

E-WASTE AS A SUSTAINABLE COARSE AGGREGATE REPLACEMENT IN CONCRETE: INNOVATIONS AND APPLICATIONS

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Abstract

The primary objective of this study is to assess the viability of integrating recycled plastic components sourced from electronic waste (E-waste) into diverse construction applications, offering a sustainable response to the growing challenges posed by the escalating E-waste crisis. This meticulous research examined key strength parameters in M20 grade concrete mixes, including compressive, split tensile, and flexural strength, varying the proportion of waste E-plastic in coarse aggregate. It aimed to reveal E-plastic's impact on concrete's mechanical properties for informed construction decisions. Durability was also assessed, covering water absorption, resistance to chloride attacks, and sorptivity. Non-destructive tests like ultrasonic pulse velocity tests were used for a holistic understanding of concrete behavior. This study contributes significantly to sustainable construction materials by offering insights into how waste E-plastic affects concrete's long-term performance and resilience in diverse environments. The investigation concentrated on a thorough examination of the mechanical, durability and micro attributes of concrete specimens featuring varying proportions of waste E-plastic content, spanning from 4% to 28%. Additionally, the research was modified by replacing a portion of the cement with fly ash, amounting to 10% of the total weight, with the intent of augmenting the overall characteristics and performance of the E-plastic-infused concrete.

Keywords: E-waste, fly ash, mechanical and durability properties, microanalysis

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Introduction

The utilization of non-metallic components extracted from printed circuit boards (PCBs) in cement concrete. He conducted a study focused on the reclamation and reuse of non-metallic materials recovered from waste PCBs, shedding light on their potential as sustainable additives in concrete formulations (Kakria and Priya, 2021). The recycling network model for reverse supply chain management incorporates multiple tiers of decision makers. This model, as outlined in this document, possesses the versatility to effectively tackle a range of recycling challenges linked to contemporary recycling policy instruments, including but not limited to the home appliances recycling law. Furthermore, this model has the capacity for expansion to accommodate the recycling industry's requirement to address uncertainties related to electronic waste quantities (Hu *et al.*, 2021).

The assessment of E-waste components, encompassing plastics, metals, and ceramics, for their applicability in concrete manufacturing is a crucial aspect. These components can be subject to processing to acquire aggregates apt for construction purposes (Islam and Huda, 2018). The attributes of E-waste aggregates display diversity contingent upon their composition and processing methodologies. Extensive research has delved into the mechanical, thermal, and chemical attributes of these aggregates. Methods for determining proportions take into account factors like aggregate dimensions, morphology, and substitution percentages (Cerminara *et al.*, 2020).

Incorporating E-waste aggregates can impact the workability and setting time of freshly mixed concrete. Furthermore, research into matured concrete demonstrates notable effects on parameters like compressive strength, durability, and shrinkage (Shinu and Needhidasan, 2020). To assess durability, investigations have focused on the resistance of E-waste-infused concrete to factors such as chloride intrusion, sulfate attacks, and alkali-silica reactions. The outcomes of these studies suggest that integrating E-waste materials can actually improve the overall durability of concrete (Tran *et al.*, 2023).

The use of E-waste as a concrete aggregate aligns with sustainable construction practices, contributing to waste reduction and resource conservation. Include the heterogeneity of E-waste materials and the need for appropriate processing techniques. Ensuring consistent quality and meeting regulatory standards remain important considerations (Ahmad *et al.*, 2022a). E-waste has significant potential as a partial replacement for coarse aggregate in concrete, offering both

environmental benefits and addressing sustainability concerns in the construction industry (Ahmad *et al.*, 2022b).

Fly ash enhancement in modifying the chemical and physical characteristics of the concrete. The presence of fly ash in the concrete has a significant impact on its strength. In contrast, the fly ashes had no noticeable effect on the values of the modulus of elasticity (Naveen Arasu *et al.*, 2023a). The fly ash's very tiny particle size influenced the concrete's pore size and further decreased water absorption. In the sulphate and chloride penetration test, the concrete mix made with fly ash and limestone performed better. They deduced through microanalysis that fly ash increased internal friction and decreased fracture propagation in concrete (Naveen Arasu *et al.*, 2023b).

Influence of Fly Ash particle Size on the Physical Properties of Concrete, in which he confirms fly ash's pozzolanic properties and filler influence on cement. It has been discovered that the filler influence of the fly ash residues is more potent than the pozzolanic features when it comes to altering the concrete's properties (Naveen Arasu *et al.*, 2018). The properties of fly ash-based concrete composite materials with various chemical admixtures and concluded that the development of new specifications and tests leads to a reduction in material-related issues when fly ash is used in structural concrete for transportation infrastructure (Zeng *et al.*, 2020).

The effect of e-waste plastic inclusion on concrete characteristics has a possible change in mechanical properties, such as compressive strength and workability. The long-term viability and environmental benefits of using E-waste plastics in concrete may be better understood by looking at its features, such as durability and structural performance (Shelorkar and Jadhao, 2018).

To enhance or preserve the workability of concrete, E-wastes are added into it within the prescribed limits. The structural strength parameters for E-waste concrete with preserved workability were examined after the addition of E-waste particles to the M20 grade of concrete (Balasubramanian *et al.*, 2021). Integrating electronic waste (E-waste) components into concrete is one potential option since it successfully recycles wasted materials while lessening the environmental impact of their disposal (Sujatha 2020).

Analysing the compressive and flexural strengths of plastic concrete, as well as its mechanical characteristics, sheds important light on

the viability of employing polymers from e-waste in building materials. A significant contribution to a comprehensive evaluation of the long-term sustainability of concrete by examining the concrete's durability and structural behaviour (Hamsavathi *et al.*, 2020).

The physical and mechanical characteristics of concrete using fly ash and light weight aggregate. Steel fibres were added for improving the tensile property in concrete. Light weight aggregate brought about reduction in self-weight of concrete (Singh and Malviya, 2019). The strength parameters by partially replacing coarse aggregate with E-waste. Replacement percentages were from 5% to 30%, incrementing by 5% for each mix. Comparison with standard concrete revealed increase in strength parameters upto 15% replacement, after which it started decreasing (Muthupriya and Kumar, 2021). Their efforts resulted in noteworthy findings, demonstrating that concrete's strength remained substantial with a 10% replacement of M20 grade coarse aggregates (Shinu and Needhidasan, 2021).

E-waste is partially replaced for coarse aggregate to make concrete of M25 grade. The results show improved compression and flexural strength for a value of 15% replacement. The load carrying capacity increased by 12.67%. But further addition of E-waste showed a pattern of decrease (Zhang *et al.*, 2017). The concrete grade under investigation was M40. The outcomes of this investigation led to the conclusion that the partial replacement of E-waste as an aggregate results in a reduction in the concrete's weight. Consequently, E-waste can be effectively employed as a constituent in lightweight concrete. This not only facilitates the efficient utilization of this hazardous waste material but also contributes to addressing the issue of diminishing natural aggregate resources (Kattoua *et al.*, 2019).

Materials Used

Cement

Ordinary Portland Cement 43 grade was carefully chosen as the cement type, a commonly used construction material. Extensive physical property tests, following IS 4031:1988 guidelines, rigorously assessed its suitability and quality. Table 1 shows the tests results of cement used in this research.

Fly Ash

Fly ash from the Mettur Thermal Power Station was utilised in place of cement in this experiment. A source of countless small, spherical

particles having pozzolanic properties is fly ash, a by-product of burning coal. The 2.18 specific gravity and 2.71 fineness modulus of this flyash make it an ideal choice for making concrete.

Fine Aggregate

As the fine aggregate, M-sand that had been meticulously sieved to pass through a 4.75 mm sieve was used. M-sand, also known as manufactured sand, is a finely crushed stone dust that, when compared to natural river sand, has a number of benefits, including constant particle size and minimal environmental effect. The 2.65 specific gravity and 2.66 fineness modulus of this M-sand make it an ideal choice for making concrete.

Coarse Aggregate

The characteristics of the coarse aggregate under examination reveal essential attributes. The specific gravity, quantified at 2.66, signifies its density. A fineness modulus of 6.58 signifies its particle size distribution. Its minimal absorption rate of 0.5% suggests durability due to low moisture absorption. The angular shape contributes to its inherent strength. A 27.2% crushing value indicates robust resistance to crushing forces, while a 24.73% impact value implies the ability to endure impact loads. These findings collectively offer crucial insights into the composition and versatility of the coarse aggregate for diverse applications.

E-waste

The particle size of waste E-plastic aggregates used is 12mm. The usage of waste E-plastic particles was considered as filler material in cement concrete in various percentages. The waste E-plastic contents were calculated as weight percent of coarse aggregate in the control mix. The E-waste's features under inspection show distinct traits. Its 1.01 specific gravity demonstrates its relative density. The crushing value of E-waste plastic is 29.8%. The e-waste exhibits little moisture absorption at a rate of less than 0.2%, indicating its potential for durability. The angular form of the E-waste symbolizes inherent strength. The crushing value and impact value are both notable less than 0.2%, demonstrating outstanding resistance to crushing pressures and amazing capacity to endure impact

Table 1. Properties of cement

Physical properties	Observations
Specific gravity	3.15
Standard Consistency	33%
Initial setting time	34 min
Final setting time	472 min
Compressive strength	44.5 N/mm ²
Soundness	1 mm

loads. Together, these observations highlight the E-waste's exceptional properties, which make it appropriate for a variety of uses. The source of E-waste from ump yards is used in this research.

Mix Proposition

The guidelines provided in IS: 10262-2019 are rigorously followed during the mix design procedure for concrete of the M20 grade. The Bureau of Indian Standards developed this standard, which offers a rigorous framework for designing concrete mixes while taking into account important elements including the intended compressive strength, workability, and durability. Various components are carefully balanced in the concrete mixture to attain the desired qualities. The concrete's binding matrix is created by the 399.24 kg/m³ cement content. Fly ash at a density of 44.8 kg/m³ improves performance and sustainability. Water is carefully measured at 201.62 kg/m³, which is essential for hydration. The workability and texture of the concrete are influenced by the fine aggregate, which has a density of 700 kg/m³. With 873.6 kg/m³, the coarse aggregate gives the structure strength and stability. Furthermore, the creative addition of E-waste, at a density of 166.4 kg/m³, not only solves environmental issues but also imparts special qualities to the concrete mixture, bringing it in line with green building techniques. This exact proportioning produces a well-balanced concrete mix that is tailored to fit the requirements of a particular project.

Methodology

The methodology employed for incorporating E-waste as a coarse aggregate partial replacement and Fly Ash as a cement partial replacement in concrete follows a systematic and sustainable approach. The initial phase involves the collection, meticulous sorting, thorough cleaning, and appropriate processing of E-Waste to create aggregates of suitable sizes. Subsequently, the mix design meticulously determines the exact proportions of cement, E-Waste aggregates, fly ash, and additional additives to achieve the desired concrete properties. A rigorous testing regimen, encompassing compressive and flexural strength assessments, evaluations of durability, and in-depth microstructure analysis, is systematically executed to comprehensively assess the performance of the resulting concrete.

Results and Discussion

Slump Cone Test

The slump value, measured in millimeters, serves as a crucial indicator of the mix's workability and consistency. In the conventional mix, M1, with no Fly Ash or E-Waste additives, the slump value stands at 118 mm, serving as the baseline. As Fly Ash is introduced at 10% in M2, the slump decreases marginally to 116 mm, indicating a slight reduction in workability. However, as E-Waste is progressively incorporated from 4% in M3 to 29% in M9, the slump values exhibit an intriguing trend. Surprisingly, as the E-Waste content increases, the slump values show an upward trend, reaching 144 mm in M9. This suggests that the combination of Fly Ash and E-Waste may yield a concrete mix that not only maintains workability but even improves it at higher E-Waste percentages, promising interesting prospects for sustainable and workable concrete formulations. The E-waste water absorption % is very less which is almost zero compared to coarse aggregate which helps to improve the workability. Figure 1 shows the graphical variation in slump cone test results.

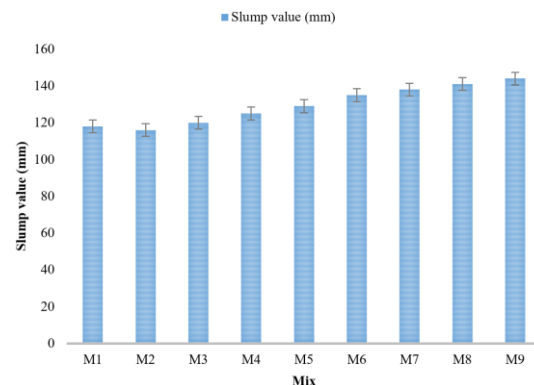


Figure 1. Graphical representation of slump cone test

Compaction Factor

The compaction factor is a crucial indicator of the ease with which concrete can be compacted and, subsequently, its workability and density. In the conventional mix, M1, with no Fly Ash or E-Waste additives, the compaction factor is recorded at 0.961, serving as the baseline for comparison. As Fly Ash is introduced at 10% in M2, the compaction factor remains relatively consistent at 0.96, indicating that this level of Fly Ash does not significantly affect the concrete's compaction properties. As the E-Waste content is progressively introduced, ranging from 4% in M3 to 28% in M9,

the compaction factor shows a steady increase. This trend suggests that the combination of Fly Ash and E-Waste has a favourable impact on the workability and compaction properties of the concrete mix. The highest compaction factor of 0.974 is observed in M9, signifying improved workability and denser concrete. These findings underscore the potential of incorporating Fly Ash and E-Waste in concrete mix designs to not only enhance sustainability but also improve the ease of construction, which can have practical implications for various construction applications. Figure 2 shows the graphical variation in test results.

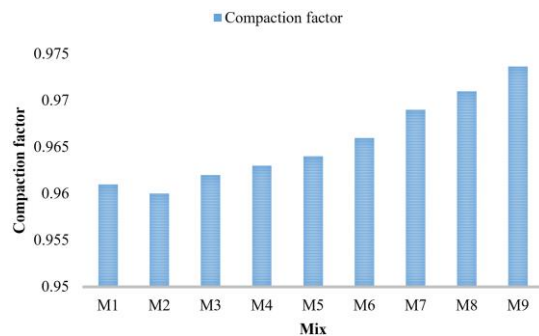


Figure 2. Graphical representation of compaction test

Compression Strength Test

The table displays the compression strengths of several concrete mixtures at varying curing times (7, 14, and 28 days) with varying amounts of fly ash (FA) and electronic trash (E-waste). Overall, the concrete mixes' compressive strengths varied depending on the amount of fly ash and electronic debris. The compressive strength of Mix M1, devoid of fly ash and E-waste, was 25.62 MPa after 28 days. There was a general tendency toward a marginal increase in compressive strength relative to M1 as the amount of fly ash in Mixes M2 to M9 rose. E-waste integration, however, produced inconsistent outcomes. While mixes containing 4% (M3) and 8% (M4) of e-waste showed strengths comparable to Mix M1, further additions gradually reduced the compressive strength. Mix M2, which included no E-waste and 10% fly ash, had the maximum compressive strength after 28 days, measuring 26.61 MPa. These findings reveal that the incorporation of both Fly Ash and E-Waste has a positive influence on the concrete's compression strength at 4% E-waste and 10% fly ash over time. Higher E-waste percentages appear to have a minimal reduction in the strength properties, indicating the potential for sustainable concrete mix designs that meet structural requirements while reducing environmental impact. The crushing strength of coarse aggregate is less compared to conventional coarse aggregate that

the reason reduction of mechanical properties of concrete. Figure 3 shows the graphical variation in the compression strength test.

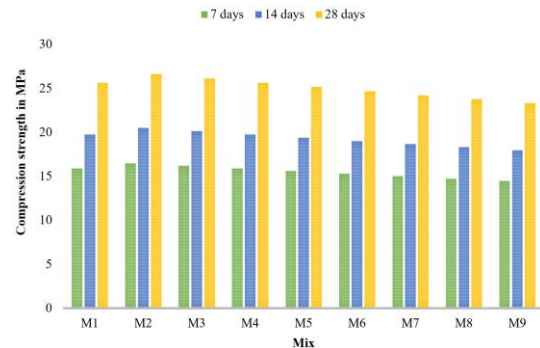


Figure 3. Graphical variation in compression strength test

Split Tensile Strength

The tabulated results show the split tensile strength of concrete mixes that have varied ratios of fly ash (FA) and electronic trash (E-waste) during different curing times (7, 14, and 28 days). These additions have an impact on the concrete's tensile strength qualities, as the data show. At 28 days, 14 days, and 7 days, respectively, Mix M1, devoid of fly ash and E-waste, showed split tensile strengths of 2.08 MPa, 1.83 MPa, and 1.31 MPa. Split tensile strength showed a general trend of improvement when fly ash percentage rose from 0% to 10% (Mixes M2 to M9). E-waste did not, however, always improve these qualities after its debut. Mix M2, which had no E-waste and 10% fly ash, had the greatest split tensile strength after 28 days at 2.15 MPa. Split tensile strength was somewhat reduced by more E-waste inputs. Higher E-Waste percentages appear to have minimal reduction in the strength properties, indicating the potential for sustainable concrete mix designs that meet structural requirements while reducing

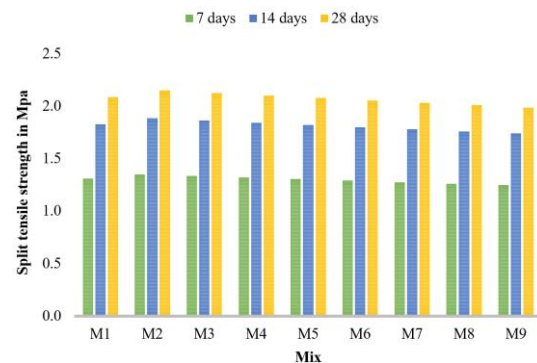


Figure 4. Graphical representation of split tensile strength test results

environmental impact. Figure 4 shows the graphical representation of the split tensile strength test results.

Flexural Strength Test

The flexural strength of concrete mixes with varied fly ash (FA) and electronic waste (E-waste) percentages at different curing times (7, 14, and 28 days). The data illustrates how these additions affect the concrete's flexural strength characteristics. At 28 days, 14 days, and 7 days, respectively, Mix M1, devoid of fly ash and E-waste, showed flexural strengths of 3.15 MPa, 2.78 MPa, and 1.99 MPa. Flexural strength was typically positively impacted by the addition of fly ash (Mixes M2 to M9). Mix M2, which included 10% fly ash and no E-waste, had the maximum flexural strength after 28 days at 3.25 MPa. The flexural strength of Mixes M3 through M9 with the inclusion of E-waste varied. Although flexural strength decreases slightly when E-waste content rises, this effect is not as noticeable as it is for other strength characteristics. Higher E-waste percentages appear to have minimal reduction in the strength properties, indicating the potential for sustainable concrete mix designs that meet structural requirements while reducing environmental impact. Figure 5 shows the graphical representation of flexural strength test results.

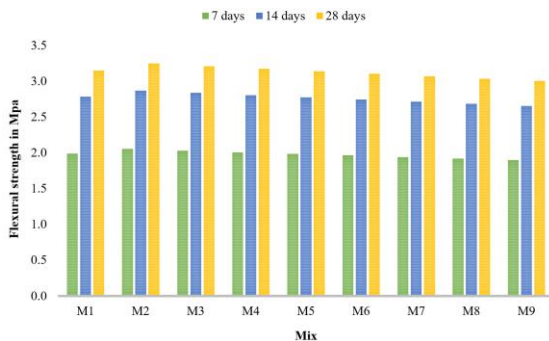


Figure 5. Graphical representation of flexural strength test results

Saturated Water Absorption

The saturated water is a concrete mix that contains varied amounts of fly ash (FA) and electronic trash (E-waste) absorbed throughout 28 days, 56 days, and 90 days of water immersion. The size of the specimen used in the saturated water absorption test is 150mm cube. The information sheds light on how the concrete's capacity to absorb water is affected over time by the addition of fly ash and e-waste. The saturation water absorption values of Mix M1, devoid of fly ash and E-waste, were 3.07%, 2.82%, and 2.66% at 28, 56, and 90 days, in

that order. In comparison to M1, the addition of 10% fly ash to Mixes M2 through M9 often reduced water absorption. Fly ash is known to contribute to the lowering of water permeability. Mix M2, which contains 10% fly ash and no E-waste, had the lowest absorption values for all periods. Different effects on saturated water absorption were seen when E-waste was added to Mixes M3 through M9. E-waste generally exhibits a modest increase in absorption as its amount increases, indicating that it may have a negligible negative effect on the concrete's water resistance. Figure 6 shows the graphical representation of saturated water absorption.

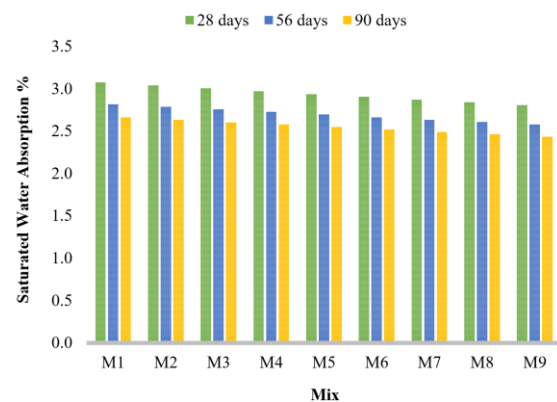


Figure 6. Graphical representation of saturated water absorption

Chloride Attack Test

The percentage of weight loss in the chloride attack test for concrete mixes at different exposure times (28, 56, and 90 days) that contain varied amounts of fly ash (FA) and electronic trash (E-waste). The size of the specimen used in the chloride attack test is 150mm cube. The information sheds light on how resistant concrete is to corrosion caused by chlorides. At 28, 56, and 90 days, respectively, Mix M1, devoid of fly ash and E-waste showed weight reduction percentages of 3.95%, 3.76%, and 2.92%. When 10% fly ash was added to Mixes M2 through M9, the weight loss was often less than that of M1. Mix M7, which contains 20% E-waste and 10% fly ash, had the least amount of weight loss throughout the course of all the durations, indicating that the addition of E-waste and fly ash strengthens the concrete's defences against chloride assault. There were differences in the impact on the weight reduction % when E-waste was added to Mixes M3 through M9. Generally speaking, weight loss increases somewhat as E-waste content increases, suggesting that E-waste may have a little negative effect on concrete's

ability to withstand chloride assault. Figure 7 shows the graphical representation of the chloride attack test.

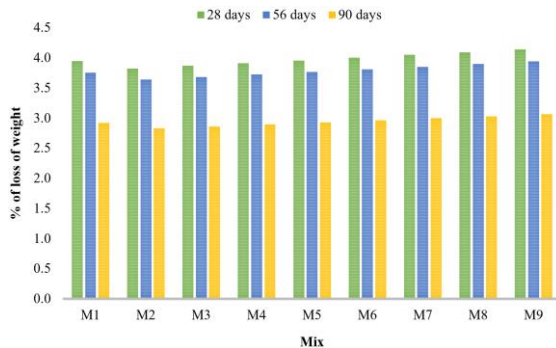


Figure 7. Graphical representation of chloride attack test

Sorptivity Test

The sorptivity values ($\text{mm/s}^{0.5}$) of concrete mixes at different curing times (28, 56, and 90 days) when fly ash (FA) and electronic trash (E-waste) percentages are varied. Concrete's permeability and durability may be inferred from the rate at which water is absorbed by it, which is measured by sorptivity. At 28, 56, and 90 days, respectively, the sorptivity values of Mix M1, devoid of fly ash and E-waste, were $0.036 \text{ mm/s}^{0.5}$, $0.031 \text{ mm/s}^{0.5}$, and $0.023 \text{ mm/s}^{0.5}$. When 10% fly ash was added to Mixes M2 through M9, sorptivity was typically lower than in M1. The combination of fly ash and E-waste, Mix M7, which contains 10% fly ash and 20% E-waste, showed the lowest sorptivity throughout all periods, suggesting that it improves the concrete's resistance to water absorption. Different impacts on sorptivity were seen when E-waste was added to Mixes M3 through M9. Although sorptivity does somewhat rise when E-waste content does, this effect is not as noticeable as it is in other durability attributes. This implies that a decent barrier to water absorption may still be maintained by combining fly ash with E-waste. Figure 8 shows the graphical representation of sorptivity test results.

Ultrasonic Pulse Velocity Test

The speed values (km/s) of concrete mixtures at different curing times (28, 56, and 90 days) that contain varied proportions of fly ash (FA) and electronic garbage (E-waste). Measurements of velocity reveal the speed at which acoustic waves travel through concrete, providing details regarding the stiffness and structural integrity of the material. At 28, 56, and 90 days, respectively, Mix M1, devoid of fly ash and E-waste, showed velocity

values of 4.839 km/s , 4.829 km/s , and 4.807 km/s . When 10% fly ash was added to Mixes M2 through M9, the velocity increased in comparison to M1. Mix M9, which contains 28% E-waste and 10% fly ash, had the greatest velocity values throughout all durations, suggesting that the addition of fly ash and E-waste strengthens the concrete's structural integrity and stiffness. The impact of adding e-waste to Mixes M3 through M9 varied in terms of velocity. Higher E-waste contents generally show a tendency toward rising velocity, indicating possible improvements in the stiffness of the material. Figure 9 visually illustrates the trends in sound wave velocity.

SEM Analysis

When contemplating the amalgamation of recycled E-waste and fly ash aggregates, an examination of the resultant microstructural complexities emerges as of paramount significance. Scanning electron microscopy (SEM) analysis stands as a valuable tool to delve into the structural attributes of these composite materials and elucidate

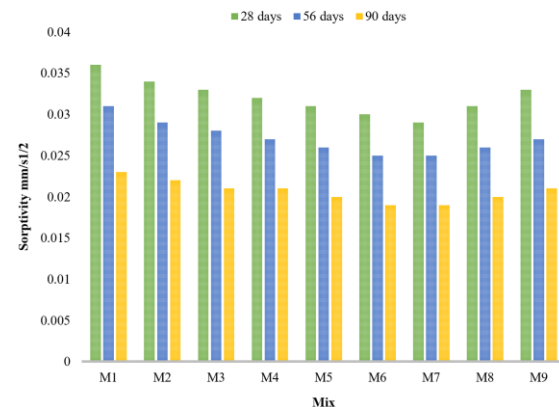


Figure 8. Graphical representation of sorptivity test results

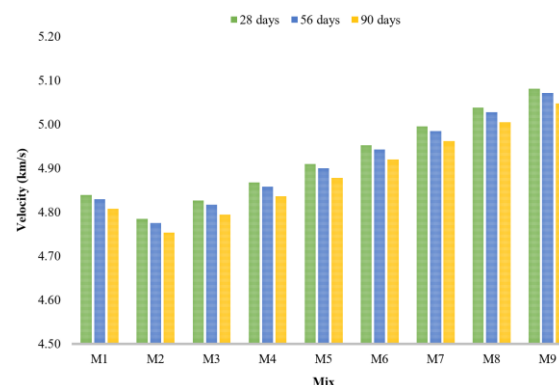


Figure 9. Shows the Graphical representation of UPV

their potential across diverse applications. SEM imaging of both recycled E-waste and fly ash aggregates reveals a multifaceted microstructure comprised of diverse electronic components and materials. Notably, the surfaces of these aggregates exhibit residual circuitry elements, encompassing soldering points, wires, and electronic components. The coexistence of these varying constituents imparts a heterogeneous composition, which may have far-reaching implications for the mechanical properties and interactions within concrete mixes incorporating recycled E-waste and fly ash aggregates. Figures 10 and 11 elucidate the hydrated C-S-H gel products alongside white crystals of unhydrated CH, with certain darker voids believed to constitute the capillary pores, thus providing visual context to the microstructural analysis for conventional concrete and M2 mix (10% fly ash and 4% E-waste).

Conclusions

The slump test 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 slump values. The highest slump value of 144 mm was observed in mix M8, which contained 10% fly ash and 28% e-waste, suggesting that this mixture had the highest workability among the tested combinations. The compaction factor results demonstrate that the addition of e-waste and fly ash to the concrete mixtures (M3 to M9) generally improved the compaction, with the highest value of 0.974 observed in mix M8, which contained 10% fly ash and 28% e-waste. The data on compression strength (MPa) at 7, 14, and 28 days reveals that incorporating e-waste with 10% fly ash (M3 to M9) consistently reduces concrete strength. The highest strength of 26.61 MPa was recorded in M2 with 4% E-waste and 10% fly ash at 28 days. The split tensile strength data at 7, 14, and 28 days suggests that incorporating e-waste with 10% fly ash (M3 to M9) consistently reduces concrete strength. The highest strength of 26.61 MPa was recorded in M2 with 4% E-waste and 10% fly ash at 28 days. The data on flexural strength (MPa) at 7, 14, and 28 days demonstrates that incorporating e-waste with 10% fly ash (M3 to M9) consistently reduces concrete strength. The highest strength of 26.61 MPa was recorded in M2 with 4% E-waste and 10% fly ash at 28 days. The data on saturated water absorption at 28, 56, and 90 days reveals that concrete mixtures incorporating e-waste with 10% fly ash (M2 to M9) exhibit reduced water absorption compared to the control mix M1. The lowest absorption rate, particularly notable at 90 days, is seen in mix M9.

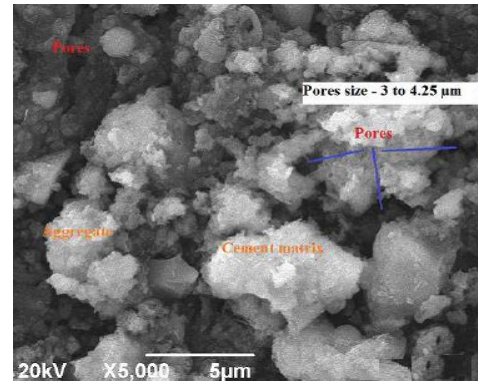


Figure 10. Microstructure of conventional concrete

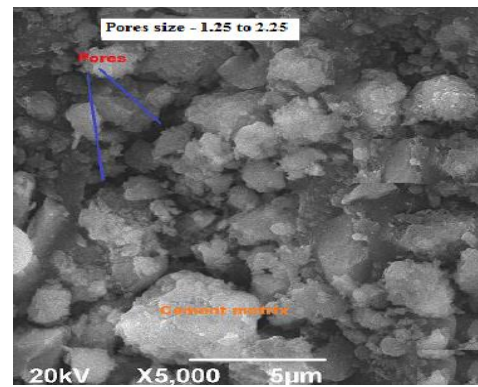


Figure 11. Microstructure of M7 concrete mix

This suggests that the addition of e-waste, along with fly ash, contributes to reduced permeability and improved durability of the concrete mixtures over time. The percentage of weight loss for the chloride attack test at 28, 56, and 90 days demonstrates that concrete mixtures incorporating e-waste with 10% fly ash (M2 to M9) generally exhibit an increased percentage of weight loss compared to the control mix M1. The sorptivity results at 28, 56, and 90 days demonstrate that concrete mixtures incorporating E-waste with 10% fly ash (M3 to M9) generally exhibits lower sorptivity values compared to the control mix M1. The lowest sorptivity values are consistently observed in mix M9, suggesting enhanced resistance to moisture penetration and improved durability. In UPV, mix M2, featuring 10% fly ash and 4% e-waste, displayed the highest velocity of 4.839 km/s at 28 days, showcasing promising acoustic performance. This upward trend in velocity continued and matured with prolonged curing periods. For instance, at 90 days, M2 maintained a substantial velocity of 4.753 km/s, highlighting its sustained long-term acoustic capabilities. The uniformity, smoothness, and consistent size distribution of these aggregates offer

promise for improved compatibility with cementitious binders, potentially enhancing mechanical properties and workability in concrete mixes.

References

- Ahmad, F., Jamal, A., Mazher, K.M., Umer W., and Iqbal, M. (2022a). Performance evaluation of plastic concrete modified with E-waste plastic as a partial replacement of coarse aggregate. *Materials*, 15(1):175. <https://doi.org/10.3390/ma15010175>
- Ahmad, F., Qureshi M.I., and Ahmad, Z. (2022b). Influence of nano graphite platelets on the behavior of concrete with E-waste plastic coarse aggregates. *Construction and Building Materials*, 316:125980. <https://doi.org/10.1016/j.conbuildmat.2021.125980>
- Balasubramanian, B., Gopala Krishna, G.V.T., Saraswathy, V., and Srinivasan, K. (2021). Experimental investigation on concrete partially replaced with waste glass powder and waste E-plastic. *Construction and Building Materials*, 278:122400. <https://doi.org/10.1016/j.conbuildmat.2021.122400>
- Cerminara, G., Raga, R., Hirata, O., and Pivato, A. (2020). Denitrification of low C/N landfill leachate in lab-scale landfill simulation bioreactors. *Waste Management*, 113:236-243. <https://doi.org/10.1016/j.wasman.2020.05.041>
- Hamsavathi, K., Soorya Prakash, K., and Kavimani, V. (2020). Green high strength concrete containing recycled Cathode Ray Tube Panel Plastics (E-waste) as coarse aggregate in concrete beams for structural applications. *Journal of Building Engineering*, 30:101192. <https://doi.org/10.1016/j.jobbe.2020.101192>
- Hu, Q., Su, P., and Xiong, F. (2021). Dynamic game strategies for construction and demolition waste recycling with learning and reference effects. *Environmental Impact Assessment Review*, 89:106592. <https://doi.org/10.1016/j.eiar.2021.106592>
- Islam, Md.T. and Huda, N. (2018). Reverse logistics and closed-loop supply chain of Waste Electrical and Electronic Equipment (WEEE)/E-waste: A comprehensive literature review. *Resources, Conservation and Recycling*, 137:48-75. <https://doi.org/10.1016/j.resconrec.2018.05.026>
- Kakria, K. and Priya, S. (2021). Use of non-metallic powder reclaimed from waste printed circuit boards in rigid concrete pavement. *IOP Conference Series: Materials Science and Engineering*, 1075(1):012032. <https://doi.org/10.1088/1757-899X/1075/1/012032>
- Kattoua, M.G., Al-Khatib, I.A., and Kontogianni, S. (2019). Barriers on the propagation of household solid waste recycling practices in developing countries: State of Palestine example. *Journal of Material Cycles and Waste Management*, 21(4):774-785. <https://doi.org/10.1007/s10163-019-00833-5>
- Muthupriya, P. and Kumar, B.V. (2021). Experimental investigation on concrete with e-waste - a way to minimize solid waste deposition. *Nature Environment and Pollution Technology*, 20(3):1185-1191. <https://doi.org/10.46488/NEPT.2021.v20i03.026>
- Naveen Arasu, A., Muhammed Rafsal, M., and Surya Kumar, O.R. (2018). Experimental investigation of high performance concrete by partial replacement of fine aggregate by construction demolition waste, *International Journal of Scientific & Engineering Research*, 9(3):46-52.
- Naveen Arasu, A., Natarajan, M., Balasundaram, N., and Parthasaarathi, R. (2023a). Utilizing recycled nanomaterials as a partial replacement for cement to create high-performance concrete. *Global NEST Journal*, 25(6):89-92. <https://doi.org/10.30955/gnj.004780>
- Naveen Arasu, A., Natarajan, M., Balasundaram, N., and Parthasaarathi, R. (2023b). Optimization of high performance concrete composites by using nano materials. *Research on Engineering Structures and Materials*, 9(3):843-859. <http://dx.doi.org/10.17515/resm2022.602ma1213>
- Shelorkar, A.P. and Jadhao, P.D. (2018). Determination of mechanical properties of slurry infiltrated steel fiber concrete using fly ash and metakaolin. *International Journal of Engineering & Technology*, 7(4.5):262-267. <https://doi.org/10.14419/ijet.v7i4.5.20082>
- Shinu, N.M.M.T. and Needhidasan, S. (2020). An experimental study of replacing conventional coarse aggregate with E-waste plastic for M40 grade concrete using river sand. *Materials Today: Proceedings*, 22(part 3):633-638. <https://doi.org/10.1016/j.matpr.2019.09.033>
- Shinu, N.M.M.T. and Needhidasan, S. (2021). Structural analysis and design of a multistoried RCC building to prevent disproportionate collapse using E-Tabs. *Materials Today: Proceedings*, 43(part 2):1911-1918. <https://doi.org/10.1016/j.matpr.2020.10.929>
- Singh, M.K. and Malviya, P. (2019). An experimental study on partial replacement of aggregate by e-waste for flexible pavement. *International Journal of Trend in Scientific Research and Development*, 3(3):382-384. <https://doi.org/10.31142/ijtsrd22865>
- Sujatha, T. (2020). A Geo-polymer concrete by partial replacement of fine aggregates with plastic waste. *International Journal of Engineering Research & Technology*, 9(8):487-489. <https://doi.org/10.17577/IJERTV9IS080204>
- Tran, N.P., Gunasekara, C., Law, D.W., Houshyar, S., and Setunge, S. (2023). Utilization of recycled fabric-waste fibers in cementitious composite. *Journal of Materials in Civil Engineering*, 35(1): 04022372(1-15). [https://doi.org/10.1061/\(ASCE\)MT.1943-5533.0004538](https://doi.org/10.1061/(ASCE)MT.1943-5533.0004538)
- Zeng, Y., Zhou, X., Tang, A., and Sun, P. (2020). Mechanical properties of chopped basalt fiber-reinforced lightweight aggregate concrete and chopped polyacrylonitrile fiber reinforced lightweight aggregate concrete. *Materials*, 13(7):1715. <https://doi.org/10.3390/ma13071715>
- Zhang, G., He, Y., Wang, H., Zhang, T., Wang, S., and Yang, X. (2017). New technology for recovering residual metals from nonmetallic fractions of waste printed circuit boards. *Waste Management*, 64:228-235. <https://doi.org/10.1016/j.wasman.2017.03.030>