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INVESTIGATIONS ON DURABILITY CHARACTERISTICS OF E-PLASTIC WASTE INCORPORATED CONCRETE

R. Lakshmi[a*] and S. Nagan[b]
[a]KLN College of Information Technology, Sivagangai Dist, TamilNadu, India
[b]Thaigarajar College of Engineering, Madurai, Tamiladu, India

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ABSTRACT

Electronic waste or **w**aste electronic and electrical equipment is an emerging issue posing serious pollution problems to the human and the environment. New effective waste management options need to be considered especially on recycling concepts. This paper presents the results of an investigation to study the performance of concrete prepared with E-plastic waste as part of coarse aggregate. An effort has been made to detail a systematic study of compressive strength of concrete with various proportions of E-waste as coarse aggregate in concrete. The test results showed that a significant improvement in compressive strength was achieved in the E-plastic concrete compared to conventional concrete. The tests were also designed to evaluate the internal pore structure, its chemical resistance to environmental agents and reactivity with some components of the cement. The results indicated that the E-plastic aggregate up to 15% weight of the coarse aggregate and replacement of cement with fly ash (10% by weight) can be used effectively in concrete and thus results in waste reduction and resources conservation.

Keywords: Waste management; E-waste; compressive strength; sorptivity; permeability

1. INTRODUCTION

Global environmental activities developing with expansion of living and nonliving resources and related social activities. The relationship of environmental issues with the electronic and electrical industries begin with the generation of E-waste and the contamination possibilities. Waste Electronic and Electrical Equipment (WEEE) is diverse and complex in terms of materials and components as well as the manufacturing process. Characterization of this waste stream is of paramount importance for developing a cost effective and environmental friendly recycling system, Jirang et al. [1].

Izumi [2] stated that most electronic and electrical appliances after use are treated as waste at present, they should be recycled from the stand point of the effective utilization of

* E-mail address of the corresponding author: lakshmiciv@gmail.com (R. Lakshmi)

natural resources and restraint of waste.

According to the definitions in the directive of the Parliament and European Union council on waste electronic and electrical equipment, WEEE can be subdivided into ten different categories as listed in Table 1.

Table 1: WEEE categories according to the EU directive on WEEE

1. Large household appliances	6. Electrical and electronic tools
2. Small household appliances	7. Toys, leisure and sports equipment
3. IT and telecommunication equipment	8. Medical devices (with the exception of the infected devices)
4. Consumer equipment	9. Monitoring and control instruments
5. Lighting equipment	10. Automatic dispensers

The generation of E-waste is the fastest growing area and the disposal poses a major problem in the related neighborhood. The use of recycled plastic in the manufacturing of new plastic consumes considerable energy, raw material use and wear and tear on machinery. The use of recycled materials in construction applications is among the most attractive option because of the large quality demand, low quality requirements and widespread extent of construction.

The use of E-waste plastic cement concrete aggregate has been focused in this investigation as a viable solution to the problem of recycling costs and high disposal costs. Kang et. al. [3] discussed the various possibilities of recycling the plastics such as coke oven process, Thermal recycling, Mechanical recycling etc. He stated that the major challenge for the plastic waste recycling is the need for a continuous and stable supply of materials to be recycled and lack of cost effective technologies for recycling.

Several research works carried out to examine the possibility of reusing waste recycled glass in concrete and construction applications as an alternative solution to the growing quantity of waste recycled glass (Bashar et al 2009) [4] Park et. al. [5]. Many research works carried out to investigate the durability of GFRP materials under different environmental conditions that are anticipated under actual service conditions. Sen et. al. [6] Mathieu et. al. [7].

1.1 E-waste an overview

Million of tones of electronic waste from obsolete computers and other electronic articles are being generated every year. E-waste contains numerous types (more than 1000 different) of substances and chemicals creating serious human health and environment problems if not handled properly. E-waste also includes many toxic substances viz heavy metals like lead, cadmium, mercury, arsenic, selenium, hexavalent chromium etc.

About 70% of the heavy metals (mercury & cadmium) in land fills come from electronic waste. Consumer electronic is the root cause for the presence of about 40% of the lead in

landfills. These toxins can cause brain damage, allergic reactions and cancer.

E-waste also contains considerable quantities of valuable materials like gold, copper and other ordinary metals.

- Iron and steel are the most common materials found in electrical and electronic equipment and amounts to nearly half of the total weight of WEEE.
- Plastic are the second largest component by weight representing approximately 21% of WEEE.
- Non ferrous metals represent approximately 13% of WEEE (With copper accounting for 7%). The constituents and their components of WEEE are given in Table 2.

Table 2: WEEE material composition

Constituents	Components in %
Iron and Steel	47.9
Non flame retarded plastic	15.3
Copper	7.0
Glass	5.4
Flame retarded plastic	5.3
Aluminium	4.7
Printed circuit boards	3.1
Wood and plywood	2.6
Concrete & ceramics	2.0
Other metals (non-ferrous)	1.0
Rubber	0.9
Others	4.6

1.2 Methods of disposal of E-waste

The E-waste that generated is usually disposed of in the following ways.

1.3 Land Fill

A land fill is a disposal area where garbage is piled up and eventually covered with dirt and topsoil. Fractions of E-waste is most often dumped into landfills. Over time, the e-waste leads to certain amount of chemical and metal teaching. This can very often lead to ground water contamination.

1.4 Incineration

E-waste is burnt in incineration process. Individuals in unorganized sectors carry out such operations in which release of harmful toxic gases like dioxins and farans, which escape to the atmosphere and contaminate it.

1.5 Reuse

About 3%-5% of the computers that have been discarded by their users are reused. Reuse made possible either direct second hand use or use after slight modification. Non working old computers are repaired and resold for profit in developing countries. These older units obviously have a limited lifespan and end up as waste sooner or later in these developing countries.

1.6 Recycling

In order to combat the environmental impact of improper electronic waste disposal many organizations have opted to recycle their old technology. After the possibilities of reuse have been exhausted, then the next preference lies on recycling process.

Recycling means that the old raw materials are reclaimed to be made of in making new products. However, the costs of recycling are high. These most recyclers, due to the task of dealing with the disposal of non cyclable parts and the expense of dealing with the toxic waste components of old computers not willing to the recycling process readily. It is necessary to arrive at a cost effective and environmental friendly recycling process, which may be considered as the real need hour.

1.7 Environment Impact of E-waste recycling

The most common method of managing E-waste is land filling and the waste includes heavy metals, glass, plastics, ferrous and Non ferrous metals and toxic matters also, which are very harmful. Hence it is essential to adopt 4R (reduce, reuse, recover and recycle) concept in minimizing the E-waste hazards.

Non recyclable E-waste components constitute a problem for solid waste disposal in many townships. The current practice is still landfill, however where ever bio degradation is not carried over, landfills do not provide an environment friendly solution. Consequently there is a strong need to utilize waste glass and plastic components of E-waste.

The following vital resources are consumed in the generation of E-waste. (Ref: Toxics link)

(i) It is estimated that in 2004, 315 million PCs become obsolete in the USA and many of which dumped in landfills, burned in incinerators and exported to developing countries as hazardous waste, where metals and other ingredients are recovered by crude practices which becomes potential cause for environmental degradation and health hazard for the processing personnel.

(ii) In India as per the statistics, during 2005, 1,46,800 tonnes of E-waste was generated in the country which is expected to increase to 800,000 tonnes by 2012.

(iii) On an average 6.53Kg plastics are used per computer.

(iv) Recover metals from E-waste account for 8.1% per year of metals manufactured from ores.

1.8 Scope of Investigation

Increasing the need for landfills is a burden to our environment. Also with the storage of landfills capacity and an increased concern about environmental quality, diverted waste treatment methods are desired

New waste management options are needed to divert End-Of-Life (EOL) electronics from landfills and incineration. However, there are several factors to consider in the

development of a successful diversion strategy. This strategy must be based on its economic sustainability, technical feasibility and a realistic level of social support for the program. One aspect of the strategy should include recycling and reuse of EOL electronic products in construction field.

1. Efforts have been made in construction industry to use waste glass as a partial replacement of the coarse or fine aggregate [9].
2. The successful use of other industrial by products of wastes such as fly ash and silica fume in concrete set as good example for waste glass to be used in a different way.
3. Trials are also suggesting utilizing shredded waste plastics usage in concrete as a partial replacement of the coarse aggregate.
4. Recent studies have shown that glass and plastic fractions generated from e-waste can be used as aggregate in road constructions and building materials such as tiles and bricks [8].

The current study is aimed to compare compressive strength of M20 grade of conventional concrete with E-plastic concrete in which different proportions of E-plastic particles are used as replacement to coarse aggregate. Based on the results obtained, the optimum percentage of replacement was arrived at. Investigations also were carried out to evaluate the durability in terms of chemical resistance and permeability indices.

2. EXPERIMENTAL DETAILS

2.1 Materials

The potential applications of industry by products in concrete are to be partial aggregate replacement or partial cementious materials depending on their chemical composition and grain size. Recent studies have shown that reuse of very finely grounded E-plastic waste in concrete has economical and technical advantages for solving the disposal of large amount of E-waste and reuse in construction industry may be the most feasible application. E-plastic waste particles can be used as coarse aggregate, fine aggregate, fine filler in concrete depending on the particle size.

E-waste sources in the form of loosely discarded , surplus, obsolete ,broken, electrical or electronic devices from commercial informal recyclers have been collected , crushed and ground to the particle size. Table 3 represents Physical properties of E-waste particle and Coarse aggregate.

The E-waste contents are calculated as weight percent of coarse aggregate in the control mix. The fineness modulus of coarse aggregate with various E-waste content is between 1.86 and 2.78. The E-plastic waste particles can be considered as partial coarse aggregate substitute retaining the mix ratio as the same. The divided particle size is assumed to be between 1.18mm–2.36mm. Since it possesses no cementious property, it is considered as replacement to coarse aggregate in cement concrete in various percentages.

Table 3: Physical properties of E-waste particles and coarse aggregate

Properties	E-waste particle	Coarse aggregate
Specific gravity	1.01	2.65
Absorption (%)	<0.2	0.5
Color	White and dark	Dark
Shape	Angular	Angular
Crushing value	<2%	27.2%
Impact value	<2%	24.73%

2.2 Concrete Mixes

Control mix concrete and concrete modified with various E-plastic waste contents listed in Table 4 & 5 were prepared. By considering the use E-waste particles in the mixes as much as possible was attempted and strength criteria of Grade M20 concrete mix was analyzed.

Table 4: Mix Specifications-A series

Mix Specification	Control mix A1	A2	A3	A4	A5	A6	A7
Proportion of E-plastic waste	0%	4%	8%	12%	16%	20%	24%
Proportion of fly ash	0%	0%	0%	0%	0%	0%	0%

Table 5: Mix specifications-B series

Mix specification	Control mix A1	B2	B3	B4	B5	B6	B7
Proportion of E-plastic waste	0%	4%	8%	12%	16%	20%	24%
Proportion of fly ash	0%	10%	10%	10%	10%	10%	10%

2.3 Tests On Concrete

2.3.1 Compressive Strength Test

Durability is directly proportional to compressive strength. The desirable characteristics of E-waste concrete are qualitatively related to its strength but mainly because of the intrinsic importance of the compressive strength of E-plastic waste concrete in construction. Tests were carried out as per IS 516-1959. The test results are shown in Tables 7 & 8 .

2.3.2 Durability Tests On Concrete

The durability of cement concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration. Durable concrete will retain its original form, quality, and serviceability when exposed to its environment. For determining the resistance of concrete specimens to aggressive environment such as acid attack, the durability factors as described in ASTM C 666 has been adopted as the base.

2.3.3 Chloride Attack Test

Chloride attack is one of the most important aspects for consideration when we deal with the durability of concrete. Chloride attack is particularly important because it primarily causes corrosion of reinforcement. Statistics have indicated that over 40 per cent of failure of structures is due to corrosion of reinforcement. The Bureau of Indian Standard earlier specified the maximum chloride content in cement as 0.05 per cent. But it is now increased the allowable chloride content in cement to 0.1 per cent.

The cubes were cast at size of 150mm x 150mm x 150mm and kept at a temperature of 27°C ± 2°C and at least 90 percent relative humidity for 24 hours. After 24 hours the cubes were removed from the mould and immersed in clean fresh water until taken out for testing. After 28 days curing the cubes were immersed in a 5% concentric sulphuric acid (H_2So_4) & 5% hydro chloric acid (HCl). After 105 days of curing, measurement of the weight and the compressive strength of cubes and calculation of durability factor were completed.

2.3.4 Sulphate Attack Test

The term sulphate attack denotes an increase in the volume of cement paste in concrete or mortar due to the chemical action between the products of hydration of cement and solution containing sulphates. In the hardened concrete, calcium aluminate hydrate (C-A-H) can react with sulphate salt from outside. The product of reaction is calcium sulphoaluminate, forming within the framework of hydrated cement paste. Because of the increase in volume of the solid phase which can go up to 227 per cent, a gradual disintegration of concrete takes place.

The cubes were cast at size of 150mmx150mmx150mm and kept in the mould at a temperature of 27°C ± 2°C and at least 90 percent relative humidity for 24 hours. After 24 hours the cubes were removed from the mould and immersed in clean fresh water until taken out for testing.After 28 days curing the cubes were immersed in a 10% Sodium sulphate solution. After 105 days of curing, measurement of the weight and compressive strength of cubes and calculation of durability factor were completed.

2.3.4 Permeability Test

Permeability of concrete plays an important role in durability because it controls the rate of entry of moisture that may contain aggressive chemicals and the movement of water during heating or freezing. Higher the permeability lesser will be the durability. Permeability of concrete primarily depends upon the micro structural properties such as porosity, sorptivity etc.

2.3.5 Saturated water absorption:

Saturated water absorption (SWA) tests were carried out on 150 mm cube specimens at the age of 28 day curing as per ASTM C 642. The specimens were weighed before drying.

The drying was carried out in a hot air oven at a temperature of 105C. The drying process

was continued, until the difference in mass between two successive measurements at 24 hours interval agreed closely.

The dried specimens were cooled at room temperature and then immersed in water. The specimens were taken out at regular intervals of time, surface dried and weighed. This process was continued till the weights became constant (fully saturated).

The difference between the measured water saturated mass and oven dried mass expressed as a percentage of oven dry mass gives the SWA.

2.3.6 Porosity

The saturated water absorption of concrete is a measure of the pore volume or porosity in hardened concrete which is occupied by the water in a saturated condition. It denotes the quantity of water which can be removed on drying a saturated specimen.

The porosity obtained from absorption tests is designated as effective porosity. It is determined using the following formula:

$$\text{Effective porosity} = (\text{volume of voids} / \text{bulk volume of specimen}) \times 100$$

The volume of voids is obtained from the volume of water absorbed by an oven dried specimen or the volume of water lost on oven drying water saturated specimen at 105 c to constant mass.

The bulk volume of the specimen is given by the difference in mass of the specimen in air and it's mass under submerged condition in water.

$$\text{Effective porosity} = (W_s - W_d / W_s - W_{sub})$$

Where,

W_S - Weight of specimen at fully saturated condition

W_D -Weight of oven dried specimen

W_{SUB} -Weight of specimen submerged in water

The test of porosity on 150mm cube specimen was carried out in accordance with process described above.

2.3.7 Sorptivity

Sorptivity measures the rate of penetration of water into the pores in concrete by capillarity suction when the cumulative volume of water that has penetrated per unit surface area of exposure "g" is plotted against the square root of time of exposure 'SQRT(t)'. The resulting graph could be approximated by a straight line passing through the origin. The slope of this straight line is considered as a measure of rate of movement of water through the capillary pores. This measurement is called sorptivity.

In this present study,the test for sorptivity was conducted on 150 mm cube specimens as per ASTM C 642 by drying the specimens in an oven at a temperature of 105^0C to constant mass and then immersing them in water after cooling the specimens to room temperature and measuring the gain in mass at regular interval of 30 minutes duration, for a period of consecutive constant value.

The sorptivity was computed by

$I = Q/(SA*\sqrt{t})$

Q = Volume of water penetrated in mm^3

I = Sorptivity in $mm/\sqrt{min}$

T = time elapsed in sec

SA = Surface area in mm^2

2.3.8 Results & Discussion

Table 6 and Figure 1 presents the 28 days compressive strength results of concrete with and without E-plastic waste replacement to coarse aggregate in concrete. The maximum strength observed was 19.89MPa with 4% replacement and 18.80MPa with 8% replacement. It was also revealed that maximum strength reduction was observed for more than 20% replacement of E-plastic waste to coarse aggregate in concrete. To administer the reduction in strength of E-plastic concrete, addition of 10% flyash to cement in concrete was adopted.

Table 6: Strength At Various percentage of E-plastic waste specimen size: 150mm x 150mm x 150mm

ID.NO	Age in days	Percentage of replacement		Compressive strength in N/mm^2
		E-waste	Fly ash	
A1	28	0%	0%	28.79
A2	28	4%	0%	19.89
A3	28	8%	0%	18.80
A4	28	12%	0%	16.40
A5	28	16%	0%	16.23
A6	28	20%	0%	08.25
A7	28	24%	0%	08.10

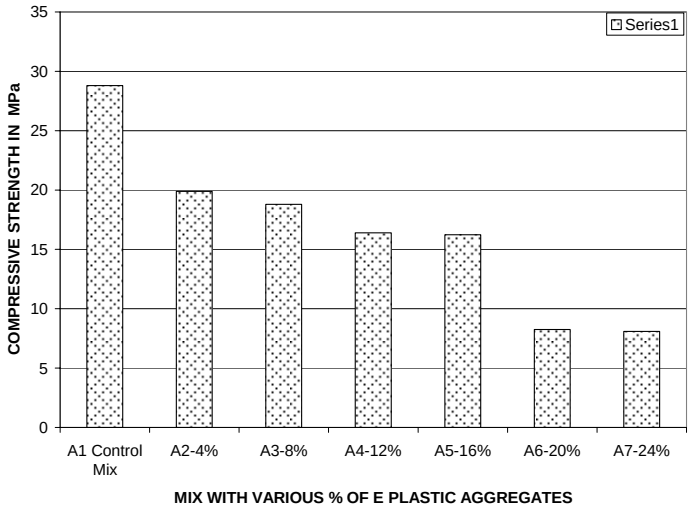

Figure 1. 28 Days compressive strength of "A" series proportion of E-plastic concrete.

Tables 7 & 8 showed that the compressive strength increases with increase in replacement of coarse aggregate with E-plastic aggregate. The maximum compressive strength for the mix with 12% of E-plastic aggregate was 29.79MPa which is higher than that of compressive strength of conventional concrete. Figures 2 & 3 described that there was apparent improvement of compressive strength of all 'B' series mixes comparing to 'A' series mixes. It was observed that 10% flyash addition to cement in concrete which in turn results in a denser concrete and thereby the enhancement in strength was achieved in early age also.However there was reduction in strength was observed for more than 20% replacement of coarse aggregate with E-plastic aggregate.

Table 7: Strength at various percentage of E-plastic waste specimen size: 150mm x 150mm x 150mm

ID. No.	Age in days	Percentage of replacement		Compressive strength in N/mm^2
		E-waste	Fly ash	
A1	28	0%	0%	28.79
B2	28	4%	10%	27.03
B3	28	8%	10%	27.38
B4	28	12%	10%	29.79
B5	28	16%	10%	26.98
B6	28	20%	10%	21.97
B7	28	24%	10%	20.10

Table 8: Strength At 12% of E-Plastic Waste Specimen size: 150mm x 150mm x 150mm

ID. No	Age in days	Percentage of replacement		Compressive strength in N/mm^2
		E-waste	Fly ash	
	7	0%	0%	16.81
A1	14	0%	0%	27.23
	28	0%	0%	28.79
	7	12%	10%	17.12
B4	14	12%	10%	27.73
	28	12%	10%	29.79

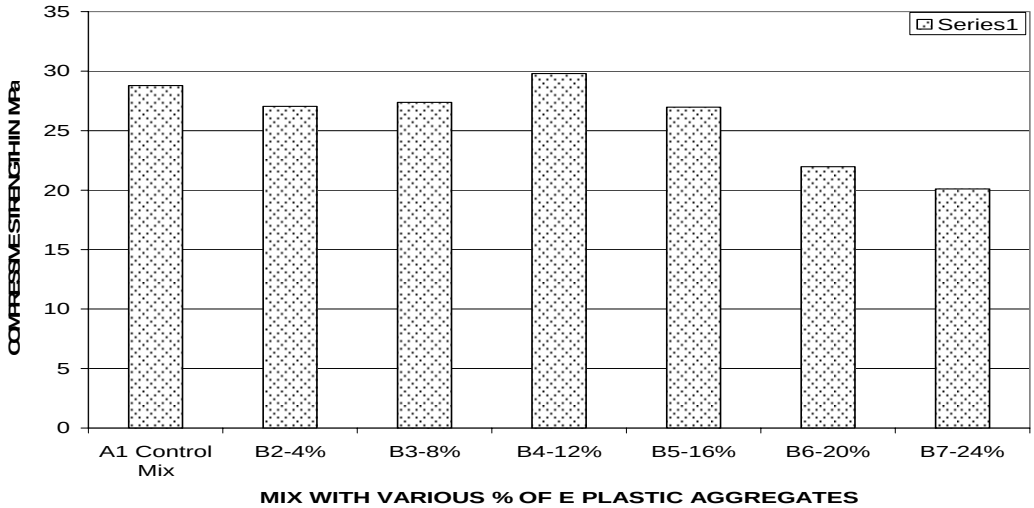

Figure 2. 28 Days compressive strength of "B" series proportion of E-plastic concrete.

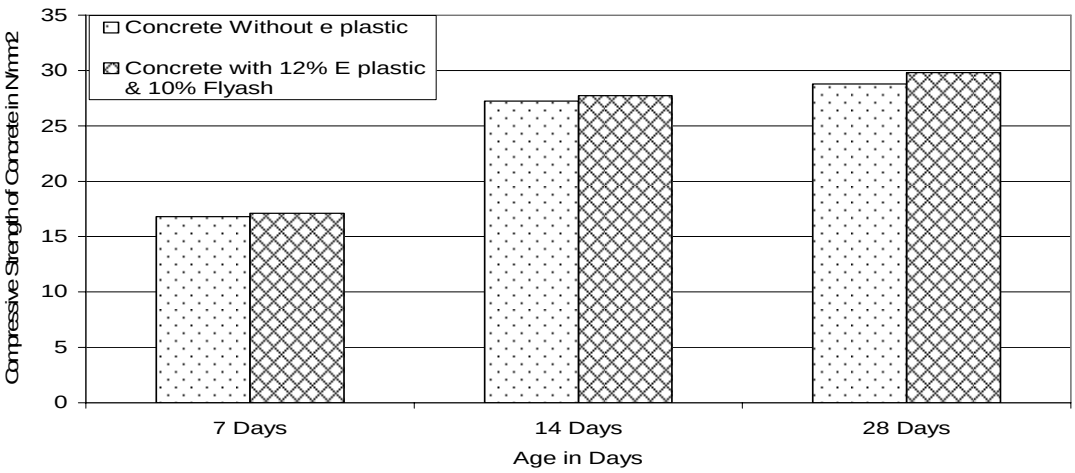

Figure 3. Strength development of concrete without and with E-plastic waste.

2.3.9 Durability Test Results

2.3.10 Chloride Attack Test Results

The Chloride attack test parameters observation were presented in Table 9. Figure 4 shows the influence of chloride attack on conventional concrete and concrete with E-plastic waste . The average loss of weight and loss of compressive strength of E-plastic concrete is considerably lesser than the corresponding loss of weight and loss of compressive strength of conventional concrete. It shows that E-plastic particles in the concrete is not influenced by chloride. As well as the addition of fly ash in the E-plastic concrete improved the density of concrete and resulted in comparatively lesser loss of weight and loss of compressive strength of concrete. Relative strength and Durability factor of E-plastic concrete also showing better results. This indicates that incorporation of E-plastic in concrete could be considered to be reasonable.

Table 9: Results of Chloride Attack Tests

Descrition	Conventional concrete	Concrete with E-plastic waste
Loss of weight in gms	265	180
Loss of compressive strength in N/mm^2	2.65	2.46
Relative strength in %	94.18	94.80
Durability factor	47.09	47.40

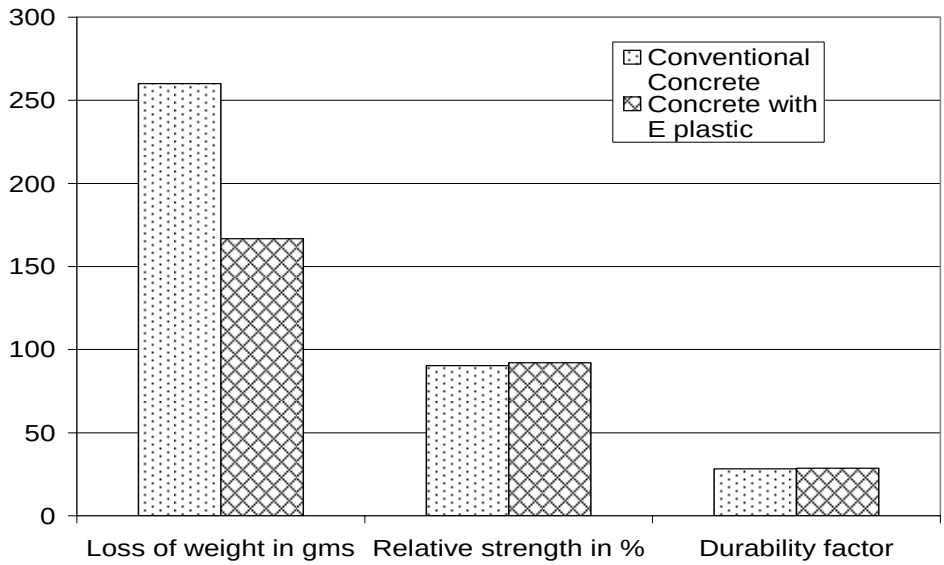

Figure 4. Influence of chloride attack on concrete without and with E-plastic waste.

2.3.11 Sulphate Attack Test Results

The Sulphate attack test observance is presented in Table 10. Figure 5 shows comparison of the influence of Sulphate attack on conventional concrete and concrete with E-plastic waste. Here also the average loss of weight and loss of compressive strength of E-plastic concrete is considerably lesser than the corresponding loss of weight and loss of compressive strength of conventional concrete. It shows that E-plastic particles in the concrete is not influenced by Sulphate. As was seen earlier, the addition of fly ash in the E-plastic concrete can likely be attributed the density of concrete and resulted in comparatively lesser loss of weight and loss of compressive strength of concrete. Relative strength and Durability factor of E-plastic concrete also showing better results. This indicates that incorporation of E-plastic in concrete could be considered to be reasonable in the aspects of acid resistance.

Table 10: Results of sulphate attack tests

Descrition	Without E-plastic waste	With E-plastic waste
Loss of weight in gms	265	178
Loss of compressive strength in N/mm^2	3.63	3.52
Relative strength in %	90.4	91.92
Durability factor	45.20	45.96

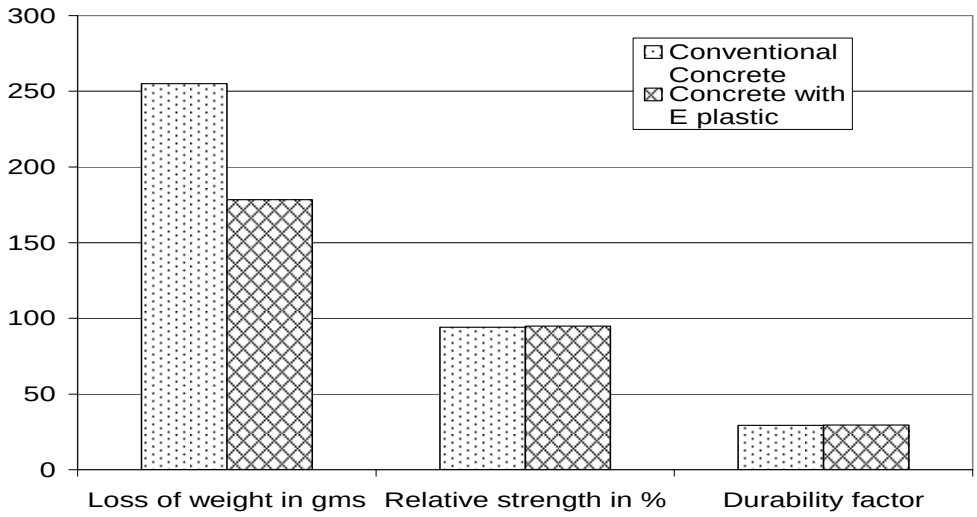

Figure 5. Influence of sulphate attack on concrete without and with E-plastic waste.

2.3.12 Permeability Test Results

Table 11 describes the experimental results obtained during the permeability tests conducted on conventional concrete and E-plastic concrete. The parameters observed were Saturated water absorption, Porosity and Sorptivity. The tests were carried out as per ASTM C 642-1997 procedures. From Figure 6 it was found that, E-plastic concrete exhibits slightly higher values than conventional concrete. This can be explained by the E-plastic aggregates dispersed in concrete may comprised of inter particle voids which may be assumed to be contributed the increase in Saturated water absorption, Porosity and sorptivity as all these factors linked directly to voids in structure. However, with proper vibration mechanism the possibility of voids can be minimized.

Table 11: Results of permeability tests

Description	Conventional concrete	Concrete swith E-plastic waste
Saturated water absorption in %	2.12	3.65
Porosity in %	5.35	7.65
Sorptivity in mm/√min	0.0580	0.0874

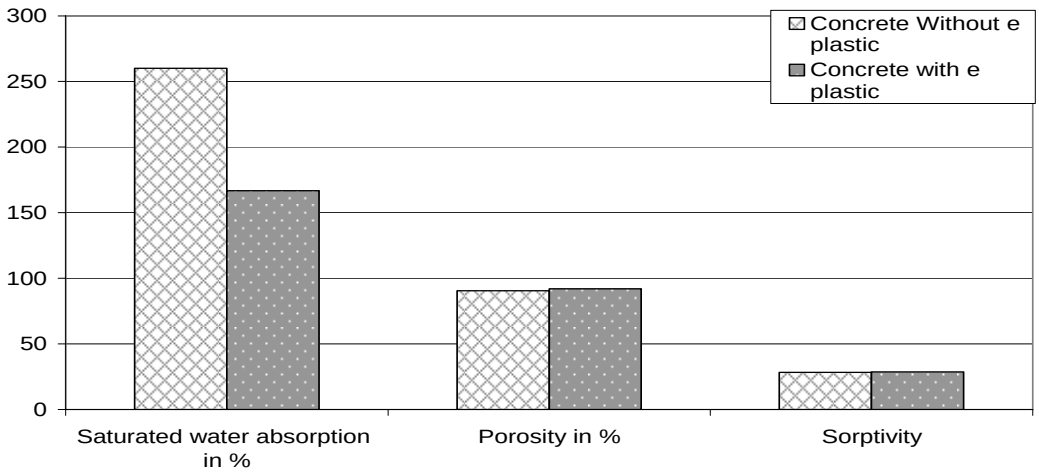

Figure 6. Results of permeability studies on concrete without and with E-plastic waste.

CONCLUSION

The E-plastic waste is not suitable to replace fine aggregate and hence it is used to replace the coarse aggregate and the compressive strength and durability tests were conducted .The following conclusions were drawn from this research.

1. From the compressive strength tests, it has been confirmed that no major changes found in the compressive strength of concrete with the presence of E-plastic as percentage replacement to coarse aggregate and fly ash as percentage replacement to cement. However when 20% of the coarse aggregate is replaced by E-plastic , the compressive strength was reduced by 23.6% compared to control mix.
2. In general strength gain of E-plastic concrete is satisfactory and it has been concluded that 12% E-plastic particles can be incorporated as aggregate replacement without any long term detrimental effects.
3. Observation of Chloride attack test, Sulphate attack tests shown that E-plastic concrete could result in a dense matrix with the incorporation of fly ash in E-plastic concrete.

4. Study of permeability parameters also confirmed that durability of E-plastic concrete is acceptable, though slightly lower than that of conventional concrete.

The data presented in this paper showed that there is great potential for the utilization of E-plastic waste in concrete. A Nationwide Awareness Campaign should be done by Government and industry to create awareness on E-waste and issues ranging from guidelines and legislation frameworks, advancement of science and technology. Impact of human lifestyles, life cycle of products should be analyzed inherently to arrive at sustainable solutions for E-waste management. Hence, we as a society need to remain prepared for many unknown challenges in the future.

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