International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 09 Issue: 11 | Nov 2022 www.irjet.net p-ISSN: 2395-0072

A Review on Strength criteria of partial replacement of E-waste and Steel slag as aggregate in concrete

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Abstract - *Concrete is the most widely used construction material. Concrete aggregates are obtained from natural resources through mining and other costly techniques, which increases concrete's cost and environmental impacts. Therefore, it becomes necessary to study alternative materials for natural aggregates. The advantages of using waste products as alternate aggregates in concrete are the reduction in cost and environmental impacts. On the other hand, the properties of concrete can also be improved by using alternate aggregates. This study presents a comprehensive review of the effect of partially replacing natural aggregates of concrete with e-waste and steel slag. This study aims to explore the effect of e-waste and steel slag on the mechanical properties of concrete. As per the literature, steel slag and e-waste have been used as coarse. Available literature has presented the effect on compressive strength, flexural strength, and split tensile strength of the concrete by partially replacing the natural aggregates in the range of 0 to 40%.*

Key Words: **E-Waste, Steel Slag, Concrete, Coarse Aggregate, Mechanical Properties.**

1. INTRODUCTION

Nowadays, the problem of disposal of industrial waste has been increasing day by day. A huge amount of e-waste, steel slag, and Aluminum Tin waste was generated in the previous years. Due to this, the decomposition of this waste becomes a serious problem for the government and society. The researchers work on the strength and economic criteria of the construction. Concrete plays an important role in the construction industry. The design of special concrete taking into account speed of construction, strength, durability, and environmental friendliness with industrial materials including fly ash, blast furnace slag, silica fume, metakaolin, e-waste, steel slag, etc. are the outcome of ongoing research in the field of concrete technology. Concrete is a composite mixture of cement, fine aggregate, coarse aggregate, and water. The partial replacement of coarse aggregate with different industrial and commercial waste materials reduces the cost of construction.

1.1. E-Waste

The rapid growth of technology, up-gradation of technical innovations, and a high rate of obsolescence in the electronics industry have led to one of the fastest-growing waste streams in the world, consisting of end-of-life Electrical and Electronic Equipment (EEE) products known as E-waste. Only 12.5% of e-waste is currently recycled also Storage of waste is a big problem in India [1]. Several tonnes of E-waste need to need year. The traditional landfill or stockpile method is not an environmentally friendly solution and the disposal process is very difficult [2]. A million tonne every year, a million tonnes of electronic waste from obsolete computers and other electronic articles are generated in numerous -types (more than 1000 different) of substances and chemicals creating serious human health and environmental 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 landfills come from electronic waste. Consumer electronics 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 [3]. As per the Central Pollution Control Board (CPCB), list of Dismantlers/Recyclers as per the authorization issued by SPCBs/PCCs under E-Waste (Management) Rules 2022 the state Wise Capacity of E-Waste. The total amount of E-waste is recycled in India 1426685.22 Metric Tons per Annum (MTA). There is some major state, which recycles the maximum amount of E-Waste are shown in Table 1[4]. Fig 1 shows examples of E-waste.

Table 1 List of major states that recycle E-waste (2022)

S.No	State	Capacity (MTA)
1	Uttar Pradesh	494042.7
2	Uttara Khand	153125
3	Haryana	137415.6
4	Tamil Nadu	132049
5	Telangana	113012
	Maharashtra	106280.5

7	Gujarat	84301.92
8	Rajasthan	83604
9	Karnataka	52842
10	Andhra Pradesh	32122.5

Fig. 1 E-waste

According to the definitions in the directive of the Parliament and European Union council on waste electronic and electrical equipment, WEEE can be sub-divided into ten different categories as listed in Table 2 [3] and the environmental impact of the processing of different electronic waste components are shown in Table 3 [5].

Table 2 WEEE categories according to the EU directive on WEEE [3]

S.No	E-waste	S.No	E-waste
1	Large household appliances	2	Electrical and electronic tools
3	Small household appliances	4	Toys, leisure, and sports equipment
5	IT and Telecommunication equipment	6	Medical devices (except the infected devices)
7	Consumer equipment	8	Monitoring and Controlling instruments

Table 3 Different electronic waste components [5]

S. No	E-Waste Component	Process Used	Potential Environmental Hazard
1	Chips and other gold-plated components	Chemical stripping using nitric and hydrochloric acid and burning of chips	Hydrocarbons, heavy metals, and brominated substances are discharged directly into rivers acidifying fish and flora. Tin and lead contamination of surface and groundwater. Air emissions of brominated dioxins, heavy metals, and hydrocarbons
2	Plastics from printers, keyboards, monitors, etc.	Shredding and low temp melting to be reused	Emissions of brominated dioxins, heavy metals, and hydrocarbons
3	Computer wires	Open burning and stripping to remove copper	Hydrocarbon ashes are released into the air, water, and soil

1.2. Steel Slag

Steel slag is the waste product of the steel industry. The successful incorporation of steel slag as an aggregate in construction products requires the consideration of certain issues. Firstly, steel slag is an industrial by-product until recently disposed of in the landfill; the question is whether it is suitable for use in construction [6]. The predominant compounds in steel slag are di-calcium silicate, tri-calcium silicate, di-calcium ferrite, calcium aluminate, calcium-magnesium iron oxides, and some free lime, and magnesia. Steel slag is mildly alkaline, with a solution pH generally in the range of 8 to 10 [7]. Then the technical characteristics of the material are examined because due to its steel slag requires special care due to its physicochemical properties, but it has a maximum value if used for specific applications [6]. The use of Steel slag reduces the need for coarse aggregate/natural rock as a construction material. Slag is useful in making eco-friendly materials. Maximum utilization of by-products, and waste materials for economic and environmental reasons. It leads to rapid development in slag utilization [8]. Fig 3 shows an example of steel slag

1. Steel slag can be used in normal concrete to improve its mechanical, chemical, and physical properties.
2. The use of steel slag by replacing coarse aggregate is the most promising concept.

Fig 3 Steel Slag

Physical properties Steel slag aggregates are angular, roughly cubical pieces having flat or elongated shapes. Some of the positives of steel slag are given in Table 4 [7] and the chemical composition of steel slag is given in Table 5 [9].

Table 4 Physical properties of steel slag [7]

Property	Value
Specific Gravity	3.2-3.6
Approximate Dry rodded Unit Weight, kg/m3 (lb/ft3)	1600-1920 (100 - 120)
Water Absorption	Up to 3%
Los Angeles Abrasion(ASTM C131)%	20-25
Sodium Sulfate Soundness Loss(ASTM C88)%	<12
The angle of internal friction	400°-500°
Hardness (measured by Mohr's scale)	6-7
California Bearing Ratio	Up to 300

Table 5 Chemical Composition of Steel Slag (%) [9]

Compounds	Steel Slag	
	Basic Oxygen Furnace Slag %	**Electric Arc Furnace Slag %**
Calcium Oxide (CaO)	43	35
Silicon Oxide (SiO3)	15	14
Iron Oxide (Fe2O3)	25	29
Magnesium Oxide (MgO)	8	8
Manganese Oxide (MnO)	5	6
Aluminum Oxide (Al2O3)	2	5
Sulfur Oxide (SO3)	0.07	0.1

2. LITERATURE REVIEW

2.1. Literature review of E-Waste

Rajiv Gupta, et. al. (2015), they use several varieties of E-waste Printed Circuit Boards (PCBs) as an aggregate in their research. The PCB e-waste was cut into pieces by using machinery. In this study different combinations of E-waste and recycled aggregate were used to perform compressive strength and flexural strength of M20 grade concrete. The replacement of e-waste varies from (0 to 20 %) and recycled aggregate varies from (95 to 80 %) in the 5 % of interval, the compressive strength test was held at the age of 7,14, and 28 days of curing, and the flexural strength test was held at 7 and 28 days. The result shows that the replacement of e-waste and recycled aggregate shows positive results at 5% and 10 %. The flexural strength test was performed on a beam, 1st beam with steel reinforcement beam and 2nd with E-waste as reinforcement beam. A comparison of both beam shows that the maximums load carried by the steel-reinforced beam and in the 2nd beam dropped 73% of load-bearing capacity increased.

Aditya Gavhane, et. al. (2016), replaced e-waste with coarse as well as fine aggregate 0%, 10%, and 20% by volume. This Electronic was collected from old computer parts, mice, keyboards, CPUs, smartphones, LCDs, etc., and Electrical and electronic waste was reused for daily life needs. The maximum compressive strength gets in 10% replacement of both fine and coarse aggregate; testing was done at 7, 14, and 28 days. Comparable results are found in the compressive strength test while on moving to 20% the compressive strength starts decreasing. Through the study, they concluded that the E-waste concrete has higher workability than the control concrete mix thus, it saves the cost of construction due to less density of e-waste particles, and the concrete prepared was lightweight concrete.

R. Lakshmi, et. al. (2011), the partially replaced e-waste with coarse aggregate (0 % to 24%) in the 2% interval and partially replaced cement with fly ash (10%). The electronic and electrical waste is obtained from large household appliances, small household appliances, Toys, leisure, and sports equipment, IT and telecommunication equipment, Consumer equipment, etc. The replacement of E-waste with coarse aggregate at 4% and 8% shows concrete is maximum compressive strength at 28 days of curing. The compressive strength of concrete at 12% replacement of e-waste and 10% replacement of cement with fly ash at 28 days of curing shows a higher compressive strength than that of conventional concrete.

Ashwini Manjunath B T (2015), in this experimental investigation the utilization of E-waste particles as fine and coarse aggregate in concrete with partial replacement, range of 0%, 10%, 20%, and 30% on the strength criteria of concrete. The compressive, split tensile and flexural strength of concrete was tested after 7, 14, and 28 days of curing. The result shows that the compressive strength of concrete gives a better result at 10% replacement of E-waste as coarse aggregate after 28 days of curing. It shows higher results in split tensile strength and flexural strength of concrete at 10% replacement. Compared with conventional concrete at 28 days the compressive strength, split tensile strength and flexural strength is reduced by 52% when coarse aggregate is partially replaced with E-waste. As a result, this concrete is used as lightweight concrete.

A. C. Umare, et. Al. (2018), in this experimental investigation the utilization of nonmetallic E-waste as a partial replacement of coarse aggregate in a higher, grade of concrete in the proportion of 0%, 5%, 10%, and 15%. The result shows that the replacement of 10% E-waste with conventional aggregate shows higher compressive, split tensile and flexural strength of concrete at the age of 28 days of curing.

2.2. Literature review of Steel Slag

Harsh Gupta, et. al. (2017), this experimental investigation is to evaluate the physical and mechanical properties of steel slag in concrete. After proper investigation of their experiment, they found that the replacement of fine aggregate with steel slag at (0% to 40%) at an interval of 10% shows the enhancement properties of concrete. The compressive strength, tensile strength, and flexural strength of M25 and M30 grades of concrete were tested at the age of 7, 14, 28, and 50 days after curing. The result shows that the replacement of steel slag at 20% and 30% gives a higher compressive strength at 28 days of curing. Tensile strength and flexural strength give higher results at 30% replacement of steel slag in the concrete mix.

M.H. Lunagaria, et. al. (2017), this experimental investigation is to evaluate the physical and mechanical properties of steel slag in concrete. In their investigation, study the partial replacement of steel slag with natural coarse aggregate. The compressive strength and split tensile strength of concrete show positive results at 30% and 40% of replacement of coarse aggregate. The increment in steel slag percentage decreases the compressive strength of concrete. The compressive strength of concrete enhances by up to 5% and the split tensile strength of concrete enhance by up to 10%.

S.P.Palanisamy, et. al. (2015), in this experimental study, they investigate the comparison of conventional aggregate and steel slag on the of basis their chemical and mechanical properties. The enhancement of conventional concrete properties such as compressive strength, split tensile strength, and flexural strength with partial replacement of steel slag powder with cement 0%, 10%, 20%, 30%, 35%, 36%, 37%, and 40%. The result shows at 36 % replacement of cement with steel slag powder gives higher compressive strength, split tensile strength, and flexural strength after 28 days of curing.

Rutwij Shah, et. al. (2021), in this experimental study, they investigate the compressive strength of concrete by replacing the coarse aggregate with steel slag by 0%, 40%, and 60% in the concrete. The result shows that the initial strength gain is the highest in conventional concrete. After 28 days of curing the highest strength gain in concrete with a 40% replacement increase in strength by 110%.

M. Gopinath, et. al. (2019), in this experimental study, they investigate the mechanical properties of the concrete. The partial replacement coarse aggregate with steel slag different proportion are 0%, 10%, 20%, 30%, 40%, and 50%. The cube and cylinder were cast for testing of mechanical properties of concrete. The replacement of coarse aggregate by up to 30% enhances the strength of concrete. The comparison of the above literature review is given in Table 6.

Table 6 Literature review and their comparison

S. No	Author	% of Range of material	Max. result at %	Material used	Strength Tests	Result and Remark
1	Rajiv Gupta. 2015	0% - 20%	5 %	E-waste and recycled aggregate	Compressive Flexural	Compressive strength decreases up to 5% Flexural strength enhance up to 4.5%
2	Aditya Gavhane, 2016	0% - 30%	10 %	E-waste	Compressive	Compressive strength decrease up to 5.5%
3	R. Lakshmi 2011	0% – 24%	12 %	E-waste and fly ash (10%)	Compressive	Compressive strength enhance up to 3.5%
4	Ashwini Manjunath B T 2015	0% - 30%	10%	E-waste	Compressive Flexural Tensile	Compressive strength decrease up to 6.5% Flexural strength decrease up to 2% Tensile strength enhance up to 1.15%
5	A.C. Umare et. al. 2018	0% - 15%	10 %	E-waste	Compressive Flexural Tensile	Compressive strength enhance up to 45.3% Flexural strength decrease up to 8.87% Tensile strength enhance up to 43.9%
6	Harsh Gupta 2017	0% - 40%	30 %	Steel slag	Compressive Tensile	Compressive strength enhance up to

						15.5% Tensile strength enhance up to 15.6%
7	M.H.Lunagaria et. al. 2017	0% - 40%	30% and 40%	Steel slag	Compressive Tensile	Compressive strength enhance up to 5% Tensile strength enhance up to 10%
8	S.P.Palanisamy 2015	0% - 40%	36 %	Steel slag powder	Compressive Flexural Tensile	Compressive strength enhance up to 13.45 % Flexural strength enhance up to 28.54 % Tensile strength enhance up to 47.64 %
9	Rutwij Shah 2021	0%, 40% and 60%	40 %	Steel slag	Compressive	Compressive strength enhance up to 10.11 %
10	M. Gopinath 2019	0% - 50%	30 %	Steel slag	Compressive	Compressive strength enhance up to 14.41 %

3. Conclusions

The literature shows that the replacement of E-waste and steel slag in concrete use as a modern construction material enhances the mechanical properties of concrete and reduces the cost of construction.

1 The use of E-waste and steel slag in concrete reduces environmental pollution and reduce the disposal problem of waste.

2 The replacement of both coarse and fine aggregate through E-waste and steel slag at a certain percentage, which leads to an eco-friendly concrete.

3 As compared to the conventional aggregate weight of E-waste is less so it is used to prepare lightweight concrete.

4 The steel slag has some similar physical and mechanical properties as conventional aggregate, due to which the researcher mainly focuses on steel slag used as a coarse aggregate in concrete.

5 It is economical to use the steel slag in the construction industry, as the cost of steel slag is 50% less than the conventional aggregate.

6 The partial replacement of steel slag up to 30% increases the compressive strength of concrete; it is used as both fine and coarse aggregate in concrete.

7 The use of E-waste in concrete increase the workability, which reduces the cost of admixture.

8 The partial replacement of E-waste with a 10% will increase the split tensile strength and flexural strength of concrete.

Based on above Table 6 literature comparison the strength criteria of concrete enhance at different percentage of partial replacement of E-waste and Steel slag in concrete. The compressive strength of concrete enhances up to range of 3% to 45%, split tensile strength of concrete enhance up to 1% to 48% and flexural strength of concrete enhance up to range of 2% to 33%. The overall strength criteria of concrete enhance up to the range of 1% to 45%.

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