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Performance of Recycled E-waste as Aggregates in Green Concrete

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ABSTRACT

This study is focused to improve strength and durability properties of green concrete with E-waste as fine (10%, 20% and 30%) and coarse aggregates (5%, 10% and 15%) replacement in fibre reinforced green concrete with 30% of ground granulated blast furnace slag (GGBS) for the replacement of cement. Since the reuse of electronic waste and the waste industrial by-product GGBS was used in this study, this also aims to design a green concrete with E-waste. The findings from this study show that E-waste as fine aggregate attained lesser compressive strength, whereas E-waste as coarse aggregate replacement exhibited similar compressive strength compared to control concrete. The results of splitting tensile strength and flexural strength of E-waste as fine and coarse aggregate replacement mixtures were superior to that of normal concrete. The chloride ion penetration of control concrete was low, whereas for E-waste concrete mixtures moderate chloride ion penetration was observed. The overall performance of E-waste as fine and coarse aggregates replacement in compressive strength, splitting tensile strength, flexural strength and chloride ion penetration was due to the combined pozzolanic action of GGBS, increase in the tensile behaviour due to the presence of steel fibres and good bonding of E-waste aggregates.

INTRODUCTION

One of the most rapid growing threats to environment that includes animals and human beings is the electronic waste. These wastes are physically and chemically different from other wastes such as municipal and industrial wastes. The electronic waste or E-waste contains more than 1000 hazardous and nonhazardous substances (Song et al. 2013). United Nation Environment Programme (UNEP) estimated that E-waste is expected to be more than 50 million tonnes per annum. India generates 8,00,000 tonnes of E-waste every year and it is expected to increase in the future (Toxic link, 2014). E-waste contains most of the toxic elements in the periodic table such as heavy metals, lead, nickel, chromium, cadmium, arsenic and mercury. These toxic E-wastes were from most developed countries that were dumped in India due to their environmental policies on recycling the E-waste (Agamuthu & Dennis 2013). Gullett et al. (2007) reported that the electronic waste during its combustion in recycling plants emitted the average emissions of polychlorinated dibenzodioxins and dibenzofurans as 92 ng toxic equivalency and 11900 ng toxic equivalency of the total mass of circuit boards and insulated wires. These polychlorinated dibenzodioxins (PCDDs) are simply referred to as dioxins that show known effects in laboratory animals and epidemiological effects on humans (Vanden & Lucier 1993).

The combustion of E-waste in recycling plants neither reduces environmental pollution nor the effects on humans. The scientists, researchers and environmental agencies were keen on reducing, recycling and reusing these electronic or E-waste in different ways. One such application was in utilizing it in the construction and building materials. The E-waste was crushed and powdered and it was used as replacement of fine or coarse aggregates replacement in concrete. Senthil & Baskar (2014) investigated on the utilization of plastic electronic wastes as coarse aggregate replacement in concrete. The test results showed that compressive strength, splitting tensile strength and flexural strength were decreased as the percentage of E-waste as coarse aggregate was increased.

Based on the literature studies in the utilization of E-waste as fine and or coarse aggregates replacement in concrete, it clearly revealed that the mechanical properties of the concrete with E-waste as aggregate replacement affected the overall behaviour of the concrete.

This study focused on attaining designed mechanical properties such as compressive, splitting tensile and flexural strengths of the concrete with E-waste as fine and coarse aggregate replacement in concrete. To reduce the cement as well as to improve the mechanical properties, ground granulated blast furnace slag (GGBS) and steel fibres were incorporated in the concrete. GGBS gained its attention owing to its physical and chemical properties that attracted several researchers to be used as a partial replacement of cement and fine aggregates in concrete. Arivalagan (2014) has evaluated the strength and strength efficiency factors for M35 grade concrete by replacing cement with ground granulated blast furnace slag and found that the strength of concrete increased when the curing age was increased. Ganesh & Sree Rama (2000) studied the efficiency on the replacement levels of GGBS for cement in attaining 28 days compressive strength. The investigation revealed that 50% of GGBS was found to exhibit compressive strength similar to normal concrete. Gengying & Xiaohua (2003) experimented with fly ash (FA) and ground granulated blast furnace slag (GGBS) as cement replacement and concluded that FA and GGBS improved both short term and long term properties of concrete by increasing the curing period. On the other hand to improve the tensile behaviour of the concrete, fibres were incorporated. The main advantage of incorporating steel fibres is its better cracking properties compared to normal concrete (Murugappan et al. 1993). The addition of steel fibres not only improves the cracking and ductility, but also enhances the fresh properties in concrete. Several investigations on the addition of steel fibres on mechanical properties such as compressive strength, split tensile strength, flexural strength, and modulus of elasticity of concrete revealed the beneficial effects of steel fibres (Thomas & Ramaswamy 2007, Kholmyansky 2002). The main impact of addition of steel fibres enhances tensile behaviour of concrete (Thomas & Ramaswamy 2007 and Hwai-Chung 2001). Vahid & Togay (2015) experimented with steel and polypropylene fibres and explained that 1% steel fibres improved the mechanical properties such as splitting tensile strength and compressive strength.

Based on the literature review on the utilization of E-waste as fine and coarse aggregates, GGBS for cement replacement and steel fibre in the concrete, the replacement levels, and fibre volume fraction and mixture proportions were chosen in order to find the efficiency of E-waste in concrete.

The E-waste was collected from the dumping yard near Pondicherry where electrical and electronic wastes were stored for reusing. The E-waste was crushed using pulveriser into the desired size such as 4.75 mm, 12.5 mm and 20 mm. The E-waste fine and coarse aggregates are shown in Fig. 1.

EXPERIMENTAL PROGRAM

The experimental program was to design concrete for 50 MPa based on IS: 10262 (2009), with E-waste as fine (10%, 20% and 30%) and coarse aggregates (5%, 10% and 15%) replacement respectively. In addition to this, cement was replaced with 30% GGBS by the weight of the cement. The water to binder ratio was maintained constant by varying

Fig. 1: E-waste aggregates.

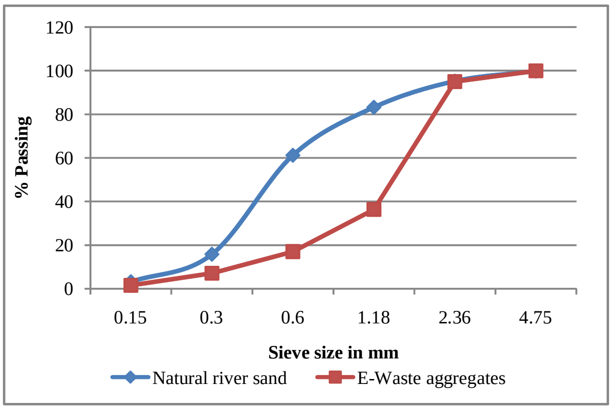

Fig. 2: Sieve analysis of river sand and e-waste fine aggregates.

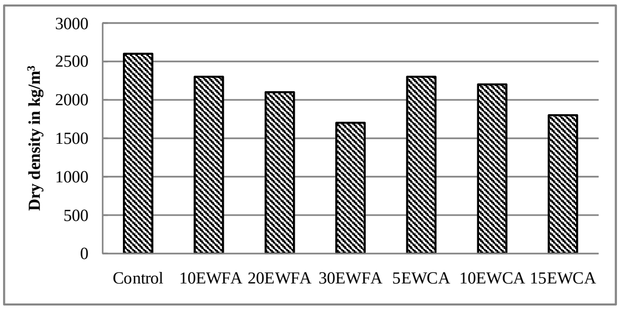

Fig. 3: Dry densities of concrete mixtures.

chemical admixture for the desired slump cone value of 100 to 150 mm. It was evident from the literature review that incorporation of E-waste decreases the mechanical properties in concrete due to its physical properties. To overcome this shortcoming 1% of steel fibres were added to the concrete mixtures.

MATERIALS USED

Ordinary Portland Cement OPC 53 grade conforming to IS: 12269 (2009) was used. Locally available fine and coarse aggregates of size 4.75 mm, 12.5 mm and 20 mm were used conforming to IS: 383(2002). Ordinary potable water was used for mixing and curing of the concrete. The water to binder ratio for all the mixtures was fixed by varying the dosage of chemical admixture. The chemical admixture used in the study was high range water reducing admixture (HRWRA) based on IS: 9013 (2004). The physical properties of cement and GGBS used in this study are given in Table 1. Table 2 shows the physical properties of aggregates. Table 3 shows the chemical properties of GGBS used in the study.

The concrete mixture design was designed with 1% steel fibre and 30% GGBS in all mixtures with partial replacement of fine and coarse aggregates in concrete with E-wastes. The sieve analysis was performed based on IS: 2386 (1997) both for natural river sand and E-waste fine aggregates and it is shown in Fig. 2. The concrete mixture design is furnished in Table 4.

Table 1: Physical properties of cement and GGBS.

Specific gravity of cement	3.15
Specific gravity of GGBS	2.6
Initial setting time (minutes)	90
Final setting time (minutes)	330
Consistency	31%

Table 2: Physical properties of aggregates.

Aggregate property	Aggregates		
	Fine	Coarse	E plastic
Specific gravity	2.6	2.7	1.26
Bulk density (kg/m^3)	1650	1620	550
Fines modulus	2.5	6.8	7.65
Water absorption %	1	0.64	Nil
Aggregate impact value	Nil	20.1	<2
Aggregate crushing value	Nil	24.8	<2

Table 3: Chemical properties of GGBS.

Chemical composition	% by mass
CaO	30%
SiO_2	38%
Al_2O_3	25%
Fe_2O_3	0.50%
MgO	17%
MnO_2	1%

RESULTS AND DISCUSSION

Fresh property: The concrete mixtures were tested for workability by slump cone test. The water to binder ratio was fixed for all the mixtures with 0.36 for the slump cone value of 100 to 150 mm. The control and concrete with E-waste were tested for the fixed slump cone value of 100 to 150 mm by the incorporation of high range water reducing admixture. The E-waste fine and coarse aggregate replacement exhibited 100 to 150 mm slump cone with 0.6% HRWRA similar to control concrete. The tendency of zero percent water absorption property for E-waste aggregates enhanced the workability.

Density: The dry density of the concrete samples was measured to compare the density of control and fibre reinforced green concrete with E-waste. The results are shown in the Fig. 3.

The dry density of the control concrete was 2600 kg/m^3 whereas, for the concrete with E-waste as fine and coarse aggregate replacement affected the density of the concrete mixtures. The low density of the E-waste concrete mixtures (1700 to 2300 kg/m^3) was due to the incorporation of fine and coarse E-waste as aggregate replacement with the bulk density of 550 kg/m^3.

Compressive strength: The compressive strength was tested at 7, 28 and 56 days for both control and green fibre reinforced E-waste concrete. The compressive strength results are shown in Fig. 4. The compressive strength of control concrete was 34 MPa, 53 MPa and 55 MPa at 7, 28 and 56 days respectively. The compressive strength of fibre reinforced green concrete with E-waste at 7 days as fine aggregate replacements (10%, 20% and 30%) were observed to be lesser than control concrete in the range of 26 to 30 MPa, whereas, for coarse aggregate replacements (5%, 10% and 15%) it was in the range of 30 to 36 MPa. The compressive strength of 10% and 20% EWFA attained higher compressive strength more than 45MPa, whereas EWCA mixtures attained compressive strength more than 50MPa at 28 days. The E-waste mixture attained similar and higher compressive strength when the curing was increased to 56 days, increase in the curing age with 30% GGBS as cement replacement, increased the pozzolanic reaction, thereby increasing the strength of the concrete mixtures.

The higher compressive strength of EWCA mixtures was due to the plastic behaviour of E-waste aggregates that did not fail during the compressive strength test and also the failure occurred in the cement and natural aggregates matrix. The incorporation of GGBS and fibre played a vital role that it holds good bonding between the natural coarse and EWCA. The failure of the natural fine and EWFA system

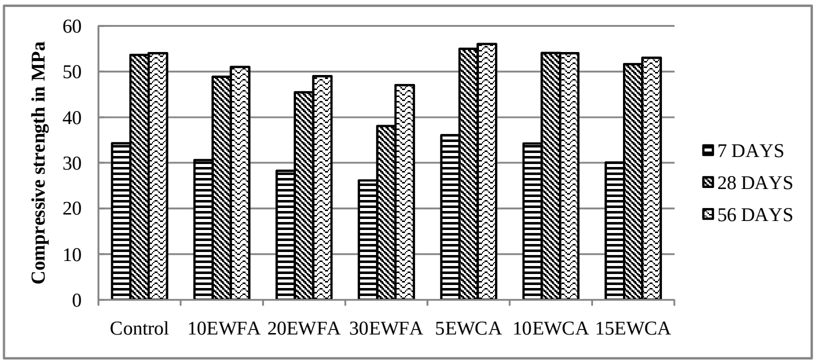

Fig. 4: Compressive strength of control and fiber reinforced green concrete.

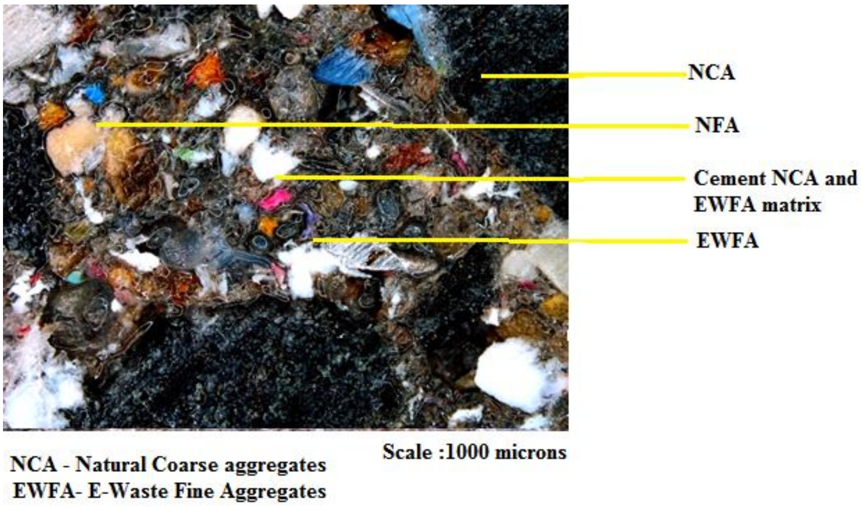

Fig. 5: Electron microscope image of E-waste fine aggregate mixture.

Fig. 8: Rapid chloride ion penetration of control and E-waste concrete mixtures.

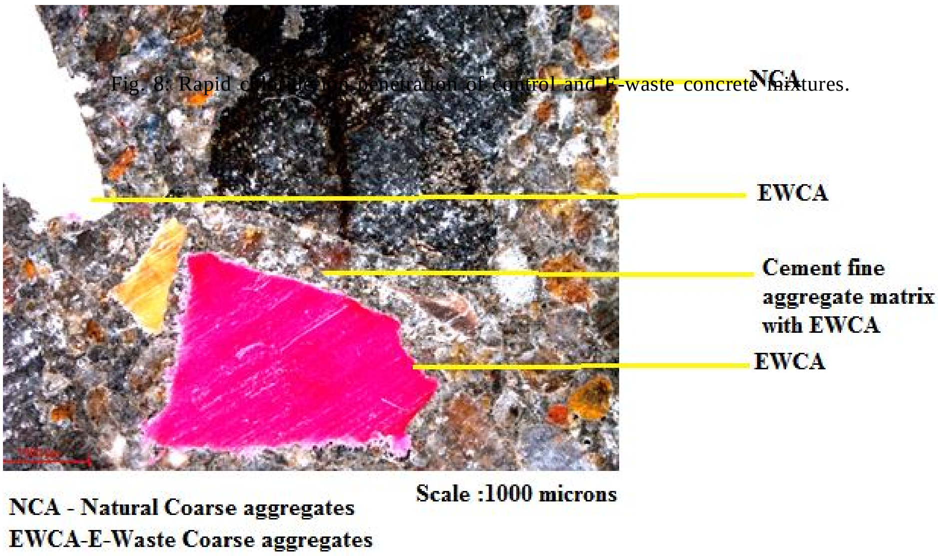

Fig. 6: Electron microscope image of E-waste coarse aggregate mixture.

Table 4: Concrete mixture proportions in kg/m^3.

Mixture	Cement	GGBS	Fine aggregate	EWFA	Coarse aggregate	EWCA	W/B	SP%
Control	389	0	720	0	1280	0	0.36	0.6
10EWFA	273	116	648	72	1280	0	0.36	0.6
20EWFA	273	116	576	114	1280	0	0.36	0.6
30EWFA	273	116	504	216	1280	0	0.36	0.6
5EWCA	273	116	720	0	1216	64	0.36	0.6
10EWCA	273	116	720	0	1152	128	0.36	0.6
15EWCA	273	116	720	0	1088	192	0.36	0.6

EWFA=E-waste Fine Aggregates, EWCA=E-waste Coarse Aggregates, GGBS=Granulated Blast Furnace Slag, SP=Super Plasticizer

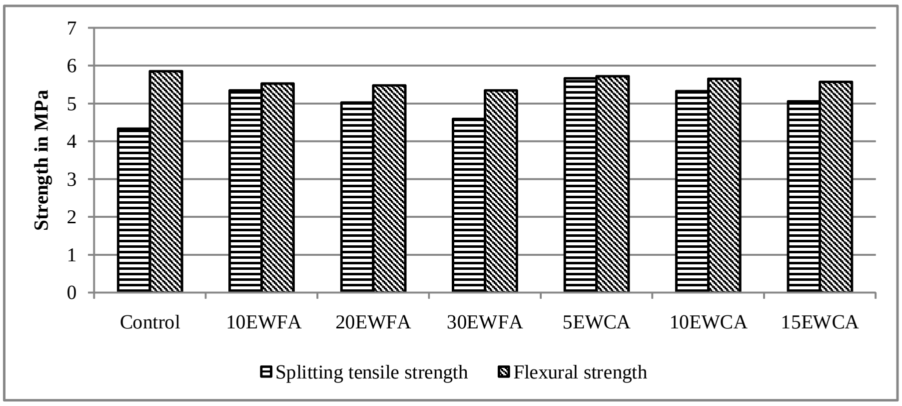

Fig. 7: Splitting tensile strength and flexural strength at 28 days.

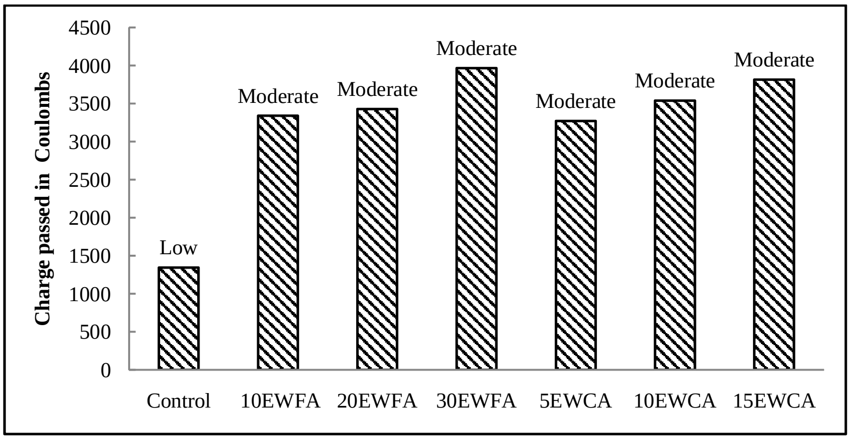

Fig. 8: Rapid chloride ion penetration of control and E-waste concrete mixtures.

would be the reason for lesser compressive strength than the control concrete when EWFA was replaced as fine aggregate in concrete. Figs. 5 and 6 show the microscopic image of the concrete sample with E-waste as fine and coarse aggregates replacement in concrete. Further, SEM analysis needs to be studied for the improvement of strength for the concrete containing E-waste as fine and coarse aggregate replacement.

Splitting tensile strength and flexural strength: The splitting tensile strength and flexural strength of control concrete at 28 days were 4.33MPa and 5.85 MPa respectively. The splitting tensile strength and flexural strength of control and fibre reinforced green concrete with E-waste were compared and it is shown in Fig. 7.

The control concrete exhibited brittle failure, whereas fibre reinforced green concrete with E-waste as fine and coarse aggregates showed ductile failure. This was due to bridging of cracks offered by steel fibres. The fibre reinforced green concrete with 10 EWFA and 5 EWCA attained higher splitting tensile and flexural strengths than control concrete. The good bonding between the steel fibres, GGBS and E-waste aggregates offered stability even after the failure of the concrete samples.

Rapid chloride ion penetration test: The control and fibre reinforced E-waste concrete with fibres were tested for rapid chloride permeability test in accordance to ASTM C 1202-10. The rapid chloride penetration of the control and E-waste concrete mixtures are shown in the Fig. 8. The chloride ion penetration of control concrete exhibited low chloride ion penetration, whereas for E-waste fine and coarse aggregate replacement exhibited moderate chloride ion penetration with the charge passed in the range of 3271 to 3966 Coulombs. The moderate chloride ion penetration may be due to the presence of steel fibres and E-waste fine and coarse aggregates in the concrete mixtures (need to be further studied).

CONCLUSIONS

The following conclusions can be drawn from the results of the experimental investigations:

The dry density of the control concrete decreased with the increase in the percentage of replacement with fine and coarse E-waste aggregates. The compressive strength of E-waste as fine aggregates decreased with the increase in the percentage of replacement except for 10% E-waste fine aggregate mixture at 28 days and 56 days respectively. The compressive strength of E-waste as coarse aggregate replacements increased when the curing was increased to 56 days. The compressive strength was similar and higher in the range of 53 MPa to 56 MPa, whereas for control concrete it was 54 MPa respectively. The splitting tensile strength and flexural strength were higher and similar to that of control concrete. The higher splitting tensile strength was due to the incorporation of steel fibres that bridged the cracks and increased the load carrying capacity of the E-waste concrete mixtures. The chloride ion penetration of the control concrete was low, whereas for E-waste concrete mixtures it exhibited moderate chloride ion penetration. The combined pozzolanic action of GGBS, bridging of fibres, and good bonding of E-waste aggregates increased the strength and durability of E-waste concrete mixtures over control concrete. This experimental study clearly shows that proper selection of E-waste materials, fibres and mineral admixtures can enhance the strength and durability of concrete.

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REFERENCES

Agamuthu, Pariatamby and Dennis, Victor 2013. Policy trends of e-waste management in Asia. J. Mater. Cycles. Waste. Manag., 15: 411-419.

Arivalagan, S. 2014. Sustainable studies on concrete with GGBS as a replacement material in cement. Jordan J. Civil. Engg., 8(3): 263-270.

Ganesh Babu, K. and Sree Rama Kumar, V. 2000. Efficiency of GGBS in concrete. Cement. Concrete Res., 30: 1031-1036.

Gengying, Li and Xiaohua Zhao 2003. Properties of concrete incorporating fly ash and ground granulated blast-furnace slag. Cement Concrete Comp., 25: 293-299.

Gullett, B. K., Linak, W. P., Touati, A., Wasson, S. J., Gatica, S. and King, C. J. 2007. Characterization of air emissions and residual ash from open burning of electronic wastes during simulated rudimentary recycling operations. J. Mater. Cycles. Waste. Manag., 9(1): 69-79.

Hwai-Chung, Wu 2001. Mechanical properties of steel microfiber reinforced cement pastes and mortars. J. Mater. Civ. Engg., 13(3): 240-241.

Indian Standard IS:10262 2009. Concrete Mix Proportioning-Guidelines. New Delhi.

Indian Standard IS:12269 2009. Specification for 53 Grade Ordinary Portland Cement. New Delhi.

Indian Standard IS:9013 2004. Admixtures-Specification. New Delhi.

Indian Standards IS:2386, Part I 1997. Methods of Test for Aggregates for Concrete, New Delhi.

Kholmyansky, M. 2002. Mechanical resistance of steel fiber reinforced concrete to axial load. J. Mater. Civ. Engg., 14(4): 311-319.

Murugappan, K., Paramasivam, P. and Tan, K. 1993. Failure envelope for steel-fiber concrete under biaxial compression. J. Mater. Civ. Engg., 5(4): 436-446.

Senthil Kumar, K. and Baskar, K. 2014. Response surfaces for fresh and hardened properties of concrete with E-waste (HIPS). J. Waste. Manag., Article ID 517219, 14 pages. doi:10.1155/2014/517219.

Song, Qingbin, Zhishi Wang, Jinhui Li, and Xianlai Zeng 2013. The life cycle assessment of an e-waste treatment enterprise in China. J. Mater. Cycles. Waste. Manag., 15: 469-475.

Thomas, J. and Ramaswamy, A. 2007. Mechanical properties of steel fiber-reinforced concrete. J. Mater. Civ. Engg., 19(5): 385-392.

Toxic Link 2014. A report on Impact of E-waste Recycling on Water and Soil. http://toxicslink.org/docs/Impact-of-E-waste-recycling-on-Soil-and-Water.pdf

Vahid, Afroughsabet and Togay, Ozbakkaloglu 2015. Mechanical and durability properties of high-strength concrete containing steel and polypropylene fibers. Construction and Building Materials, 94: 73-82.

Vanden, Heuvel J.P. and Lucier, G. 1993. Environmental toxicology of polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans. Environ. Health Perspect., 100: 189-200.