Waste plastic as partial replacement for aggregates - a review

Edmund T.S.J.*, Jun Hon C., F Hejazi and M. S. Jaafar

Department of Civil Engineering, Faculty of Engineering, University Putra Malaysia, 43400 UPM

*Edmundtsj@gmail.com, Chinjunhon@gmail.com

Abstract. By replacing coarse aggregate as well as fine aggregate with waste plastic known as green innovation. As the years go by, waste plastic increases day by day, since most of the plastic used by human is non-biodegradable. The idea behind this review is to identify research done by the researchers who uses recyclable material such as plastic obtained mostly from waste plastic that the people had generated around the world by utilisation of waste plastic in becoming of construction materials in order to overcome the environment problem that the society are facing. This paper aim to review the using of waste plastic to replace fine and coarse aggregate and stated the mechanical properties of the concrete. With different percentage replacement of aggregates will affect the different properties such as slump, compressive strength and ultimate strength of the concrete and compare with the control sample in order to find the suitable percentage of the waste plastic to replacement of aggregates for the concrete used. It was found that plastic as replacement for fine and coarse aggregate both have has lower compressive quality of the concrete, almost the same or lower slump test value for ordinary concrete and waste plastic concrete and lower density for the waste plastic concrete compare to the ordinary concrete.

1. Introduction:
Plastic waste become a major problem effect environment as it is not easy biodegradable. Each year of waste plastic increase as population grow. Recycling using the plastic waste into useful product is one of the solution to decrease the quantity of plastic waste. Used plastic will be landfill and litter on land if without recycle. National Environment shown that 7.70 million tones of plastic waste was generated in 2017. Malaysia is the worst 8 country of plastic waste in the world. In order that motivate the researchers and engineers to use plastic waste as a material for the concrete. Concrete has been widely used in the construction work, so determine the properties of the concrete by replacing plastic waste. Sreenath & Harishankar, (2017) stated that 500 million plastic bags per year was used in different industries. Low-Density Poly Propylene (LDPP) are the major plastic waste and used LDPP replacement fine aggregates are used in concrete mixture with grade M25. Moreover, Jaffe et al., (2015) used high-density polyethylene (HDPE) types of plastic to full or partial replace the fine aggregates in the concrete. Due to others research had shown that increase in plastic ratio in the concrete mixtures decrease the compressive strength. Ghernouti et al. (2009) found that plastic bag had been rejected into nature, so the research is focus studying using rushing the waste plastic bag replacing fine aggregates in the concrete mixtures. Moreover, Amalu et al, (2016) investigates used recycle plastic material to replacing the fine aggregates in the concrete mixture with concrete grade M20 as it is most commonly used in the constructional work. Suganthy et al., (2013) stated that increased waste material as shortage of construction materials. So, waste plastic replacement for fine...
aggregates in concrete grade M25 as construction material to overcome the problem. Aravind & John, (2015) stated that using plastic waste can decreasing the construction cost and reduce the river sand used protect the environment. Ramadevi & Manju, (2012) explored that around 12.3% waste plastic which from discarded water bottles. By using replacing sand in concrete mixture to overcome the problem. Arivalagan.S, (2016) conducted experiment to identify of advantages using PET waste plastic as replacement of sand. Guendouz et al., (2016) studied that using Low Density Polyethylene (LDPE) powder with diameter 1.5mm as new material to replace sand in concrete mix design, due to more economic.

Kibria et al., (2017) stated that disposing plastic require huge area land space to fill it and utilization of waste plastic for aggregates replacement in concrete to help can overcome the problem. Purnomo et al., (2017) had investigated properties of uncoated and coated plastic aggregates in the concrete mixture as to improve the surface texture of the aggregates. Pešté et al., (2016) explored the mechanical and serviceability properties of concrete which reinforced with HDPE fibres and also explore any subsequent advantages. Ishaya et al., (2016) determined possibility using waste bottle cap as partial replacement of coarse aggregates in order to have low concrete and less environment effect of concrete structure. Besides that, Rai et al., (2012) studied see whether the plastic wastes mixed in the concrete in different form with lessor without effect properties of concrete. Ismail & AL-Hashmi, (2008) investigate using plastic waste as cementitious binder in concrete to arrest the micro crack. Siddique et al., (2008) reviewed plastic waste as partial replacement in concrete mixture design on the effect properties of concrete. This paper is to review using waste plastic as replacement of aggregates effect the mechanical properties of the concrete.

2. Properties of concrete waste plastic replacement by fine aggregates

Properties of concrete such as slump test, density, tensile strength, compressive strength and split tensile strength replacement of fine aggregates by waste plastic stated as below:

2.1 Slump test

Ghernouti et al., (2009) had determine replacing 10, 20, 30 and 40% of sand by using plastic bag waste (PBW) by increasing percentage of plastic bag waste the fluidity of concrete increase as plastic particles have more smoother surface than sand. Suganty et al., (2013) reported with same 90mm height of slump, the require of water cement ratio will be higher with increase replacement of fine aggregates by plastic. With replacement of 100% of fine aggregates by plastic, shown that require 0.6 water cement ratio. Amalu et al., (2016) shown that increasing percentage containing plastic in the concrete, given the highest slump. The slump test shown that increasing when containing more PBW. Containing 40% of PBW showed that highest slump as plastic can’t absorb water so increase the fluidity of concrete. Arivalagan.S., (2016) stated that workability increase when increase percentage of PET waste plastic as replacing sand. Guendouz et al., (2016) determined that with increase replacement 40% LDPE powder as sand and increasing workability due to more free water in the concrete mixture.

2.2 Compressive strength:

Amalu et al., (2016) stated that decrease in compressive strength increasing plastic contain at 28 days. But remain close to the concrete of 10% and 15% contain have fall around 10% and 13% different. Ghernouti et al., (2009) and Jaffe et al., (2015) shown that the compressive strength at 28 days for containing 10 and 20% remain close to the control sample but when replacing until 30% the concrete has turn to unusually weak. The compressive strength has shown much different to the control sample. Sreenath & Harishankar, (2017) stated that replacing sand by LDPP with 10% increasing of compressive strength from 34.96N/mm2 to 38.957N/mm2. Ramadevi & Manju, (2012) reported that replacing 2% of sand by PET fibres has increase the compressive strength but more than 2% the strength start decrease. Aravind & John, (2015) determined that with replace any percentage fine aggregates by plastic fines decrease the compressive strength at 28 days. Arivalagan.S., (2016) found that replacing 10% of PET waste plastic as sand in concrete, the compressive strength is increased by
26% compare to control sample but replace more than 15% the compressive strength less than control sample. Guendouz et al., (2016) determined that at replacement 20% of sand by using LDPE powder increase 30% of compressive strength as concrete have more ductile tolerant.

2.3 Bulk Density
Ghernouti et al., (2009) has determined the bulk density of the concrete cube at 28days. It shown that if containing higher plastic waste the density will be lower so, with containing 40% of the plastic waste is lighter than the others as the plastic waste lighter 70% than the sand. Suganthy et al., (2013) carried out that replacing percentage of sand by plastic, the cube weight decrease and seen like the linear with replacement of sand by plastic. Guendouz et al., (2016) reported that replace 40% of the sand by using LDPE powder decrease 10% of bulk density of the concrete at 28days.

2.4 Split Tensile Strength:
Sreenath & Harishankar, (2017) stated that replacing 10% sand by LDPP has increasing to the control sample. (Ramadevi & Manju, 2012) reported that with replacing 2% of sand by PET fibres increasing the split tensile strength but when replacing more than 2% started decrease. Jaffe et al., (2015) determined that replacement 20% of fine aggregates by plastic increased splitting tensile strength compare to control sample but after replace more than 30% start decrease. Aravind & John, (2015) shown that replace 5% of fine aggregates by plastic fines more higher than control sample but more than 10% much lower than control sample.

2.5 Flexural Strength:
Amalu et al.,(2016) shown that with increasing ratio of waste plastic, the flexural strength will decrease. By replacing 25% of sand by plastic has lowest value flexural strength at 28days. Sreenath & Harishankar, (2017) reported that replacing 10% sand by LDPP, the flexural strength has increasing but replacing from 10% to 20% has decreasing. Ramadevi & Manju, (2012) reported that with increase percentage replacement fine aggregates by PET bottle fibres increasing flexural strength but remain same at the 4% and 6% replacement. Aravind & John, (2015)stated that replacement 5% of fine aggregates by plastic fines increase the flexural strength but replace more than 10% start decrease. Guendouz et al., (2016) determined that at replacement 20% of sand by using LDPE powder get the highest flexural strength compared to control sample and replace 10%, 30% and 40%.If replace more than 30% start reducing the flexural strength of concrete.

3. Properties of concrete waste plastic replacement by coarse aggregates

3.1 Types of plastic as coarse aggregate
Plastic can be classify into many different kind where many of the researcher uses different kind of plastic in their experiment. For instance research conducted by Md. Golam Kibria, OsikurRahaman, Md. Ferdous Wahid and Abdus Salam (2017) focus on a type of plastic called polystyrene polymer waste with the aim of producing light weight concrete by partially replacing certain percentage of coarse aggregate as well as to server as a purpose for recycling. Another review from Lei Gu, TogayOzbakkaloglu (2015) quoted some of the researcher who uses other kind of plastic as coarse aggregate such as Akçaozog‘tu et al. (2010) uses Polyethylene terephthalate bottles, Kumar and Prakash (2006) using of high density polyethylene (HDPE).
Table 1: Types of plastic (Rodriguez-Jorquera et al., 2015)

| Symbols | Description | Commonly found in |
|---------|-------------|-------------------|
| PETE    | Polyethylene Terephthalate | Soda, water, and beer bottles; salad dressing containers |
| HDPE    | High Density Polyethylene | Milk jugs; household cleaner containers; juice bottles; yogurt tins |
| Vinyl   | Vinyl        | Shampoo bottles; cooking oil bottles; medical equipment; piping |
| LDPE    | Low Density Polyethylene | Squeezable bottles; shopping bags; carpet; frozen food; food wraps |
| PP      | Polypropylene | Yogurt containers; ketchup bottles; syrup bottles; medicine bottles |
| PS      | Polystyrene  | Meta trays; egg cartons; disposable plates and cups |
| OTHER   | Miscellaneous| Sunglasses; iPod cases; computer cases; bullet-proof materials |

3.2 Compressive strength
The compressive strength of the 28th day will be taken for this investigation. The compressive strength S. Vanitha, V. Natrajanand M. Praba (2015) shown that the strength decreases as the percentage of waste plastic increases with maximum of 26.9 n/mm² and minimum of 14 n/mm². While another research from Md. Golam Kibria, OsikurRahaman, Md. Ferdous Wahid and Abdus Salam (2017) found that the compressive strength for the polystyrene polymer waste as coarse aggregate produces 955 psi value around 6.59 n/mm² which also indicated that as the percentage of the plastic waste increases the compressive strength will show a significant decrease in strength which was due to the poor bond between cement and polymer materials. Similarly research by Al-Manaseer and Dalal (1997) stated that a huge reduction from 34% to 51% to 61% of compressive strength as the plastic content increases by 20% each. In the other hand, research from Kumar and Prakash (2006) were able to obtain twice the compressive strength compared to Md. Golam Kibria, OsikurRahaman, Md. Ferdous Wahid and Abdus Salam (2017) due to the fact that the the materials used is measured based on total weight of cement and sand. In addition to that, another research by Zainab Z. Ismail, Enas A. Al-Hashmi(2007), although it is not mention the exact compressive strength the article stated that the strength obtain is fairly poor.

3.3 Percentage of plastic used in concrete
As for the percentage of plastic used in the research different researcher uses different percentage of plastic content which varies from 2% to 30-40% of plastic content. As show by S. Vanitha, V. Natrajanand M. Praba (2015), start off with 2%, 4%, 6%, 8%, and 10% of plastic waste with increment of 2% each. WhileBaboo Rai, S. TabinRushad, Bhavesh Kr, and S. K. Duggal (2012) reported use the percentage of 5%, 10%, 15% of plastic waste with increment of 5% each. Md. Golam Kibria, OsikurRahaman, Md. Ferdous Wahid and Abdus Salam (2017) replaces starting with 10%, 20%, 30% and 40% of platic replaced with coarse aggregate. Pešić, N., Živanović, S., Garcia, R. et al. (1 more author) (2016) uses the least percentage starting from 0.4%, 0.75%, 1.25% of plastic
fibre. From the result obtain it can be conclude that the percentage of plastic added will greatly affect the quality of the concrete such as the compressive strength, slump test, density.

![Graph 1: Comparison of plastic usage](image)

**3.4 Specific gravity**
From the research conducted by S. Vanitha, V. Natrajanand M. Praba (2015), conducted that a specify gravity of 2.6 for aggregate and 1.04 for plastic. While Baboo Rai, S. TabinRushad, Bhavesh Kr, and S. K. Duggal (2012) uses specific gravity for coarse aggregate of 2.85 and they did not state any for plastic. Youcef Ghermouti, Bahia Rabehi, Brahim Safi and Rabah Chaid (2010), used specific gravity for aggregate of 2.56 and 0.87 for plastic. In addition to that Lakshmi R, Nagan S (2010) determined that specific gravity for aggregate of 2.65 and waste plastic of 1.01. Md. Golam Kibria, Osikur Rahaman, Md. Ferdous Wahid and Abdus Salam (2017) used specific gravity for sand as 2.62 and coarse aggregate for 2.6 and stated none for plastic. Based on the specific gravity result obtain it clearly show that every research have their own different value which may lead to an important role in different final result obtain.

**3.5 Slump test**
Consistency of mix property concrete which had different ability properties of finish ability, mobility, compatibility, stability and place ability determined by Youcef Ghermouti, Bahia Rabehi, Brahim Safi and Rabah Chaid (2010), whereas the percentage of plastic increases the fluidity of the concrete increases as well from minimum of 5 cm to maximum of 11 cm. However, research done by Baboo Rai, S. Tabin Rushad, Bhavesh Kr, and S. K. Duggal (2012), concluded that the higher the plastic percentage the lower the workability of the concrete it gets from the difference of 80mm to 35mm.

Also as stated by Lei Gu, Togay Ozbakkaloglu (2015) who reviewed Ismail and Al-Hashmi (2008) reported that the slump reduces up to 95% difference compared to the controlled sample concrete when substitute with 20% of plastic content. While another research by Kou et al., (2009), Tang et al. (2008) identify that there are no significant differences or influences on the slump where both sample showing similar slump. In addition to that, Zainab Z. Ismail, Enas A. AL-Hashmi (2007) indicated that the slump decreases as the plastic content increases by minimum of 3 cm to maximum of 6 cm difference.
Graph 2. Slump vs plastic content obtained from Zainab Z. Ismail et al. (2007)

Graph 3. Slump vs plastic content with and without plasticizer (Baboo Rai et al. 2012)

5. Conclusion
The main conclusion that can be drawn from this review is that the compressive strength of all concrete involving plastic as partial substitution most likely to be significantly lower than the ordinary or controlled concrete. It is much clearer when the percentage of plastic content as partial substitution increases the lower the strength of the concrete gets. Same conclusion can be made for the slump test result where higher percentage of plastic lower the slump test which was caused by the irregular shape, angularity as well as the surface smoothness of the plastic used as the substitution. As for the bulk density for the ordinary and plastic concrete it was shown that the plastic concrete will definitely weight lesser compared to the ordinary concrete since it is made out of plastic. This shows that plastic will be a good platform in producing lightweight concrete if proper research were to conducted which in other hand will produce good compressive strength in the meantime.

Although some researcher that manage to obtain satisfying compressive strength, it may due to the low percentage of plastic content used as well as types of plastic used which may be an important factor as some plastic material are tougher and stronger than others such as polypropylene. Other than the low plastic percentage used, it may also due to the additional binding agent called plasticizer. As show by Baboo Rai et al. (2012) the addition of plasticizer will increases or improve the result obtain with plastic as substitution for concrete. In addition to that, from the review above it can be concluded that plastic as fine aggregate substitution in concrete manage to produce a much more better result compared to the substitution for coarse aggregate since most of the research conducted with fine
aggregate give positive feedback rather than mostly negative result from coarse aggregate as substitution. Therefore, it is much more recommendable to use plastic as partial replacement for fine aggregate instead of coarse aggregate and using of plasticizer will manage to enhance the outcome of the plastic concrete.

References

[1] Amalu, Azeef Ashraf, Muhammad Hashim, Rejith.K.U, Vijitha.V, R. . (2016). Use of Waste Plastic As Fine Aggregate Substitute in. International Journal of Scientific & Engineering Research, 7(4), 172–177.

[2] Aravind, S., & John, E. (2015). Replacement of Fine Aggregate by Crumb Rubber and Plastic Fines, 4(11), 305–309.

[3] Arivalagan.S. (2016). Experimental Investigation on Partial Replacement of Waste Plastic in Concrete. International Journal of Engineering Sciences & Research Technology, 5(11), 443–449.

[4] Ghenouni, Y., Rabehi, B., Safi, B., & Chaid, R. (2009). USE OF RECYCLED PLASTIC BAG WASTE IN THE CONCRETE Youcef Ghenouni, Bahia Rabehi, Brahim Safi and Rabah Chaid Research Unit: Materials, Processes and Environment, University M’Hamed Bougara of Boumerdes. Algeria. Journal of International Scientific Publications: Materials, Methods and Technologies, 8, 480–487.

[5] Guendouz, M., Debieb, F., Boukendakdjii, O., Kadri, E. H., Bentchikou, M., & Soualhi, H. (2016). Use of plastic waste in sand concrete. Journal of Materials and Environmental Science, 7(2), 382–389.

[6] Ishaya, A., Oyemogun, I. M., Arinze, A., Abah, J. C., Polytechnic, F., & Namoda, K. (2016). Properties of Concrete Produced with Waste Bottle Caps (WBC) as a Partial Replacement of Coarse Aggregate and Orange Leaves Powder as Plasticizer, 8(7), 91–95.

[7] Ismail, Z. Z., & AL-Hashmi, E. A. (2008). Use of waste plastic in concrete mixture as aggregate replacement. Waste Management, 28(11), 2041–2047.

[8] Jaffe, N., Koppitz, M., & Weimer, W. (2015). Concrete Mixture With Plastic As Fine Aggregate, (4), 49–53.

[9] Kibria, M. G., Rahaman, O., Wahid, M. F., & Salam, A. (2017). Effect of Recycled Polystyrene Polymer in Concrete as a Coarse Aggregate, (November).

[10] Pešić, N., Živanović, S., García, R., & Papastergiou, P. (2016). Mechanical properties of concrete reinforced with recycled HDPE plastic fibres. Construction and Building Materials, 115(April 2018), 362–370.

[11] Purnomo, H., Pamudji, G., & Satim, M. (2017). Influence of uncoated and coated plastic waste coarse aggregates to concrete compressive strength. MATEC Web of Conferences, 101.

[12] Rai, B., Rushad, S. T., Kr, B., & Duggal, S. K. (2012). Study of Waste Plastic Mix Concrete with Plasticizer. ISRN Civil Engineering, 2012, 1–5. https://doi.org/10.5402/2012/469272

[13] Ramadevi, K., & Manju, R. (2012). Experimental Investigation on the Properties of Concrete With Plastic PET (Bottle) Fibres as Fine Aggregates. Journal of Emerging Technology and Advanced Engineering, 2(6), 42–46.

[14] Rodriguez-Jorquera, I., Yang, Y.-Y., & Toor, G. (2015). Contaminants in the Urban Environment: Bisphenol-A 1. EDIS University of Florida Extension Outlet.

[15] Siddique, R., Khatib, J., & Kaur, I. (2008). Use of recycled plastic in concrete: A review. Waste Management, 28(10), 1835–1852. https://doi.org/10.1016/j.wasman.2007.09.011

[16] Sreenath, S., & Harishankar, S. (2017). Effect of partial replacement of fine aggregate in concrete with low density polypropylene. International Journal of Civil Engineering and Technology, 8(4), 644–647.

[17] Suganthy, P., Dinesh Chandrasekar, & Sathish Kumar. P. K. (2013). Utilization of pulverizes plastic in cement concrete as fine aggregate. International Journal of Research in Engineering and Technology, 2(6), 1015–1019.