Recycling Electronic Waste and Plastic Waste as Construction Material: A critical review

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ABSTRACT

The disposal of waste glass electronics waste in landfills is an important environmental challenge that many countries face around the world. The reuse of waste glass electronic plastic waste into a construction material reduces the consumption of natural resources, minimizes greenhouse emissions and alleviates landfill scarcity. Over the last many years, numerous investigators have studied reusing crushed waste glass and electronic waste as a construction material in waste glass concrete and ultra-lightweight fibre reinforced concrete containing expanded waste glass, and the use of glass powder as filler in asphalt.

Reuse of waste and recycled plastic materials in concrete mix as an environmental friendly construction material has drawn attention of researchers in recent times, and a large number of studies reporting the behavior of concrete containing waste and recycled plastic materials have been published.

***Keywords**: Electronic plastic waste (e-plastic), Unsaturated polyester resin, Polymer Concrete, Compressive strength, Polycarbonate Recycling electronic waste, Gamma radiation*

INTRODUCTION

Polymer concrete is a composite material obtained by polymerization of aggregate and polymer binder (resin) subsequent to addition of hardener and accelerator at specific ratios. Aggregate and polymer binder are replaced by cement and water in production of polymer concrete. Polymer material covers aggregates like glue thereby forming the structure in this type of concrete. The resin types utilized most commonly as binder in polymer concrete production are polyester styrene, acrylic and epoxy. They are also employed in resins such as vinylester, furan and urea. It is observed that polymer concrete has numerous advantages compared to traditional Portland cement concrete. These advantages include high strength and durability, superior chemical resistance, very fast curing features, low shrinkage, improved fracture toughness and high adherence with aggregate. [1]

On the other hand disadvantages of polymer concretes include high costs, odor thereof especially in the production process, toxicity and flammability of polymer materials and their poor resistance to high temperatures. Polymer concrete is utilized in numerous different applications. For example, they are employed in repair works, decoration panels, piping and drainage works, underground tunnels, as coating materials in surfaces subject to abrasion and as lining materials in construction of pools and acid tanks. Meanwhile, natural resources are rapidly deteriorating due to causes like technological developments, rapid population growth and changes in consumption habits while particularly the harm given through industrial wastes is increasing day by day. Wastes such as plastic, glass, paper, industrial waste, construction waste, medical waste, organic waste or electronic waste are not only polluting nature but also threatening human health in our day. There has been a rapid increase in production and consumption of electrical and electronic equipment as from the last quarter of the 20th century. The usage life of these devices has been shortened and electronic waste has emerged in enormous dimensions when the rapid development of technology has combined with the consumer's unlimited consumption desire. The most significant difference distinguishing electronic waste from other types of waste is its being the fastest growing type of solid waste. Systematic recycling or disposal of electronic waste is necessary because of the dangerous substances they contain. There has been awareness in the world and in our country, more apparently in developed countries, in recent years. Various institutions coming together to develop legislation under the name of electronic waste management processes has been evaluated as a substantial development in this context. [1]

Polycarbonate (PC) is a high-performance thermoplastic that offers a combination of favorable properties such as transparency, high impact resistance, and easy molding. Polycarbonate market include mainly automotive, construction and electronics Polycarbonate waste recycling involves two different kinds of processes: 1) Mechanical processing where polycarbonate is pelletized by extrusion, then, the produced particles can be employed for elaboration of novel plastic products, and 2) Chemical processing, where polycarbonate is employed for production of monomers. Unfortunately, major impediments have been observed for products recycling with flame retardants. However, polycarbonate waste from optical discs, sheets or water containers can be used. [2]

Recycling and reuse of plastic wastes in cement concrete, appears to be one of the best solutions, due to its economic and environmental advantages, which is in favor of the sustainable management of natural resources and in unity with the goal ‘‘Ensure sustainable consumption and production patterns” of the 2030 Agenda for Sustainable Development from United Nations. [2]

Material properties of used in concrete

Polymer

Unsaturated polyester resin binder material was used in production of polymer concrete samples by Bulut H.A and Sahin R [1]. Polyester resin was preferred due to superior mechanical and chemical features thereof; it was being more affordable compared to epoxy resin as well as its advantages such as widespread commercial accessibility in polymer concrete production. The selected polyester resin was the unsaturated polyester resin which is sold in the market produced through the company named Cam Elyaf under CE 70 Casting Type Polyester code number and designed as orthophtalic based polymer concrete polyester. The technical information of polyester resin received by Bulut H.A and Sahin R [1] from the producer is provided in the table below.

Table 1. Technical information of polyester resin [1]

Feature	Concentration (%)
Unsaturated Polyester Resin	60
Styrene	40
Physical State	Liquid
Color	Yellowish
Smell Characteristic	styrene odor
Flash Point	34ºC
Ignition Point (Solvent)	490ºC
Explosion Limits (Solvent)	Lower limit is 1,1%; Upper limit 8.0% (volume)
Vapor Density	Heavier than air
Water Solubility	Insoluble
Specific weight	1,13
Viscosity	475 ± 75 cp
Gelling Time	(25ºC) 4 ± 1 min
Hardness	Minimum 35 Barcol
Bending Strength	Minimum 100 (N/mm2 = MPa)
Tensile Strength	Minimum 55 (N/mm2 = MPa)

Aggregates

Hardness, high strength, low void ratio were important in selection of aggregates used in production of polymer concrete. Quartz sand, gravel and e-plastic waste having the characteristics mentioned herein above were used by Bulut H.A and Sahin R [1] as filling material. Sieve analysis of these materials were determined according to TS 802/ June 2009. The aggregate was determined to be centered on the standard curves (A16/B16) recommended for aggregates with a maximum grain size of 16 mm. Accordingly, 0/2 mm 29.5%; 2/4 mm 11.5%; 4/8 mm 14.5%; 8/16 mm 44.5% as aggregate of each class has been taken. Quartz sand and gravel were included in the mixture as (0/2 mm, 2/4 mm and 4/8 mm) and (4/8 mm, 8/16 mm) respectively. The specific weight of sand having a hardness of 7 was 2.64; while the specific weight of the 4/8 and 8/16 classes of gravel were 2,625 and 2.61 respectively. [1]

Electronic plastic waste

Electronic plastic wastes (e-plastics) used by Bulut H.A and Sahin R [1] in sample production were the wastes obtained from recycling of monitor plastics coming to the factories of the company named Exitcom Recycling in Kocaeli province and their specific weight is 1.29. Electronic plastic waste was used at specific ratios in lieu of three classes (0/2 mm, 2/4 mm and 4/8 mm) of aggregates (quartz sand and gravel) utilized as filling material in the study. As such, the electronic plastic wastes were also divided into different classes according to size. It has been noticed after classification according to size that the wastes forming the 0/2 mm grain class were black. [1]

Hardener and accelerator materials

Materials starting (hardening) and accelerating chemical reaction were utilized by Bulut H.A and Sahin R [1] in production of polymer concrete. The technical information received from the supplier company polyester hardener which was the substance that initiates the chemical reaction thereby leading to cross-linking for resin and monomer hardening and the polyester accelerator used as reaction accelerator in this study are provided in the following table.

Table 2. Technical information of the hardener [1]

Product code	AKPEROX A1
Product description	Methyl Ethyl Ketone Peroxide mixture
Density	1,16 gr/cm³
Color	Colorless
Active Oxygen Content	9,4% - 9,6%
Peroxide Content	40%

Table 3. Technical information of the accelerator [1]

Product code	COBALT OCTOATE (EGEDry 12201)
Usage places	As a dryer in oil paints, as a polyester catalyst accelerator, in sticking rubber to metal
Density	0,98 gr/cm³
View	Clear Fluid
Co Metal (%)	10
Total Solid (%)	639

Polymer Concrete Production

PC was produced from a liquid resin and inorganic aggregates. Small dosages of initiators and promoters were added to a resin by Bulut H.A and Sahin R [1] to start the curing or hardening process. The initiators initiate polymerization and the promoters accelerate the reaction. Immediately after the addition of initiators and promoters, the liquid resin was mixed with coarse and fine inorganic aggregates such as gravel or crushed stone and sand. After curing, the material consists of well graded inorganic aggregates bonded together by a strong resin binder. [1]

Filling materials (quartz sand, gravel and e-plastic), firstly precisely weighed, were mixed in the concrete mixer for 1 minute in the production of polymer concrete samples. Subsequently the resin to which accelerator was added and mixed for about 1 minute was poured over the filling material and 10 mixed for 3 minutes in the mixer. Finally, hardener was added to this mixture and all of the ingredients were mixed for 2 more minutes. [1]

Concretes were placed in the molds lubricated with mold release agent following production. Concretes were placed into cylindrical samples as 2 layers by rodding 15 times and as 1 layer by rodding 25 times into prism samples. After placement, the samples were subjected to vibration for 2 minutes by a table type vibrator. The samples were removed after 24 hours from the molds and were cured in the air by being kept in the laboratory for 27 days. [1]

Polycarbonate

Polycarbonate particles, size 1 mm diameter and 3 mm length (1mm-3.0 mm), were obtained by extrusion from electronic waste. Polycarbonate particles were from electrical outlets wall switcher waste, and they were donated by Polyvima Company (located at San Lorenzo Tepaltitlán, Toluca, Mexico). The physical and mechanical properties of polycarbonate presented by Ana et. al. [2] is as below.

Table 4 Physical and mechanical properties of polycarbonate [2]

Property	Units Values
Specific Gravity g/cm3	1.2
Water Absorption %	0.15
Compressive Strength MPa	86.1
Flexural Strength MPa	93.0
Tensile Strength Ultimate MPa	65.5
Tensile Modulus GPa	2.37
Compressive Modulus GPa	2.38
Rockwell Hardness	M70/R118
Abrasive resistance mg/1000 cycles	10–15
Glass Temperature ^{o}C	145
Elongation %	110

Irradiation of recycled polycarbonate particles

Recycled polycarbonate particles used by Ana et. al. [2] were gamma irradiated at doses of 600, 800, 1000 and 1200 kGy, by using an industrial cobalt-60 source, model JS-6500 with a dose rate of 14.6 kGy/h, located at the National Institute of Nuclear Research in Mexico(ININ). [2]

Physical and chemical characterization of gamma irradiated

Polycarbonate particles the morphological characterization of gamma irradiated polycarbonate particles was evaluated by Ana et. al. [2] by scanning electron microscopy (SEM), in a JEOL-JSM-6510 LV, located at the Joint Center of Research in Sustainable Chemistry (CCIQS) of the Autonomous University of the State of Mexico (UAEM). Samples were observed in secondary electron mode at 5 kV. Additionally, digital photographs were obtained. [2]

Sand and gravel aggregates

Sand and gravel aggregates used by Ana et. al. [2] was obtained by Comercializadora Trimar (located at Toluca, Mexico). The sieve analysis of sand reveals a Fineness Modulus (FM) of 1.62, it indicate that the sand can be classified as fine. The sieve analysis of gravel shows a material that can be classified as a mixture of fine gravel and coarse sand. [2]

Preparation of cement concrete test specimens: Three different kinds of cylindrical cement concrete specimens were elaborated and tested by Ana et. al. [2] which were: a) Cement concrete with Portland cement (CPC 30R RS), sand, gravel and water; these were denominated as control cement concrete (PCI-0); b) Cement concrete with gamma irradiated polycarbonate particles (1 mm _ 3 mm) at concentrations of 3%, 6% and 15% by volume; and c) Cement concrete with cut irradiated polycarbonate particles size 1 mm diameter and 1.5 mm length (1 mm _ 1.5 mm) at concentrations of 3%, 6% and 15% by volume. It is necessary to mention that the specific gravity employed for sand was 2.85 g/cm3 and the density utilized for irradiated polycarbonate was 1.2 g/cm3. The specimens were placed in a controlled temperature room for curing according to ASTM C192 / C192M – 16a standard. [2]

Review of properties of concrete containing plastic aggregates and plastic fibers

Bulut H.A and Sahin R [1] determined 28 days axial compressive, flexural tensile and splitting tensile strength on the specimens of polymer concrete specimens mixture calculations of which were made in the ratio of 10%-90%, 15%-85%, and 20%-80% for the resin/filling and in the ratio of 0%, 5%, 15% and 25% for the e-plastic/filling. The strength results obtained by Bulut H.A. and Sahin R [1] from the tests were used in the form of SI – N/mm2 = MPa. [1]

When the samples with 0% electronic plastic/filling ratio were examined, it was observed by Bulut H.A. and Sahin R [1] that there was an increase in compressive strength when the resin ratio was increased. Similar strength increase was observed in samples with 5%, 15% and 25% e-plastic/filling rate. Increase in the ratio of resin firstly increased the compressive strength. This was because, increase of the ratio of resin may led to resin's better wetting and covering the filling materials and thus causing a strong adherence. Oussama *et al.* [4] have stated that the ideal resin ratios were 15%, between 12.8% and 18.8%, 19% and 13% respectively in their studies. It was stated in a study that the ratio of resin was the most important factor on the compressive strength of polymer concrete. As such, no adherence between the filling material and the resin occurred in the series where 10% resin was used by Bulut H.A. and Sahin R [1]. There was segregation between resin and filling materials (quartz sand, gravel, e-plastic) even in the batches where the electronic plastic waste was used as 15% and 25%. The compressive strength decreased to 1,63 MPa in the R10EP25 coded sample. The highest compressive strength was obtained by Bulut H.A. and Sahin R [1] in the sample R15EP0 with a resin content of 15%. The compressive strength was observed as 76,33 MPa. This value was about 3-4 times higher compared to normal concrete. The highest compressive strength obtained was about 69 MPa in the studies in which epoxy resin was used as binder in polymer concrete. Bulut H.A and Sahin R [1] obtained the strength values reached up to 76,33 MPa with the use of polyester resin. This was an indication that the polymer as a resin was superior to polyester in concrete. [1]

When the samples with 0% e-plastic/filling ratio were examined Bulut H.A and Sahin R [1] observed that there was almost no change in flexural strength as the resin ratio increased. When the samples with 5% eplastic/ filling ratio were examined it was seen that as the resin ratio increased, the flexural strength firstly increased and then decreased slightly. When the samples with e-plastic/filling ratio of 15% were examined it was found by Bulut H.A. and Sahin R [1] that the flexural strength increased as the resin ratio increased. When the samples with 25% e-plastic/filling ratio were examined it was detected that flexural strength increased considerably when the resin ratio increased. The increase in the proportion of resin in the samples without e-plastic did not cause a dramatic increase or decrease in the flexural strength. Sure enough, the flexural strength of the batches with 10% and 15% resin ratios increased to 15,4 MPa and 14,3 MPa respectively, while the flexural strength of the batch with 20% resin ratios increased to 17,1 MPa. As the ratio of resin increases, the flexural strength of the e-plastic added specimens increases. Just as mentioned in the results of compressive strength, with the increase of the resin ratio, the e-plastics adhered better to the resin and increased the strength. On the other hand, it cannot be said that the unsaturated polyester resin has less increase in flexural strength of polymer concrete than other (e.g. epoxy) polymer binders. Indeed, the flexural strength increased to 12,6 MPa in a study using 12,4% epoxy resin. Bulut H.A. and Sahin R [1] studied where 10%, 15% and 20% polyester resins were used, even the lowest strength (14,3 MPa) was found to be higher than the polymer concrete in which the epoxy resin was used as binder. [1]

When the samples with e-plastic/filling rate of 0% were analyzed, almost the same results were obtained by Bulut H.A and Sahin R [1] in splitting tensile strength as the ratio of resin was increased. When the samples with eplastic/ filling rate of 5% and 15% were analyzed splitting tensile strength increased as the ratio of resin was increased. When the samples with e-plastic/filling rate of 25% were analyzed, a great increase occurred in the splitting tensile strength as the ratio of resin was increased. Increase of resin rate in samples to which e-plastic was not included has not led to a dramatic increase or decrease in neither flexural strength nor splitting tensile strength. Splitting tensile strength values were almost the same for each 3 different resin ratios (10%, 15%, 20%). These strength values were obtained as 8,1, 8,8 and 8,65 MPa respectively. The splitting tensile strength values obtained by Bulut H.A and Sahin R [1] in this study have been compared with normal concrete results obtained by Senthil Kumar and Baskar [3] in which coarse aggregate has been replaced by e-plastic ratios at 10-20-30-40-50%. Strength of the samples in which e-plastic has not been used in the normal strength has arisen to 3 MPa and as the e-plastic ratio has increased the strength value has decreased. Almost three-fold (above 8 MPa) values were obtained in this study. So much so that, splitting tensile strength values has been obtained at the range of 4-7,3 MPa even in the batches e-plastic especially when the resin ratio has increased to 15% and 20%. The splitting tensile strength obtained by Bulut H.A. and Sahin R [1] was almost similar in particular, as a result of the use of e-plastics batch with 20% of resin values . These values were 8,65, 6,97, 7,12 and 6,18 MPa for R20EP0, R20EP5, R20EP15 and R20EP25 respectively. These results showed that the compatibility between e-plastic and resin was not damaged in mixtures containing a high dose resin by the increase of e-plastic /filling ratio. [1]

Ana *et. al.* [2] Mixed gamma irradiated polycarbonate particles to cement concrete. In Fig. 1, compressive strength values of concrete with irradiated polycarbonate particles (PCI-6b-x) were shown. Two well-defined phases were observed: a) the values diminish for cement concrete with particles irradiated at 600 and 800 kGy, b) these values increased for higher irradiation doses (1000 and 1200 kGy). Such behaviors can be attributed to the morphological changes of the polycarbonate particles, caused by gamma irradiation. This sudden jump in compressive strength (at 1000 kGy) happens when the texture of the polycarbonate turns rough, facilitating the polycarbonate adherence to cement concrete. This behavior showed that the -rough texture- and not other, was required to generate an important change (an improvement of 12% compared to controlling concrete) on the concrete resistance. [2]

Ana *et. al.* [2] Observed behavior of irradiated specimens at 1000 and 1200 kGy, because at these doses the compressive strength values were improved, i.e., with major values as control cement concrete (Fig. 1). Thus, in the third experimental stage, cement concrete specimens were elaborated with cut polycarbonate particles irradiated at 1000 kGy size 1 mm _ 1.5 mm, varying particle concentrations (3, 6 and 15% by volume). Compressive strength tests were evaluated and compared with specimens without irradiated particles. [2]

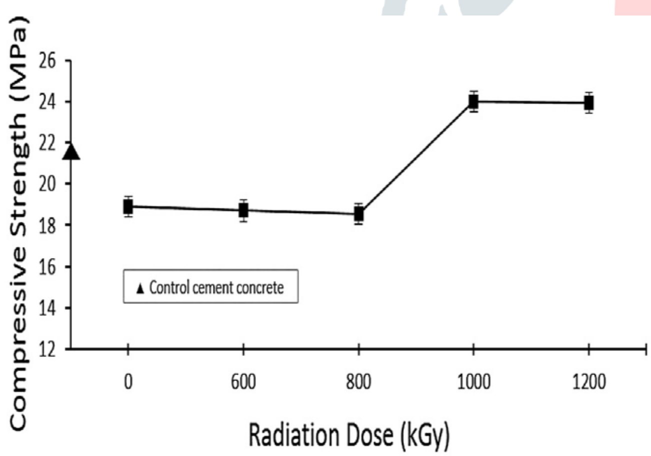

Fig. 1 Compressive strength of concrete with irradiated polycarbonate particles [2]

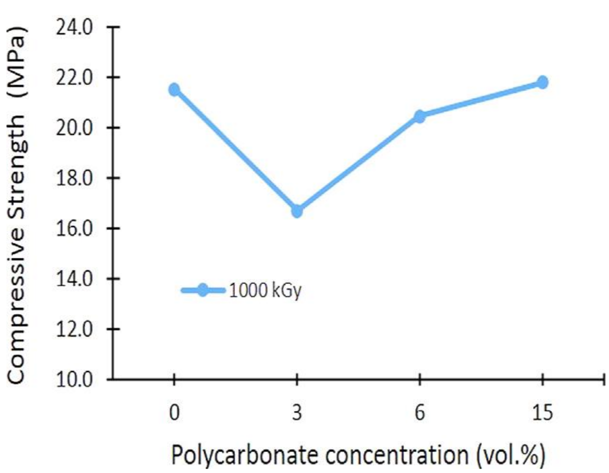

Fig. 2 Compressive strength of concrete with irradiated polycarbonate particles at

1000 kGy (PCI-yc-1000). [2]

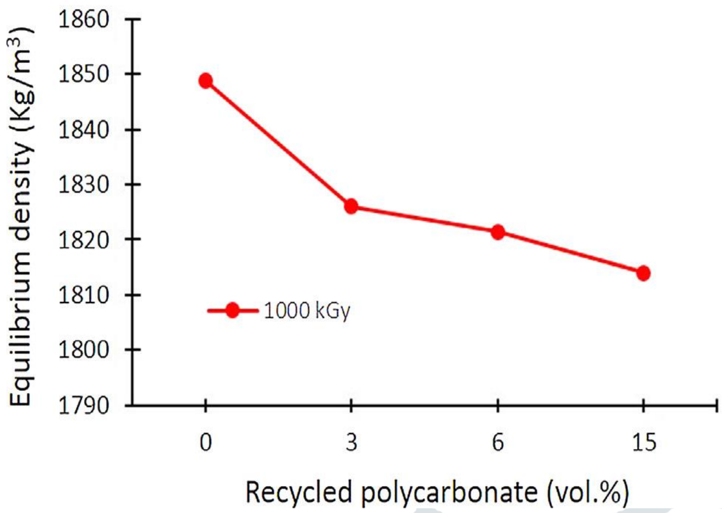

Fig. 3 Equilibrium density of concrete with irradiated recycled polycarbonate (PCIyc-1000) [2]

The compressive strength values of cement concrete with irradiated polycarbonate particles (1 mm _ 1.5 mm) at 1000 kGy (PCI-yc-1000) are shown in Fig. 2. The results obtained by Ana et. al. [2] for concrete with irradiated particles shown that the lowest values were obtained for cement concrete with 3% of irradiated particles. Such values were 20% lower as those for controlling cement concrete. A low percentage of polycarbonate disorders the initial balance of the mixture and the resistance fall. This was because polycarbonate, at this concentration, couldnot offer the same benefits that the removed sand. Diminutions on the values were attributed to the morphological changes, where major fragmentation of brittle particles and lower plasticity were decisive. Fortunately, for concrete with irradiated particles the values gradually increase for higher particle concentrations. Higher percentages make possible for the polycarbonate to offer comparable benefits that the removed sand. Thus, a combination of high ionizing energy (1000 kGy) and high particle concentrations (15%) allow having similar compressive strength values as those for controlling cement concrete. [2]

Equilibrium density values are shown in Fig. 3. The results were evaluated on the basis of the concentration of irradiated polycarbonate particles size (1 mm _ 1.5 mm) (PCI-yc-1000). When the concentration of irradiated polycarbonate particles increase, the equilibrium density of the concrete diminishes of a logarithmic form. This suggests that the equilibrium density depends on the quantity of irradiated recycled polycarbonate added. On the other hand, this material can be considered as lightweight concrete, which equilibrium densities were generally between 1120 and 1920 kg/m3. [2]

CONCLUDING REMARKS

- The use of electronic plastic waste in polymer concrete decreases the flexural strength. This decrease in flexural strength varied depending on the resin/filling ratio and amount of the e-plastic. [1]
- The highest flexural strength (17,1 MPa) was obtained in the batch with resin/filling ratio of 20%-80% and e-plastic (R20EP0) was not used and in the batch with resin/filling ratio of 15%-85% and 5% e-plastic was used (R15EP5). [1]
- An optimum condition for flexural strength was when the resin/filling ratio was 15%-85% and e plastic/filling ratio to be 5%. [1]
- As the e-plastic rate increased (especially as a result of the use of 25% e-plastics) increase in the amount of deflection of the prisms increased very significantly.
- Increase of resin rate in the samples to which e-plastic was not added did not lead to a dramatic increase or decrease in flexural and splitting tensile strength.[1]

- A decrease occurred in splitting tensile strength with the use of e-plastic waste in polymer concrete. It was determined as a result of the splitting tensile strength test results that the ideal resin/filling ratio was 15%-85% and e-plastic/filling ratio giving the best results was 5% and 15%.[1]
- Environmental pollution caused by polycarbonate from electronic waste, can be reduced when polycarbonate was gamma irradiated and used as aggregate into cement concrete.[1]
- Gamma-rays contribute to modify the texture, from smooth to rough, of recycled polycarbonate particles. This facilitates its adherence to the cement concrete and contributes to increase its compressive strength up to 12% with respect to the controlling concrete. To do so, 6% of these particles size (1 mm _ 3 mm), irradiated at 1000 kGy were added. In this scenario, the irradiated particles become less plastic and brittles. This shows that the particles of waste polycarbonate with these characteristics can be recycled in moderate percentages (6%). [1]
- When particles of polycarbonate size (1 mm _ 3 mm) gamma irradiated at 1000 kGy were cut to reach a smaller size (1 mm _ 1.5 mm), they lose its regularity in size. It was promising that cement concrete with irradiated recycled polycarbonate were consistent with the ACI Manual of Concrete Practice Index—2015 and they follow the structural lightweight concrete criterion. [2]
- Mechanical properties along with the equilibrium density depend on the polycarbonate particle sizes and its concentration as well as gamma irradiation doses.[2]
- The increase of the resin ratio has increased compressive strength. This was because increase of the ratio of resin might leads to resin's better wetting and covering the filling materials and thus causing a strong adherence. [2]
- Highest compressive strength was obtained in the mixtures where ratio of the resin was 15%. E-plastics have reduced the compressive strength of concrete. However, strength loss caused by addition of 5% the e-plastic was small.[2]
- Therefore, the mixtures where the resin/filling ratio was 15%-85% and e-plastic/filling ratio was 5% can be considered to be "optimal". Hence, it can be concluded that eplastic polymer can be used in concrete.[2]

REFERENCES

1. Bulut H.A. and Sahin, R., "A Study on mechanical properties of polymer concrete containing electronic plastic waste". Composite structures (2017).
2. Ana Laura De la Colina Martínez , Gonzalo Martínez Barrera, Carlos Eduardo Barrera Díaz, Liliana Ivette Ávila Córdoba, Fernando Ureña Núñez and David Joaquín Delgado Hernández, "Recycled polycarbonate from electronic waste and its use in concrete:Effect of irradiation". *Construction and Building Materials 201* (2019) 778–78.5
3. C. Vipulanandan and E. Paul, "Characterization of polyester polymer and polymer concrete". *Journal of Materials in Civil Engineering, 5 (1)* (1993) 62-82.
4. C. Ma, J. Yu, B. Wang, Z. Song, J. Xiang, S. Hu, S. Su and L. Sun, "Chemical recycling of brominated flame retarded plastics from e-waste for clean fuels production: a review". *Renewable Sustainable Energy Revision* 61 (2016) 433–450.
5. D.S. Achilias and E.V. Antonakou, "Chemical and Thermochemical Recycling of Polymers from Waste Electrical and Electronic Equipment, in: Recyclable Materials Based Environment Friendly Technology, *IntechOpen, London, United Kingdom,* 2015, pp. 37–61.
6. E. Oussama, G. Elhem, M. Valérie and B.O. Mongi, "Mechanical and physical properties of epoxy polymer concrete after exposure to temperatures up to 250 ºC". *Construction and Building Materials*, 27 (2012) 415-424.
7. H.A. Bulut, "Investigation of mechanical properties of polymer concrete containing electronic plastic waste". MS Thesis, Atatürk University, (2016) (in Turkish).
8. J.P. Gorninski, D.C. Dal Molin and C.S. Kazmierczak, "Study of the modulus of elasticity of polymer concrete compounds and comparative assessment of polymer concrete and portland cement concrete". *Cement and Concrete Research, 34* (2004) 2091–2095
9. J. Pandya and B.M. Purohit, "Experimental study on the mechanical properties of concrete incorporating PET fibers". *International Journal of Science Research Dev. 2* (2014) 43–45.
10. K.S. Kumar and K. Baskar, "Recycling of E-plastic waste as a construction material in developing countries". *Journal of Material Cycles and Waste Management,* 17 (4) (2015) 718-724.

11. Mordor Intelligence, Polycarbonate Market - Segmented by Product Type, Enduser Industry and Geography - Growth, Trends and Forecast (2018–2023), 2018.
12. M.A. Jibrael and F. Peter, "Strength and Behavior of Concrete Contains Waste Plastic". *Journal. Ecosyst. Ecography. 6* (2016) 1–4.
13. M. Muthukumar and D. Mohan, "Studies on polymer concretes based on optimized aggregate mix proportion". *European Polymer Journal. 40* (2004) 2167–2177.
14. OECD, OECD Environmental Performance Reviews: Mexico 2013, OECD Publishing, 2013.
15. S.S. Karanth, V.G. Ghorpade and H.S. Rao, "Shear and impact strength of waste plastic fibre reinforced concrete". *Adv. Concr. Constr. 5* (2017) 173–182
16. United Nations, Transforming our world: the 2030 Agenda for Sustainable Development. A/RES/70/1, 2015.
17. V. Toufigh, M. Hosseinali and S.M. Shirkhorshidi, "Experimental study and constitutive modeling of polymer concrete's behavior in compression". *Construction and Building Materials. 112* (2016) 183–190.

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