene yogurt containers as partial substances for coarse (gravel) aggregates and then compared the attained results to the traditional concrete mix. (cement, fine (sand) aggregates and coarse (gravel) aggregates.

2. **Experimental**

2.1 **Materials**

Waste polypropylene yogurt containers used in this study has been collected from various local supermarkets located in Diwaniyah city – south of Iraq. Some of the PP waste containers is shown in Figure 1.
Figure 1. Waste polypropylene yogurt containers

High sulphate resistance Portland cement (Al-Jesr trade mark) type V, CEM I 42.5 SR, coarse aggregates (gravel), and fine aggregates (sand) were supplied from one the local building materials store in Diwaniyah city – south of Iraq. The cement source is Lafarge Iraq and manufactured according to the Iraqi standard number 5-1984. The properties of cement used are summarized in Table 1.

Table 1. Cement resistant sulfate-properties typical.

| Parameters                              | Range          |
|-----------------------------------------|----------------|
| Lime Saturation Coefficient             | 0.9 - 1.0      |
| Magnesium Oxide (MgO) %                 | 1.5 - 2.5      |
| SO3 Content %                           | 2 - 2.3        |
| Loss on Ignition %                      | 2.2 - 3.2      |
| Insoluble Residue %                     | 0.5 - 1.2      |
| Tricalcium Aluminates (C3A) %           | 2.4 - 3.1      |
| Fineness (m³/kg)                        | 320 - 335      |
| Initial Setting Time (min)              | 125 - 175      |
| Final Setting Time (Hr)                 | 3 - 3.7        |
| Soundness: Lechatelier (mm)             | 0 - 2          |
| Specific Gravity (kg/litter)            | 3.10 - 3.18    |
| Bulk Density (kg/m³)                    | 1.440 ± 0.1    |
| Compressive Strength as per Iraqi Standard (MPa) | 30 - 36 |
|                                        | 70             |
|                                        | 40 - 45        |
|                                        | 28d            |
|                                        | 55 - 60        |

2.2 Preparation of low weight concrete samples:

The processing steps that were followed to preparation of recycled PP aggregate as follows:

Step one washed the waste plastic after collected with water to remove all remaining products inside the containers and then cleaning the outer surface from contaminants (coating materials) with aprotic solvent (acetone).
Step two shredded and crushed in a plastic crushed machine which has blades that break the plastic into smaller flake sizes (Figure 2).

![Image of shredded waste polypropylene](image1.png)

**Figure 2.** Waste polypropylene shredded.

Step three the waste plastic crushed were processed in an extruder – molding machine. The extruded PP recycling sheets cutting to small size (8 – 12 mm angular) and then used to replace coarse aggregate (gravel) for making the concrete cubic samples.

![Image of waste polypropylene aggregates](image2.png)

**Figure 3.** Waste Polypropylene aggregates used in concrete.

2.3 Preparation of low weight concrete samples

A steel cube molds of dimension 100 mm × 100 mm × 100 mm respectively was prepared. For the preparation procedure of concrete is done using hand lay-up technique. Calculated of concrete samples were produced using cement: fine aggregates (sand): coarse aggregates (gravel and recycled PP) ration of 1:2:4 and water to cement ratio of 0.5 and cured for 28 days according to ASTM C192.
Five different concentrations of recycled PP aggregates (5%, 10%, 15%, 20% and 25%) of total weight of gravel aggregates were added to the concrete mix proportions. Table 2 illustrated the compositions of the concrete mixtures.

**Table 2. Composition of examined concrete mixtures.**

| code | Waste PP weight fraction % | No. of samples |
|------|----------------------------|----------------|
| C0   | 0                          | 3              |
| CP5  | 5                          | 3              |
| CP10 | 10                         | 3              |
| CP15 | 15                         | 3              |
| CP20 | 20                         | 3              |
| CP25 | 25                         | 3              |

**2.4 Testing**

2.4.1 Compressive Test

The compressive strength test of cubes samples of concrete with and without PP aggregates for that three cubes were prepared for each mix. The test was performed according to ASTM C109 using machine. The compressive load was applied continuously until the cube sample failed.

2.4.2 Density

In this work, the density of different concrete cube samples is the theoretical density. The density was tested according to ASTM C 642 on the same samples, which utilized for compressive test and calculated by dividing the weight on the volume of each cube sample.
2.4.3 Water Absorption

The water absorption was tested according to ASTM C642 by drying each of cube sample in an oven at 105 °C for 24 hours after curried and then weighting it. The samples were immersed in water for 24 hours. The cube samples were taken out from the water, dried and reweighed.

3. Results and Discussion

3.1 Compression Test

Results of summarizes compressive strength of all different of cube concrete samples after 28 days of curing was illustrated in Table 3.

| code | Waste PP weight fraction % | Average weight kg | Average compressive strength MPa |
|------|----------------------------|------------------|---------------------------------|
| C0   | 0                          | 2.370            | 19.885                          |
| CP5  | 5                          | 2.356            | 16.835                          |
| CP10 | 10                         | 2.160            | 14.94                           |
| CP15 | 15                         | 2.095            | 13.865                          |
| CP20 | 20                         | 2.075            | 11.52                           |
| CP25 | 25                         | 1.925            | 10.385                          |

The experimental results indicated that the average value of the compressive strength of traditional concrete slightly decrease to 15 % when coarse aggregate (gravel) replaced by 5% wt with the recycled PP aggregate. The values of compressive strength are more decreasing when the concentrations of recycled plastic aggregate increased to 10%, 20% and 25% wt. the highest reduction was 50% of cube samples with 25% wt waste PP aggregate as shown in Figure 5.

![Figure 5. Compression strength of concrete cubes after 28 days.](image)

The lower values of average compressive strength of cube concrete samples containing waste plastic aggregate than samples containing natural aggregates is due to reduction in bonding between plastics.
pieces with cement matric Raghatate Atul M. 2012 and the lower compressive strength value of PP aggregate.

3.2 Density

The results reported that the density of cube concrete samples decreased with the increase of plastic aggregate ratio in composition by respectively when compared to the traditional concrete as shown in Figure 6. The reduction in densities is related to the lower density of waste PP aggregate than the coarse (gravel) aggregate. The largest reduction in density about 19 % for cube samples containing 25% wt waste PP aggregate.

![Figure 6. Density of concrete cubes after 28 days.](image)

3.3 Water Absorption

In the case of water absorption, the relationship between the percentages of water absorption and waste plastic content are illustrated in Figure 7. It was observed that the percentage of water absorption of concrete increased the double with increasing the amount of waste PP aggregate up to 15% wt. The percentage of water absorption was 3% for natural coarse aggregate and 6% for concrete with 15% wt waste PP aggregate. Then the percentage of water absorption starts to decrease as polymer content in concrete mix increases, reaching a minimum value of 4.6% for concrete cube sample containing 25% wt of plastic aggregate higher than the value of the concrete sample without any plastic aggregate.

![Figure 7. Percentage of water absorption of concrete cubes after 28 days.](image)
The results of values of water absorption of all concrete mixes is very low under 10 %. This displays the good quality of all concrete mixes in this work (Neville, A.M. 2011)

4. Conclusions

It may be possible to use recycled PP yogurt containers as a partial substance of traditional coarse (gravel) concrete mix up to 15% wt for applications include those where low compressive strengths are desirable.

The density of all types of recycled PP concrete was lesser than that of traditional concrete (only sand and gravel aggregate).

It has been noticed that compressive strength values of concrete containing different concentrations of plastic aggregate decreased between and when compared to the traditional concrete.

Water absorption increased as the plastic aggregate content increased up to 15% wt and then decreased when replaced coarse aggregate by 20% wt and 25% wt by recycled PP aggregate.

References

[1] Richard, P., Catherine, A., Rod Fox & Bill Hopkins (2018). Re-Formative Polymer Composites from Plastic Waste: Novel Infrastructural Product Application. Recycling, 3(54), doi:10.3399/recycling3040054

[2] Ossi Marttika & Timo Karki (2019). Promoting Recycling of Mixed Waste Polymers in Wood-Polymer Composites Using Compatibility. Recycling, 4(6), doi:10.3399/recycling4010006

[3] M., Sulyman, J., Haponiuk & K., Formela (2016). Utilization of Recycled Polyethylene Terephthalate (PET) in Engineering Materials: A Review. International Journal of Environment and Science Development, 7(2), doi:10.7763/IJESD.2016.V7.749

[4] M. B. Hossain, P., Bhowmik, & K. M. Shaad (2016). Use of Waste Plastic Aggregation in Concrete as a Constituent Material. Progressive Agriculture, 27(3), 383-391.

[5] Mohd Syahrul Hisyam Mohd Sani, Muhammad Isha Ismail, Marzuki Ab Rahman & Fadhluhartini Muftah (2019). Waste Paper Ash Pellets as Coarse Aggregate Replacement in Concrete. International Journal of Engineering and Advanced Technology (IJEAT), 8(4), 1112-1117.

[6] E. Q. R. Santiago, P. R. L. Lima, M. B. Leite & R. D. Toledo Filho (2009). Mechanical Behavior of Recycled Lightweight Concrete Using EVA Waste and CDW under Moderate Temperature. IBRACON Structures and Materials Journal, 2(3), 211-221.

[7] A. O. Sojobi and H. I. Owamah (2014), Evaluation of the Suitability of Low Density Polyethylene (LDPE) as Fine Aggregate in Concrete, Nigerian Journal of Technology (NIJOTECH), 33(4), 409-425, dx.doi.org/10.4314/njt.v33i4.1.

[8] Manish Chaudhary, Vikas Srivastava and V. C. Agarwal (2014), Effect of Waste Low Density Polyethylene on Mechanical Properties of Concrete, Journal of Academia and Industrial Research (JAIR), 3(3), 123-126.

[9] Deividas Rumšysa, Darius Bačinskasa, Edmundas Spudulisa & Adas Meškėnasa (2017), Comparison of material properties of lightweight concrete with recycled polyethylene and expanded clay aggregates, Procedia Engineering, 172, 937 – 944

[10] Gopal Swarup Sangal (2018). Study the Effect of Plastic Waste on Strength of Concrete. International Journal of Advance Research and Development, 3(7), 36-39.

[11] Martina Záleská, Milena Pavliková, Ondřej Jankovský, Jaroslav Pokorný & Zbyšek Pavlík (2018), Lightweight Concrete Made with Waste Expanded Polypropylene-Based Aggregate and Synthetic Coagulated Amorphous Silica, Ceramics-Silikáty 62 (3), 221-232.

[12] S.C. Kou, G. Lee, C.S. Poon & W.L. Lai (2009), Properties of lightweight aggregate concrete prepared with PVC granules derived from scraped PVC pipes, Waste Management 29, 621–628.
[13] N. Haghighatnejad, S.Y. Mousavi, S.J. Khaleghi, A.T. Tabarsa & S. Yousefi (2016), Properties of recycled PVC aggregate concrete under different curing conditions, *Construction and Building Materials* 126 943–950.

[14] Y. Senhadji, G. Escadeillas, A.S. Benosman, M. Mouli, H. Khelafi & S. Ould Kaci (2015), Effect of incorporating PVC waste as aggregate on the physical, mechanical, and chloride ion penetration behavior of concrete, *Journal of Adhesion Science and Technology*, 29(7), 625–640.

[15] H. H. Hussein, O.A. Edan & M.K. Ahmed (2017), Mechanical, thermal and acoustical properties of concrete with fine polyvinyl chloride (PVC), *Iraqi Journal of Civil Engineering*, 12(2), 81-91.

[16] Andrea Petrella, Rosa Di Mundo & Michele Notarnicola (2020). Recycled Expanded Polystyrene as Lightweight Aggregate for Environmental Sustainable Cement Conglomerates. *Materials*, 13(988), doi:10.3390/ma13040988

[17] Fahad K. Alqahtani, Gurmel Ghataora, M. Iqbal Khan, Samir Dirar, Azzedine Kioulk & Mansour Al-Otaibi (2015). Light Weight Concrete Recycled Plastic Aggregates *International Conference on Electromechanical Control Technology and Transportation (ICECTT)*.

[18] Raghate Atul M. (2012), Use of Plastic in A Concrete to Improve Its Properties, *International Journal of Advanced Engineering Research and Studies (IJAERS)*, 1(3), 109-111.

[19] Neville, A.M. (2011), "Properties of Concrete", Longman Group Ltd., United Kingdom.