AN EXPERIMENTAL LABORATORY STUDY ON UTILISATION OF E-WASTE AS A PARTIAL REPLACEMENT OF FINE AGGREGATES IN CONCRETE

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Abstract

The Growth in the Electronics sector has been rapid and this rapid growth is due to continuous upgradation of technology and introduction of new technologies to the market. This has led to one of the fastest growing solid waste in the world, simply called as E-waste. India is the 5th highest e-waste producer in the world. The rapid increase in the construction activity in India, has resulted in huge demand for the aggregates to be used in the concrete. This has led to depletion of natural resources and adverse changes in the environment. This rapid development in the infrastructure sector has led to shortage of natural sand. This paper outlines the experimental work carried for utilisation of e-waste as a partial replacement for the fine aggregates. Strength tests and durability tests are conducted on hardened concrete. Results show that the partial use of E- waste as fine aggregates results in much higher workable and less dense concrete. This study gives an Economic, environment friendly and efficient disposal method for E-waste to be used as a partial replacement to the fine aggregates in concrete.

Keywords: *E-waste, M-Sand, Fine aggregate replacement, Concrete, Durabilityetc.*

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1. INTRODUCTION

It is inevitable to avoid concrete in construction activities. Concrete is used extensively due to its strength and durable properties. In general, basic ingredients for concrete are cement, fine and course aggregates and water. These coarse aggregates (Igneous rock) and the fine aggregates (natural sand) account for 70-75% of the total volume in the concrete.The rapid increase in the construction activity in India, has resulted in huge demand for the aggregates to be used in the concrete. This has led to depletion of natural resources and adverse changes in the environment. This rapid development in the infrastructure sector has led to shortage of natural sand that is to be used as fine aggregates. Manufactured sand (MSand) was found to be the best alternative to the natural sand. It is being used successfully as a replacement for the natural sand in the fine aggregates.

1.1 E-Waste

One of the fastest growing waste sectors in the world is the electrical and electronic waste (e-waste). The used electronic devices and house hold appliances which are unfit for their original intended use form the Electronic waste. They can be recovered, recycled or disposed. It refers to end of life for the products such as Computers, ACs, televisions, printers and mobile phones made of plastics, metals, etc. The electronic industry is the world's fastest and largest growing manufacturing industry. It is seen that over 95% of the e-waste is managed by the unorganized scrap dealers who just dismantle the disposed products instead of recycling them. The collection, treatment, recovery and disposal of e-waste is needed at national and regional level for reducing the adverse effects. Newer approaches are required to make the process feasible.

1.2 Literature Review

- Aditya Gavhane et al. (2016) worked on the Utilization of E - Plastic Waste in Concrete as Coarse aggregates and fine aggregates. Strength tests and durability tests were carried out on M20 grade conventional concrete and concrete with e-plastic waste as coarse aggregates and e-plastic waste as fine aggregates. The results were same as the conventional concrete up to 10% replacement for both coarse and fine aggregate replacements. E-plastic waste as Fine aggregates showed good usability than as coarse aggregates due to the bonding problem of e-plastic coarse aggregates and segregation of concrete. It showed good workability improvements in e-plastic fine aggregates than river sand due to the water absorption problems of river sand. [1]

- Rajiv Gupta et al. (2015) experimented in utilization of different combinations of e-wastes and recycled coarse aggregate together as a substitute for conventional aggregates. The site-tested concrete specimens which would contain recycled aggregates were collected and were combined with the e-waste (PCBs) as complete replacement of coarse aggregates by altering the proportions of these wastes. M20 grade of concrete was made. The e-waste PCBs strips were also used as reinforcement in concrete to enhance the tensile properties. The results show that optimum mix of recycled aggregates and e-waste as coarse aggregates can be effectively used in the sub base preparation for the rigid pavements, also in the construction of low volume concrete pavements. The best orientation of e-waste strips to be used as reinforcement in concrete was found to be perpendicular to the width because to get the tensile property of the e-waste. [2]

- P. Krishna Prasanna et al. (2014) experimented the e-waste particles that were used as coarse aggregates in M30 mix grade of concrete. 0%, 5%, 10%, 15% and 20% proportions were used in the design as replacement of coarse aggregates. Also fly ash (10%) was used along with the e-waste for same proportions. Compressive strength and split tensile strength tests were carried for 7, 14 and 28 days cured samples. The results indicated 33.7% decrease in strength values for 15 percent replacement in coarse aggregates by e-waste and 16.86% decrease when coarse aggregates are replaced by 20 % e-waste plus fly ash (10%). The optimum strength was obtained at 15% replacement of coarse aggregates by e-waste. [3]

1.3 Significance of the Present Research

- Past studies done on utilization of e-waste in concrete deals with e-waste by using it as partial replacement for coarse aggregate and fine aggregate. Studies were also made on using e-waste fibers in concrete to improve the tensile strength.
- Based on past studies, it was found that the e-waste has excellent impact and crushing value (< 2 %). And research was carried out for M20, M25 and M30 grade concrete with normal water content.
- This present research involves studying the strength and durability of the E-waste utilized as partial replacement of fine aggregates in the concrete for a target strength of M40 with reduced water cement ratio.
- Complete replacement of natural sand as the fine aggregate is achieved by using MSand along with different proportions of e-waste to make this type of concrete better and economical than the conventional concrete.

For this purpose, research was taken-up to develop e-waste (EC) concrete using e-waste and M-sand as fine aggregates at different proportions.

1.4 Objectives of the Study

- To procure and process e-waste.
- To convert the e-waste materials into e-waste fine aggregates (EWFA) by grinding the e-waste chips to the required grain size distribution of Fine Aggregates.
- To utilise M-sand as an alternate material to natural sand in the production of concrete.
- To produce EC (E-waste concrete) of M40 grade (Target strength)
- To study the effect on workability and density of the different mixes (different combinations of EWFA & M sand) at constant w/c ratio.
- To study strength properties of EC by casting specimens (cubes, cylinders, and beams) and curing it for 7, 14 and 28 days ‘period.
- To study durability properties of EC
- Cost analysis of the EC.

2. METHODOLOGY

a) Procurement of ingredients for E waste concrete research are as follows.
  - The e-waste chips were collected from the local e-waste dismantling vendor and it was converted into e-waste fine aggregates (EWFA) by grinding the chips.
  - The coarse and fine aggregates were procured from the nearest crusher
  - OPC 53 grade cement of good quality was procured.
  - MasterGlenium SKY 8233 which is a High-performance Superplasticizer based on PCE (polycarboxylic ether) for concrete, was sponsored by BASF (Construction chemical division).

b) Basic Tests were carried out on the materials (aggregates, cement) to determine their physical properties.
  - The tests were carried out as per the guidelines set by BIS.

c) Mix design was developed for M40 grade of concrete(EC) as per the IS 10262-2009.
  - Different Mixes were developed for different proportions of e-waste as partial replacements in fine aggregates.
  - The Water cement ratio, cement content and coarse aggregates was kept constant for all proportions and the variations were made in the e-waste replacements in the fine aggregates.

Table-2.1: Mix proportions

Mix Code	E-waste (%)	M sand (%)	Natural sand (%)
H	0	0	100
H 1	5	95	0
H 2	10	90	0
H 3	15	85	0
H 4	20	80	0

d) To determine the workability of the fresh concrete, Slump test was conducted for different mixes.

e) Specimens(cube, beam, cylinder) of standard sizes were casted with e-waste in concrete of M40 gradewith different E-waste and M sandproportions.
  - Superplasticizer (High performance)was used for reducing water and also obtaining high workability.

- The coarse aggregates wereused in the mixture of 2 proportions (60% of 20mmdown size and40% of 12mm down size) aggregates as per IS: 383-1970

f) The specimens were kept in laboratory curing tankfor the period of 7,14 and 28 days.

g) To conduct the durability Test, the specimens from the water tank (after 28 days' water curing) were removed and kept to dry at room temperature for 24 days and then immersed into the acid solution (Sodium Sulphate and Hydrochloric acid) for the acid curing (30 and 60 days).

h) The compressive strength along with the flexure and split tensile strength which indicate the strength parametersof the EC- were computed by conducting tests on 7, 14, and 28 days' cured specimens.
- Durability of the E waste concrete was analyzed by subjecting the concrete specimen to chemical attack test.
- Chemical attack tests like Sulphate attack and chloride attack tests were conducted on the specimens
- The specimens were immersed in the acid solution for 30 and 60 days' durability values.
- The strength and durability values were compared with the conventional concrete.

3. EXPERIMENTAL INVESTIGATION

3.1 Cement

Table-3.1: Test Results of cement properties

SL. No	Description	Results	Specification (IS 12269-1987)
1	Specific Gravity	3.14	-
2	Consistency	32%	-
3	Fineness	3.3	Not exceed 10%
4	Initial setting time	125 min	Minimum 30 minutes
5	Final setting time	210 min	Max 600 minutes
6	Compressive strength at 7 and 28 days	44.3 and 56 MPa	Target strength is achieved

3.2 Coarse Aggregates

Table-3.2: Test Results of Coarse aggregates

Sl. No	Description	Result	Specification (IS 383-1970)
1	Specific Gravity	2.67	2.50 – 2.90
2	Water Absorption	0.39	Less than 2%
3	Fineness Modulus	3.42	3.25 – 5.70
4	Bulk Density (Kg/m^3)	1596.92	1500 – 1700

3.3 M-sand

Table-3.3: Test Results of M Sand

SL. No	Description	Result	Specification (IS 383-1970)
1	Specific Gravity	2.65	2.50 - 2.90
2	Water Absorption	3.66	Less than 2%
3	Fineness Modulus	2.63 (Zone II)	Medium sand (2.60 – 2.90)
4	Bulk Density (Kg/m^3)	1836.01	1500 – 1900

3.4 E-waste Fine Aggregates (EWFA)

Fig -3: Pictorial representation of e-waste used in present study

Table-3.4: Properties of EWFA

SL. No	Description	Result
1	Specific Gravity	1.2
2	Water Absorption	0.1 %
3	Shape	Angular
4	Impact Value	1.8 %
5	Crushing Value	1.6%

3.5 Fine Aggregate Composite

M-Sand and EWFA was mixed in various proportions in order to ensure effectiveness of used materials against conventional aggregates.

Properties of FA Composite (combination of M-Sand 90% & EWFA 10%) were computed as per the IS: 383-1970.

Table-3.5: Test Results of fine aggregate composite

SL. No	Description	Result	Specification (IS 383-1970)
1	Specific Gravity	2.51	2.50 – 2.90
2	Water Absorption(%)	3.2	Less than 2%
3	Fineness Modulus	2.75 (zone II)	Medium sand (2.60 – 2.90)
4	Bulk Density (g/cc)	1.82	1.50 – 1.90 g/cc

3.6 Concrete Preparation and Casting

- All the materials to be used were stored in advance prior to casting of concrete.
- Standard Moulds were cleaned, oiled, checked for joint tightness before the casting.
- The materials like cement, coarse aggregates, fine aggregates, water and admixture were weighed accurately according to the mix proportion for which the casting was carried out**.**
- The materials were then fed into the drum mixer one by one and 25% of water content was added to the mix.
- Remaining 75% percent of water was then added to the mixer and mixed for few mins.
- The Superplasticizer was added to small quantity of water (taken from the remaining 75% of the water) and fed into the mixer and was mixed for about a minute.
- Once a homogenous mix is obtained, the concrete in its fresh state was assessed for its workability. Slump cone was used to determine the workability. It was done for every batch to ensure uniformity.
- The concrete thus prepared was poured into the standard cube, beam and cylinder moulds, in three layers. The moulds were subjected to Vibratory compaction, given at uniform intervals by placing them on the vibratory table.
- The concrete surface was given good finishing with the help of hand tools like trowels and finishing tool.
- The concrete moulds were then demoulded after 24 hrs. of casting.
- The Specimens were then placed in water tank to carry out pond curing process. (7,14 and 28 days' period)

4. TESTS AND RESULTS

4.1 Compressive Strength

Fig-4.1: Cube Compression Test

Table-4.1: Cube compression strength

Mix Proportion	Cube Compressive Strength(MPa)			Remarks as per (IS 456: 2000) for 28 days
	7 Days	14 Days	28 Days	
H	31.93	41.06	45.62	> 40 MPa
H1	35.84	43.01	47.78	> 40 MPa
H2	29.63	37.56	41.73	> 40 MPa
H3	26.17	33.64	37.38	< 40 MPa
H4	26.11	33.10	36.78	< 40 MPa

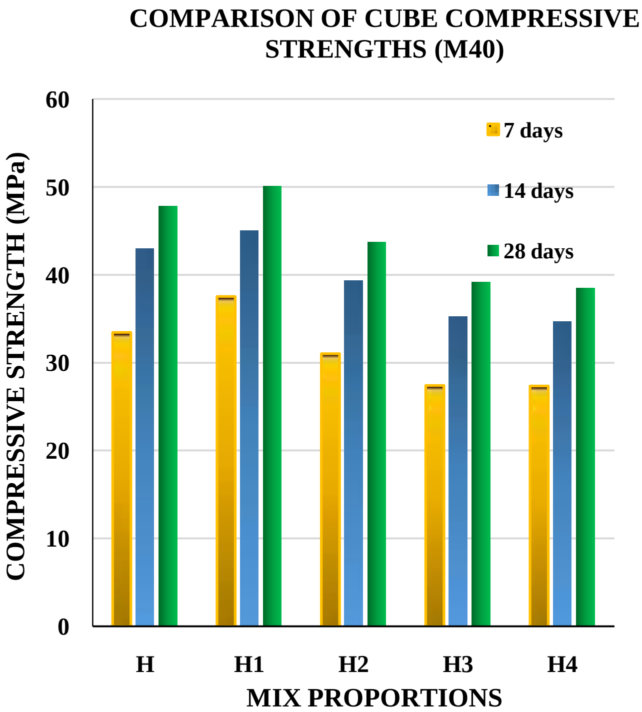

Chart-4.1: Cube compression strength comparison

Fig-4.2: Cylinder Compression Test

Table-4.2: Cylinder compression strength

Mix Proportion	Cube Compressive Strength(MPa)			Remarks as per (IS 456: 2000) for 28 days
	7 Days	14 Days	28 Days	
H	27.77	35.70	39.67	> 33 MPa
H1	31.91	38.30	42.55	> 33 MPa
H2	26.07	33.05	36.72	> 33 MPa
H3	22.48	28.90	32.12	< 33 MPa
H4	22.16	28.09	31.21	< 33 MPa

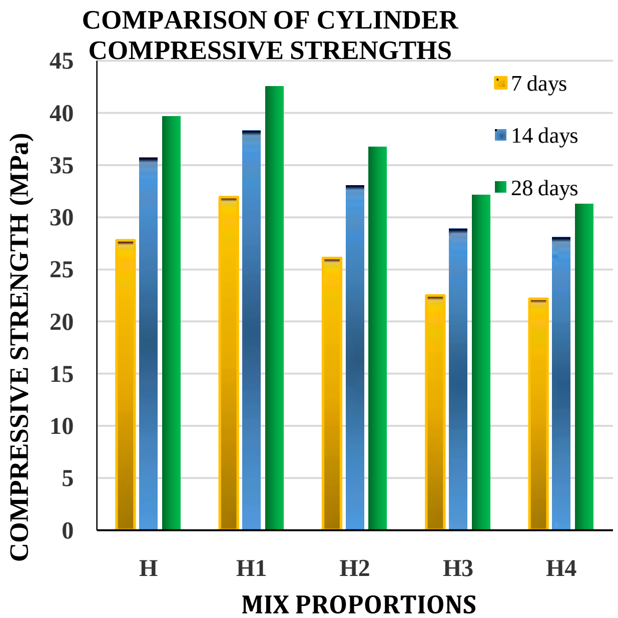

Chart-4.2: Cylinder compression strength comparison

4.2 Split Tensile Strength

Fig-4.3: Split tensile testing

Table-4.3: Split tensile strength

Mix Proportion	Split Tensile Strength(MPa)		
	7 Days	14 Days	28 Days
H	2.87	3.69	4.10
H1	3.25	3.90	4.33
H2	2.81	3.57	3.96
H3	2.48	3.19	3.55
H4	2.15	2.73	3.03

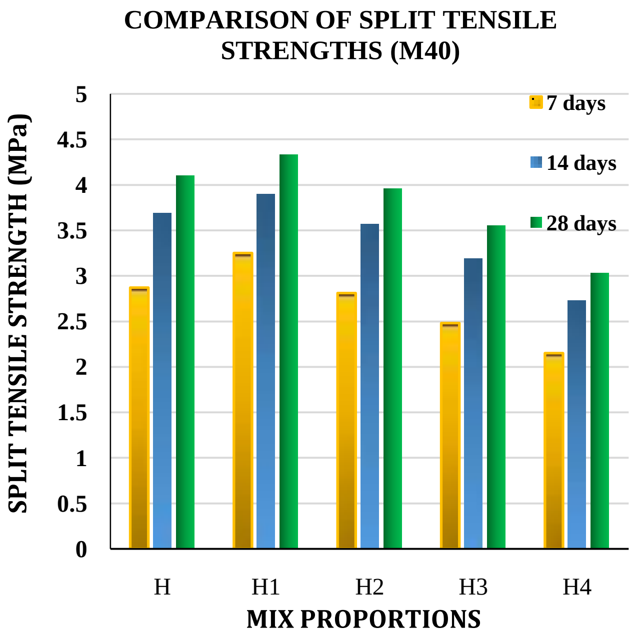

Chart-4.3: Split tensile strength comparison

4.3 Flexural Strength

Fig-4.4: Flexural testing of beam

Table-4.4: Flexure strength

Mix Proportion	Flexure Strength(MPa)		
	7 Days	14 Days	28 Days
H	4.04	5.19	5.77
H1	3.97	4.76	5.29
H2	3.92	4.97	5.52
H3	3.56	4.57	5.08
H4	3.51	4.45	4.94

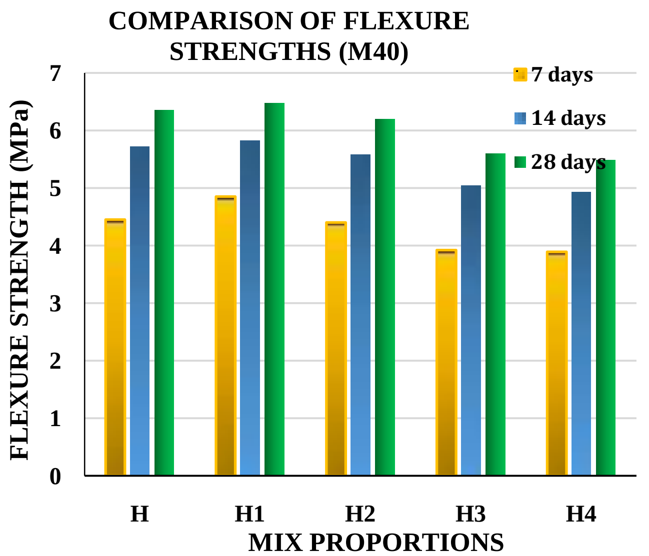

Chart-4.4: Flexural strength comparison

4.4 Durability Test (Chemical Attack Test)

- The specimens were subjected to chemical attack test in order to ensure its durability, if the concrete is exposed to adverse effects of chemicals in its lifetime.
- Once the concrete specimens had attained their target strength that is after 28 days curing period, the specimens were taken out of the curing tank and were left to dry for 24 hrs.
- Once the specimens were dry, initial weight of the specimens (different mix proportions) were taken.
- Then the specimens were immersed into acid solution to carry out acid curing for 30 and 60 days.
- Sulphate attack test was done by immersing the specimens into 6 % Sodium Sulphate solution (6% Na_2S0_4+ 94 % water)
- Chloride attack test was done by immersing the specimens into 6% hydrochloric acid solution (6 % HCl+ 94% water)
- The acid concentration was maintained throughout the acid curing period to ensure uniformity.
- After 30 and 60 days' period, the concrete specimens were taken out of the acid solution and kept for drying (24 hrs. period).
- Final weights of the specimens were taken.
- Percentage weight loss was calculated from the initial and final weights.
- The specimens were also tested for compressive strength to determine its percentage strength loss.

Fig-4.5: Specimens immersed in HCl and Na_2S0_4 Solutions for chemical attack test

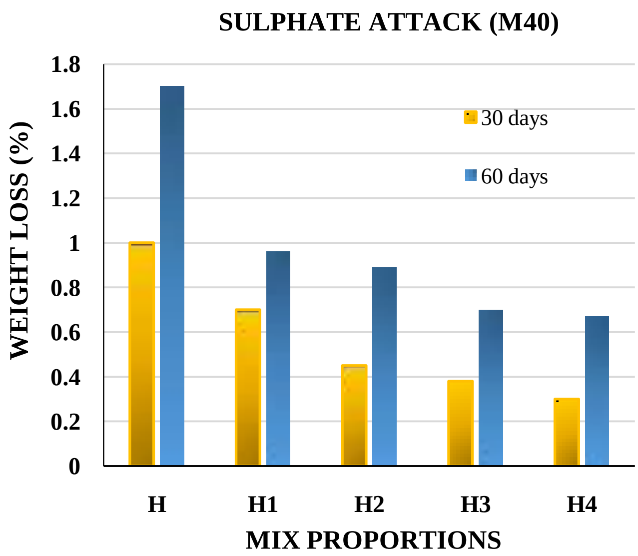

Chart-4.5: Weight loss (Sulphate Attack)

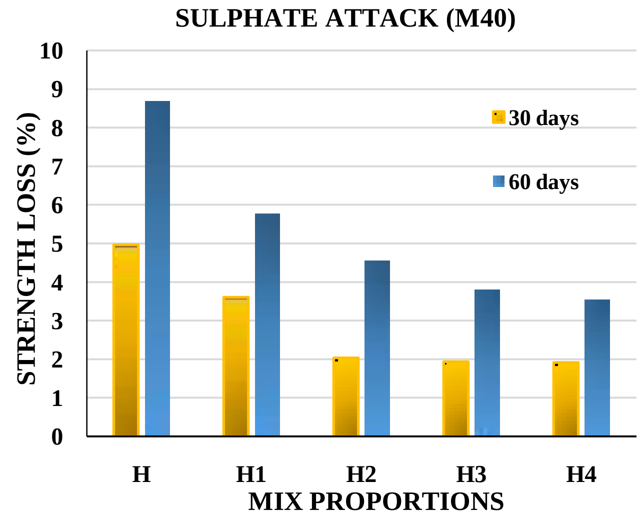

Chart-4.6: Strength loss (Sulphate Attack)

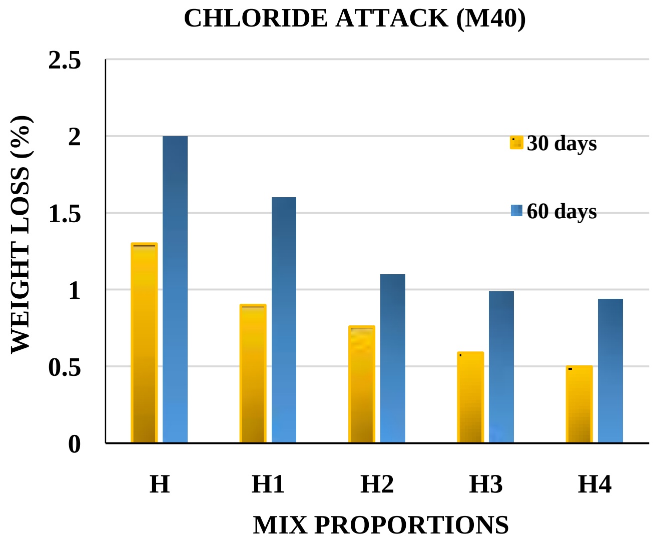

Chart-4.7: Weight loss (Chloride Attack)

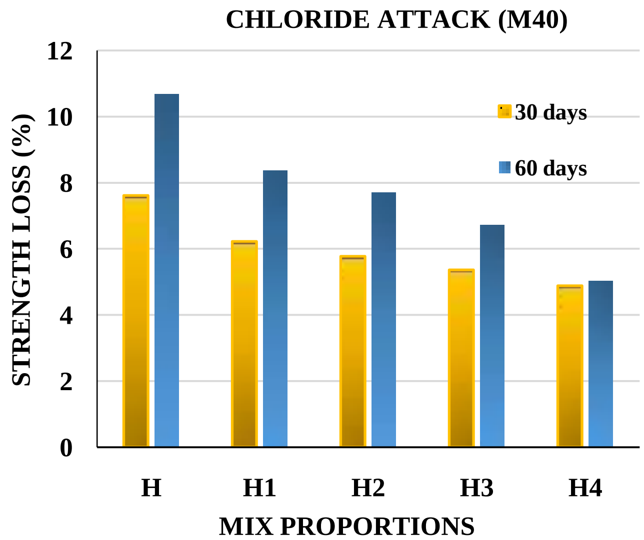

Chart-4.8: Strength loss (Chloride Attack)

4.5 Workability and Density

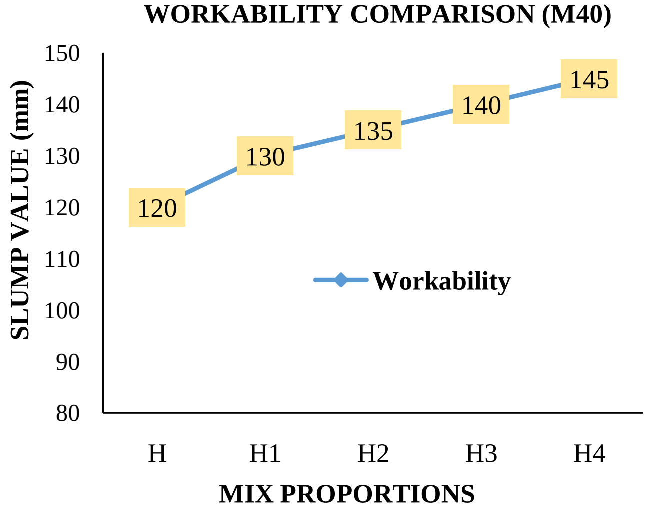

Chart-4.9: Slump value of different mix proportions

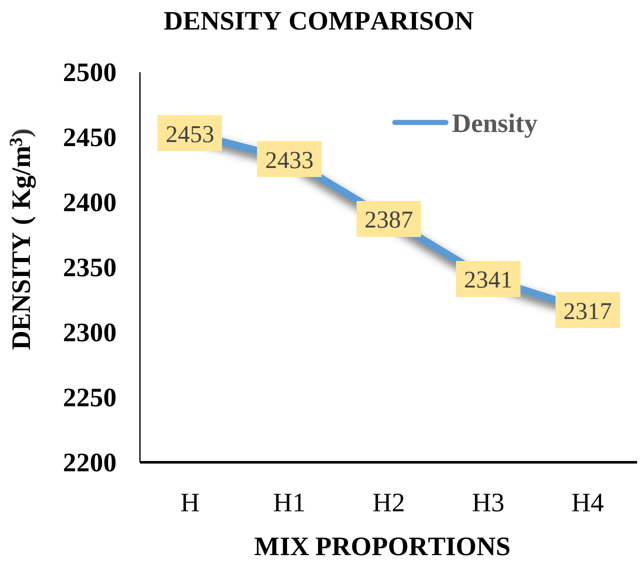

Chart-4.9: Density comparison of different mix proportions

4.6 Cost Analysis

Cost of the materials is as important as the beneficiary properties of different materials in a construction project. As it is a well-known fact that materials cost constitute a major portion of the total cost of projects. Hence to sustain economic feasibility, it's important to develop and study cost analysis for the different materials that are used in the Project.

The analyzed costs are as per current market prices in Bangalore and it may differ based on regions and time.

Studying the processes, it can be said that if the government would take initiative to utilize this e-waste which is now the fastest growing solid waste, in concrete for its disposal then the price would be highly reduced (around 80-90%). Since it is a waste material the disposal costs would be saved and also the production cost in concrete would involve the dismantling and preparing it to be suited as fine aggregates which would be easily compensated by the cost saved in disposal activities.

Table-4.5: Rates of different materials

Sl. No.	Material	RATE in ₹/Kg	Remarks
1	Cement	7	Includes Transportation
2	M-Sand	0.8	
3	Coarse aggregate	0.56	
5	E-waste	1.5	Processing and Transportation
6	Water	0.05	Includes Transportation
7	Admixture	150	

Table-4.6: Cost of Conventional M40 grade Concrete

Sl. No.	Material	Content kg/m^3	RATE in ₹/Kg	Cost ₹/m3
1	Cement	335	7	2345
2	Natural sand	715.5	1.8	1287.9
3	Coarse aggregate	1281.6	0.56	717.696
4	Water	166	0.05	8.3
5	Admixture	1	150	150
TOTAL COST in ₹/m^3				**4510**

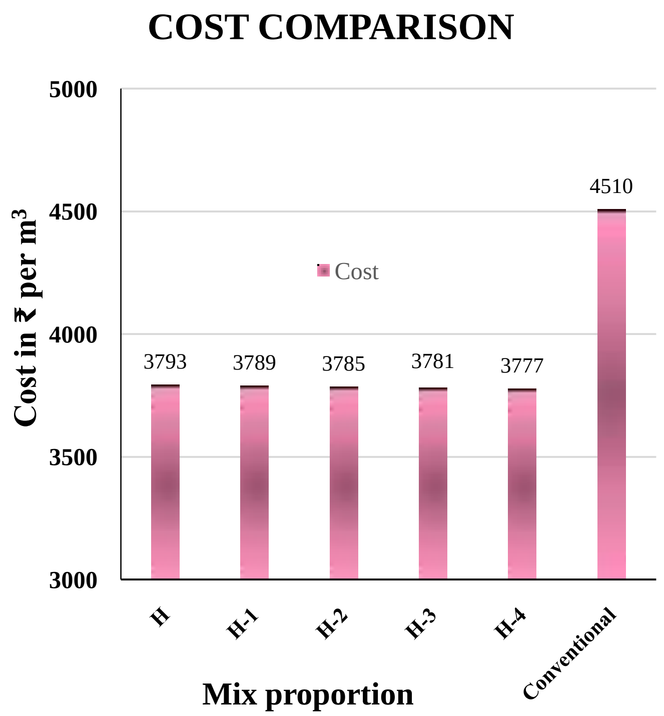

Chart-4.10: Cost Comparison of different mix proportions

5. CONCLUSION

1. The workability of E- waste concrete mix increases with increase in percentage of e-waste in concrete.
2. Compressive strength of E waste concrete having 5% E-waste as a partial replacement to fine aggregates shows a significant increase in comparison to conventional concrete.
3. From the durability (chemical attack) test it is evident that the e-waste concrete offers more resistance to the chemicals.
4. Due to the high durable property of EC, it may be used in marine conditions.
5. Considering both strength and durability aspect it can be said that the 10 % EWFA (e-waste fine aggregates) replacement satisfies to be the optimum percentage of e-waste as partial replacement in fine aggregate that can be utilized in concrete mixes.
6. 100 % replacement of natural sand was achieved by using the e-waste along with M-sand as fine aggregates for all proportions.
7. The Density of the concrete was found to be reducing with the increase in the e-waste quantity.
8. Cost of the EC can be reduced and made further economical if proper support, and legal amendments are made through government organizations to process it on a large scale.
9. Utilization of e-waste in concrete may be the efficient, economical and best way of disposing the e-waste which is now the fastest growing solid waste in the world.

5.1 Advantages of EC (E-waste Concrete)

- It has Good Compressive and Flexural Strength.
- It offers good performance to Chemical acid attacks.
- Considerable change in Self Weight of concrete
- Better workability.
- Water absorption in E-waste is lesser than 0.2% due to which, it doesn't affect the hydration of cement.
- Easy manufacturing technique.
- Use of E-waste in concrete, reduces its volume for disposal.
- It may be used in marine conditions.
- May solve the problem of adverse effects of e-waste disposal.
- Provides economical and safe disposal of e-waste.

5.2 Drawbacks

- The quantity of E-waste that can be used as partial replacement for fine aggregate in concrete is limited only up to 10%.
- Segregation occurs if it is used after a certain limit, due to which there could be rapid decrease in the strength value.

5.3 Scope for Future Work

- The current study was carried out for e-waste utilized for just fine aggregates but further study can be done by

using the e-waste as both fine and coarse aggregates in a same mix.
- This study was done in controlled lab conditions, but further study needs to be done for the application of the same in site conditions.
- Evaluation of strength at longer duration can be carried out to find long term effect of this concrete.
- Further study can be taken up on studying the strength and durability parameters of concrete with fine aggregate replacement done by combining the e-waste along with other known waste replacements like LD slag, copper slag, foundry sand, ceramic waste etc.
- Study can be carried out on improving the bond strength between the e-waste particles and other ingredients of concrete so that a large percentage of e-waste can be disposed in this effective way

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