Evaluation and Analysis of M20 Grade Concrete Blended with Nonperforming Battery Cells As a Replacement of Coarse Aggregate

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Abstract— E-wastes are emerging as a tremendous source of various health hazards as well as environmental problems. With the up rise in number of consumers in the global digital market scenario and the flurry of modern electrical products, the e-waste being generated has been growing leaps and bounds. Battery is an e-waste, with production of several tons per year. Batteries are mostly sent to landfill with high management cost. Further due to poor infrastructure for disposal, the various types of batteries which contain very toxic metals in it are dumped over landfill which pollutes the soil, ground water as well as surface water sources. The study intended to look out for a path to use these spent battery cells in the concrete as a coarse aggregate so that the burden of the management of the gigantic amount of e-wastes can be relieved a bit. In the following study, the focus was upon the consumption of the spent e-waste AA battery cells used in households for the purpose of making M20 grade of concrete by replacing the natural coarse aggregate by 5% and 10% of it. The results revealed that as we increase the amount of replacement of the spent battery cells, there is a decrease in the strength of the concrete. But the decrease is small for up to the range of 10% of the replacement. The parameters tested were the compressive strength and the split tensile strength of the M20 grade of concrete. The test also concluded that the self-weight of the concrete decreases with respect to the control mix as the percentage replacement increases.

Keywords: Batteries, e-waste, environmental impact, M20 grade, Compressive strength

I. INTRODUCTION

India was ranked 5th among the highest e-waste generating countries in the world in the year 2016 as a result of generating an estimated 1.85 million tons of e-waste annually [1]. The e-waste generated by the developing nations, due to the casual handling of these wastes, may lead to issues relating to contamination and health. The developing nations have a very restricted solutions and obsolete approaches for tackling of the ever-evolving e-waste problem. Appropriate care needs to be taken to ensure to curb any chances of spilling of materials and utilization of any unsafe practices in reusing of the e-wastes.[2]

Statistics report that in India itself, a whopping 2.7 billion pieces of dry cell is used on a yearly basis. It also reported the domination of non-rechargeable batteries in the battery scenario of India because of them being cheaper. With 97% of the dry cell market share, the zinc-carbon cells ruled the market. Heavy metals such as cadmium, nickel, zinc, manganese, lithium, copper, mercury, lead etc. is contained by these batteries. These heavy metals are majorly toxic in nature.[3]

The rural areas have the majority share of the consumption of these dry cells since they are used as substitute for electricity and are cheap and largely available there. Due to this there lies a grave threat of the agricultural land being polluted by the leaching of heavy toxic elements present in these cells and which in turn would affect the agricultural produces.[3]

The smaller battery because of the shorter life span joins the waste stream quickly relatively to the other batteries. This causes even more burden on the environment. These small batteries are usually used in wall clocks, remotes and flashlights. In India the small battery market is dominated by the single use batteries which is also known as the primary cells.[3]

V. S. Damal[4] replaced the fine aggregate with e-waste in the conventional mix design of M30 grade of concrete. He created many samples utilizing the e-wastes in the range from 0% to 21.5% and then studied the variation in the hardened properties. For the utilization in rigid pavement construction, he concluded that 7.5% is the optimum replacement percentage where there is no major deviation of the strength from the conventional mix. So this can be used for the pavement construction.

Hamsavathi[5] blended recycled CRT panel plastics to the M25 grade concrete mix as a partial replacement for the coarse aggregate by 5%, 20%, 15%, 18% and 20%. He intended to analyze the behaviour of the beams to be used in buildings when they are made by utilizing the e-wastes shredded to a size of 12mm. The structural properties of the concrete grew till the percent replacement went up to 15% and post 15% there was decline in the strength. He concluded that the e-waste incorporation caused appreciable decrease in weight of concrete as well in its density. As the water cement ratio increases there is a decrease in its strength as a result of loss of bond between the e-waste and the cement paste.

Needhidasan[6] evaluated the structural properties of the M40 grade concrete when conventional coarse aggregate replaced by the e-waste plastics and at the same time addition of super plasticizers. The range explored for the experiment was 0% to 22%. The result showed gain in strength increased.

Needhidasan[2] utilized the printed circuit boards as a replacement to the natural coarse aggregates in the range of 0% to 15% for the M20 grade of concrete. He evaluated and compared the hardened properties of concrete specimens. He noted that till the replacement of 10%, there is only a marginal variation of strength in concrete. He also found out that with the increase in the replacement, there was increase in the split tensile strength.

Mary Treasa Shinu and Needhidasan[7] investigated a path to utilize the huge amount of e-waste being generated due to the boom in the digital market. They tried to incorporate the waste printed circuit boards in the concrete as a replacement for the coarse aggregate. They envisioned that this would bring down the burden of waste plastic management. The authors replaced the coarse aggregate for M40 grade of concrete with the printed circuit boards by 12%, 17% and 22%. They analyzed the concrete containing various percentage of PCBs and compared it with the properties of the control mix. The properties evaluated included compressive strength, split tensile strength and flexural strength. From the study, the authors concluded that with increase in the percentage replacement, the strength of concrete decreases. The weight of the concrete also decreases with increase in the percentage replacement.

Ahirwar[8] examined the changes in the strength of concrete when the design mix is simultaneously replaced with the e-waste for coarse aggregate and the fine aggregate as well as replacement of cement by fly ash. The aggregates were replaced in the range of 0% to 30% and the fly ash was added by 10%, 20% and 30%. The result showed increase in compressive strength. He observed that at 30% aggregate replacement and 30% cement replacement with fly ash increases the compressive strength of concrete even higher than the conventional.

B.T.Manjunath[9] replaced conventional coarse aggregate present in the M20 grade concrete by 0%, 10%, 20% and 30%. He found out that the concrete gets more ductile when the e-waste is blended into the concrete.

Lavanya[10] proceeded with the aim to replace the e-waste generated as a replacement for the M25 grade of concrete. He evaluated several structural properties of concrete prepared as a result of a percentage replacement of 10%, 20% and 30%. He reported that at a replacement of 20% of coarse aggregate with e-waste, there was enhancement in the structural properties in comparison to the concrete mix.at higher percentage of replacement there was a substantial decrease in the structural properties of concrete He advocated the utilization of e-waste blended concrete based on the results he observed during the study.

Prasanna and Rao[11] studied the hardened properties of M30 grade concrete by replacing the coarse aggregate in the concrete with the e-waste by a wide range that is 5%, 10%, 15% and 20%. The study revealed that there is a dip of 303.7% in the strength at a replacement of 20%. The dip in the strength of concrete narrows down with the addition of fly ash in the concrete. At a replacement of 15%, the study found the values for the strength criteria of the concrete to be optimum.

II. MATERIALS AND METHODS

The procedure under taken was firstly introduction which was latter followed by literature review, materials procurement, analyzing physical properties of materials, casting and testing of concrete for strength at an interval of 7, 14 and 28 days. The cement used was Ordinary Portland cement of 53 grade in conformation to IS:12269 [12]. The properties of cement are listed in Table 1.

Property	Value
Specific gravity	3.2
Initial setting time	35 min
Final setting time	190 min
Consistency	30%

Table 1: Physical properties of Cement

Table 2 lists the physical properties of sand which was used for the experimental purpose. It was Kshipra river sand and conformed to IS:383-1970 [13]. The sand used for the experiment belonged to the Zone II.

Property	Value
Specific gravity	2.265
Fineness modulus	2.4247
Water absorption	1.729
Sieve Analysis	Zone II

Table 2: Physical properties of Sand

IS Sieve size mm	Weight retained in gm	%Weight retained	Cumulative % of weight retained	Cumulative% of weight passing
10	0	0	0	100
4.75	12	1.2	1.2	98.8
2.36	28.4	2.84	4.04	95.96
1.18	139	13.9	17.94	82.06
0.6	236	23.6	41.54	58.46
0.3	436.1	43.61	85.15	14.85
0.15	74.5	7.45	92.60	7.40
0.075	71.5	7.15	99.75	0.25
Pan	2.5	0.25	100	0

Table 3: Sieve Analysis for sand

The aggregate used in the experiment had a nominal size of 20 mm which were angular in shape. The aggregates were cleaned prior to be used in the experiment. The physical properties of the aggregates are listed in Table 4.

Property	Value
Specific Gravity	3.0046
Water absorption in %	1.702
Maximum size of aggregate used	20mm

Table 4: Physical properties of Coarse Aggregates

The spent battery cells were used to replace the conventional coarse aggregates. After splitting them into two parts, the spent battery cells were of size approximately 20 mm. The spent battery cells were of size mostly AA and which were primarily being used in the households. Table 5 lists the properties of the spent battery cells to be used in concrete.

Fig. 1: Spent battery cells

Property	Value
Maximum size	20 mm
Specific gravity	1.166
Type of cell used	AA

Table 5: Physical properties of spent cells

According to the requirements of IS:456-2000 [14], the tap water present in the lab was utilized for preparing the concrete mix, since it was conforming to the guidance of the IS code.

III. MIX DESIGN

The design mix for the concrete intended was prepared in accordance to IS: 10262-2009 [15]. The design characteristic strength for mix to be prepared was taken as 20 N/mm^2. M20 grade concrete having mix proportions 1:1.6:3.5 as per weight and w/c ratio 0.5 was mixed for the experimental study. The literature survey revealed that the replacement of conventional coarse aggregate and fine aggregates with the e-waste plastics have been done already. In this experiment, replacement using spent battery cells as coarse aggregate is done and the comparison with the control mix is performed. For the experiment purpose, 3 specimens were prepared that were of control mix, with 5% spent battery cells replacement and 10% battery cells replacement.

IV. MIXING AND CASTING

Cement, sand and coarse aggregates after being weighted over a weighing balance are placed over a clean and dry tray. They are mixed using a shovel and then appropriate amount of water as calculated well in advance is weighted and poured over them. It is then very nicely mixed so as to achieve a uniform mix. The moulds are then prepared by cleaning and then applying mould releasing agents, to be filled by the concrete mix. The concrete mix is then filled in these steel moulds in 3 layers with each layer being compacted 25 times using a tamping rod of 16mm diameter. A total of 12 numbers of 150mm cubes, 6 numbers of 150mm X 300mm cylinders were casted. After 24 hours, the samples were taken out of the moulds and then kept in a water tank for curing purpose for a period of 28 days. After 7, 14 and 28 days the samples were taken out and tested for the compressive strength and split tensile strength. Fig. 5 illustrates the compressive strength and split tensile strength tests respectively.

V. RESULTS AND DISCUSSION

A. *Unit weight*

Table 7 lists down the unit weight of the 3 specimens of M20 grade of concrete that has been prepared. The result suggests that as there is an increment in the percentage replacement of the coarse aggregates with the spent battery cells, there is a decrease in the unit weight of the concrete. The decrease in the unit weight can be owed to the lower specific gravity of the battery cells.

Specimen designation	Unit weight (kg/m^3)
Control mix	2476.97
5%	2440.37
10%	2376.91

Table 7: Unit weight of specimens

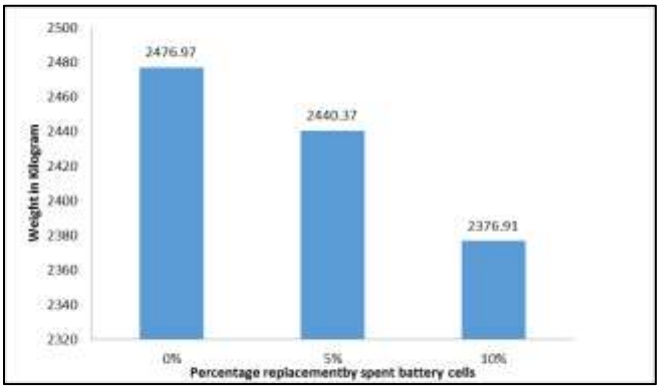

Fig. 2 Bar graph showing self-weight of concrete

B. *Compressive strength*

The compressive strength of the concrete specimen was tested in the compressive testing machine and the results pointed out an increasing trend in the gaining of strength by the concrete as the day passed. The result further showed that the concrete prepared by the spent battery cells had compressive strength lower than the control mix. This gap of the compressive strength even widened further when the percentage replacement of the conventional coarse aggregate with the spent battery cells is increased.

The compressive strength of the specimens was calculated using the following formula

$$F_{ck} = P_c / A, \quad [7]$$

Where,

P_c = Load at which specimen fails in Newtons

A= Loaded area of specimen in mm^2

The values of the compressive strength obtained for the different specimens at an interval of 7, 14 and 28 days are listed in Table 8.

Mix specification	Value (N/mm^2)	Value (N/mm^2)	Value (N/mm^2)
Percentage of spent battery cells	0%	5%	10%
7 days	17.076	16.35	16.277
14 days	25.288	24.779	23.689
28 days	29.793	28.994	27.32

Table 8: Compressive strength values

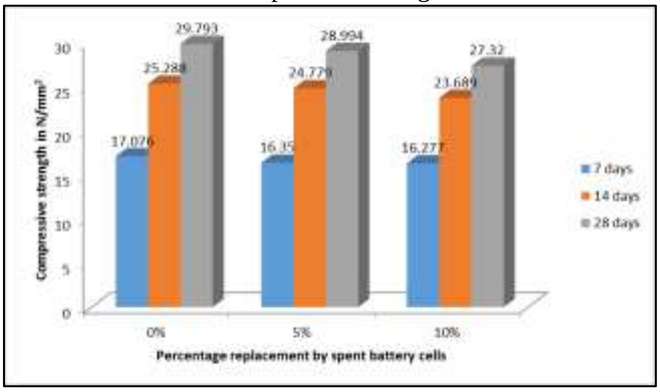

Fig. 3: Bar graph depicting compressive strength

C. *Split tensile strength*

The split tensile strength of the concrete mix was determined using the cylindrical specimen prepared. The size of the cylindrical specimen used was of 150 mm diameter and a length of 300 mm. The cylindrical specimen was put into the compression testing machine for the determination of split tensile strength. It was placed horizontally. The results showed an increasing trend for the concrete specimen as they aged. However, there was a decline of tensile strength as the percentage replacement of conventional coarse aggregate with spent battery cells started to be increased.

The split tensile strength of concrete specimen was calculated using the following equation

$$T = 2P / \pi l D, \quad [7]$$

Where,
P = maximum load at failure in Newtons
l = length of specimen in mm
D = diameter of specimen in mm

Mix specification	Value (N/mm^2)	Value (N/mm^2)	Value (N/mm^2)
Percentage of spent battery cells	0%	5%	10%
7 days	1.805	1.666	1.3885
14 days	2.638	2.568	2.082
28 days	3.610	3.471	3.055

Table 9: Split tensile strength values

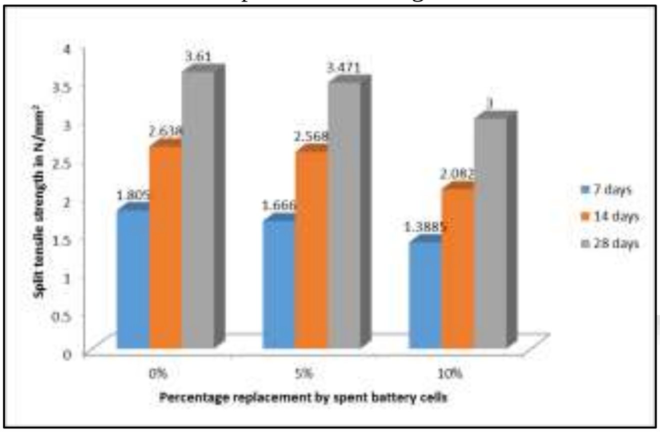

Fig. 4: Bar graph depicting split tensile strength

a) Compressive strength test

b) Split tensile strength test

Fig. 5: a) Compressive strength test b) Split tensile strength test

VI. Conclusion

The ever increasing e-waste battery cells swarming the landfills and causes a great deal of environmental hazards by leaching to the surrounding air, water and soil. Through the study carried out, it was determined that the partial replacement of the natural coarse aggregate by the AA battery cells in the M20 grade of concrete in the range of up to 10% does not affect the strength of the concrete to a great extent and thus can be used as a concrete mix for the non-structural works. The compressive strength as well as the split tensile strength of the concrete was tested and the data showed a decreasing trend in strength which was minor in nature. The experimental data also revealed that the self-weight of the concrete developed by replacement was less than the weight of the control mix. The concrete so developed can be used for the non-structural works such as for sidewalks, fillings, borders, concrete panels used in facades etc.

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