Experimental Investigation on Utilization of E-Waste in Concrete-Taguchi's Approach: A Review

Vivek Pratap Maurya[1], Mr. Rajneesh Kumar[2]

[1]*Master of Technology in Civil Engineering, Lucknow Institute of Technology, Lucknow, India*
[2]*Assistant Professor, Civil Engineering, Lucknow Institute of Technology, Lucknow, India*

---***---

Abstract - *The cement-free wastepaper-based lightweight block (CWLB) is a newly created eco-friendly non-load bearing block made mostly from cellulosic wastes. Wastepaper aggregate (WPA), waste additive, and sand are the major components of CWLB. This research was carried out in order to discover the best mix composition as well as the strength and stiffness attributes that go with it. The Taguchi statistical optimisation method (TSOT) was used to optimise the mix composition of CWLB, as well as to determine the compressive strength, density, elastic modulus, and ultrasonic pulse velocity (UPV) of the best CWLB specimen. According to the results of the TSOT, the ideal CWLB mix composition includes processing characteristics such as a 2.5 WPA/sand ratio, 0.75 water/binder ratio, and 3.5 metric tonne (i.e. 13.7 MPa) compacting force. The ideal CWLB also had an average compressive strength of 2.71 MPa, an average density of 901.5 kg/m3, an average UPV of 989.9 m/s, and an estimated elastic modulus of 883.4 MPa, according to the findings. When these attributes are compared to the necessary standard criteria, it is clear that CWLB is suitable for non-load bearing applications. Furthermore, the inclusion of 75% waste material in the CWLB mix composition demonstrates its eco-friendliness and potential to contribute to building sector sustainability by reducing natural resource use. The creation of a suitable optimal mix composition of component materials for the innovative CWLB, the discovery of elements that impact its strength qualities, and the assessment of its engineering properties are all examples of innovation reported in this work. Other features of CWLB that will be investigated in the future include capillary water absorption, thermal conductivity, and fire response.*

Key Words: Taguchi method, compressive strength, non -load bearing, block, Wastepaper, Mix composition, Optimization, Density, Ultrasonic pulse velocity (UPV), Elastic modulus.

1. INTRODUCTION

In the construction business, concrete is the most widely utilised construction material [1]. It is a widely utilised man-made construction material that is sometimes referred to as the second most important substance used on the planet after water [2,3]. The building industry's needs and advances have been greatly raised as a result of fast rising industrialisation, urbanisation, and population [4]. Because of its low cost, the convenience of its raw materials, great compressive strength, and durability, concrete has become more important in the building sector [5]. The features of aggregates, which generally account for 65–80 percent of the volume of concrete, have a considerable impact on its qualities [6]. By the end of 2025, the global aggregates construction industry predicts that aggregate consumption will have climbed by 59 percent [7]. Many nations are currently experiencing issues as a result of a scarcity of natural resources, and they must rely on imports to meet their needs [8]. Concrete components are widely employed, and the use of coarse aggregates from rocks results in a rapid depletion of natural resources, resulting in calamities such as global warming and land slide. The conservation of raw resources must be stressed to decrease the negative consequences connected with concrete manufacturing [9,10]. The rate of obsolescence of electronic equipment has grown as a result of technical innovation, updates, and progress of technological items, making E-waste a rising waste in the globe. The degrading process of E-waste is comparably more difficult than that of other waste materials, causing substantial environmental damage. According to reports, the output of plastic items reached over 299 million tonnes in 2013 [23]. The Environmental Protection Agency (EPA) of the United States (US) estimates that annual E-waste creation rises by 6–10 percent, with barely 5 percent recycled globally [24]. To safeguard the environment from the harmful, unpleasant, and destructive consequences of E-waste goods, proper recycling and disposal are required. Incorporating waste plastic into the building sector is the greatest way to combat this problem. The usage of E-waste as a concrete aggregate alternative can assist to mitigate and address the environmental pollution issues associated with plastic. E-waste recycling is an excellent method for decreasing solid waste and lowering dangerous and damaging environmental effects [12]. In comparison to natural aggregate, E-waste aggregate is lower in weight, reducing fuel consumption and associated expenses during transportation. Furthermore, the cost of manufacture is quite low. As a result, plastic concrete may be utilised as a lightweight material with a variety of benefits, including ease of handling during consumption, reduced production effort, and acceptable thermal insulation [25]. Furthermore, earthquake forces are determined by the structure's self-weight, and the usage of plastic aggregate can reduce the self-weight of concrete buildings, reducing seismic effects [26]. Durability, in addition to strength, is a key feature of structural concrete. Durability tests were also conducted to analyse the durability properties of plastic concrete [35,36], which revealed that concrete containing plastic aggregate is acceptable and has better results than control concrete. It was discovered that the plastic concrete appears to be suitable for use in aquatic structures, as durability is a significant problem in marine constructions [5], and the plastic concrete has showed superior resistance to sulphate and chloride attack when compared to control concrete [8,37]. Furthermore, recent research has shown that the workability of concrete containing plastic aggregates improves above control concrete due to the plastic aggregate's negligible water absorption capability [11,15]. Because of their enhanced toughness, plastic aggregates have been claimed to have higher abrasion resistance than natural aggregates [38]. According to Zeeshan et al. [32], the ultrasonic pulse velocity (UPV) value decreases as the quantity of plastic aggregate in concrete increases. At 10%, 15%, and 20% partial substitution of NCA with PCA, the UPV value reduced by 1.2 percent, 1.9 percent, and 3.3 percent, respectively. However, no research has been done on the behaviour of produced plastic aggregate concrete when subjected to alternating wetting and drying (W–D).

Figure-01: E-Waste

1.1 Taguchi Method

The Taguchi method [20] is a statistical optimisation methodology invented by Genichi Taguchi in the 1950s. It's a design of experiment DOE [21] technique based on quality philosophy that aims to create goods and processes that are resistant to environmental and other sources of variation. The extent to which a product or process can run effectively and consistently with minimum influence from unpredictable noise elements caused by operation or production may be characterised as robustness [21]. The Taguchi technique to product development provides design engineers with a method for identifying near-optimal design parameters for quality performance that is both efficient and structured. The Taguchi approach incorporates the idea of signal-to-noise ratio, which allows for the evaluation of the variability of performance response compared to the intended value under various noise situations. Taguchi's technique understands that certain elements that generate variability in product development may be managed, while others are uncontrolled. Noise factors are the uncontrolled variables. The discovery of controllable variables is critical in Taguchi DOE because noise factors are regulated during experimentation to drive variability, which leads to the determination of optimal control factor settings that make the process or product robust or resistant to noise factor fluctuation. Noise issues are thought to be the source of performance variability and product failure. The S/N ratio can be used to assess the consistency of an output characteristic's performance [22].

2. LITERATURE REVIEW

[1] Lakshmi, Nagan [2010] The goal of this research was to develop efficient techniques to repurpose hard plastic waste particles as concrete aggregate. The following are the findings of a study of the strength qualities of concrete incorporating recycled waste plastic and fly ash: It has been discovered that e-waste may be recycled into building materials. Because e-waste is ineffective as a fine aggregate replacement, it is utilised to replace coarse material. In contrast to controlled concrete specimens, the compressive strength and split tensile strength of concrete containing e plastic aggregate is maintained more or less. When the e-plastic percentage was greater than 20%, however, the strength was considerably reduced. The addition of fly ash to the mix enhances the strength index of both the control and e-waste concrete significantly. Although the strength development of fly ash-based e plastic concrete was discovered to be weaker in the early days, 28 days of compressive and split tensile strength has proved results in comparison to controlled concrete up to 25% e plastic substitution. It has been determined that 20% E-waste aggregate may be used as a coarse aggregate substitute in concrete with no long-term negative impacts and adequate strength development qualities.

[2] Nadeem, Arun [2012] The compressive strength of concrete rose by 4% to 6% when coarse and fine aggregates were replaced from 30% to 50% of the total. In M20, M30, and M40 grade concrete, however, the compressive strength rose by 5% to 7% for coarse aggregate and reduced by 7% to 10% for fine aggregate at 100% replacement over control mixes. In all combinations, 100% replacement of conventional crushed coarse aggregate with slag aggregate increased flexure and split tensile strength by roughly 6% to 8%. The rough surface roughness, which provided strong bonding and adhesion between aggregate particles and cement paste, was credited with the increase in strength. When natural fine aggregate was replaced with slag fine aggregate, the strength improved by 50% to 6%, but was lowered by 6 to 8% at 100% replacements. The presence of coarser particle sizes, which may be addressed by the inclusion of finer materials, could be the cause of the drop in strength for 100 percent replacement. The analysis revealed that Taguchi's optimisation technique aided in identifying the elements influencing the findings. Based on the foregoing summaries and conclusions, it could be suggested that slag, due to its chemical composition and chemical inertness to aggregate and concrete, could be effectively used as aggregates (coarse and fine) in all concrete constructions, including plain concrete and reinforced cement concrete, including pavement concrete, either as partial or full re- placements over a 50 to 100 percent observed range. Because such slag performs similarly to ordinary aggregates, their immediate usage in plain and reinforced concrete, including pavements, would greatly cut building costs.

[3] Rajeswari et al [2015] The Taguchi technique was presented for determining the ideal combination with various responses for concrete containing RCA and NS in this study. With responses compressive strength, split tensile strength, flexural tensile strength, modulus of elasticity, rebound number, and ultrasonic pulse velocity, control factors such as water/cement ratio, recycled coarse aggregate (percent), maximum cement content (kg m-3), and Nano-Silica (percent) were chosen. The outcomes of the experiments are evaluated using ANOVA, and the conclusions of the analysis are explained. According to the statistical analysis of the 28-day CS, all of the specified parameters had a substantial impact on the test outcomes. Among these parameters, however, the W/C ratio and NS(percent) are more relevant than the other two. The effect of the control factor W/C ratio is ranked one, followed by NS(percent), indicating that W/C ratio and NS (percent) have more influence factors than the other two components, according to the split tensile strength data. In the case of flexural strength findings, a similar observation may be made. However, the factor RCA(percent) is determined to be the most important among all other components in the examination of elastic modulus test data. The relevance of each element is assessed by analysing non-destructive test findings. The impact of the W/C ratio and NS(percent) is likewise corroborated by the results of the research. In most situations, the W/C ratio and NS (percent) are dominant variables, according to the ANOVA analysis. Verification studies were carried out to examine the performance of the chosen mix proportions, and the error between the experimental and predicted values was determined to be within acceptable bounds.

[4] Bevan Jayrajsinh [2015] Various forms of e-plastic waste have been used as aggregate in concrete in a few studies. According to the investigations, e-plastic waste may be utilised as a partial substitute for natural aggregate. The following conclusions may be derived from the findings of these studies: E-plastic can be utilised to replace coarse aggregate in concrete by up to 50% by volume. An increase in E-plastic lowered compressive, splitting tensile, and flexural strength. It is advised that up to 30% replacement by volume be done; the distinctive strength of concrete was attained up to this point. [7]. The loss in tensile splitting strength and flexural strength caused by the addition of e-plastic aggregate was less pronounced than the drop in concrete compressive strength. When coarse aggregate is replaced with e-waste plastic in concrete, the concrete's durability metrics are also affected. The durability of concrete using e-plastic particles has received little attention. Existing statistics, on the other hand, reveal that permeability metrics also confirm that E-plastic concrete's durability is adequate, but somewhat lower than conventional concrete's. Due to the inclusion of several forms of e-plastic aggregates, shrinkage is significantly enhanced. With the addition of fly ash in e-plastic concrete, chloride and sulphate attack tests revealed that e-plastic concrete might result in a thick matrix. To build or achieve effective strength and durability features, e-waste plastic may be utilised to substitute coarse aggregate in concrete with different admixtures such as fly ash, silica fume, and so on.

[5] Panneer, Gopala [2015] The goal of this research was to develop efficient techniques to repurpose hard plastic waste particles as coarse aggregate. It's also been discovered that replacing 20% of the coarse material with E-Waste improves the compressive strength of concrete. The compressive strength is deteriorating beyond that point. The following are the outcomes: It has been discovered that e-waste may be recycled into building materials. Because e-waste is ineffective as a fine aggregate replacement, it is utilised to replace coarse material. In contrast to controlled concrete specimens, the compressive strength and split tensile strength of concrete containing e plastic aggregate is maintained more or less. When the e-plastic percentage was greater than 20%, however, the strength was considerably reduced. It may be determined that 20% of E-waste aggregate can be used as a coarse aggregate substitute in concrete with no long-term negative consequences and adequate strength development qualities.

[6] Ashwini Manjunath [2016] Plastics can be used to replace some of the aggregates in a concrete mixture, according to the findings of several experiments conducted by various researchers. This adds to the concrete's unit weight being reduced. This is suitable in applications that need for non-bearing lightweight concrete, such as facade panels. Plastics in the mix reduce the density, compressive strength, and tensile strength of concrete for a given w/c. Plastics in concrete tend to make it ductile, enhancing its capacity to flex greatly before failure. This property makes concrete helpful in circumstances where it will be exposed to extreme weather conditions such as expansion and contraction, or freeze and thaw. From an energy standpoint, using recycled aggregates in the concrete of the structures under examination is helpful.

[7] Aditya et al [2016] We concluded from this experiment that E-plastic may be disposed of by employing it as a building material. As a result, there is less pollution in the environment and less waste to be disposed of in landfills. In harsh chemical assault circumstances, E-plastic-containing concrete performs similarly. Because e-plastic concrete has a lower density than traditional concrete, lightweight concrete buildings may be built. We discovered that e-plastic concrete had greater workability than traditional mix concrete by comparing slump values for the same W/C ratio; it reduces admixture costs, resulting in cost-effective concrete. The results showed that concrete incorporating e-plastic is more resistant to sulphate assault.

[8] Gayathri et al [2016] Based on earlier research, the Geopolymer mix envisaged for this project with the substitution of E-Waste was shown to be feasible and cost-effective. In this study, industrial wastes fly ash and GGBS completely replace cement. The following conclusions were drawn from the research. It has been proven in previous investigations that incorporating E-waste has little effect on the characteristics of geopolymer concrete. With 90% fly ash and 10% GGBS, the first setting time was 19.9 hours. The typical consistency was achieved at a rate of 28%. It is cost-effective to utilise E-waste as a partial replacement for fine aggregate. E-waste reuse decreases environmental risks. Partially substituting Ewaste for fine aggregate resulted in well-graded aggregate.

[9] Saranya et al [2017] Compressive strength and split tensile strength for various replacements of coarse aggregate (32 percent, 32 percent, 36 percent, 38 percent) by E-waste were investigated in this study. The optimal replacement percentage is 34 percent. It has a higher strength than traditional concrete. In comparison to traditional concrete building, e-waste concrete delivers a high level of non-permeability and safety. E-waste is recommended in concrete for cost-effective building based on the findings.

[10] Asha, Sangeetha [2017] It may be deduced that E-plastic can only be used as a partial replacement for natural aggregate in small quantities, and that adding e-fiber improves the strength qualities. It should be noted that while the compressive strength of E-plastic concrete is equivalent to that of ordinary concrete, E-plastic may be used to manufacture compressive members up to 15% of the time. The results demonstrate that specimens with 15% coarse aggregate replacement and 0.8 percent E-fibre added had a compressive strength improvement of 8.8 percent when compared to the control specimen. In comparison to the control specimen, specimens with 15% coarse aggregate replacement and 0.8 percent E-fibre addition had a 2.26 percent improvement in tensile strength. Because E-plastic is lighter than natural aggregates, it reduces the volume of concrete, and this loss in concrete volume may cause a drop in strength as the amount of E-plastic waste increases. Lightweight roofs, curbs, road dividers, partition walls, and other non-load-bearing building elements can all benefit from the E-plastic replacement concrete. Two objectives may be completed with the replacements: trash disposal and alternative material for replacing natural aggregate.

[11] Nuruddin, Bayuaji [2018] The Taguchi technique is used to develop a novel method for determining the optimal material proportions and the influence of MIRHA characteristics on the qualities of foamed concrete. Because LWFC has a large number of components, the Taguchi technique with an L16 (45) orthogonal array is used to examine the ranking of the effective parameters and the optimum potential mix proportions for LWFC. By minimising the number of trial batches, the Taguchi approach can simplify the test procedure necessary to optimise the mix fraction of LWFC, according to the results of this study. This study shown that it is feasible to construct foamed concrete that meets the high strength lightweight concrete criterion.

[12] Jafar et al [2018] An experiment was conducted on concrete utilising e-waste as coarse aggregate, and the following findings were discovered. It has been discovered that e-waste may be recycled into building materials. Because e-waste cannot be used to replace fine material, it is better suited for coarse aggregate replacement. Concrete specimens using e-waste aggregate can have the same compressive and split tensile strengths as conventional concrete specimens. When the e-waste percentage was greater than 20%, however, the strength was considerably reduced. It has been determined that 20% of E-waste aggregate may be used as coarse aggregate replacement in concrete without causing long-term problems and with appropriate strength development qualities.

[13] Salmabanu, Ismail [2020] The following conclusions are drawn from the results of the experiments: The most important elements in increasing the compressive strength of rubberized geopolymer concrete are the curing temperature, NaOH concentration, and sodium silicate to NaOH ratio. According to the ANOVA approach, they were ranked 1, 2, and 3 accordingly. An increase in the values of these parameters was shown to enhance the compressive resistance of rubberized geopolymer concrete. The evaporation of water caused by a longer cure period after 48 hours lowered the strength of rubberized concrete. The compressive strength of rubberized geopolymer concrete is highest when the alkaline solution to fly ash ratio is 0.35, the sodium silicate to sodium hydroxide ratio is 2.5, the concentration of NaOH is 14M, the cure temperature is 90°C, the cure time is 48 hours, the water content is 20%, the rest period is one day, and the superplasticizer is 2%.

[14] Aniket et al [2020] There is a bond content that provides a most concrete quality for a certain arrangement of resources in a partner degree passing concrete blend [29]. As a result, one of the most insightful approaches to improve quality will be to utilise ash among the blend e-waste ash proportioned utilising the ideas presented in this work has appeared to bless attributes above and above those supplied by a bond concrete [30]. The proportioning move proposed throughout this research allows for the use of a greater than average change of E-waste ash. However, it has been observed that the variety of that quality a portion of the mean is more important than the nature of the e-waste fiery remains [31]. Astute cement is often proportioned with a partner degree of intermittent quality fiery until the quality does not deviate significantly [32]. The most advantageous position for employing e-waste fiery remains in cement is the freedom it provides in terms of mix extents [33]. A rather extensive range of probable mixes is routinely investigated for any determination using the fiery remnants [34]. It's the capacity to choose between the least valuable mix, the best to place, or the most difficult [35] in each case. E-waste flammable debris has a lower unit weight, which means that the larger the offer of ash among the glue, the higher the greased up totals are, and thus the higher the concrete streams. E-waste flammable debris consolidates with lime in concrete over time, increasing compressive quality. It enables the concrete blend to earn a life of the highest quality in a shorter period of time. This proves that e-waste flammable residues may be used as a viable material in concrete road surface [36].

[15] Joshi et al [2020] The following are the particular findings of the research: When samples are carefully chosen and crushed, the physical and mechanical characteristics of NCA and RCA exhibit a reasonable variety. It may be assumed that building demolition rubble, if properly selected, cleaned41, and crushed, might be used for structural purposes. Taguchi's OA18 orthogonal array research revealed that mix design optimisation is simple. Thus, the Taguchi approach is thought to aid in the efficient and cost-effective optimisation of mix design. When RCA was applied at levels 0 and 2, the compressive strength was lower than when it was utilised at levels 1 and 3. It was deduced that using Taguchi's orthogonal array design approach made achieving the optimal mix simple, and this was proven by the software-based technique. As a result, the Taguchi approach is found to be a better strategy for optimising mix design than the traditional way. When it came to the mechanical characteristics of concrete, compressive and flexural strength were effectively attained, although splitting tensile strength of concrete showed a minor variance. This can be due to inadequate aggregate-to-mortar bonding, which was confirmed by a microstructure investigation of cured concrete. At the conclusion of 56 days, it may be deduced that initial strength is due to binary cement mixing, and ultimate strength may rise owing to subsequent hydration of pozzolanic material in the concrete. To get a good picture of strength, it's advised that the eco-friendly concrete's strength be tested after 56 and 91 days of curing. It is also suggested that the Taguchi technique be used to test the durability of environmentally friendly concrete.

[16] Rituraj, Dr. Divya [2020] After reviewing all studies, we discovered that the strength of concrete was degraded by increasing the percentage of E-plastic waste, that there was a lack of adhesion between the concrete matrix and the E-plastic waste, that there was a lack of work on permeability, workability, and durability of concrete, and that these gaps needed to be filled. I'm excited to work on concrete innovation to improve its properties by using E-plastic waste as a replacement for coarse and fine aggregate at a greater percentage (> 20%), as well as the addition of supplemental cementation materials such as fly ash and silica fume.

[17] Chen et al [2021] To investigate the possibility of generating low-density CLSM, dimension stone sludge was utilised to substitute fine aggregates, and lightweight aggregates were used to replace regular coarse aggregates. The results of the tests demonstrated that producing low-density CLSM with stone sludge and lightweight particles was quite possible. The following conclusions can be formed based on the above-mentioned test findings and analysis. The use of more stone sludge to substitute fine particles lengthened the time it took for the concrete to set. Furthermore, most specimens' compressive strength at 28 days did not surpass the top limit of 8.83 MPa set by Taiwan's Public Construction Commission. The Taguchi technique may be used to optimise the process parameters of generating controlled low-strength materials employing dimension stone sludge and lightweight aggregates, given the varied technical requirements of CLSM. The stone sludge dosage, lightweight aggregate dosage, water–binder ratio, and accelerator dosage were the most important control parameters in lowering the unit weight of CLSM. Furthermore, the ANOVA findings revealed that the stone sludge dose was the most important factor impacting unit weight, with a contribution percentage of 90.95 percent. The stone sludge dosage, the water–binder ratio, the accelerator dosage, and the lightweight aggregate dosage were the most important control parameters for improving CLSM's 12-hour compressive strength. Furthermore, the ANOVA findings revealed that the stone sludge dosage was the most important component impacting compressive strength, with a contribution percentage of 60.22 percent. The following mixture design of the large-scale production CLSM containing stone sludge was chosen based on the performance of the fresh properties, compressive strength, utilisation rate of renewable resources, and economy: a water–binder ratio of 1.1, an amount of accelerator agent of 3%, replacement of 60% fine aggregates with stone sludge, and a lightweight aggregate content of 250 kg/m3. The quantity of stone sludge in these combination proportions was greater, and the mechanical performance met CLSM criteria. Stone sludge CLSM has a material cost per cubic metre that is around NT$1079.5 less than standard public works CLSM, resulting in a cost reduction of 60.7 percent. In terms of cost, the manufacture of CLSM from stone sludge is quite competitive.

3. CONCLUSION

In the case of flexible concrete, the influence of the water-cement ratio on strength growth is minimal. The reason for this is that plastic particles weaken the concrete's binding strength. As a result, the link between the cement paste and the plastic particles fails, resulting in concrete failure. Geopolymer concrete is a type of green concrete that is also environmentally beneficial since it minimises CO2 emissions. Partially replacing E-Waste is a relatively new method of disposing of non-metallic E-Waste. E-plastic may be utilised as a coarse and fine aggregate to partially replace traditional aggregates, preserving natural aggregates and resulting in an environmentally sustainable building. E-plastic may be used as a coarse and fine aggregate up to 10% of the time. Both coarse and fine aggregates provide equivalent outcomes when replaced by 10%. For 14, 28 days, the hardening parameters of traditional concrete and e-plastic concrete are equivalent, with less strength fluctuation.

REFERENCES

[1] Iqbal, M.; Zhao, Q.; Zhang, D.; Jalal, F.E.; Jamal, A. Evaluation of tensile strength degradation of GFRP rebars in harsh alkaline conditions using non-linear genetic-based models. Mater. Struct. 2021, 54, 1–20. [CrossRef]

[2] Ali, K.; Qureshi, M.I.; Saleem, S.; Khan, S.U. Effect of waste electronic plastic and silica fume on mechanical properties and thermal performance of concrete. Constr. Build. Mater. 2021, 285, 122952. [CrossRef]

[3] Vashisht, R.; Shukla, A. Potential application of bacteria to improve the self-healing and strength of concrete. J. Build. Pathol. Rehabil. 2020, 5, 1–13. [CrossRef]

[4] Ahmad, F. Influence of nano graphite platelets on the behavior of concrete with E-waste plastic coarse aggregates. Constr. Build. Mater. 2021, 316, 125980. [CrossRef]

[5] Santarsiero, G.; Masi, A.; Picciano, V. Durability of Gerber Saddles in RC Bridges: Analyses and Applications (Musmeci Bridge, Italy). Infrastructures 2021, 6, 25. [CrossRef]

[6] Gasperi, J.; Wright, S.L.; Dris, R.; Collard, F.; Mandin, C.; Guerrouache, M.; Langlois, V.; Kelly, F.J.; Tassin, B. Microplastics in the air: Are we breathing it in? Curr. Opin. Environ. Sci. Health. 2018, 1, 1–5. [CrossRef]

[7] Saikia, N.; De Brito, J. Use of plastic waste as aggregate in cement mortar and concrete preparation: A review. Constr. Build. Mater. 2012, 34, 385–401. [CrossRef]

[8] Suchithra, S.; Kumar, M.; Indu, V. Study on replacement of coarse aggregate by E-waste in concrete. Int. J. Tech. Res. Appl. 2015, 3, 266–270.

[9] Paul, S.C.; Šavija, B.; Babafemi, A.J. A comprehensive review on mechanical and durability properties of cement-based materials containing waste recycled glass. J. Clean. Prod. 2018, 198, 891–906. [CrossRef]

[10] Ragaert, K.; Delva, L.; Van Geem, K. Mechanical and chemical recycling of solid plastic waste. Waste Manag. 2017, 69, 24–58. [CrossRef] [PubMed]

[11] Alagusankareswari, K.; Kumar, S.S.; Vignesh, K.; Niyas, K.A.H. An experimental study on e-waste concrete. Indian J. Sci. Technol. 2016, 9. [CrossRef]

[12] Manikandan, M.; Arul Prakash, D.; Manikandan, P. Experimental Study On E-Waste Concrete And ComparingWith Conventional Concrete. Jr. Ind. Pollut. Control 2017, 33, 1490–1495.

[13] Manjunath, B.A. Partial replacement of e-plastic waste as coarse aggregate in concrete. Procedia Environ. Sci. 2016, 35, 731–739. [CrossRef]

[14] Prasanna, P.K.; Rao, M.K. Strength variations in concrete by using E-waste as coarse aggregate. J. Educ. Appl. Res. 2014, 4. Available online: http://ijear.org/vol4/spl2/ec0046.pdf (accessed on 23 November 2021).

[15] Rumpf, H. The characteristics of systems and their changes of state disperse. In Particle Technology, Chapman and Hall; Springer: Berlin/Heidelberg, Germany, 1990; pp. 8–54.

[16] Ali, B.; Qureshi, L.A.; Shah, S.H.A.; Rehman, S.U.; Hussain, I.; Iqbal, M. A step towards durable, ductile and sustainable concrete: Simultaneous incorporation of recycled aggregates, glass fiber and fly ash. Constr. Build. Mater. 2020, 251, 118980. [CrossRef]

[17] Kurad, R.; Silvestre, J.D.; de Brito, J.; Ahmed, H. Effect of incorporation of the high volume of recycled concrete aggregates and fly ash on the strength and global warming potential of concrete. J. Clean. Prod. 2017, 166, 485–502. [CrossRef]

[18] Bahij, S.; Omary, S.; Feugeas, F.; Faqiri, A. Fresh and hardened properties of concrete containing different forms of plastic waste–A review. Waste Manag. 2020, 113, 157–175. [CrossRef]

[19] Tamanna, N.; Tuladhar, R.; Sivakugan, N. Performance of recycled waste glass sand as partial replacement of sand in concrete. Constr. Build. Mater. 2020, 239, 117804. [CrossRef]

[20] Ahmad, F. Optimum values for mixing ratio and tire shred size of sand tire mix. In Proceedings of the 1st Conference on Sustainability in Civil Engineering, CUST, Islamabad, Pakistan, 1 August 2019.

[21] Ahmad, A.; Adil, M.; Khalil, A.; Rahman, M. Mechanical properties and durability of board create blocks prepared from recycled cardboard. J. Build. Eng. 2021, 33, 101644. [CrossRef]

[22] De la Colina Martínez, A.L.; Barrera, G.M.; Díaz, C.E.B.; Córdoba, L.I.Á.; Núñez, F.U.; Hernández, D.J.D. Recycled polycarbonate from electronic waste and its use in concrete: Effect of irradiation. Constr. Build. Mater. 2019, 201, 778–785. [CrossRef]

[23] Barnes, D.K.; Galgani, F.; Thompson, R.C.; Barlaz, M. Accumulation and fragmentation of plastic debris in global environments. Philos. Trans. R. Soc. B Biol. Sci. 2009, 364, 1985–1998. [CrossRef]

[24] Pramila, S.; Fulekar, M.; Bhawana, P. E-waste-A challenge for tomorrow. R Res. J. Recent Sci. ISSN. 2012, 2277, 2502.

[25] Colangelo, F.; Cioffi, R.; Liguori, B.; Iucolano, F. Recycled polyolefins waste as aggregates for lightweight concrete. Compos. Part B Eng. 2016, 106, 234–241. [CrossRef]

[26] Akçaözo˘ glu, S.; Ati¸s, C.D.; Akçaözo˘ glu, K. An investigation on the use of shredded waste PET bottles as aggregate in lightweight concrete. Waste Manag. 2010, 30, 285–290. [CrossRef]

[27] Shinu, N.M.T.; Needhidasan, S. An experimental study of replacing conventional coarse aggregate with E-waste plastic for M40 grade concrete using river sand. Mater. Today Proc. 2020, 22, 633–638. [CrossRef]

[28] Sabau, M.; Vargas, J. Use of e-plastic waste in concrete as a partial replacement of coarse mineral aggregate. Comput. Concr. 2018, 21, 377–384. [CrossRef]

[29] Tafheem, Z.; Rakib, R.I.; Esharuhullah, M.; Alam, S.R.; Islam, M.M. Experimental investigation on the properties of concrete containing post-consumer plastic waste as coarse aggregate replacement. J. Mater. Eng. Struct. 2018, 5, 23–31.

[30] Kumar, K.S.; Baskar, K. Recycling of E-plastic waste as a construction material in developing countries. J. Mater. Cycles Waste Manag. 2015, 17, 718–724. [CrossRef]

[31] Rathore, V.; Rawat, A. Effective utilization of electronic waste in concrete mixture as a partial replacement to coarse aggregates. In Proceedings of the International Conference on Sustainable Materials and Structures for Civil Infrastructures (SMSCI2019), Bhopal, India, 25 September 2019; AIP Publishing LLC: Melville, NY, USA; Volume 2158, p. 020037.

[32] Ullah, Z.; Qureshi, M.I.; Ahmad, A.; Khan, S.U.; Javaid, M.F. An experimental study on the mechanical and durability properties assessment of E-waste concrete. J. Build. Eng. 2021, 38, 102177. [CrossRef]

[33] Nadhim, S.; Shree, P.N.; Kumar, G.P. A Comparative Study On Concrete Containing E-Plastic Waste And Fly Ash Concrete With Conventional Concrete. J. Sci. Technol. 2016. Available online: http://gist.edu.in/gist/wp-content/uploads/2019/03/ Parishodhana-2018-1.pdf#page=31 (accessed on 23 November 2021).

[34] Akram, A.; Sasidhar, C.; Pasha, K.M. E-waste management by utilization of E-plastics in concrete mixture as coarse aggregate replacement. Int. J. Innov. Res. Sci. Eng. Technol. 2015, 4. Available online: http://www.ijirset.com/upload/2015/july/8_E-Waste.pdf (accessed on 23 November 2021).

[35] Lakshmi, R.; Nagan, S. Investigations on durability characteristics of E-plastic waste incorporated concrete. Asian J. Civ. Eng. (Build. Hous.) 2011, 12, 773–787.

[36] Lakshmi, R.; Nagan, S. Utilization of waste E plastic particles in cementitious mixtures. J. Struct. Eng. 2011, 38, 26–35.

[37] Gourmelon, G. Global plastic production rises, recycling lags. Vital Signs 2015, 22, 91–95.

[38] Ferreira, L.; de Brito, J.; Saikia, N. Influence of curing conditions on the mechanical performance of concrete containing recycled plastic aggregate. Constr. Build. Mater. 2012, 36, 196–204. [CrossRef]

[39] ASTM C1602/C1602M-12Standard Specification for Mixing Water Used in the Hydraulic Cement Concrete, ASTM International: West Conshohocken, PA, USA, 2012.

[40] ASTM C150Standard Specification for Portland Cement, ASTM International: West Conshohocken, PA, USA, 1994.

[41] Rutkowski, J.V.; Levin, B.C. Acrylonitrile–butadiene–styrene copolymers (ABS): Pyrolysis and combustion products and their toxicity—a review of the literature. Fire Mater. 1986, 10, 93–105. [CrossRef]

[42] ASTM C143/143M-10aStandard Test Method for Slump of Hydraulic-Cement Concrete, Annual Book of ASTM Standards, American Society for Testing and Materials (ASTM): West Conshohocken, PA, USA, 2010; 4.

[43] ASTM C138/C138M-17aStandard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete, ASTM International: West Conshohocken, PA, USA, 2017.