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ORIGINAL ARTICLE

Recycling of E-plastic waste as a construction material in developing countries

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Abstract This paper presents an experimental investigation on structural concrete with partial replacement of coarse aggregate using electronic plastic waste (E-plastic). In view of utilizing the non-degradable waste in the construction industry, the E-plastic from computer plastics was considered as coarse aggregate. Coarse aggregate was replaced with different percentages (10, 20, 30, 40 and 50 %) of E-plastic by volume. Tests were performed for properties of fresh and hardened concrete at different ages such as 7 and 28 days. From the investigation, it was noted that the workability of the mix was reduced against the increase in percentage of E-plastic. The compressive strength, split tensile strength, flexural strength of partially replaced concrete was comparatively less than that of the control concrete. The effect of adding the E-plastic in concrete reduced the dry density of the concrete and showed the high deformability behavior before failure. The lesser dry density may be having advantage in self-weight reduction in structural elements which leads to lesser attraction of pseudo inertia forces in the seismic prone area.

Keywords Fresh concrete · Compressive strength · Aggregate · Waste management · Electronic waste

Introduction

Due to highly dynamic technological advancement, the electrical and electronic equipment production, and its consumption rate is more rapid in the past decades. The rapid changes in equipment production, its component and features, reduced the electronic product cost and the consumers throw away the old products, showing fascination to new products with latest technology. This has created a large amount of junk electrical and electronic devices. Electronic waste comprises of waste from equipments such as computers, mobile phones, television, printers, laptops, personal stereo, washing machines, air conditioner, refrigerators and other household appliances. Electronic waste is growing at almost three times the rate of municipal waste globally [1]. Electronic waste comprises of different materials and chemicals such as lead, cadmium, mercury, beryllium, brominated flame-retardants and plastics including polychlorinated biphenyls, poly vinyl chloride, and polystyrene, many of which are toxic and are likely to create serious problems for the environment and human health if not handled properly. These electronic wastes require intense care in its disposal; otherwise, it can cause serious health problems to human beings. These necessitate a large collection network, recycling infrastructure, sound technology for handling and disposal of electronic waste. The globalized trade of this complex and toxic electronic waste poses a challenging task for its management and causes hazardous environmental concerns in both developed and developing nations [1]. Most of the nations have evolved stringent norms for recycling these electronic wastes to avoid adverse impact on environment and human health. However, the absence of facilities for recycling as well as stringent norms in developing nations is posing serious threats. The large-scale unethical export of electronic waste from the western countries to Asian and African nations has increased the burden on the later nations, since they are poorly equipped to deal with such waste.

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India, with a population of over 1 billion, is a rapidly growing economy and showing increased rate in electronic appliances consumption. A joint study on electronic waste generation was carried out by the Manufacturer's Association of Information Technology (MAIT) of India and Gesellschaft für Technische Zusammenarbeit (GTZ) of German in India during 2007. The estimated generation of electronic waste was approximately 400,000 tonnes of waste annually (from computers, mobile phones and television sets only), which is expected to grow at a rate of 10–15 % per year [1]. Plastic is one of the dominant materials used in electronic appliances and it normally constitutes about 21 % [2]. In India, most of the plastic from electronic products is recycled by the informal sector. At present, there is no definite process for electronic plastic recycling in the informal sector. In formal sector, current recycling processes can recycle only 20 % of plastic efficiently. Since the current recycling process is not efficient to recycle the electronic plastic, disposal of electronic plastic waste done by combustion, recycling in the informal sector and landfills, is the final way of disposing electronic plastic waste into the environment.

The continuous depletion of natural resources and ever-increasing cost of raw materials, the utilization of waste materials in the construction industry, add extra aggregate source and reduce the impact on the environment. Worldwide many researches have been carried out by utilizing plastics from municipal solid wastes such as polyethylene terephthalate (PET) bottle, poly vinyl chloride (PVC) pipe, and polyethylene bags made up of high-density polyethylene (HDPE), low-density polyethylene (LDPE). These plastics were shredded and used as an aggregate mostly like fine aggregate, a filler or a fibre in the preparation of cement mortar and concrete [3–14]. Although extensive research has been done on recycled plastic materials, there have been very few studies, which incorporate electronic plastic waste in cement mortar and concrete. Waste glass material chopped from electronic grade glass yarns has been used as fine aggregate in concrete [15]. Recently, asphalt binders modified with electronic waste from recycled computer plastics to improve asphalt binder performance versus conventional asphalt binders was experimentally studied [16] and waste printed circuit board powder was used as admixture in cement mortar [17]. Lakshmi and Nagan [18–20], have carried out an experimental study using E-plastic particles as coarse aggregates in concrete with a percentage replacement ranging from 0 to 30 % by weight on the strength criteria of M20 Concrete. Strength tests like compressive strength, tensile strength and flexural strength of concrete were carried out. Results show that the strength decreased with increase of E-plastic aggregates [18, 19]. Concrete with E-plastic aggregate and fly ash were investigated and the results [18–20] show that up to 20 % replacement of E-plastic in concrete with fly ash improved the compressive and tensile strength. Durability tests were also conducted [19, 20], which show that E-plastic concrete is acceptable, although slightly lower when compared to conventional concrete.

Table 1 Physical properties of ordinary Portland cement

Physical properties	Test results
Specific gravity	3.13
Standard consistency	32 %
Initial setting time	45 min
Final setting time	190 min
Fineness	282 m^2/kg
Compressive strength of cement (days)	
3	31 N/mm^2
7	43 N/mm^2
28	58 N/mm^2

The electrical and electronic equipments are made up of different kinds of plastics. In this research, an effort was made to replace the coarse aggregate partially by electronic plastic waste that is obtained from particular source. E-waste plastics were obtained from computer and accessories equipment alone is used in this study as replacement for coarse aggregate. The coarse aggregate was partially replaced with different percentages of E-plastic by volume ranging from 10 to 50 %.

Experimental program

Material properties

Cement

The cement used in the concrete mix design was Ordinary Portland cement conforming to IS 12269-1987 [21]. Various laboratory tests were carried out and the physical properties are mentioned in Table 1.

Aggregate

The physical properties of the coarse and fine aggregate as found through laboratory test are given in Table 2, conforming to IS 2386 (Part I–IV)-1963 [22].

Water

Potable water free from impurities and salt was used for mixing and curing the concrete specimens as per IS 456-2000 [23].

Table 2 Physical properties of coarse and fine aggregate

Physical properties	Coarse aggregate	Fine aggregate
Specific gravity	2.79	2.65
Bulk density	1624.22 kg/m^3	1656.09 kg/m^3
Fineness modulus	6.86	2.53
Water absorption	0.64 %	1 %
Aggregate impact value	20.9 %	NIL
Aggregate crushing value	24.8 7 %	NIL

Fig. 1 E-plastic aggregates (computer plastics)

E-plastic as coarse aggregate

The E-plastic used as a partial replacement for coarse aggregate was in the form of chips, which was flaky in shape and black in colour. A sample of E-plastic is shown in Fig. 1. The properties are found as per IS 2386 (Part I–IV)-1963 [22], the maximum size considered was 12.5 mm, the fineness modulus and specific gravity for E-plastic were 7.69 and 1.29, respectively. The density of E-plastic was 595.30 kg/m^3. The aggregate impact value and crushing value were less than 2 %.

Concrete mix design

The design reference mix of M25 grade concrete (1:2.14:3.08) with a W/C ratio of 0.49, using 12.5 mm maximum size of coarse aggregate and 2.36 mm maximum size of fine aggregate was based on IS 10262:2009 recommendations [24]. The ratio of water:cement:fine aggregate was fixed; coarse aggregate was replaced with different percentages of E-plastic by volume (10, 20, 30, 40 and 50 %) are shown in Table 3.

Results and discussions

Fresh concrete properties

Fresh concrete properties such as slump, fresh unit weight, were determined according to Indian Standard specifications IS: 1199-1959 [25]. Slump test was conducted to study the workability of concrete. The concrete mix was designed for slump 25–50 mm and the design slump was achieved with control concrete. The increase of E-plastic in the concrete mix resulted in decrease of workability, which affected the slump and fresh density. The shape and size of the E-plastic aggregates influence the consistency of the concrete mix. There is a decline in the slump and fresh concrete density as E-plastic is incorporated in concrete. The fresh density tends to decrease by 1.10, 4.87, 7.58, 10.70 and 13.58 % for 10, 20, 30, 40 and 50 %, respectively; below the control mixture. Due to density of the E-plastic aggregate being lower than the coarse aggregate, this leads to a reduction in the fresh density. The slump and fresh density results are shown in Figs. 2 and 3.

Hardened concrete properties

The concrete cubes of size 150 mm were cast for compressive strength, 150 × 300 mm cylinders for splitting tensile strength, 100 × 100 × 500 mm beams for flexural strength. Tests were performed at 7 and 28 days in accordance with the provisions of the Indian Standard specifications IS: 516-1959 [26].

Saturated surface dry density

The saturated surface dry density (SSD density) values for E-plastic concrete are shown in Fig. 4. The densities tend to decrease with increasing E-plastic content in each concrete mix, because the density of E-plastic is lower than that of coarse aggregate by 63.35 %. The lowest dry density at 28 days is 2139.26 kg/m^3, which is well below the range of structural concrete.

Compressive strength

The concrete cube specimens were loaded to failure using a constant loading rate in compression testing machine of 3000 kN. It was observed that concrete cubes containing E-plastic failed at lower compressive loads as compared with those made of control concrete. The E-plastic concrete cubes underwent significant deformation and did not experience brittle failure. At failure, most of the specimens were reduced to two pyramids in the vertical direction. The similar observation was made by Ashraf and Michael [3]. The results of compressive strength test are shown in

Table 3 Proportions of the concrete mixtures (kg/m^3)

E-plastic (%)	0	10	20	30	40	50
Water/cement ratio	0.49	0.49	0.49	0.49	0.49	0.49
Cement (kg/m^3)	367.34	367.34	367.34	367.34	367.34	367.34
Water (kg/m^3)	180	180	180	180	180	180
Fine aggregate (kg/m^3)	789.14	789.14	789.14	789.14	789.14	789.14
Coarse aggregate (kg/m^3)[a]	1133.32	1019.98	907.44	793.52	679.59	565.67
E-plastic (kg/m^3)	0	52.40	104.80	157.11	209.78	261.55

[a] Aggregates are in saturated surface dry condition

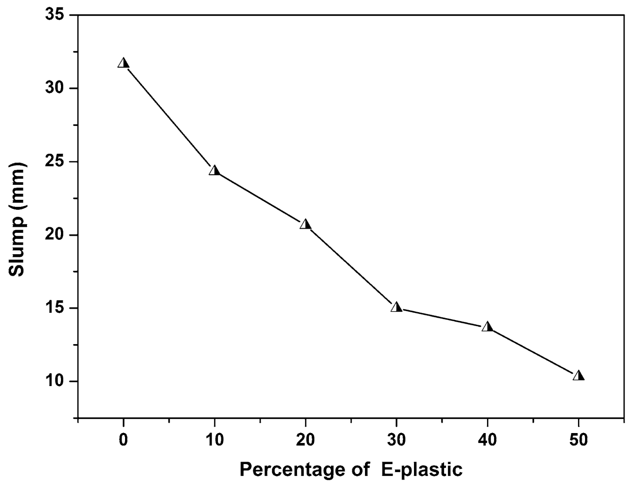

Fig. 2 Slump versus percentage of E-plastic content by volume

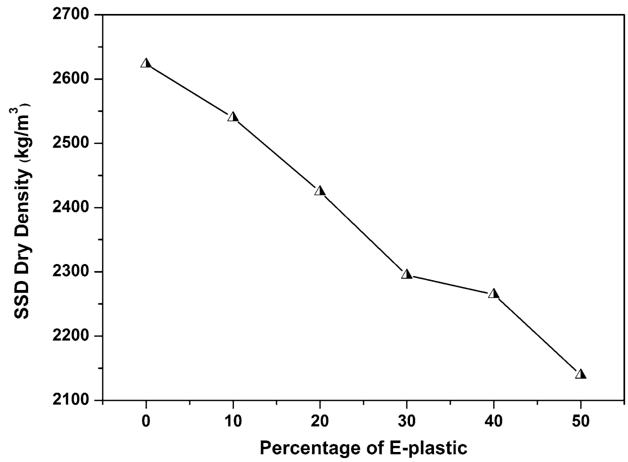

Fig. 4 Saturated surface dry density versus percentage of E-plastic content by volume at 28 days

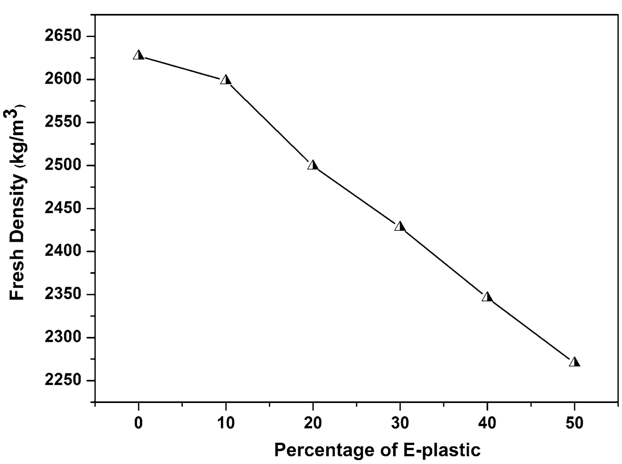

Fig. 3 Fresh density versus percentage of E-plastic content by volume

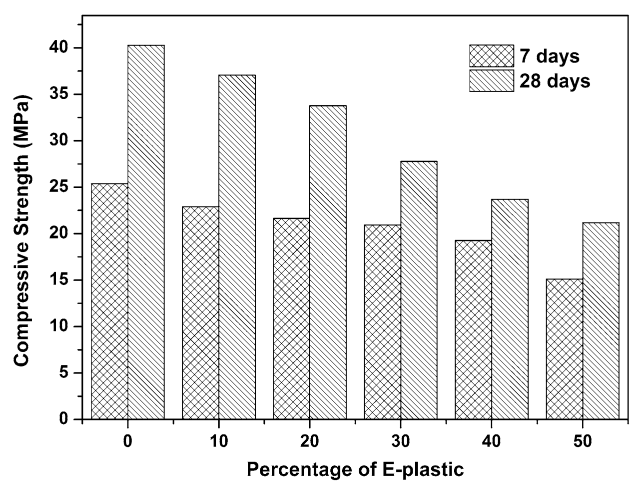

Fig. 5 Variation in compressive strength with age and E-plastic content

Fig. 5. It is interesting to note that the compressive strength of concrete mix containing E-plastic, resulted in the rate of reduction in strength.

The factors that may be responsible for low compressive strength of concrete containing E-plastic aggregate are: (1) the shape, size and texture of the E-plastic aggregate (2) quantity of coarse aggregate reduced due to volume replacement (3) poor bonding between E-plastic and cement mortar.

In this study, regression analysis was performed on the compressive strength and dry density using linear regression models. The linear model showed the linearity between the

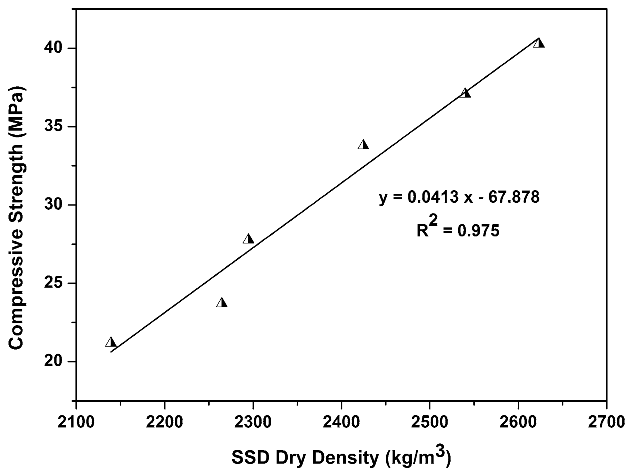

Fig. 6 Relationship between compressive strength and dry density at 28 days

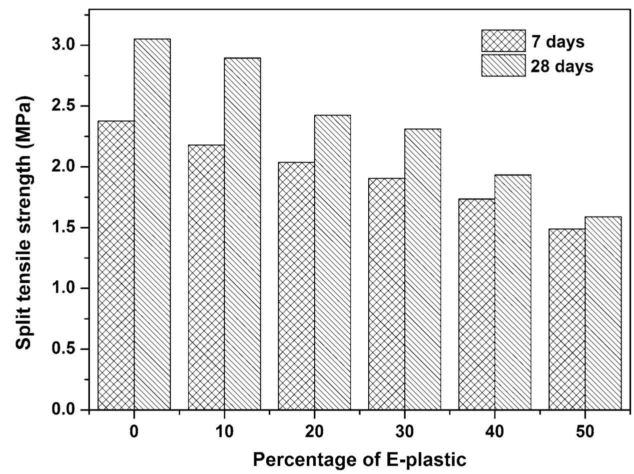

Fig. 8 Variation in split tensile strength with age and E-plastic content

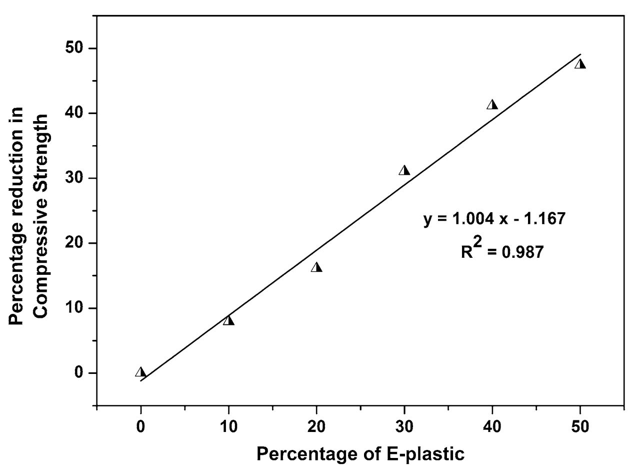

Fig. 7 Relationship between percentage reduction in compressive strength and percentage of E-plastic

compressive strength and density as shown in Fig. 6. The compressive strength was directly proportional to the density of hardened concrete. Higher R^2 value of 0.975 for linear model showed that the regression was established under good fit, which means that there was no remarkable variation in the compressive strength and density of concrete results. Figure 7 shows the relationship between the percentage reduction in compressive strength and the percentage of E-plastic in the concrete mix. This figure shows a general trend where the value of the compressive strength decreases with the increase of the percentage E-plastic in the mix, showing a loss of about 47.41 % of the compressive strength at 50 % of E-plastic replacement. The linear curve was found to best fit the data. The correlation coefficient squared in this relationship is 98.7 %.

Split tensile strength

The splitting tensile strength decreased with the increase in E-plastic aggregates percentage as shown in Fig. 8. It was observed that the splitting failure of concrete specimens containing E-plastic aggregates did not exhibit the typical brittle failure observed in the case of control concrete. The failure was found to be more ductile in nature when the percentage of E-plastic aggregates was increased. The E-plastic aggregates have tensile property, which exhibits the splitting tensile failure as gradual failure and resisting the splitting load after failure without full breakdown of cylinder specimens as shown in Fig. 9. The percentage reduction in split tensile strength was plotted versus the percentage of E-plastic and is shown in Fig. 10. The trend in the figure indicates that as the percentage E-plastic increases, the split tensile strength of concrete decreases, showing a loss of about 47.89 % of the split tensile strength at 50 % of E-plastic replacement. The correlation coefficient squared is 98.10 %.

Flexural strength

Similar to compressive strength and split tensile strength, the flexural strength of concrete decreased with the increase in the E-plastic content. The test results of flexural strength are shown in Fig. 11. It is of interest to note that the flexural strengths of the E-plastic concrete shows ductile behavior before failure. The trend in the Fig. 12 shows the equation representing the relationship of percentage reduction in flexural strength and percentage of E-plastic. The correlation coefficient squared in this relationship is 93.4 %.The strength loss is about 37.38 % at 50 % of E-plastic replacement.

Fig. 9 Splitting failure mode of the E-plastic concrete specimen after ultimate load

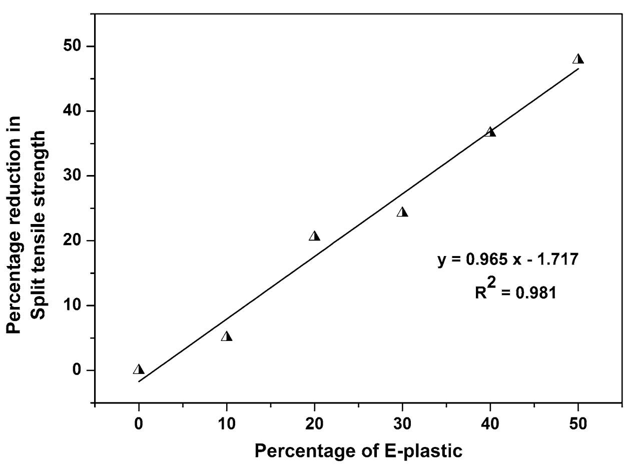

Fig. 10 Relationship between percentage reduction in split tensile strength and percentage of E-plastic

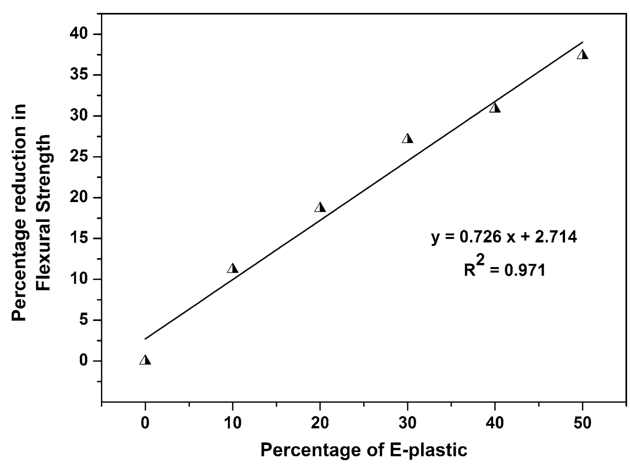

Fig. 12 Relationship between percentage reduction in flexural strength and percentage of E-plastic

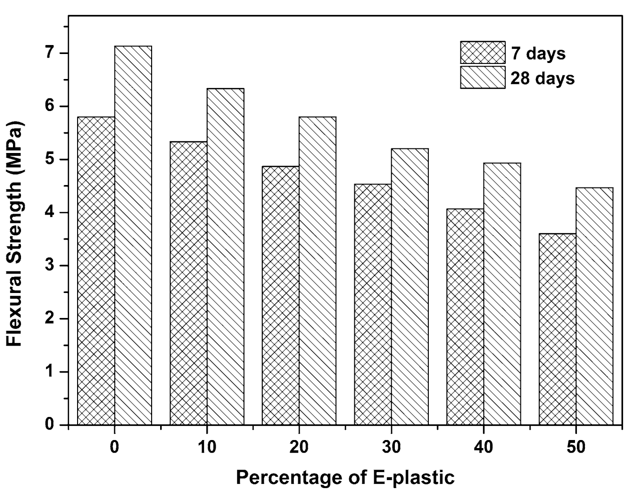

Fig. 11 Variation in flexural strength with age, and E-plastic content

The addition of E-plastic in mortar and concrete shows the decreasing trend in compressive strength, split tensile and flexural strength with the increase in E-plastic content. Similar observations were made by other researchers also [3, 17–20]. Even though the reduction in strength was observed, the E-plastic can be used in concrete by certain replacement.

Conclusions

Based on the experimental test results obtained in this study, the following conclusions may be deduced:

1. E-plastic can be used to replace coarse aggregates in a concrete by volume (10, 20, 30, 40 and 50 %).
2. The compressive, splitting tensile and flexural strength were reduced with increase in E-plastic. The E-plastic aggregates have poor shape and surface texture is smooth which greatly influenced the fresh and hardened properties of concrete.
3. Mathematical relationships have been given to correlate the percent of E-plastic in the mix with the percent reduction in compressive strength, split tensile strength, flexural strength. It is notable that the rate of strength reduction with increasing E-plastic was

nearly the same in compressive strength as it is in splitting tensile strength around 48 % for 50 % replacement and for flexural strength around 37.38 % for 50 % replacement. Although a trend can be detected, caution should be exercised in using the given equations due to the limited number of data points. Generalization of trends requires more data points.

4. It is recommended that up to 30 % replacement by volume can be done; up to this limit, the characteristic strength of M25 concrete was achieved. Another observation is up to 50 % replacement by volume, 50 % of strength was retained in concrete after failure. It is recommended that 40 and 50 % replacement by volume can be used for non-structural lightweight elements. The experimental results limit the use of electronic plastic waste (E-plastic) as coarse aggregate, when the strength is the prime requirement.
5. The recycling of electronic plastic waste to produce new materials, such as cement concrete composites, appears as one of the subtle solution for disposing of electronic plastic waste, instead of combustion and land filling.

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