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Enhancing concrete performance with e-plastic waste and fly ash: a sustainable approach

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ABSTRACT

This extensive research project investigates the innovative use of electronic plastic waste, referred to as e-plastic, as an additional component in the production of concrete. This transition from an informal sector to a more structured and regulated system is vital not only for addressing the growing problem of E-waste but also for environmental preservation. To accomplish this goal, the study collected and employed waste E-plastic particles obtained from obsolete electronic devices. The research primarily concentrated on conducting a comprehensive analysis of the mechanical, durability properties and micro properties (XRD) of concrete specimens containing varying proportions of waste E-plastic, ranging from 4% to 24%. Additionally, the study introduced a modification by substituting a portion of the cement with fly ash, amounting to 10% of the total weight, with the aim of improving the overall characteristics and performance of the E-plastic-infused concrete. These experiments were carried out to gain a more holistic understanding of the concrete's behavior, encompassing both its structural integrity and overall performance characteristics. This research significantly enhances the concrete's workability, mechanical strength, and durability properties.

Keywords: E-waste; flyash; XRD; mechanical; durability properties.

1. INTRODUCTION

The significance of repurposing electronic waste components for construction materials, emphasizing the importance of eco-friendly practices and waste reduction in the electronics industry. It contributes to the growing body of knowledge on innovative and sustainable solutions for managing electronic waste in construction applications [1]. By investigating its potential to replace conventional coarse aggregates in concrete. E-waste-based concrete's applicability for diverse building applications must be assessed in light of these physical changes. This study directly targets environmental sustainability and waste reduction by recycling plastics from e-waste into building components [2]. Increasing challenge of electronic waste (E-waste) disposal in 2020 by looking into its potential as a sustainable replacement for conventional coarse aggregates in concrete. The construction industry is actively looking for environmentally friendly alternatives, which is where our research is positioned in the framework of sustainable building materials [3].

Tests based on recorded research show that increasing fly ash utilisation generates a net of environmental advantages. Partially replacing cement with extra cementing ingredients decreases greenhouse gas emissions proportionally and resulting in a more "green" concrete due to lower energy consumption and prevention of natural resource depletion [4]. The findings indicated that 40% Flyash replacement resulted in a significant decrease in chloride permeability across all phases, which may be considered the ideal quantity to be utilised in concrete. All of the cement-replacing materials evaluated in this research show a propensity to reduce water permeability while increasing axial strength [5].

A substantial decrease in density and workability was observed alongside significant strength reduction in concrete at higher replacement percentages. Additionally, a notable increase in deformity extent was observed [6]. Plastic bags are substituted to varying degrees (10, 20, 30 and 40%). According to the experimental findings, adding between 10% and 20% of plastic trash to concrete will decrease its compressive strength while increasing its workability and density [7]. The research highlights potential sustainability benefits, including reduced demand for conventional construction materials and e-waste diversion from landfills. These findings offer practical insights for the construction industry, aiding the development of environmentally friendly and resource-efficient building practices [8].

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The study investigates the intricate interactions between nanomaterial and E-waste constituents, alongside assessing their influence on the mechanical properties, durability, and structural integrity of concrete. This comprehensive examination aims to elucidate the multifaceted dynamics within sustainable concrete compositions [9]. The mechanical properties of concrete using E-waste as coarse aggregate in percentages of 0% to 30%. Cement was replaced by fly ash in percentages of 10%, 20% and 30%. A total of 252 cubes were cast for investigate all combinations in testing compressive strength. Curing period of 7, 14 and 28 days were observed. According to the tests and results obtained, E-waste percentage of 10% to 20% and fly ash of 30% produced best results [10].

E-waste has been incorporated in various percentages of 10%, 20% and 30%. In this study, there are no additional materials like admixtures or supplementary cementitious materials added. This concrete was also observed to be lighter in weight. Though sufficient compressive strength results and split tensile strength values were obtained it was not as good as those of the control specimen. The decrease in compressive strength for 10% replacement was 7.6%, 20% replacement was 21.47% and for 30% was 26.11% [11, 12]. Less than 15% addition of E waste showed a slight decrease in compressive strength and flexural strength. Further percentage increase of E waste showed gradual decline in strength values [13].

E-waste and plastic waste in concrete as a replacement for fine aggregate. Replacement was done upto 4%. An increase of 5% was observed in compressive strength. Cost effectiveness of 7% was also an added advantage at optimum replacement percentage [14]. Recycled E-waste material, used as coarse aggregate. This concrete was designed for M40 grade. It was also noted to be lighter in weight. Replacement was done upto 25% to study strength characteristics. Fly ash was also incorporated [15]. Concrete include Rebound Hammer test, Ultrasonic pulse velocity test, Modulus of Elasticity, stiffness of prism and density of concrete. Besides these, durability properties were also studied. The study on hardened concrete, revealed facts pertaining to use of E-waste in concrete. The rebound hammer test values show that conventional concrete possesses the maximum value. Beyond this, the value decreased with increasing E-waste content. On measuring the ultrasonic pulse velocity, the value of velocity was maximum for 10% replacement [16, 17].

The strength properties, durability properties and thermal properties were investigated. The strength characteristics reviewed are those of axial strength, split tensile strength, modulus of rupture and shear strength. E waste from Cathode Ray tubes was utilized for the purpose [18].

2. MATERIALS AND METHODS

2.1. Cement

This study meticulously evaluated Ordinary Portland Cement 43 grade, a common construction material, for its suitability by conducting physical property tests as per IS 4031:1988 guidelines. [19] Adhering to these rigorous testing standards is foundational to the research, as this cement will replace traditional coarse aggregates in lightweight concrete in subsequent phases. The physical property tests conducted on the material yielded valuable insights. The specific gravity of 3.15 indicates a moderate density, while the standard consistency of 33% suggests an appropriate water-cement ratio. With an initial setting time of 34 minutes and final setting time of 472 minutes, it demonstrates reasonable workability. The compressive strength of 44.5 N/mm^2 signifies a robust material, and a soundness value of 1 mm indicates minimal expansion upon hydration.

2.2. Flyash

The material composition primarily dominated by silica (67.44%) and alumina (21.66%). This composition suggests its potential suitability for various industrial applications. The presence of iron oxide (6.19%), calcium oxide (1.25%), and magnesium oxide (0.81%) further contributes to its versatility. The trace amount of sulphur trioxide and other components (2.65%) indicates a relatively pure and well-balanced composition, making it valuable for various industrial and construction purposes. The fly ash's specific gravity of 2.18 and fineness modulus of 2.71 render it a perfect selection for research work.

2.3. Fine aggregate

With a specific gravity of 2.65 and a fineness modulus of 2.66, this M-sand proves to be an excellent option for concrete manufacturing. The fineness modulus depicts its particle size distribution, while its specific gravity reveals its relative density to water. These characteristics make sure that the M-sand enhances the overall performance and quality of the concrete mixture in the research work.

2.4. Coarse aggregate

The properties of the material were evaluated, yielding significant findings. The specific gravity of 2.66 indicates its moderate density, while the high fineness modulus of 6.58 suggests a diverse particle size distribution. With low absorption at 0.5%, it exhibits good resistance to moisture. The angular shape is favorable for concrete cohesion, and while the crushing value is 27.2%, indicating moderate strength, the impact value of 24.73% suggests reasonable toughness. These characteristics collectively affirm its suitability for various construction applications. The size of coarse aggregtae used in the research is 20 mm.

2.5. E-waste

The material exhibits noteworthy properties. Its specific gravity of 1.01 indicates low density, while the minimal absorption (<0.2%) highlights its excellent resistance to moisture. The angular shape is advantageous for construction purposes. Furthermore, both the crushing value and impact value being less than 0.2% signify outstanding durability and strength. These findings collectively establish its suitability for various construction applications, particularly where density, high durability, and moisture resistance low are essential. The size of E-waste aggregtae used in the research is 12 mm .

3. METHODOLOGY

3.1. Slump cone test

During the slump cone test, a portion of newly mixed concrete is deposited into a conical mold in three distinct layers, with each layer being compacted using a standardized rod. Subsequently, the cone is meticulously lifted in a vertical manner, facilitating the natural spreading and settling of the concrete within. The precise measurement of the reduction in height, expressed in millimeters, serves as a valuable indicator of the workability of the concrete. A higher degree of slump implies an increased level of workability, which, in turn, simplifies the processes of concrete placement and shaping. This vital test plays a pivotal role in verifying that the concrete mixture attains the desired consistency, ensuring its effective applicability in various construction tasks.

3.2. Compression strength test

Concrete cubes of 150 mm × 150 mm × 150 mm were utilised for cube compression testing. After removing the surface moisture, all of the cubes were examined in their saturated state. Three cubes for each mix combination were evaluated using a compression testing machine in accordance with IS: 516-1959 at ages of 7, 14 and 28 days after curing. [20] Following specimen centering in the testing apparatus, tests were conducted at a uniform stress of 140 kg/cm^2/minute. The dial gauge needle was just beginning to move in the other way as the loading progressed. The direction of the needle's motion changing indicates that the specimen has failed. It was noted the current reading on the dial gauge, which represented the maximum load. The axial strength of the ultimate cube relates to the ultimate load divided by the specimen's cross-sectional area.

3.3. Split tensile strength

Three different curing ages (7, 14, and 28 days) were used using cylinders that were cast and submerged in water with a 150 mm dia and 300 mm high. The cylinders were tested in accordance with the IS: 5816-1999 specifications after curing. In the 2000 kN capacity compression testing machine, the cylinders were laid out horizontally. The load was gradually added, and the cylinder failure load was recorded. [21]

3.4. Flexure strength test

A 100 mm × 100 mm × 500 mm prisms were made and submerged in water for 28 days. Prisms were taken from the curing tank after water curing and evaluated in the flexural testing equipment with a two-point load at a loading rate of 400 kg/min according to IS: 516-1959. [20]

3.5. Permeability test

Concrete's capacity to absorb water in a saturated state is measured by the amount of pore space, or porosity that is occupied by water in hardened concrete. It indicates the amount of water that may be removed after drying a saturated specimen. Effective porosity is the porosity measured using absorption testing. The amount of water lost when a specimen that is saturated with water is dried in the oven at 105°C to constant mass is used to calculate the volume of the voids. The difference between the specimen's mass in air and its mass when submerged in water determines the specimen's bulk volume.

3.6. Acid resistance

According to ASTM C267- 01 (2012), the acid resistance tests were performed on 150 mm-size cube specimens at ages 28, 56 and 90 days after curing. [22] In this test, the samples were submerged for a total of 28 days in water that had been diluted with H2SO4 separately. The pH of the H2SO4 solution was held constant at 2 and it was five percent of 0.01 normalcy. The cubes' surfaces were then cleaned once the specimens had been removed from the acidic water. The specimens' compressive strengths and weight loss were then calculated.

3.7. X-ray diffraction (XRD)

X-ray diffraction analysis may be used to check for the presence of calcite and calcite-silicate-hydrate (C-S-H) gels in bacterial concrete samples. The existence of calcite peaks will demonstrate that bacterial precipitation of calcite, which increases the strength and durability of concrete, has taken place. The evolution of concrete's strength will be explained by the existence of C-S-H peaks. Using a pestle and mortar, broken cube specimen fragments from the compressive strength test were collected and ground into powder. The portion that made it through a sieve with a 5 mm opening was examined using XRD analysis.

4. RESULTS AND DISCUSSION

4.1. Slump cone test

The results reveal a clear correlation between the proportions of fly ash and E-waste in the concrete mixtures (M1 to M9) and their respective variations in slump values. As the fly ash and E-waste percentages increased, there was a consistent improvement in workability, with progressively higher positive variations in slump values. These findings highlight the potential benefits of incorporating fly ash and E-waste in concrete, indicating that these additives can significantly enhance workability and, consequently, influence the suitability of concrete mixtures for specific construction applications. Figure 1 shows the graphical variation in slump cone test results.

4.2. Compression strength test

The study reveals a clear relationship between the proportions of fly ash and E-waste in the concrete mixes (M1 to M9) and their respective variations in compression strength at different curing periods. As the percentages of fly ash and E-waste increased, there was a consistent trend of reduce compression strength above 4% of E-waste, compared to the control mixture (M1). The enhancements were particularly notable at 28 days, with mixtures M2 exhibiting the highest increases in strength. These findings underscore the potential of fly ash and E-waste as additives in terms of compressive strength of concrete, which can have significant implications for construction projects requiring durable and sustainable materials. Figure 2 shows the graphical variation in compression strength test.

4.3. Split tensile strength

The study illustrates a consistent relationship between the proportions of fly ash and E-waste in the concrete mixes (M1 to M9) and their respective variations in split tensile strength at different curing periods. As the

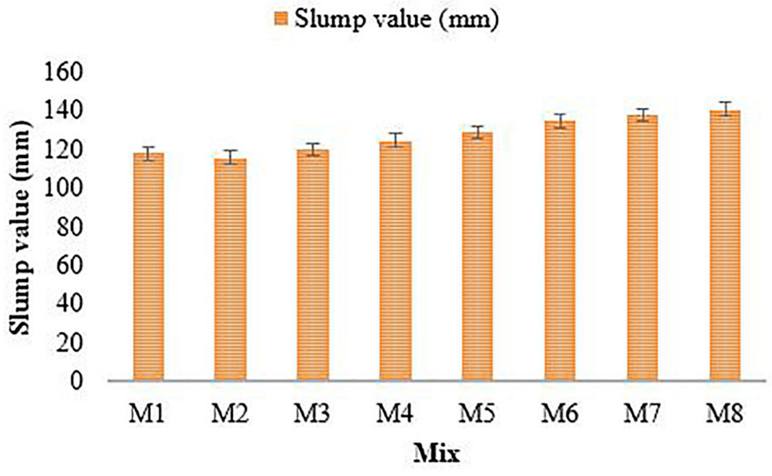

Figure 1: Graphical representation of slump cone test.

percentages of fly ash and E-waste increased, there was a consistent trend of reduce split tensile strength above 4% of E-waste, compared to the control mixture (M1). The most significant enhancements were observed at 28 days, particularly in mixtures M2. These findings underscore the potential of fly ash and E-waste as additives to in terms of split tensile strength of concrete, which can have substantial implications for construction projects requiring greater tensile resilience and sustainability. Figure 3 shows the graphical variation in split tensile strength test.

4.4. Flexural strength test

The study demonstrates a consistent relationship between the proportions of fly ash and E-waste in the concrete mixes (M1 to M9) and their respective variations in flexural strength at different curing periods. As the percentages of fly ash and E-waste increased, there was a consistent trend of reduce flexural strength above 4% of E-waste, compared to the control mixture (M1). The most significant enhancements were observed at 28 days, especially in mixtures M2. These findings highlight the potential of fly ash and E-waste as additives to in terms of flexural strength of concrete, which can have substantial implications for construction projects requiring greater structural resilience and sustainability. Figure 4 shows the graphical representation of flexural strength test results.

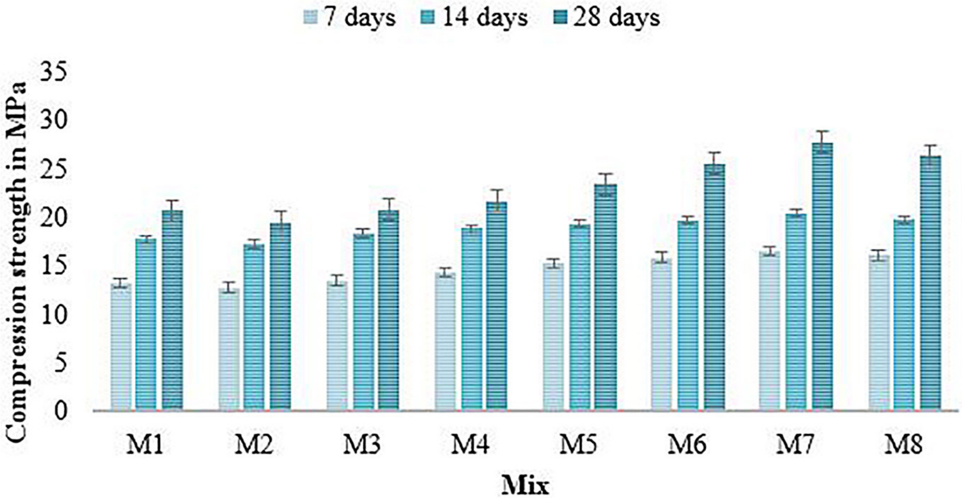

Figure 2: Graphical variation in compression strength test.

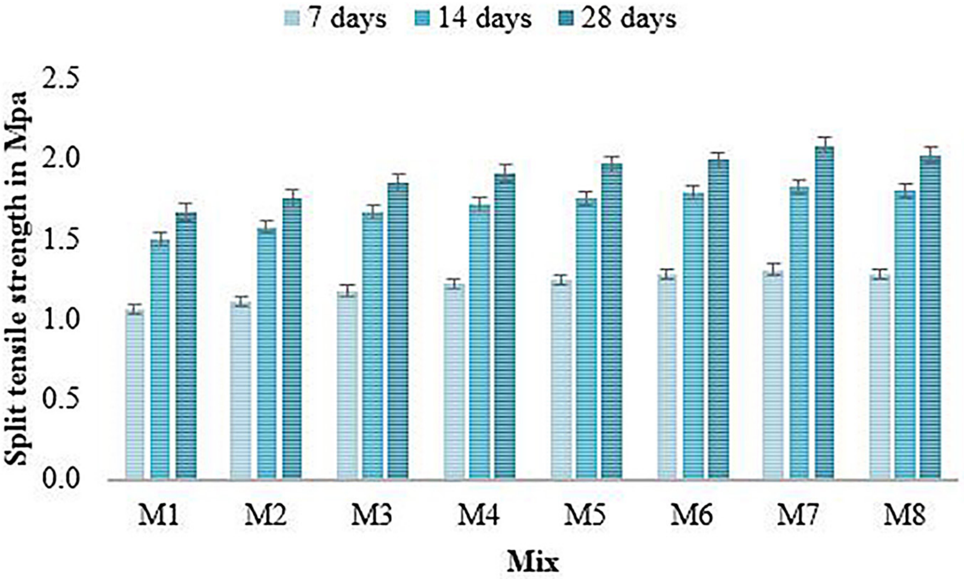

Figure 3: Graphical representation of split tensile strength test results.

4.5. Permeability test

The study reveals a consistent relationship between the proportions of fly ash and E-waste in the concrete mixes (M1 to M9) and their respective variations in permeability at different test durations (28 days, 56 days, and 90 days). As the percentages of fly ash and E-waste increased, there was a progressive reduction in permeability compared to the control mixture (M1). The most significant improvements were observed at 90 days, particularly in mixtures M6, M7, and M8. These findings underscore the potential of fly ash and E-waste as additives to reduce permeability in concrete, which can have significant implications for constructing durable and sustainable structures with improved resistance to moisture and environmental factors. Figure 5 shows the graphical representation of permeability test results.

4.6. Acid resistance test

The study demonstrates a consistent relationship between the proportions of fly ash and E-waste in the concrete mixes (M1 to M9) and their respective variations in the loss of weight due to sulphate attack at different test durations (28 days, 56 days, and 90 days). As the percentages of fly ash and E-waste increased, there was a consistent trend of reduce loss of weight above 4% of E-waste, compared to the control mixture (M1). The most significant improvements were observed at 90 days, especially in mixture M2. These findings highlight the potential of fly ash and E-waste as additives in terms of the resistance of concrete against sulphate attack, which is vital for its long-term durability in environments prone to such challenges. Figure 6 shows the graphical representation of chloride attack test.

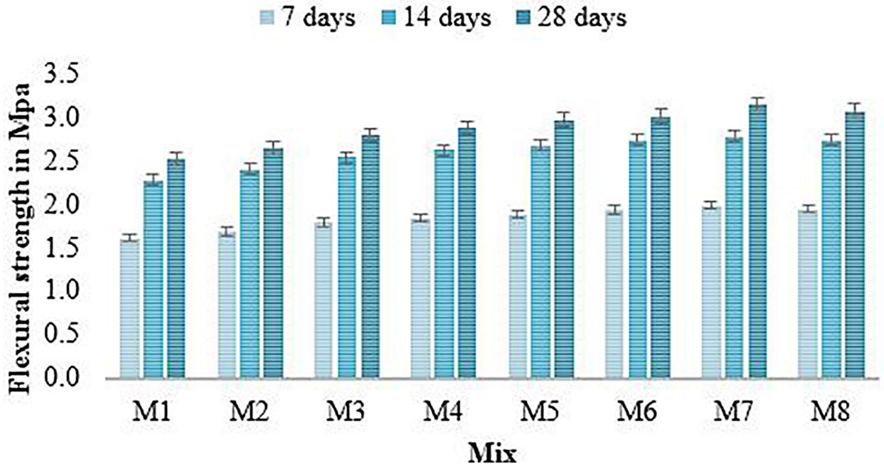

Figure 4: Graphical representation of flexural strength test results.

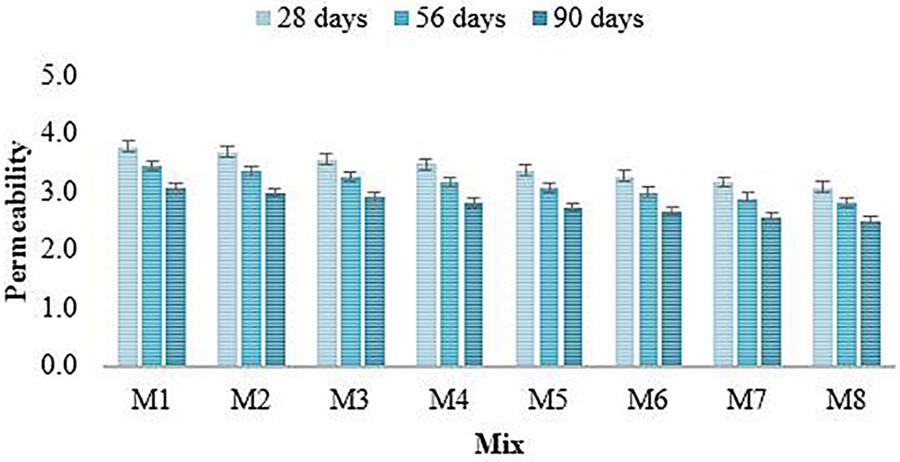

Figure 5: Graphical representation of permeability test.

4.7. X-ray diffraction (XRD)

X-ray diffraction (XRD) analysis is an effective method for detecting the presence of specific compounds, such as calcite and calcite-silicate-hydrate (C-S-H) gels, in various concrete samples, including those containing recycled E-waste and fly ash aggregates. The identification of these compounds through XRD analysis provides critical insights into the structural characteristics and potential benefits of these materials in concrete applications. XRD analysis of the selected powder enables the identification of specific compounds within the recycled E-waste and fly ash aggregates. This phenomenon is known to enhance the strength and durability of concrete. The identification of calcite formation provides valuable evidence of the positive influence of these aggregates on concrete properties. The presence of C-S-H peaks in the XRD analysis is equally significant. C-S-H gels play a vital role in explaining the evolution of concrete's strength over time. The detection of C-S-H gels in concrete samples containing recycled E-waste and fly ash aggregates signifies their contribution to the enhancement of concrete strength and performance. Figures 7 and 8 depict the XRD images of 28-day conventional concrete and M2 mix (10% fly ash and 4% E-waste) for visual reference and further analysis.

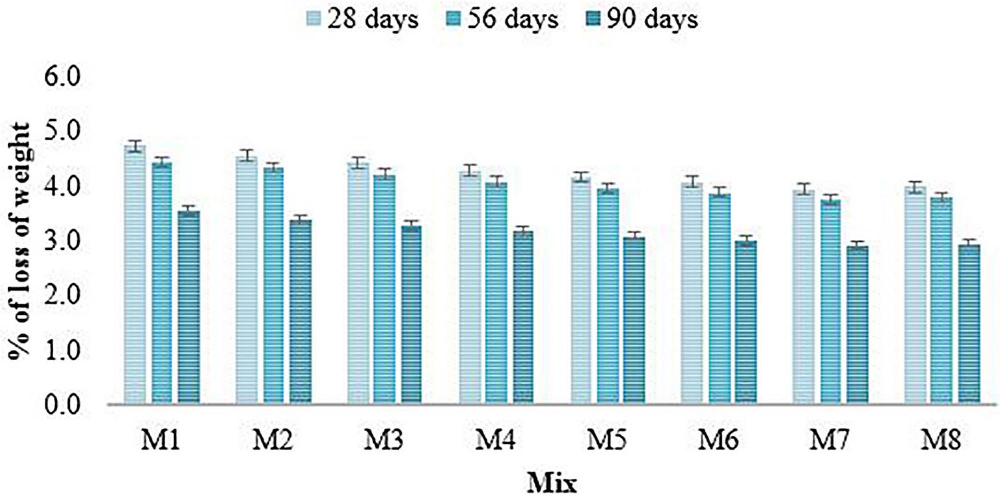

Figure 6: Graphical representation of chloride attack test.

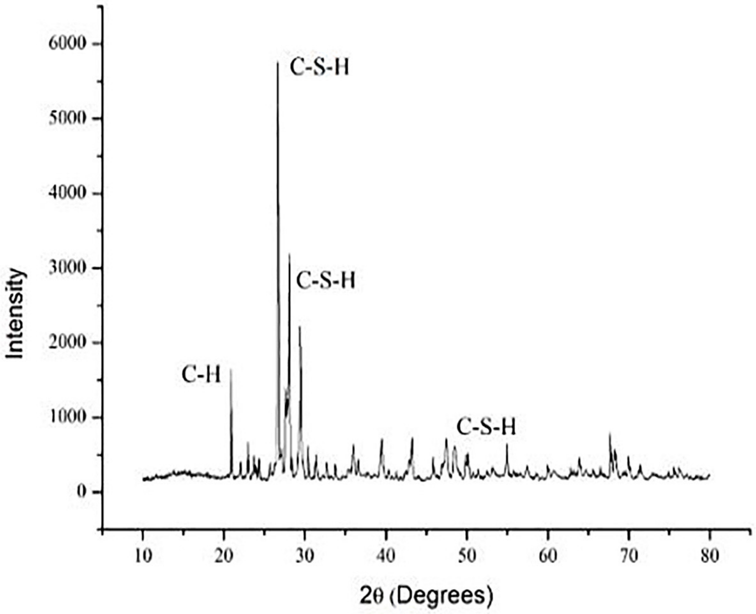

Figure 7: XRD of conventional concrete.

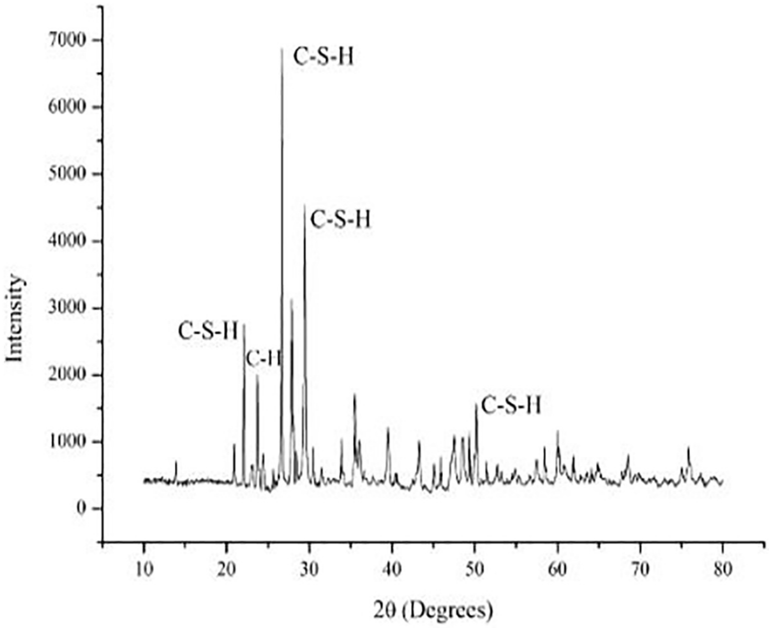

Figure 8: XRD of M7 concrete mix.

5. CONCLUSION

The workability results indicate that the addition of e-waste and fly ash to the concrete mixtures (M2 to M9) generally led to an increase in the workability. The highest observed in mix M9, which contained 10% fly ash and 28% e-waste, suggesting that this mixture had the highest workability among the tested combinations. The data on mechanical properties (MPa) at 7, 14, and 28 days reveals that incorporating e-waste with 10% fly ash M2 consistently improves concrete strength. The highest strength of was recorded in M2 at 28 days. The porosity data at 28, 56, and 90 days indicates that concrete mixtures containing e-waste with 10% fly ash (M2 to M9) exhibit lower porosity compared to the control mix M1. The lowest porosity levels, particularly notable at 90 days. The percentage of weight loss for sulphate attack test at 28, 56, and 90 days shows that concrete mixtures incorporating e-waste with 10% fly ash (M2 to M9) generally exhibit a lower percentage of weight loss compared to the control mix M1. Mix M8, with 10% fly ash and 28% e-waste, consistently displays the lowest weight loss percentage at all-time intervals, indicating enhanced durability. XRD analysis is vital for identifying compounds like calcite and C-S-H gels in concrete with recycled E-waste and fly ash aggregates.

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