Malaysian Journal
Of Civil
Engineering

Full Paper

STUDY ON WASTE PCB FIBER REINFORCED CONCRETE

Khandaker Hadiatul Jannat, Mottakin Sheikh, Mahmudul Hasan, Razesh Kanti Sarkar, Sharmin Reza Chowdhury*

Department of Civil Engineering, Ahsanullah University of Science and Technology, 141 & 142, Love Road, Tejgaon Industrial Area, Dhaka, Bangladesh.

Article history
Received
22 January 2025
Received in revised form
18 May 2025
Accepted
19 May 2025
Published online
31 July 2025

*Corresponding author
chowdhury.ce@aust.edu

Graphical abstract

Abstract

The accumulation of electronic waste (e-waste) has become a significant global environmental challenge, driven by the rapid advancement of technology and the widespread use of electronic devices. Addressing this issue requires a sustainable approach to manage and repurpose e-waste effectively. One such solution involves using e-waste, particularly printed circuit board (PCB) fibers, as an additional material in concrete production. This innovative approach not only enhances the properties of conventional concrete but also reduces the volume of electronic waste discarded in the environment. This paper provides a comprehensive overview of utilizing e-waste fiber in concrete. It specifically investigates the mechanical properties of concrete containing PCB fibers in proportions of 1%, 2%, 3%, 4%, and 5% by weight of cement, with aspect ratios of 10, 20, 30, and 40. The findings, based on an extensive literature review, reveal that the size and adding percent distribution of e-waste fibers significantly influence the concrete properties.

Keywords: Electronic waste (E-waste), Sustainable approach, Printed Circuit Board (PCB), Aspect ratio, Concrete Properties.

1.0 INTRODUCTION

Concrete is globally acknowledged as one of the most essential construction materials due to its excellent compressive strength, long-term durability, cost-effectiveness, and ease of use. These properties make it the material of choice for a wide variety of infrastructure applications, such as buildings, roads, bridges, and dams. However, a significant limitation of conventional concrete is its inherently low tensile strength. This deficiency results from its primary constituents—cement and aggregates like crushed stone or gravel—which are inherently weak in tension.

To overcome this mechanical shortcoming, different reinforcement techniques have been adopted. Among these, the use of discrete fibers has emerged as a promising solution. Fibers enhance crack resistance by bridging microcracks and dispersing internal stress more evenly, thereby reducing the risk of crack formation and propagation. Beyond crack control, fiber inclusion also improves compressive, tensile, and flexural strength, resulting in a composite material with enhanced mechanical performance (Zhang et al., 2023). Furthermore, fiber-reinforced concrete (FRC) exhibits improved resistance to abrasion and impact loads (Wu et al., 2023), along with reduced drying shrinkage and long-term creep.

This advanced formulation, known as Fiber Reinforced Concrete (FRC), not only addresses the mechanical limitations of ordinary concrete but also contributes to its overall durability and sustainability (Vishnupriyan and Annadurai, 2023). To complement these advancements, researchers are increasingly investigating the use of recycled materials in concrete, among them, waste components like printed circuit boards (PCBs), as illustrated in the following Figure 1.

Figure 1 Recycled PCB (Newbury Electronics 2023)

While enhancing the performance of concrete is a pressing need, another global issue gaining serious attention is the management of electronic waste. The rapid pace of technological advancements and declining product lifespans have led to a dramatic increase in discarded electronic devices. Printed Circuit Boards (PCBs), being essential to all electronics, constitute a significant portion of this waste, estimated to be around 4% of total electronic waste (Richter et al., 1997).

Globally, over 20 million metric tons of electronic waste are produced each year (Mishra et al., 2018). Waste Printed Circuit Boards (WPCBs), in particular, are growing at a rate of approximately 8.7% annually (Priyan et al., 2023). According to Ghimire et al. (2020) and Forti et al. (2020), the global generation of electronic waste reached approximately 53.6 million metric tons in 2019. This figure represents an average of 7.3 kilograms per person and is expected to rise to 65.3 million metric tons by 2025.

Certain electronic devices contribute heavily to WPCB generation, including mobile phones (21.30%), personal computer control units (18.76%), and color televisions (7.04%) (Duan et al., 2011). Table 1 provides a clear insight into the regional distribution of WPCB generation along with corresponding recycling rates, offering a comparative understanding of global management practices.

Table 1 The table below presents a regional overview of WPCB generation and environmentally sound recycling rates (Baldé et al., 2022).

Region	Total E-waste Generation (Mt)	Waste Printed Circuit Board Generation (Mt)	Rates of Environmentally Sound WPCBs Collection and recycling (Mt)	Rates of not Environmentally Sound WPCBs Collection and recycling (Mt)
Africa	2.9	0.1	13%	87%
America	13.1	0.3	44%	56%
Asia	24.9	0.6	17%	83%
Europe	12.0	0.3	61%	39%
Oceania	0.7	0.01	31%	69%

Figure 2 below illustrates the proportion of e-waste generated in Bangladesh relative to global e-waste production, highlighting the country's contribution within the broader international context.

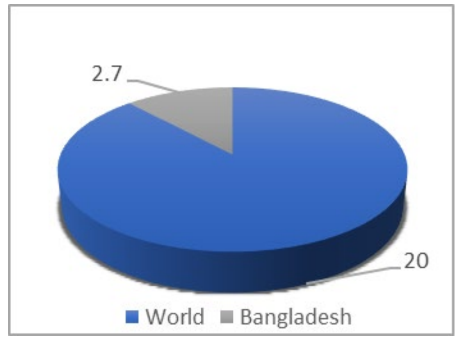


Figure 2 E-waste (Electronic Waste) Generation in Bangladesh Vs World (million MT) (Hossain et al. 2010)

Like other countries of the world, the electronic waste generation rate in Bangladesh also increases. The issue is that Bangladesh has grown to be a desirable location for the disposal of e-waste. One example of the cost difference in recycling is that, in the United States and other developed countries, recycling a PCB costs about $20, whereas in Bangladesh, the same procedure only costs about $2 (Hossain et al. 2011). In Bangladesh and various other developing countries, approximately 20-30% of their total electronic waste is recycled, whereas the majority, around 70-80%, is disposed of in landfills (Yousuf 2011). The leachate generated by landfills, which includes acids produced from melting computer chips, leads to soil acidification and consequently releases harmful metals into both soil and water sources. Waste from Electrical and Electronic Equipment (WEEE) may comprise as many as 1,000 various toxic substances, such as lead, chromium, and plastic additives, posing significant health risks to the population (Department of Environment Ministry of Environment, Forest and Climate Change Government of the People's Republic of Bangladesh 2019).

Metal contents of WPCBs are Be, Pb, Hg, Brominated Flame, Retardants, Sb, Au, Ag, Pd. Among them, Lead and Cadmium are toxic constituents. Due to open burning and the use of acid bath causes air emissions, along with discharges into rivers, can release hazardous substances such as glass dust, tin, lead, brominated dioxins, beryllium, and cadmium. These pollutants can have severe environmental and health impacts (Department of Environment Ministry of Environment, Forest and Climate Change Government of the People's Republic of Bangladesh 2019). Urban areas close to PCB workshops have a significant level of contamination, according to analyses of hazardous components in soils. In comparison to other locations, the amounts of lead (Pb) and copper (Cu) were found to be 371 and 155 times higher, respectively (Leung et al. 2008).

The most dangerous, valuable, and complex parts of electronic waste, or "e-waste," are Waste Printed Circuit Boards (WPCBs), which have been deeply studied and documented in many research papers and reports (Fang et al. 2013, Fu et al. 2013, Labunska et al. 2014, Wu 2010 and Ogunseitan et al. 2009). It is challenging to recycle waste-printed circuit boards (PCBs). Their complexity arises from the intricate manufacturing processes they undergo, involving various specialty chemicals and valuable materials (Xiang et al. 2007). Waste Printed Circuit Boards (WPCBs) contain pollutants such as brominated flame retardants, polybrominated dibenzo-p-dioxins, dibenzofurans, chlorinated dioxins, and polycyclic aromatic hydrocarbons. It is crucial to focus on effective recycling and waste management practices to protect the environment (Huang et al. 2009, Stone 2009 and Wang et al. 2013). Human health is severely impacted by the spread of these hazardous substances through the air, water, and soil. Significant amounts of lead and copper have been detected in residents and employees, especially children, and can cause skin, gastrointestinal, and respiratory problems. Furthermore, there have been recorded situations of leukemia and increased chromium levels found in umbilical cords (Huo et al. 2007, Leung et al. 2006, Li et al. 2008 and Zheng et al. 2008).

To address the environmental challenges posed by Waste Printed Circuit Boards (WPCBs), their recycling and utilization in concrete as fiber reinforcement presents a promising and sustainable solution. This method not only contributes to reducing the growing burden of electronic waste but also supports the development of environmentally friendly construction materials. By incorporating WPCBs into concrete, both ecological and structural benefits can be achieved. On one hand, the reuse of e-waste helps in minimizing landfill disposal and the release of hazardous substances into the environment. On the other hand, it enhances the mechanical performance of concrete.

Research by Nagajothi and Felixkala (2014) demonstrated that the addition of up to 2.5% electronic fiber waste into concrete led to a nearly twofold increase in compressive strength compared to traditional concrete mixes. Furthermore, concrete incorporating such waste fibers exhibited a reduction in density, offering improved thermal insulation and decreased production and transportation costs (Colangelo et al., 2016).
This study focuses on evaluating the performance improvement of concrete by incorporating WPCBs as fiber. The topic holds significance in promoting sustainable construction and effective e-waste management.

2.0 PRINTED CIRCUIT BOARD (PCB) FIBER

Printed Circuit Board (PCB) is a thin board or plate where chips and other electronic parts are mounted. PCBs are made up of different metals such as copper, carbon, aluminum, iron, tin, and lead, as well as non-metals like thermosetting resins and glass fiber (Silica). Silica is indeed the main ingredient in PCBs. Its specific gravity is generally around 2.68, and the tensile strength of PCB fibers can achieve up to 170 MPa (Annadurai et al. 2023). PCBs are typically made from fiberglass fabric that is impregnated with epoxy resin, making them fire-resistant. Figure 3 represents a sample of PCB material, while Figure 4 illustrates a sample of PCB fiber.

Figure 3 PCB (Sonic Manufacturing Technologies 2020)

Figure 4 PCB fiber

2.1 Properties of Printed Circuit Board (PCB) fiber

Table 2 represents an overview of the fundamental properties of Printed Circuit Board (PCB) fibers, which are essential for evaluating their suitability in composite materials.

Table 2 Properties of Printed Circuit Board (PCB) fiber (Marimuthu and Ramasamy 2023)

Property	Values
Tensile strength (N/mm^2)	170
Elongation at peak (mm)	2.45
% Elongation	1.92
Elongation at break	2.67
Specific Gravity	2.68
Water absorption (%)	0.20
Crushing Value (%)	<2
Impact Value (%)	<2

2.2 Process of making PCB fibers

Process of making PCB fiber according to **Priyan et al. 2023-**

Stage 1 Waste PCB collection: The process begins with the collection of waste PCBs from recycling plants. These discarded PCBs serve as the raw material for the fiber production process.

Figure 5 depicts a representative sample of the collected waste PCBs.

Figure 5 Collected Waste PCB

Stage 2 Desoldering: In this stage, a heat gun is employed to loosen the solder that holds components on the PCB. The heat softens the solder, enabling easier removal of the electronic components attached to the board. A visual representation of this desoldering process is provided in Figure 6.

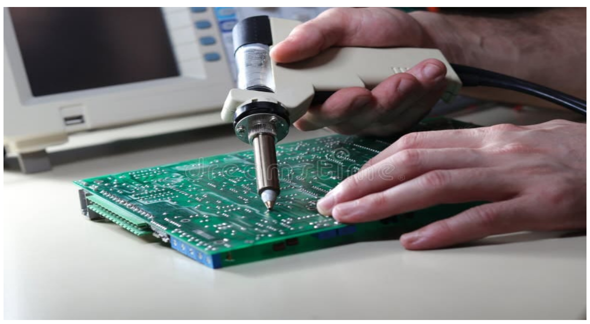
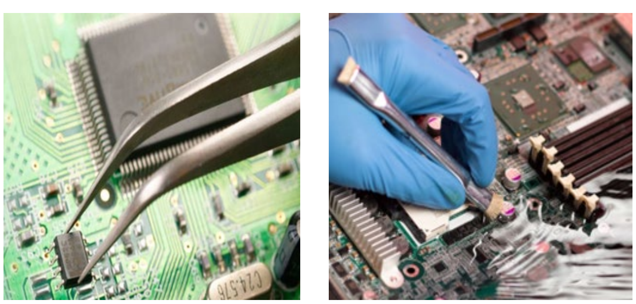


Figure 6 Desoldering process

Stage 3 Removal of Metal and Plastic Components: Once the desoldering process is complete, sharp tools are used to separate the different materials on the PCB physically:

- Plastic components (a) are removed.
- Metal components (b) are extracted.

This step ensures that the PCB is stripped down to its base material. A visual representation of this process is shown in Figure 7.



(a) (b)

Figure 7 Metal and plastic components removal process (a) Metal removal (b) Plastic Removal

Stage 4 PCB Cutting: The stripped PCBs are then cut into uniform strips using a tool and a cutting machine. This machine slices the PCBs into fibers with the desired aspect ratios, shaping them for subsequent applications. Figure 8 shows a sample of how this process is carried out.

Figure 8 Cutting of PCB

Stage 5 PCB Fibers: The process concludes with the production of PCB fiber strips, which are collected as the final output. These fibers are ready to be used in various industries or further processed as required. This systematic approach transforms electronic waste into valuable PCB fibers, promoting recycling and sustainable practices. Figure 9 provides a clear representation of the PCB fiber, which is intended main material for use.

Figure 9 PCB fiber

3.0 SURVEY OF LITERATURE ANTECEDENT TO EXPERIMENTAL ANALYSIS

Many researchers have investigated the impact of adding PCB fibers to concrete. This section overviews the experimental findings from the available literature on PCB fiber-reinforced concrete (PCB-FRC). Notably, Annadurai et al. (2023) worked on PCB fibers with an aspect ratio of 10, while Marimuthu and Ramasamy (2023) focused on PCB fibers with an aspect ratio of 20. Following this, Priyan et al. (2023) concentrated on PCB fibers with aspect ratios of 30 and 40, investigating how these higher aspect ratios impact mechanical behavior.

In the research carried out by Annadurai et al. (2023), the effect of the aspect ratio (AR) (L/W) on PCB fiber reinforced concrete was investigated by using AR 10 PCB fibers. The research was focused on the results of varying the fiber's quantity and dimensions. PCB fiber with an aspect ratio of 10 has a length of 50 mm, a width of 5 mm, and a thickness of 1.6 mm. Concrete of both conventional type and PCB fiber-reinforced type (PCB-FRC) was cast using the M40 mix ratios, following the guidelines set by BIS 10262:2009, and ensuring compliance with the specifications from BIS 9103-1999. The outcomes are presented in Figures 10, 11, and 12, as reported by Annadurai et al. (2023).

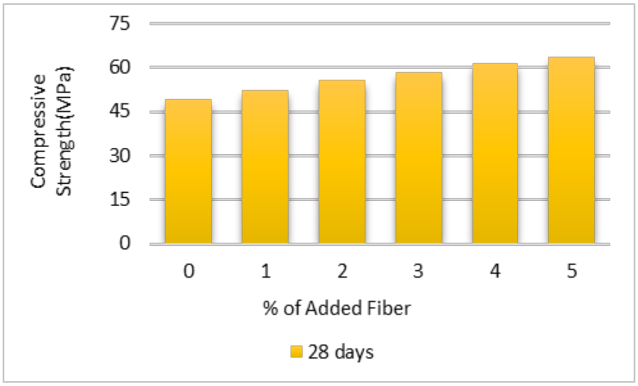


Figure 10 Compressive Strength of Cube specimens (AR 10) (Annadurai et al. 2023)

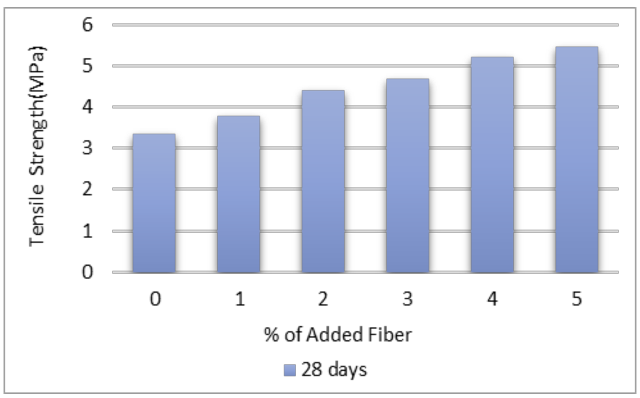


Figure 11 Tensile strength of Cylinder specimens (AR 10) (Annadurai et al. 2023)

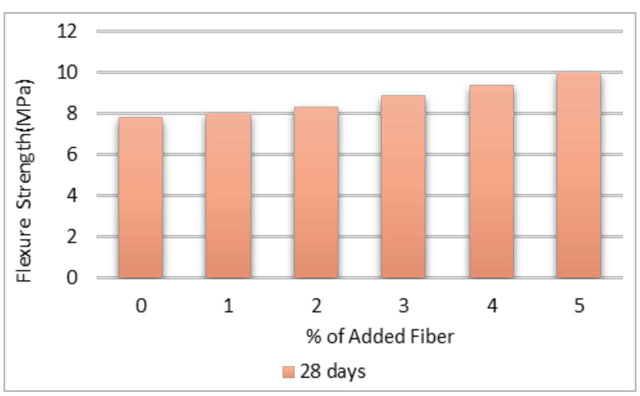


Figure 12 Flexural Strength of Beam (AR 10) (Annadurai et al. 2023)

The three graphs demonstrate the mechanical properties of fiber-reinforced concrete incorporating PCB fiber with an aspect ratio of 10. after 28 days of curing with varying fiber additions, focusing on compressive, tensile, and flexural strengths. The compressive strength of cube specimens shows significant improvement, increasing from 49.35 MPa at 0% fiber content to 63.55 MPa at 5%. This represents an increase of approximately 28.8% compared to the compressive strength of conventional concrete. Similarly, the tensile strength of cylindrical specimens rises consistently from 3.35 MPa at 0% to 5.45 MPa at 5%, reflecting improved resistance to tensile forces. Additionally, the flexural strength of beam specimens improves from 7.8 MPa at conventional concrete to 10 MPa at 5%, demonstrating better resistance to bending. Overall, the addition of fibers effectively enhances the mechanical properties of concrete, with the best performance observed at 5% fiber content.

Marimuthu and Ramasamy (2023), compared the strength of conventional concrete with PCB-FRC using beam, cube, and cylinder specimens. For that reason, PCB fiber with an aspect ratio of 20 and dimensions (length of 50 mm, width of 2.5 mm, and thickness of 1.6 mm) was taken from 0% to 3% by weight of cement. The mechanical behavior after 7 days and 28 days of curing are observed and demonstrated in a graphical representation, as shown in Figures 12, 13, 14, and 15.-

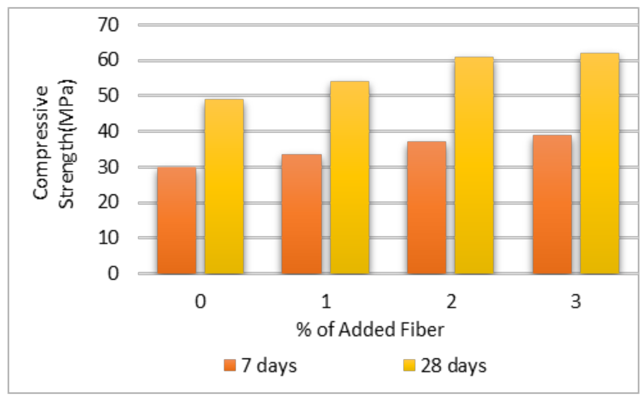


Figure 13 Compressive Strength of Cube specimens (AR 20) (Marimuthu and Ramasamy 2023)

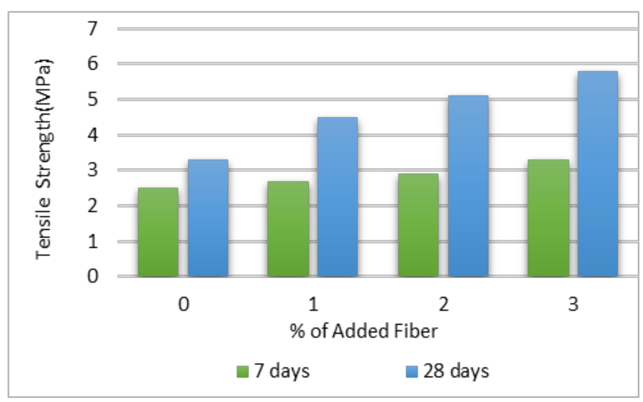


Figure 14 Tensile strength of Cylinder specimens (AR 20) (Marimuthu and Ramasamy 2023)

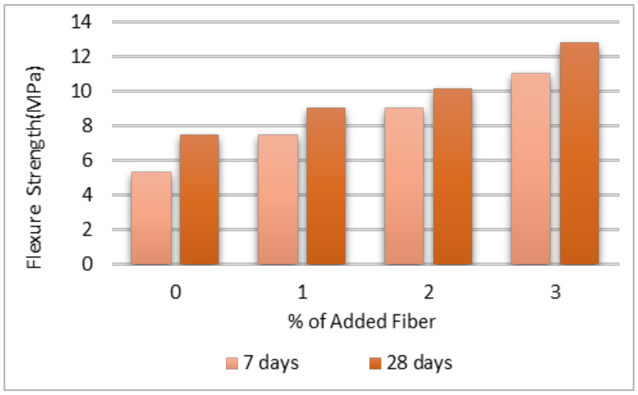


Figure 15 Flexural strength of Beam (AR 20) (Marimuthu and Ramasamy 2023)

The provided graphs illustrate the compressive, tensile, and flexural strengths of concrete with varying percentages of added fiber (0%, 1%, 2%, and 3%) after 7 and 28 days of curing. Here's an explanation of the trends. For compressive strength. At 7 days, the compressive strength rose from 29.8 MPa (conventional concrete) to 39 MPa (3% fiber). At 28 days, the compressive strength also improved with higher fiber content. Conventional concrete exhibited 49 MPa, while the 3% fiber mix reached 62 MPa, a 26.5% increase. Tensile strength also showed significant improvement; at 28 days, it increased from 3.3 MPa for conventional concrete to 5.8 MPa with 3% fiber, a 75.8% enhancement. The 7-day results exhibited similar trends but with comparatively lower values. For flexural strength, conventional concrete (0% fiber) achieved 7.5 MPa at 28 days, while 3% fiber addition enhanced it to 12.8 MPa, marking a 72.7% increase. Similarly, the compressive strength of conventional concrete was 49 MPa at 28 days, which rose to 62 MPa with 3% fiber, reflecting a 26.5% increase.

According to research conducted by Priyan et al. (2023), for an aspect ratio of 30, the PCB fiber measures 45 mm in length, 1.5 mm in width, and 1.6 mm in thickness. In contrast, for an aspect ratio of 40, the dimensions change to 40 mm in length, 1 mm in width, and 1.6 mm in thickness. The specimen (with PCB fiber of AR 30 and 40) having the following properties underwent compressive strength, tensile strength, and flexural strength tests after 7 and 28 days of curing, and obtained values from the test were considered to assess the mechanical properties (compressive strength, tensile strength, flexural strength) of the WPCBs fiber reinforced concrete. The results for specimens with AR 30 are illustrated in Figures 16, 17, and 18, while those for AR 40 are presented in Figures 19, 20, and 21.

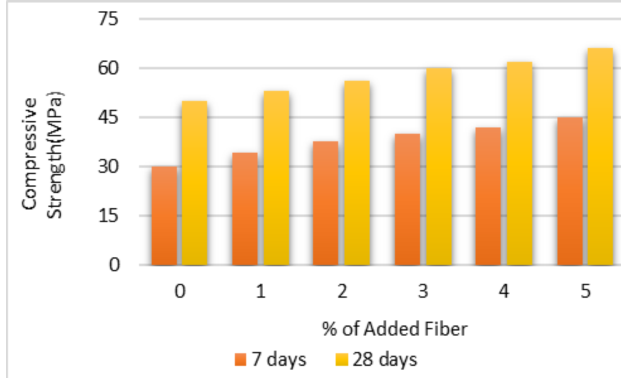


Figure 16 Compressive Strength Test Result on Cubic Specimens for AR 30 (Priyan et al. 2023)

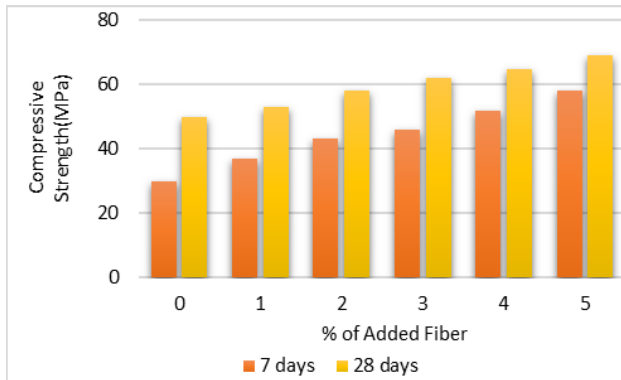


Figure 17 Compressive Strength Test Result on Cubic Specimens for AR 40 (Priyan et al. 2023)

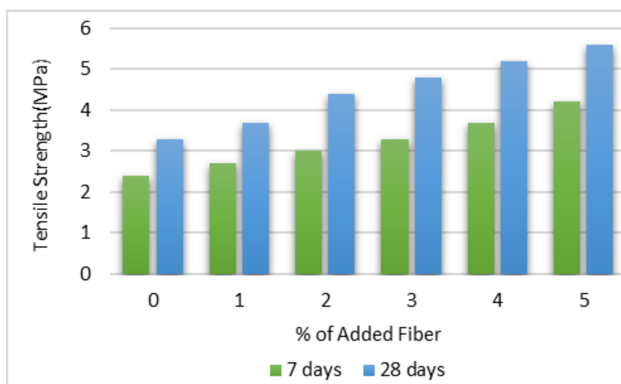


Figure 18 Split tensile Strength Test Result on Cylindrical Specimens for AR 30 (Priyan et al. 2023)

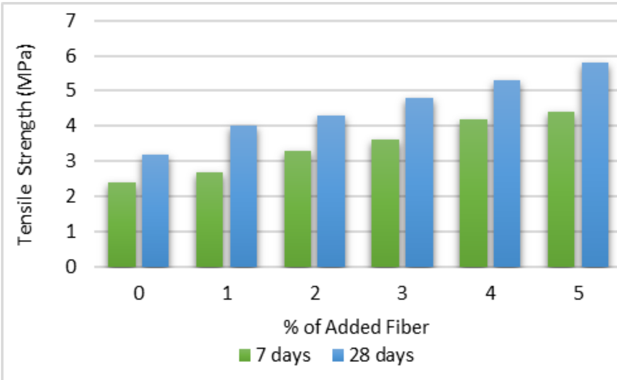


Figure 19 Split tensile Strength Test Result on Cylindrical Specimens for AR 40 (Priyan et al. 2023)

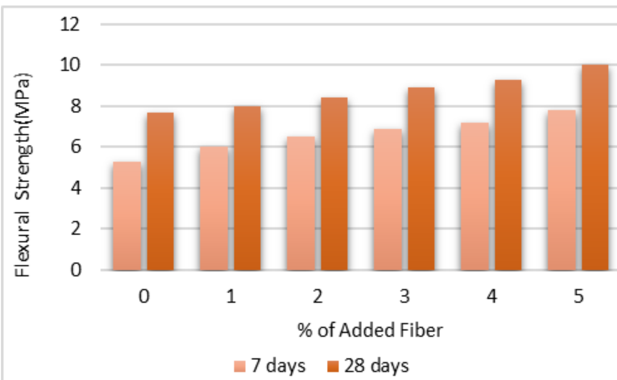


Figure 20 Flexural Strength Test Result on beam Specimens for AR 30 (Priyan et al. 2023)

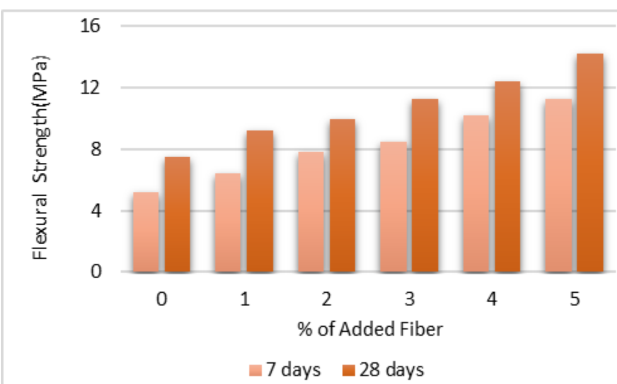


Figure 21 Flexural Strength Test Result on beam Specimens for AR 40 (Priyan et al. 2023)

The graphs illustrate the effect of varying percentages of added fiber (0% to 5%) on the compressive, tensile, and flexural strength for different aspect ratios (AR), AR 30, and AR 40, measured at 7 and 28 days. In terms of compressive strength, AR 30 increases from 29.9 MPa to 45 MPa at 7 days and from 49.8 MPa to 66 MPa at 28 days, showing a 32.53% increase, while AR 40 rises from 30 MPa to 58 MPa at 7 days and from 50 MPa to 69 MPa at 28 days, representing a 38.0% increase**.** For tensile strength, AR 30 grows from 2.4 MPa to 4.2 MPa at 7 days and from 3.3 MPa to 5.6 MPa at 28 days, indicating a 69.7% increase, whereas AR 40 increases from 2.4 MPa to 4.4 MPa at 7 days and from 3.3 MPa to 5.8 MPa at 28 days, marking a 75.76% increase**.** Similarly, flexural strength in AR 30 improves from 5.3 MPa to 7.8 MPa at 7 days and from 7.7 MPa to 10 MPa at 28 days, while AR 40 sees an increase from 5.2 MPa to 11.3 MPa at 7 days and from 7.5 MPa to 14.2 MPa at 28 days that is almost 89.33% higher than the conventional concrete. The mix that included AR 40 WPCB fibers exhibited better compressive strength, tensile strength, and flexural strength compared to the mix with AR 30 fibers, likely due to the higher quantity of WPCB fibers used.

3.1 Comparison between different Aspect Ratios (10, 20, 30 and 40)

Comparison of Compressive Strength for different aspect ratios are shown in Figure 22-

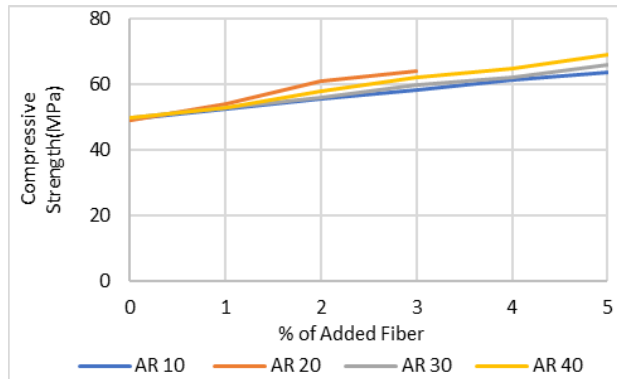


Figure 22 Combined graph of compressive strength for different AR (10,20,30 and 40) (Annadurai et al. 2023, Priyan et al. 2023 & Marimuthu and Ramasamy 2023)

The line graph illustrates the compressive strength for different aspect ratios—AR 10, AR 20, AR 30, and AR 40—at different percentages of added fiber ranging from 0% to 5%. Overall, the compressive strength increases steadily for all materials as the percentage of added fiber rises. For an aspect ratio of 20, the graph exhibits an increasing trend. Up to a 3% incorporation of PCB fiber, shows the best results compared to the aspect ratio 10, 30, and 40. If this linear increasing trend continues, it is possible that aspect ratio 20 could reach its maximum mechanical strength. Based on the comparison graph, it appears that aspect ratio 20 has the highest potential for achieving superior strength. Among aspect ratios 10,30 and 40, AR 40 demonstrates the highest compressive strength across all fiber percentages, while AR 10 consistently shows the lowest values. For conventional concrete, AR 10 starts with a compressive strength of approximately 50 MPa, while AR 40 begins at around 50 MPa as well. However, with the addition of fiber, the gap between the materials becomes more pronounced. At 5% fiber, AR 40 reaches the highest value of nearly 70 MPa, while AR 10 increases to about 58 MPa. AR 30 exhibits better compressive strength (66 MPa) than AR 10.

Comparison of Split tensile Strength for different aspect ratios are shown in Figure 23-

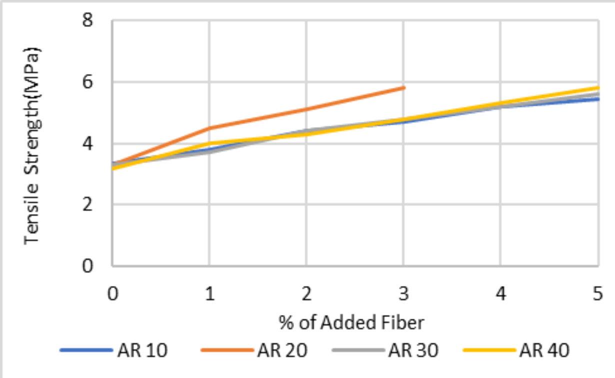


Figure 23 Combined graph of tensile strength for different AR (10,20,30 and 40) (Annadurai et al. 2023, Priyan et al. 2023 & Marimuthu and Ramasamy 2023)

AR 20 shows better results compared to AR 10, AR 30, and AR 40. It exhibits an increasing trend, and up to 3% addition of PCB fiber, it achieves the best performance. At 3%, the tensile strength reaches 5.8 MPa, which is approximately 75.76% higher than that of conventional concrete. On the other hand, AR 40 performs better when the incorporation of PCB fiber is higher, such as at 5%. For 3% fiber addition, the tensile strength of AR 40 is 4.8 MPa, and for 5%, the value increases to 5.8 MPa, which is similar to AR 20 at just 3% fiber addition. Thus, it can be stated that AR 20 shows a consistent increasing trend and may provide better results. However, based on the available data, it can be concluded that AR 40 demonstrates better overall performance when the tensile strength values at 5% fiber addition are considered.

Comparison of flexural Strength for different aspect ratios are demonstrated in Figure 24-

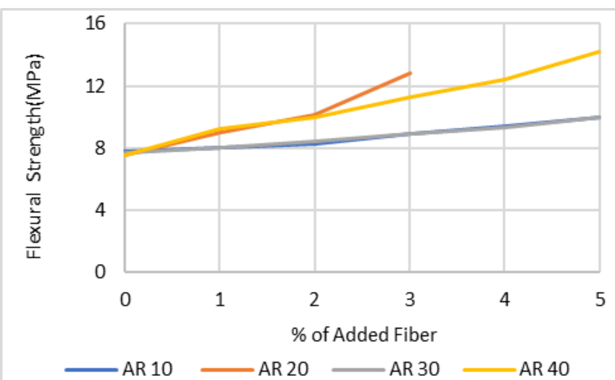


Figure 24 Combined graph of flexural strength for different AR (10,20,30 and 40) (Annadurai et al. 2023, Priyan et al. 2023 & Marimuthu and Ramasamy 2023)

In comparison to AR 10, AR 30, and AR 40, AR 20 has superior flexural strength at lower fiber percentages. It exhibits an upward trend, with the optimum outcome occurring at 3% fiber insertion, when the flexural strength approaches 12.4 MPa. Comparing this value to traditional concrete, it is noticeably greater. But when the fiber percentage rises above 3%, AR 40 starts to function better than AR 20. AR 40 outperforms the other materials in terms of flexural strength, reaching a maximum of 14.2 MPa with 5% fiber addition.AR 10 and AR 30 demonstrate consistent improvements in flexural strength as the fiber percentage increases; however, their performance remains lower than that of AR 20 and AR 40. From the data, it can be observed that AR 20 performs best at up to 3% fiber addition, while AR 40 surpasses all other materials at higher fiber percentages, particularly at 5%.

The combined graph for different aspect ratios (AR) shows that as the aspect ratio increases, the overall mechanical characteristics, such as compressive, tensile, and flexural strength, also improve. The material under analysis has the highest strength at an aspect ratio of 40 (AR40), indicating that this value represents an optimum balance. Using different percentages of PCB fiber with concrete specimens improved mechanical behavior by obtaining more strength than conventional concrete.

4.0 CONCLUSIONS

The incorporation of PCB fiber in concrete mixes has demonstrated significant improvements in strength characteristics, particularly notable when percentages of PCB fiber are optimized. This alternative or recycled fiber will reduce environmental hazards and offer improved performance while also contributing to electronic waste management efforts. The following conclusions emerge from the various researchers:

Better compressive, tensile, and flexural strength findings are obtained when the quantity of WPCB fibers increases. AR 40 for a length of 40 mm and width of 1 mm is preferable in concrete applications. Beyond 5% addition of WPCB fiber diminishes the concrete's mechanical qualities in the intended grade. When PCB content exceeds 5%, concrete's mechanical properties are impacted by the balling action of WPCB fiber, which also decreases workability. The optimal PCB fiber content is 5%, the maximum strength obtained.

5.0 RECOMMENDATIONS

Due to some limitations, future research needs to be taken because of the inability to perform shrinkage tests and durability tests in the experiment. Future studies should focus on addressing gaps in understanding of durability, particularly fire resistance, by establishing standardized testing methods and performance metrics. The use of admixture and additives that can enhance the reactivity and performance of PCB fiber in concrete mixes should be explored. Other qualities like creep, fatigue, and shear strength should also be studied. In the case of aspect ratio 20, compressive, split tensile, and flexural strength increases with the addition of PCB fiber up to 3%. Even after 3%, the strength may continue to increase. This needs to be further studied.

Acknowledgments

The completion of this paper was made possible through the collective efforts of the writers. We are grateful to the faculty of the Department of Civil Engineering at Ahsanullah University of Science and Technology in Dhaka, Bangladesh, for their important guidance and help which were necessary to the accomplishment of this study.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

References

[1] Zhang, Y., Zhang, S., Zhao, W., Jiang, X., Chen, Y., Hou, J., Wang, Y., Yan, Z., and Zhu, H., 2023. Influence of multi-scale fiber on residual compressive properties of a novel rubberized concrete subjected to elevated temperatures. *Journal of Building Engineering*, 65: 105750.

[2] Wu, H., Shen, A., Ren, G., Ma, Q., Wang, Z., Cheng, Q., and Li, Y., 2023. Dynamic mechanical properties of fiber-reinforced concrete: A review. *Construction and Building Materials,* 366: 130145.

[3] Vishnupriyan, M., and Annadurai, R., 2023. A study on the macro-properties of PCB fiber-reinforced concrete from recycled electronic waste and validation of results using RSM and ANN. A*sian Journal of Civil Engineering*, 24(6): 1667-1680.

[4] Newbury Electronics, 2023. Can printed circuit boards be reused or recycled? Newbury Electronics. https://www.newburyelectronics.co.uk/news/can-printed-circuit-boards-be-reused-or-recycled/ [Accessed: 18 Nov, 2024].

[5] Richter, H., Lorenz, W., and Bahadir, M., 1997. Examination of organic and inorganic xenobiotics in equipped printed circuits. *Chemosphere*, 35(1-2): 169-179.

[6] Mishra, S.M., and Trivedi, M.K., 2018. Utilization of PCB and cost-reduction of Concrete. *International Journal of Applied Engineering Research*, 13(14): 11461-11465.

[7] Priyan, M.V., Annadurai, R., Onyelowe, K.C., Alaneme, G.U., and Giri, N.C., 2023. Recycling and sustainable applications of waste printed circuit board in concrete application and validation using response surface methodology. *Scientific Reports,* 13(1): 16509.

[8] Ghimire, H., and Ariya, P.A., 2020. E-wastes: bridging the knowledge gaps in global production budgets, composition, recycling and sustainability implications. *Sustainable Chemistry,* 1(2): 154-182.

[9] Forti, V., Balde, C.P., Kuehr, R., and Bel, G., 2020. The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential.

[10] Duan, H., Hou, K., Li, J., and Zhu, X., 2011. Examining the technology acceptance for dismantling of waste printed circuit boards in light of recycling and environmental concerns. J*ournal of environmental management,* 92(3): 392-399.

[11] Duan, H., Li, J., Liu, Y., Yamazaki, N., and Jiang, W., 2011. Characterization and inventory of PCDD/Fs and PBDD/Fs emissions from the incineration of waste printed circuit board. *Environmental science & technology*, 45(15): 6322-6328.

[12] Baldé, K., D'angelo, E., Luda, V., Deubzer, O., and Kühr, R., 2022. Global transboundary e-waste flows monitor 2022. United Nations Institute for Training and Research (UNITAR).

[13] Hossain, S., Sultan, S., Shahnaz, F., Akram, A.B., Nesa, M., and Happell, J., 2010. Study on E-waste: Bangladesh Situation. *Environment and Social Development Organization*-ESDO, 1–36.

[14] Hossain, S., Sulatan, S., Shahnaz, F., and Hossain, M. L., 2011. Illegal import and trade off of e-waste in Bangladesh. Environment and Social Development Organization (ESDO): Dhaka, Bangladesh, 11.

[15] Yousuf, T. B., 2011. E-Waste management in Bangladesh: Present trend and future implication. *ISWA,* 2011: 394-403.

[16] Department of Environment (DoE), 2019. Assessment of generation of e-waste, its impacts on environment and resource recovery potential in Bangladesh. Department of Environment, Ministry of Environment, Forest and Climate Change, Government of the People's Republic of Bangladesh, Dhaka, December 2019, ISBN: 978-984-34-6949-6.

[17] Leung, A. O., Duzgoren-Aydin, N. S., Cheung, K. C., and Wong, M. H., 2008. Heavy metals concentrations of surface dust from e-waste recycling and its human health implications in southeast China. *Environmental science & technology,* 42(7): 2674-2680.

[18] Fang, W., Yang, Y., and Xu, Z., 2013. PM10 and PM2. 5 and health risk assessment for heavy metals in a typical factory for cathode ray tube television recycling. *Environmental science & technology*, 47(21): 12469-12476.

[19] Fu, J., Zhang, A., Wang, T., Qu, G., Shao, J., Yuan, B., Wang, Y., and Jiang, G., 2013. Influence of e-waste dismantling and its regulations: temporal trend, spatial distribution of heavy metals in rice grains, and its potential health risk. *Environmental Science & Technology,* 47(13): 7437-7445.

[20] Labunska, I., Harrad, S., Wang, M., Santillo, D., and Johnston, P., 2014. Human dietary exposure to PBDEs around E-waste recycling sites in Eastern China. *Environmental Science & Technology,* 48(10): 5555-5564.

[21] Wu, K. S., 2010. Exposure to polybrominated diphenyl ethers (PBDEs) of neonates in association with relevant factors and adverse birth outcomes in an e-waste recycling area (Doctoral dissertation, Ph. D. Dissertation, Shantou University, Shantou, China, 2010, (in Chinese). Google Scholar There is no corresponding record for this reference).

[22] Ogunseitan, O. A., Schoenung, J. M., Saphores, J. D. M., and Shapiro, A. A., 2009. The electronics revolution: from e-wonderland to e-wasteland. *Science,* 326(5953): 670-671.

[23] Xiang, D., Mou, P., Wang, J., Duan, G., and Zhang, H. C., 2007. Printed circuit board recycling process and its environmental impact assessment. *The International Journal of Advanced Manufacturing Technology*, 34, 1030-1036.

[24] Huang, K., Guo, J., and Xu, Z., 2009. Recycling of waste printed circuit boards: A review of current technologies and treatment status in China. *Journal of hazardous materials,* 164(2-3): 399-408.

[25] Stone, R., 2009. Confronting a toxic blowback from the electronics trade. Science (New York, NY), 325(5944), 1055-1055.

[26] Wang, Y. L., Wang, Q. Y., Gao, M., Chen, F. Q., and Liu, G. F., 2013. A method for separation of components and solders from waste printed circuit boards. Chinese patent: 2013101808637.

[27] Huo, X., Peng, L., Xu, X., Zheng, L., Qiu, B., Qi, Z., Zhang, B., Han, D., and Piao, Z., 2007. Elevated blood lead levels of children in Guiyu, an electronic waste recycling town in China. *Environmental health perspectives*, 115(7): 1113-1117.

[28] Leung, A., Cai, Z. W., and Wong, M. H., 2006. Environmental contamination from electronic waste recycling at Guiyu, southeast China. *Journal of Material Cycles and Waste Management,* 8: 21-33.

[29] Li, Y., Xu, X., Liu, J., Wu, K., Gu, C., Shao, G., Chen, S., Chen, G., and Huo, X., 2008. The hazard of chromium exposure to neonates in Guiyu of China. *Science Of The Total Environment,* 403(1-3): 99-104.

[30] Zheng, L., Wu, K., Li, Y., Qi, Z., Han, D., Zhang, B., Gu, C., Chen, G., Liu, J., Chen, S., and Xu, X., 2008. Blood lead and cadmium levels and relevant factors among children from an e-waste recycling town in China. *Environmental Research,* 108(1): 15-20.

[31] Nagajothi, P. G., and Felixkala, T., 2014. Compressive strength of concrete incorporated with E-fiber waste. *International Journal of Emerging Technology and Advanced Engineering*, 4(4): 23-27.

[32] Colangelo, F., Cioffi, R., Liguori, B., and Iucolano, F., 2016. Recycled polyolefins waste as aggregates for lightweight concrete. *Composites Part B: Engineering,* 106: 234-241.

[33] Annadurai, R., Priyan, M. V., Alaneme, G. U., Ravella, D. P., Pradeepkumar, S., and Olaiya, B. C., 2023. A study on waste PCB fibres reinforced concrete with and without silica fume made from electronic waste. *Scientific Reports,* 13(1): 22755.

[34] Sonic Manufacturing Technologies, 2020. Top 5 things to consider when designing a PCB. Sonic Manufacturing Technologies. https://www.sonicmfg.com/top-5-things-designing-pcb/ [Accessed: 18 Nov, 2024].

[35] Marimuthu, V., and Ramasamy, A., 2023. Investigation of the mechanical properties of M40-grade concrete with PCB fiber from recycled electronic waste. *Journal of Hazardous, Toxic, and Radioactive Waste*, 27(1): 04022034.