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STUDY ON EFFECT OF E-WASTE AND STEEL SLAG ON STRENGTH OF SELF-HEALING CONCRETE

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Abstract
Concrete is the substance that is used in building the most. Natural aggregate makes up the majority of a concrete blend, making up more than 70% of its volume. The rise in aggregate demand brought on by the building industry's increased demand for concrete has an impact on the environmental problems associated with the quarrying of natural aggregates. On the other side, industrial waste pollutes the environment. Therefore, the best method to reduce the use of natural resources and the environmental pollution load is to use byproducts from other industries as aggregates in concrete. In today's digital world, both population growth and the use of electronic products are on the increase. Large quantities of electronic waste and products are produced in both established and developing countries. Around 20% of crude steel is produced on a bulk basis by producing steel slag. Steel factories use cold slag for both internal consumption and exterior sale. The slag is crushed and used as road metal and train ballast after cooling. The study's objectives are to lower building costs and improve concrete's mechanical properties. In the current research, e-waste and steel slag were substituted for coarse aggregate to varying degrees (0, 10, 20, and 30%). The paved path. Although the structure has a 30-year lifespan, the deterioration often begins just 10 or even 1 year after creation. After a certain number of years, the cement and concrete road develops tiny cracks, either structural cracks or superficial cracks. The experts worked on self-healing concrete to address this. The inclusion of bacteria and calcium sources improves the concrete's strength. Bacillus subtilis bacteria and calcium lactate as a calcium source were introduced at 2% and 5%, respectively, in the present. The research examines self-healing micro-cracks in the road and the economics of building cement-concrete roads.

Keywords:
Steel slag, *B. subtilis,* calcium carbonate, e-waste, self-heling, mechanical properties

I. Introduction

The preferred building substance is concrete. It is well known that despite its building adaptability, it has several limitations. Concrete is a brittle, readily cracked material with little ductility. Based on ongoing research conducted worldwide, different modifications have occasionally been made to address the shortcomings of cement concrete. The result of ongoing research in the area of concrete technology is the creation of special concrete that incorporates industrial materials like fly ash, blast furnace slag, silica fume, metakaolin, steel slag, and E-waste while also taking into account speed of construction, strength, durability, and environmental friendliness. However, the demand for natural or river sand has increased due to the growing use of concrete in virtually all kinds of construction projects. Sand supplies are being depleted as a result of excessive riverbed mining to meet building industry demand. Rivers have been compelled to alter their courses due to a lack of sand supply, which also contributes to environmental issues. Sand is becoming more and more costly and rare due to governmental restrictions on its extraction. The sustainable construction sector has increased its use of leftovers from other sectors as a result of pressure to stop overusing natural quarries.
Due to the increased interest in recycling waste materials, various studies are being conducted on the use of lots of different materials, such as coal ash, blast furnace slag, fiberglass waste, e-waste plastics,

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rubber waste, steel slag, sintered sludge pellets, and others, as aggregate substitutes. Cement mortar and concrete usage might increase considerably if waste resources are used as an aggregate. By reusing waste materials, this strategy could reduce environmental issues caused by garbage disposal and aggregate mining while addressing worries about a shortage of aggregate at different building sites. Utilizing leftover materials lowers the cost of producing concrete. Since the aggregate properties greatly affect how concrete acts, they are very important. Natural stones can be replaced with alternative materials.

1.1 E-Waste

All electrical and electronic equipment (EEE) and any parts that have been discarded as refuse by their owner without any thought of being reused collectively are referred to as "e-waste." The broad category of goods known as "e-waste" includes nearly all household, commercial, and educational items with circuitry or electrical components with a power or battery source. Over 347 Mt of unrecycled e-waste will be present on Earth in 2022, according to the worldwide statistical report. The report also reveals that the US, China, and India are the countries that generate the most e-waste globally. The global Transboundary E-waste Flow Monitor 2022 report, divided E-waste majorly into 6 Categories shown in Table 1.1.

Table 1.1. Global E-waste Flow Monitor 2022

S. No	Categories	Equipment
1	Temperature exchange equipment	More Commonly referred to as cooling freezing equipment. Typical equipment includes refrigerators, freezers, air conditioners, and heat pumps.
2	Screens, monitors, and equipment containing screens	Typical equipment includes televisions, monitors, laptops, and tablets.
3	Lamps	Typical equipment includes fluorescent lamps and LED lamps
4	Large equipment	Typical equipment includes washing machines, large printing devices, and photovoltaic panels.
5	Small equipment	Typical equipment includes vacuum cleaners, microwaves, ventilation equipment, toasters, electric kettles, electric shavers, scales, electric toys, small medical devices, and control instruments.
6	Small IT and telecommunication equipment	Typical equipment includes mobile phones, personal computers, printers, game consoles, calculators, and other small IT equipment.

As e-waste production rises, the environment is put in danger while companies have the opportunity to extract the low-cost, valuable, and necessary raw materials that are contained therein. The pie chart of E-waste development and E-waste use is shown in Fig. 1.1(a) and Fig. 1.1(b).

Fig. 1.1 (a) Growth of E-waste

Fig. 1.1 (b) E-waste

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According to the Central Pollution Control Board's (CPCB) 2021 Annual Report, the amount of recycled and dismantled electronic refuse in India there are major 10 states, that dismantle the maximum e-waste is shown in Fig. 1.2.

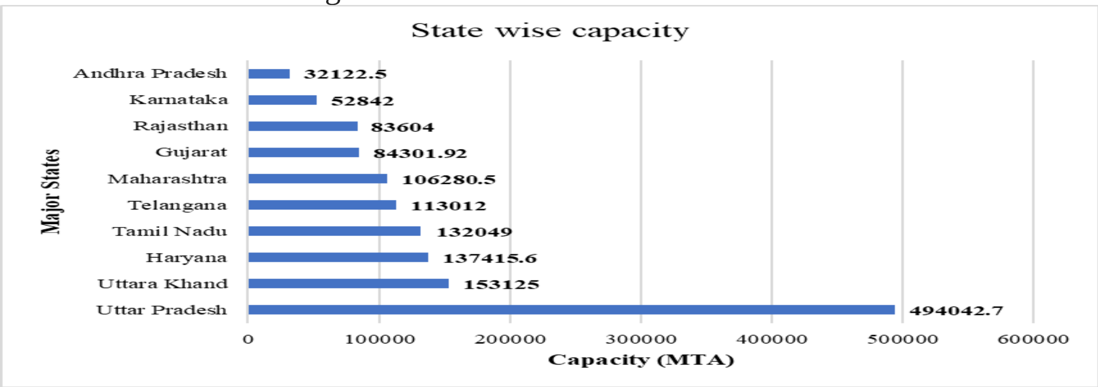

Fig. 1.2 Maximum state-wise capacity

1.2 Steel slag

Steel slag, also known as BOF slag, is another waste of the iron and steel sector. It can produce as much as 10% of the raw materials needed to create cement clinker. Steel slag can replace powdered blast furnace slag in Portland slag cement by up to 10%. In a steel melting factory, steel slag is produced during the making of steel. Steel is made by oxidizing excess silicon and carbon from iron with limestone and charcoal. Steel slag is a useful barrier substance when heavy metals tend to leach into the atmosphere from waste sites. It is primarily used as a landfill and a supplier of concrete material.

The following categories are used to categorize the primary slag types produced by the steelmaking industries:

1. Basic oxygen furnace (BOF) slag
2. Electric arc furnace (EAF) slag
3. Ladle slag (open hearth process)

According to the Indian Mineral Book 2021, India's steel industry produces 12 million metric tonnes of steel slag and 24 million metric tonnes of blast furnace slag each year. The annual output of BOF slag is anticipated to range between 15 and 20 million metric tonnes and that of BF slag to range between 45 and 50 million tonnes by 2030. Table 1.2 shows the plant-wise capacity of iron and steel slag in India and Fig. 1.3 shows Steel slag use in study.

Table 1.2 Plant-Wise Capacity of Iron and Steel Slag in India

S. No.	Plant	Capacity (tonne per year)
1	Bhilai Steel Plant	2675
2	Bokaro Steel Plant	7884
3	Rourkela Steel Plant	1570
4	Durgapur Steel Plant	566
5	IISCO Steel Plant	400 kg/THM
6	Visvesvaraya Iron & Steel Plant	400 kg/THM
7	Rashtriya Ispat Nigam Ltd	1440
8	IDCOL Kalinga Iron Work Ltd	53
9	Tata Steel Ltd	2100
10	Visa Steel Ltd	175

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Fig. 1.3 Steel slag

1.3 Self-Healing Concrete

Concrete that can repair itself after being damaged or cracked is known as self-healing concrete. This form of concrete contains additives like fibers, microcapsules, or bacteria that, when combined with water or other chemicals, create a healing agent that can heal cracks. The lifespan of concrete structures could be greatly increased by self-healing concrete, which could also lower maintenance costs and increase safety. It is still a fairly new technology, so more investigation is required to ascertain its long-term viability and efficiency in practical uses.

1.4 Bacteria

Bacillus family that grows in alkaline habitats, such as concrete, include Bacillus pasteurii, Bacillus sphaericus, Escherichia coli, Bacillus subtilis, Bacillus cohnii, Bacillus halodurans, and Bacillus pseudofirmus. Bacillus subtilis, a rod-shaped bacterium, was used in this research. B. subtilis has thick enough outer cell membranes to maintain life even in unfavorable circumstances. The B. subtilis strain isolated from soil exhibits exceptionally high urease activity, good physical stability, and continuous precipitation of solid, insoluble calcium carbonate crystals (CaCo3). [29]. Bacillus subtilis was selected because it is capable of withstanding the high stresses caused by its mass and can survive environments with high pH levels, like concrete.

Equations (1) to (3) show that Microbial-induced carbonate precipitation depicts the mechanism by which the metabolites of urease-producing bacteria react with substances in the surrounding atmosphere to form calcium carbonate crystals (CaCO3). Fig. 1.4 show Bacteria use in study.

$$CaO + H_2O \rightarrow Ca(OH)_2 \quad \text{(Eq.1)}$$

$$CO + Ca(OH)_2 \rightarrow CaCO_3 + H_2O \quad \text{(Eq.2)}$$

$$Ca(C_3H_5O_2)_2 + 7O_2 \rightarrow CaCO_3 + 5CO_2 + 5H_2O \quad \text{(Eq.3)}$$

Fig. 1.4 Bacteria

II. Literature

2.1 Literature of E-waste as coarse aggregate partial replacement

2.1.1 Effect of partial replacement of aggregate on compressive strength of concrete

V.M. Divyadharshini, et al. (2022), tests were done after 7, 14, and 28 days, and PCB E-waste and GGBS were substituted at various percentages of 10%, 15%, and 20%. The 15% replacement of coarse aggregate with e-waste and GGBS produces a better result than the other replacement percentages. The findings show that as E-waste and GGBS percentages increase, concrete loses compressive strength.

Zeeshan Ullah, et al. (2021), used varied amounts of E-plastic aggregate in their investigation, including 0%, 10%, 15%, and 20%. The workability of E-waste concrete dramatically improved as the percentage of E-waste grew. The results show that the compressive strength of E-waste concrete has decreased from 6% to 17%. As a result, more e-waste is utilized in the production of lightweight concrete because it lowers the weight of the finished product.

Arivalagan S, (2020), E-waste, also known as computer accessories, wires, switches, chips, etc., was used to make concrete with a water-cement ratio of 0.45 and a partial replacement of aggregate with E-waste at varying ratios of 10%, 20%, and 30%. The test was conducted after 7, 14, and 28 days. As a result, the compressive strength of E-waste concrete increased by up to 18% for a 20% partial substitution. The compressive strength value drops once 20% of the concrete made of E-waste is changed.

Ashwini Manjunath B T, (2016), the incorporation of e-waste-derived fine and coarse aggregate in concrete at varying ratios of 0%, 10%, 20%, and 30%. The 28-day result shows that 10% E-waste replaced with aggregate produces satisfactory results for the compressive strength of concrete when compared to conventional concrete. The compressive strength of concrete rapidly decreases as e-waste percentages increase.

Aditya Gavhane, et al. (2016), E-waste was used in their experiment as a variable percentage of coarse aggregate (0%, 10%, and 20%) and fine aggregate (0%, 10%). E-waste replacement of coarse aggregate and fine aggregate showed improved compressive strength at 10% partial replacement.

2.1.2 Effect of partial replacement of aggregate on flexural strength and split tensile strength of concrete

V.M. Divyadharshini, et al. (2022), Concrete is made with PCB E-waste and GGBS instead of some of the coarse material. Testing took place after 7, 14, and 28 days. Concrete's flexural strength and split tensile strength are increased by gradually substituting 10% and 15% of E-waste and GGBS, respectively. The results show that when the percentages of E-waste and GGBS increase, concrete is flexural, and split tensile strengths drop.

Zeeshan Ullah, et al. (2021), the various replacement rates of coarse aggregate with E-waste aggregate, which are 0%, 10%, 15%, and 20%. Between 23% and 32% of the concrete's split tensile strength and flexural strength are lost, respectively. This is due to the cement's weak connection with the e-waste aggregate.

Arivalagan S, et al. (2020), E-waste is being replaced in concrete to varying degrees (10%, 20%, and 30%). The tests' findings show that a 20% increase in flexural and split tensile strengths equates to a 20% replacement of E-waste. Due to the poor link between E-waste plastic and cement, as the percentage of E-waste exceeds 20%, the strength of E-waste concrete drops.

Ashwini Manjunath B T, (2016), the partial replacement of e-waste with coarse aggregate in concrete at varying percentages of 0%, 10%, 20%, and 30%. The outcome demonstrates that at 10% replacement, concrete's split tensile strength increases. Beyond 20%, the tensile strength of the partial replacement of E-waste split falls and the flexural strength increases up to a partial replacement between 10% and 20%. Flexural strength declines after 30% replacement.

2.2 Literature of Steel slag as coarse aggregate partial replacement

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2.2.1 Effect of partial replacement of aggregate on compressive strength of concrete

Rutwij Shah, et al. (2021), in there, investigated the coarse aggregate in M30-grade concrete and substituted steel slag at 0%, 40%, and 60% at different rates. The test was run after 7, 14, and 28 days of cure. Consequently, it proves that concrete's compressive strength decreases during the first seven days in a manner identical to that of regular concrete. After 28 days of curing, the compressive strength of 40% replacement coarse aggregate yields a higher compression result than conventional concrete.

Abhijit Warudkar, et al. (2020), in their experiment, replaced coarse aggregate with steel slag in M30-grade concrete at varying rates of 0%, 25%, 50%, 75%, and 100%. Consequently, it indicates that after 75% replacement of coarse aggregate after 28 days, the concrete's better compressive strength is visible and has increased by 45.32 N/mm2.

Harsh Gupta, et al. (2017), in their experimental study, several ratios of 0%, 10%, 20%, 30%, and 40% of steel slag substitution for fine aggregate in concrete grades M-25 and M-30 were examined. The test was carried out within 7, 14, 28, and 50 days after the water had finished hardening. The outcome demonstrates that M 25 and M 30 grades of concrete increased compressive strength with 30% replacement compared favorably with standard concrete. After 7 days of curing, compressive strength increases by around 32%, 20% after 14 days, and 18% after 28 days.

S.P. Palanisamy, et al. (2015), in their experimental study, replaced steel slag as a fine aggregate in M 55-grade concrete and was examined at various ratios ranging from 0% to 40%. After curing for 7, 14, and 28 days, the test was conducted. The test results at various percentages demonstrate that concrete with a 36% replacement of coarse aggregate has the maximum compressive strength. Compressive strength improves by 26.62% after 7 days of cure, 25.3% after 14 days, and 11.85% after 28 days.

V. Subathra Devi, et al. (2014), In their inquiry, steel slag replaced fine and coarse aggregate at rates of 40% and 30%, respectively, and tests were run after 7 and 28 days of curing. The outcome indicates that replacing the coarse aggregate by 30% raised the concrete's compressive strength by 4.6%. Similarly, when 40% steel slag was used in place of fine aggregate, concrete's strength increased by 27.04%.

2.2.2 Effect of partial replacement of aggregate on flexural strength and split tensile strength of concrete

Abhijit Warudkar, et al. (2020), in their experimental study, the coarse aggregate was used in place of steel slag in the M30 grade of concrete. The results indicate that steel slag replaced coarse aggregate at a rate of 75%, yielding higher results for flexural strength (5.16), split tensile strength, and other properties (3.96).

Harsh Gupta, et al. (2017), in their study of the split tensile and flexural strength of concrete, showed that the strength was enhanced by replacing up to 30% of the fine aggregate in conventional concrete with steel slag. For the M-25 grade of concrete, the increase in split tensile strength and flexural strength is approximately 16.7% and 36.7%, respectively, for 28 days of curing. For the M-30 grade of concrete, the increase in split tensile strength and flexural strength is approximately 15.6% and 24.7% after 28 days of curing.

S.P. Palanisamy, et al. (2015), in their experimental investigation, that fine aggregate was replaced with steel slag range of 0% to 40%. The result shows that the split tensile strength and flexural strength increase at 36% of the replacement of steel slag with fine aggregate. The increment in split tensile strength and flexural strength is approximately 22.2 % and 32.27% after 28 days of curing.

V. Subathra Devi, et al. (2014), In their investigation, after 28 days of curing, the flexural strength improved by 28.1 for 30% replacement of coarse aggregate and 74.2% for 40% replacement of fine aggregate when compared to conventional concrete.

2.3 Literature of Self-Healing Bacterial Concrete

2.3.1 Effect of partial replacement of aggregate on compressive strength of concrete

N Iswarya, et al. (2020), in their experimental study, the replacement of aluminum powder with cement weight varied between 25%, 35%, 45%, and 55%; meanwhile, the addition of bacillus subtilis bacteria varied between 15 mL, 25 mL, 35 mL, and 45 mL by cement weight in M-20 grade of concrete. The test was conducted at the age of 7 and 28 days of curing. The outcome reveals that the cement with the maximum compressive strength, 26.4 N/mm2, was that with 15 ml of bacteria and 25% of aluminum powder by weight.

Mohammed Safiuddin, et al. (2021), in their experimental work, combined calcium lactate (a bacterial food source) at a constant 5% by weight of cement at all mix changes while using Bacillus subtilis and Escherichia coli bacteria at varying percentages of 2%, 3%, 4%, and 6% by weight of cement. According to the results, cracks were self-healed in 48 hours for Bacillus subtilis 2%, 32 hours for Bacillus subtilis 3%, and 72 hours for Bacillus subtilis 4%. For 6% Bacillus subtilis, all percentages of Escherichia coli, or mixed bacteria, there was no sign of obvious healing. In comparison to conventional concrete, the results show that compressive strength was observed at a dosage of 3% addition of Bacillus subtilis and Escherichia coli bacteria.

Rohini. I, et al. (2020), investigated the effects of substituting varying amounts of E-waste for coarse aggregate in M-30 grade concrete, including 0%, 5%, 10%, 15%, and 20%. When added to concrete in varying amounts of 0%, 1%, and 2%, Bacillus subtilis improves its mechanical qualities. When E-waste was replaced with 15% e-waste and 2% bacteria than regular concrete, the outcome showed that the compressive strength of the concrete increased. The compressive strength of concrete increased up to 5.6% as compared with normal concrete.

P. Pachaivannan, et. the researcher in their examination has studied al. (2020), the addition of cultured Bacillus subtilis bacterial spore from 7-day-old and 14-day-old bacteria. The result shows that 14-day-old bacteria raised the compressive strength of concrete, increasing it by up to 16.3%.

2.3.2 Effect of partial replacement of aggregate on flexural strength and split tensile strength of concrete

Mohammed Safiuddin, et al. (2021), in their experimental work, researchers found that adding 3% of Escherichia coli and Bacillus subtilis to concrete increased the split tensile strength of the material. When Bacillus subtilis and Escherichia coli were added to concrete, the split tensile strength of the concrete rose by up to 27.3% and 45.9%, respectively.

C. Manvith Kumar Reddy, et al. (2020), researchers use laboratory-cultured Bacillus subtilis bacteria in their experiments because they can assist concrete in self-healing microcracks. 10^7 cells/mL of bacteria were employed in the investigation. The experiment was carried out at the age of 7 and 28 days after the beam sample had been cured. In comparison to regular concrete, the outcome demonstrates that the flexural strength of concrete rose by 41% and 45% in 7 and 28 days, respectively.

Rohini. I, et al. (2020), in their experimental study, the researchers observed that adding 2% Bacillus subtilis bacteria to concrete and replacing 15% of the coarse aggregate with E-waste increased the concrete's flexural and split tensile strengths compared to normal concrete.

P. Pachaivannan, et. al. (2020), discovered that the addition of 14-day-old bacteria increased concrete's split tensile strength and flexural strength. The outcome demonstrates that adding Bacillus subtilis increases the split tensile strength and flexural strength of concrete by 17.8% and 14.24%, respectively.

2.4 Summary

In all the above-mentioned literature, the researcher uses E-waste and steel slag as a partial replacement for coarse aggregate, and various works of literature illustrate self-healing bacterial concrete. After the study of various research papers, it was found that E-waste plastic can be used up to 10%–20%, and steel slag can be used up to 10%–30% as a replacement for coarse aggregate. Bacteria should be added as an additive up to 2% and 2% to 5% of the calcium source by the weight of cement in concrete.

III. Methodology

The material was properly handled and supervised during preparation in the lab. A mixed design process was used to determine the calculated dose of the constituent. The constituent was blended in the mixer, followed by the addition of half of the water to the dry mixture, half of the remaining water, and a superplasticizer. The material was combined in the mixer, water was added of half of the water was to the dry mixture, and the final addition of the remaining water and a superplasticizer. Concrete that had been properly mixed was poured into moulds that had been well oiled, and the vibrating table compacted the material. After 24 hours of air-drying, the sample was removed from the moulds and immersed in water to cure it. A total of 120 samples in total were cast for the study.

The amount of e-waste, steel slag, microorganisms, and calcium lactate in the cube varies. The amounts of utilized steel slag and e-waste are 0%, 10%, 20%, and 30%, respectively. Utilizing several trial sample methods with fixed bacteria percentages based on the self-healing theory. Calcium lactate percentages range between 2% and 5%. The beam contains a varying percentage of E-waste and Steel slag of 0% 10%, 20%, and 30%. In addition, the cylinder contains E-waste and Steel slag at a percentage of 0% and 10%. Also, cast the cube of combined replacement of the coarse aggregate with 10% E-waste and 10% Steel slag.

The physical properties of the material are also tested in the laboratory to find out the properties of materials like cement, sand, aggregate, steel slag, and e-waste. The compressive strength, flexural strength, and split tensile strength tests were conducted on different types of mixes.

3.1 Trial Sampling of Bacterial Concrete

Based on different trial combinations, the bacterial and calcium lactate ratios are chosen. To evaluate the self-healing requirements and setting time, a 70.6×70.6×70.6 mm cube was cast.

In the study, the replacement of cement with marble powder at various percentages. The use of marble powder as a calcium source for the bacteria, but the result shows that the setting time of mortar paste is increased and some of the samples are dissolved in water. So the results show that the replacement marble powder is not suitable for the calcium source of Bacteria.

The addition of 2% Bacteria and calcium lactate at varying percentages of 1.5%, 2%, 2.5%, 3%, and 5% in cement mortar paste. In the study bacteria percent is fixed based on literature and the addition of food source (calcium lactate) is 2% and 5% based on trial process.

IV. Tests on Concrete

Three strength tests are conducted on concrete. Also performed a workability test on fresh concrete

1. Workability test (slump cone test)
2. Compressive strength test
3. Flexural strength test
4. Split tensile strength

4.1 Workability Test

Workability is how easily the fresh concrete can be mixed, placed, and finished. The workability of concrete is determined through the slump cone test. The various slump values are shown in Table 1.3 for all design mixes and Fig. 1.5 for the Values of the slump test.

Table 1.3 Value of slump for different concrete mixes

S. No.	Concrete Mix	Steel slag (%)	E-waste (%)	Bacteria (%)	Calcium lactate (%)	Slump (mm)
1	C	0	0	0	0	6
2	R1	10	0	0	0	5
3	R2	20	0	0	0	7
4	R3	30	0	0	0	9
5	G1	0	10	0	0	10
6	G2	0	20	0	0	12
7	G3	0	30	0	0	20
8	D	0	0	2	0	10
9	E1	0	0	2	5	23
10	E2	0	10	2	5	26
11	E3	10	0	2	5	24
12	F1	0	0	2	2	21
13	F2	0	10	2	2	24
14	F3	10	0	2	2	22

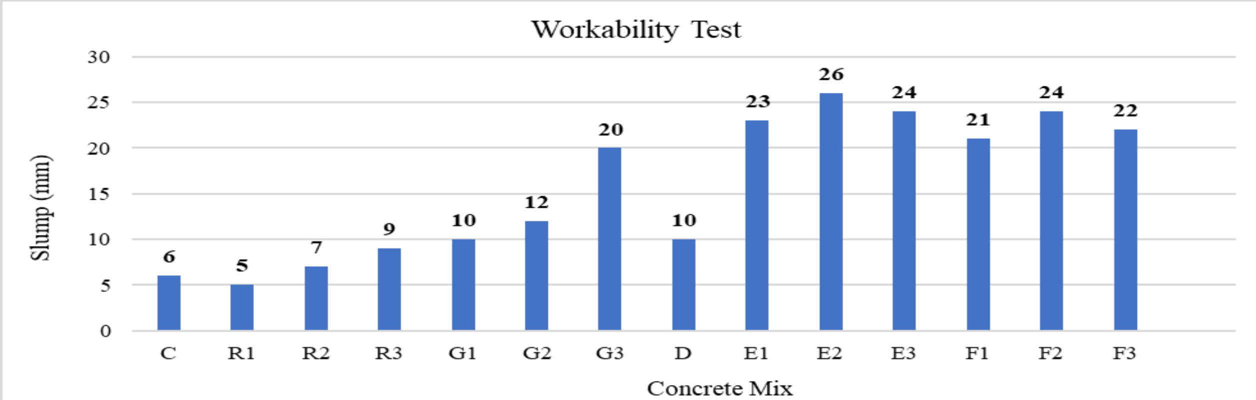

Fig. 1.5 Values of the slump test.

As a result, concrete's typical slump value is reduced. concrete mixtures containing varying proportions of e-waste and steel slag in place of the coarse aggregate The results show that when the percentages of e-waste and steel slag rise, the slump value rises as well. The 10% Steel slag, 2% Bacillus subtilis, and 5% calcium lactate mixture exhibit a greater slump value as compared to normal concrete. According to bacterial concrete, the mixture of 10% E-waste, 2% Bacillus subtilis, and 5% calcium lactate demonstrates a higher slump value. Additionally, when compared to standard concrete, the mixture of 10% E-waste, 2% Bacillus subtilis, and 2% calcium lactate performs well.

4.2 Compressive strength test result of partially replaced with E-waste and steel slag at various percentages with aggregate

The compressive strength test result by replacing coarse aggregate with steel slag and E-waste at various percentages is shown in Table 1.4 and Fig. 1.6

Table 1.4 The compressive strength test results

S. No.	Concrete Mix	Steel slag (%)	E-waste (%)	Compressive Strength(MPa)	
				7 days	28 days
1	C	-	-	38.95	45.84
2	R1	10	-	31.05	42.5
3	R2	20	-	33.6	33.4
4	R3	30	-	27.55	31.8
5	G1	-	10	24.62	34.68
6	G2	-	20	8.39	9.19
7	G3	-	30	3.74	4.24

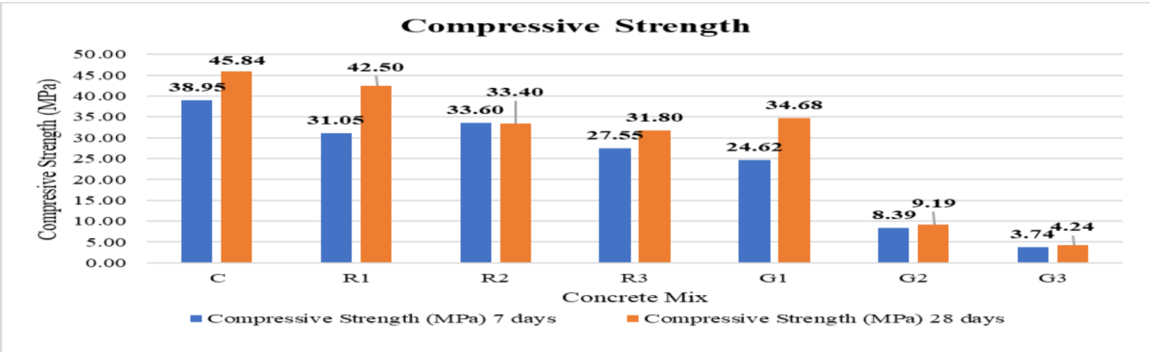

Fig. 1.6 (7 days & 28 days) Compressive strength at the varying percentage of Steel slag and E-waste

The results show that the compressive strength of concrete decreases when the percentage of steel slag and E-waste increases. The Compressive strength 7 days and 28 days result shows that the optimum percentage of steel slag and E-waste replacement is 10%, which gives a satisfactory result as compared with conventional concrete.

4.3 Flexural strength test result of partially replaced E-waste and steel slag at various percentages with aggregate

The flexural strength test result by replacing coarse aggregate with steel slag and E-waste at various percentages is shown in Table 1.5 and Fig. 1.7

Table 1.4 Flexural strength of concrete with coarse aggregate replacement by E-waste

S. No.	Concrete Mix	Steel slag (%)	E-waste (%)	Flexural strength (MPa) 28 Days
1	C	-	-	5.32
2	R1	10	-	4.85
3	R2	20	-	4.24
4	R3	30	-	3.68
5	G1	-	10	4.58

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6	G2	-	20	1.14
7	G3	-	30	1.02

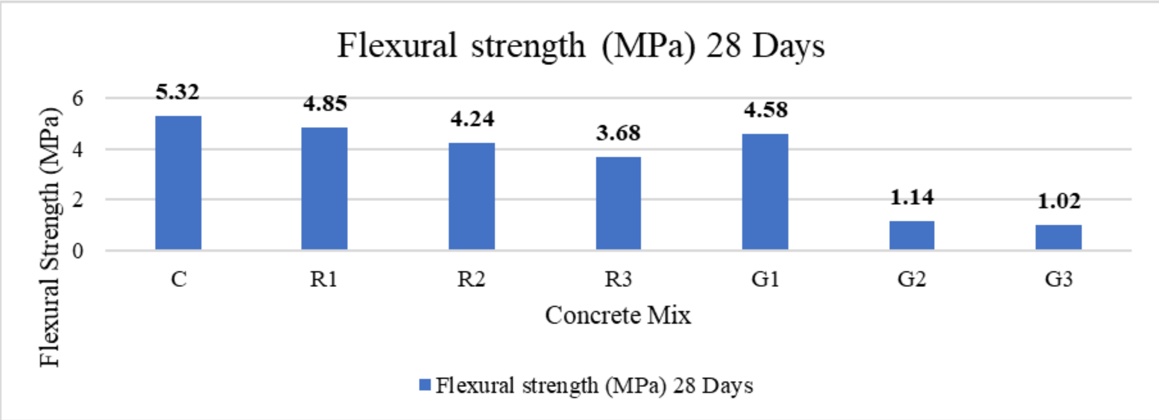

Fig. 1.7 (28 days) Flexural strength at the varying pin percentage of Steel slag and E-waste

The result shows that the flexural strength of concrete decreases with an increase in the percentage of Steel slag and E-waste in concrete. The flexural strength 28 days result shows the higher flexural strength of concrete at 10% replacement of Steel slag and E-waste as compared with conventional concrete.

4.4 Split tensile strength test result of partially replaced E-waste and steel slag at various percentages with aggregate

The flexural strength test result by replacing coarse aggregate with steel slag and E-waste at various percentages is shown in Table 1.6 and Fig. 1.8

Table 1.6 Split tensile strength of concrete with coarse aggregate replacement by Steel slag and E-waste

S. No.	Mix	Steel slag (%)	E-waste (%)	Split tensile strength (MPa) 28 days
1	C	-	-	4.17
2	R1	10	-	4.74
3	G1	-	10	4.64

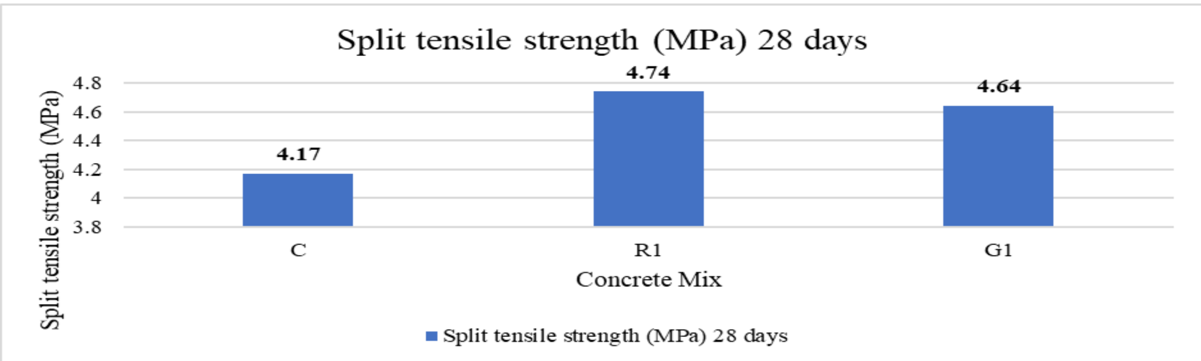

Fig. 1.8 (28 days) Split tensile strength at the 10% percentage of Steel slag and E-waste

The result shows that the Split tensile strength of concrete is 28 days resulting shows a higher Split tensile strength of concrete at 10% replacement of steel slag and E-waste as compared with conventional concrete.

4.5 Compressive strength test result of Bacterial concrete

The 7 days and 28 days of the compressive strength test results by the addition of 2% for Bacillus Subtilis, 2% and 5% for Calcium lactate, and optimum 10% for Steel slag and E-waste are shown in Table 1.7 and Fig. 1.9.

Table 1.7 Compressive strength test results of Bacterial concrete

S. No.	Concrete Mix	Bacillus subtilis (%)	Calcium lactate (%)	E-waste (%)	Steel slag (%)	Compressive strength (MPa)	
						7 days	28 days
1	C	-	-	-	-	38.95	45.84
2	D	2	-	-	-	29.57	40.95
3	E1	2	5	-	-	6.85	32.5
4	F1	2	2	-	-	43	56.4
5	E2	2	5	10	-	9.76	32.2
6	F2	2	2	10	-	31.6	50.3
7	E3	2	5	-	10	8.35	38.6
8	F3	2	2	-	10	44.8	55.6

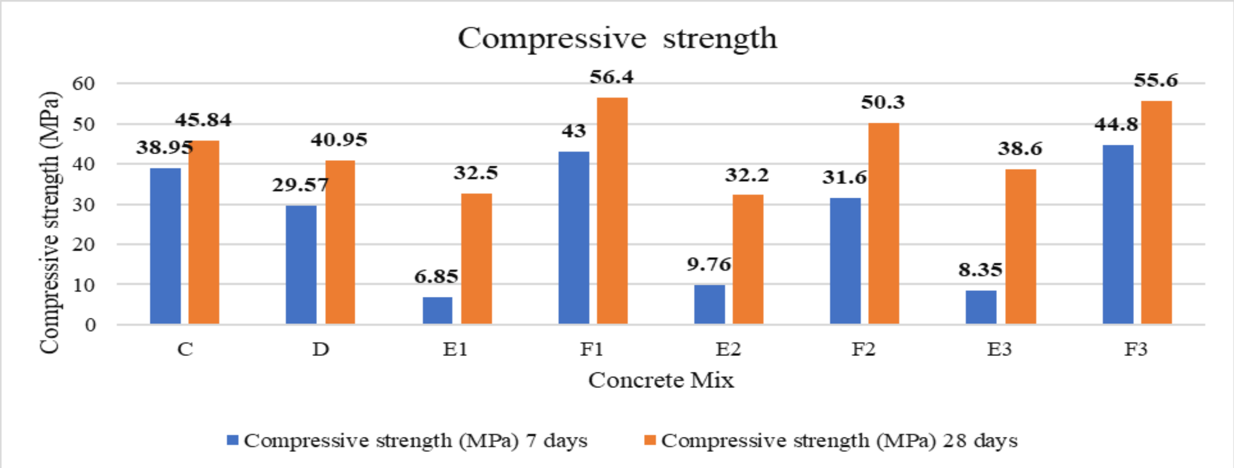

Fig. 1.9 (7 days and 28 days) Compressive strength of Bacterial Concrete

The result shows that the optimum dosages of 10 % Steel slag and E-waste, 2% Bacteria, and 2% Calcium lactate give higher compressive strength in 28 days.

4.6 Discussion on Results

The results showed that as we raise the proportion of steel slag up to 10%, the compressive strength, flexural strength, and split tensile strength of concrete increase. The mechanical characteristics of concrete decrease as the percentage of steel slag increases. The 28-day flexural strength of concrete improves by 1.1%, and the 28-day split tensile strength of concrete increases by 12% with a 10% replacement of steel slag. It produces better results than traditional concrete. Adding 2% bacteria, 2% calcium lactate, and 10% increase steel slag concrete to conventional concrete, the compressive strength of the concrete. In comparison to 10% steel slag replacing the concrete, the bacterial concrete's compressive strength increased by 30.6% after 7 days and by 23.56% after 28 days.

Compressive, flexural, and split tensile concrete strength all decrease as e-waste proportion increases. Both the compressive strength which may decrease by up to 36% in just 7 days and by 24% in just 28 days and the flexural strength which drops by 2.4% over the course of 28 days decline in comparison to ordinary concrete. Concrete's split tensile strength has risen by 10.1% in comparison to normal concrete. When 2% bacteria and 2% calcium lactate are added to conventional concrete and 10% is partially replaced by E-waste concrete, the compressive strength of the concrete increases. When 10% E-waste is used to replace the concrete, the bacterial concrete has compressive strengths that are up to 22.08% higher after 7 days and 31.05% higher after 28 days.

In comparison to standard concrete, the compressive strength of concrete improved with the addition of 2% bacteria and 2% calcium lactate. Compressive strength improves after 7 days by 9% and after 28 days by 18.8%.

V. Conclusions

Conclusions from this experimental investigation include the following:

1 Maximum strength was seen at a 10% substitution of steel slag and e-waste for coarse aggregate. The strength of concrete dropped as the percentage of steel slag and e-waste increased.

2 The 10% replacement of coarse aggregate with steel slag yields good results in compressive strength, and the concrete's flexural and split tensile strengths increased by 1.1% and 12%, respectively.

3 The split tensile strength of concrete increases by up to 12% when E-waste is replaced with coarse aggregate by 10%, compared to conventional concrete. Concrete loses some of its flexural and compressive strength.

4 On the other hand, the addition of 2% calcium lactate and 2% bacteria increases the compressive strength of concrete. The compressive strength of the concrete improved by up to 9% after 7 days of curing and by up to 18.8% after 28 days of curing when compared to ordinary concrete.

5 In comparison to conventional concrete, the inclusion of 10% Steel slag, 2% Bacteria, and 2% Calcium lactate enhances compressive strength by 23.56% for 28 days of curing and by 30.6% for 7 days.

6 In comparison with conventional concrete, adding 10%, 2%, and 2% of E-waste, bacteria, and calcium lactate enhances compressive strength by 22.08% for 7 days and by 31.05% for 28 days.

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