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Review on Waste PCB Fibers Reinforced Concrete

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Abstract:
Concrete, which is the world's most prevalent construction material, has become more popular because of the rapid building of urban centers, infrastructure construction, and population increase, particularly in developing countries. Just as the demand for concrete has increased, the demand for electronic devices has skyrocketed due to the digital transformation of nearly every aspect of modern life. Due to the technological advancements and the introduction of less expensive devices, the production of Waste Electrical Equipment (WEE) also increases and waste PCBs (WPCBs) contributes the huge amount of the E-Waste. [1] WPCBs contain different kinds of harmful substances, including heavy metals and brominated flame retardants, which pose a high environmental hazard, especially if not treated or disposed of appropriately. In recent times, sustainability has become a major concern, particularly in the context of the Eco-Friendly Built Environment (EFBE). Utilising printed circuit board (PCB) fibre in concrete offers a sustainable solution and a radical concept because it helps to reduce environmental pollution and resolve waste management issues.[2] This study explores the effect of using PCBs fibers in concrete. This paper also summarizes the experimental findings of the mechanical properties of PC fiber sample containing 1,2,3,4 and 5% fiber by weight of cement. PCB fibers of aspect ratio 10,20,30 and 40 was added to M15 grade concrete and the properties of PCB fiber concrete was compared with those of conventional concrete after 7, and 28 days of curing. In this investigation, it is also revealed that PCB fiber concrete showed increased strength compared with control concrete.
***Keywords**: E-Waste, PCB, Concrete Properties, EFBE, WEE etc.*

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I. INTRUDUCTION:

Concrete is one of the most commonly used construction material throughout the world because of its strength, versatility, durability and relatively low cost and easy to work. All of these characteristics make concrete an ideal choice for a variety of construction projects, including roads, buildings, bridges, and other infrastructure improvements.

Concrete is weak in tension yet comparatively strong in compression. The main cause of this phenomenon is the composition of concrete, which comprises cement and aggregate (such as crushed stone or gravel), both of which have comparatively poor tensile strength.[3] The tensile strength can be improved by adding reinforcement, such as steel bars, using fibers in concrete.[4] Fibers play a crucial role in enhancing concrete performance for several reasons. Concrete becomes more crack-resistant when fibers are added because fibers increase the concrete's compressive, tensile and flexural strengths.[5] Additionally, fibers aid in stress distribution within the concrete, mitigating cracking tendencies and reducing crack sizes under load. Moreover, fibers elevate concrete's resilience to impact and abrasion, rendering it suitable for heavy loads [6]. Furthermore, fibers contribute to diminishing concrete shrinkage and creep, thereby minimizing the risk of cracks and associated damage. “Fiber Reinforced Concrete”, often abbreviated as “FRS”, is the term utilized for this particular concrete formulation.

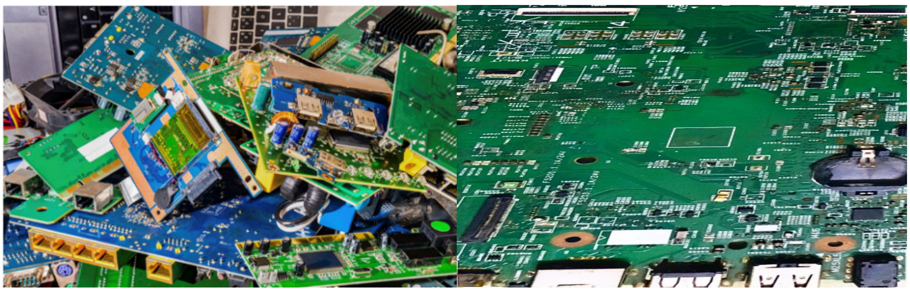


Figure 1 : Recycled PCB

Printed Circuit Boards are an essential component in every electronic device, serving as the backbone of modern technology. Because of the effects of technological advancement, such as the shorter lifespan of electronic devices, there is an excess of PCB waste. Printed Circuit Boards make up to about 4% of all electronic waste.[7] More than 20 million tons of e-waste are created annually. PCB waste (WPCB) is an electronic waste (e-waste) which is nonbiodegradable and may persist for a long time in the environment as well. In the recent past, WPCBs are manufactured at a growth rate of 8.7%. According to data from the Telecommunication Development Sector (ITU-D), In 2019, 53.6 million tons of electronic waste were produced annually worldwide, which averages out to 7.3 kilogram of waste per person.[8] By 2025, this quantity is expected to rise to 65.3 million tons. Certain EEEs, such as cell phones (21.30%), PC control units (18.76%), and color televisions (7.04%), have extremely high waste PCB (WPCB) percentages. A regional overviews of waste printed circuit board generation are given bellow:

Table 1: A regional overviews of waste printed circuit board generation:

Country	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%

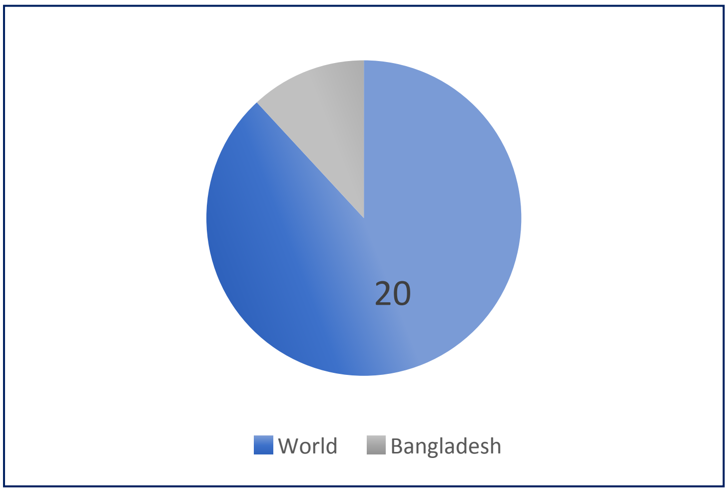


Figure 2: E-waste(Electronic Waste) Generation in Bangladesh Vs World(million MT) [9]

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.[9] 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. 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. 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.

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. Urban areas close to PCB workshops have a significant level of contamination, according to analyses of hazardous components in soils. [10] In comparison to other locations, the amounts of lead (Pb) and copper (Cu) were found to be 371 and 155 times higher, respectively.

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. 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. Waste Printed Circuit Boards (WPCBs) contain pollutants such as brominated flame retardants, polybrominated dibenzo-p-dioxins, dibenzofurans, chlorinated dioxins, and polycyclic aromatic hydrocarbons. [11] It is crucial to focus on effective recycling and waste management practices to protect the environment. 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.

To mitigate environmental problems related to WPCBs, recycling of WPCBs and used in concrete as a fiber- can be a novel approach. This approach not only addresses the challenge of e-waste accumulation but also facilitates the production of eco-friendly concrete, thereby mitigating adverse environmental effects. According to Nagajothi et al. (2008), adding up to 2.5% of E-Fiber waste to concrete increased its compressive strength by almost twice when compared to conventional mixes.[12] The lightweight nature of concrete derived from electronic waste offers adequate thermal insulation qualities and reduces production and handling costs.[13] The study mainly focuses on the use of WPCBs as a fiber used in conventional cement concrete which potentially lowering construction cost, demand for natural resources.

2.1 Printed Circuit Board (PCB) fiber:

A 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.[14]PCBs are typically made from fiberglass fabric that is impregnated with epoxy resin, making them fire-resistant.

Figure 3: PCB

Figure 4: PCB fiber strip

2.2 Properties of Printed Circuit Board (PCB) fiber:

Table 2: Properties of Printed Circuit Board (PCB) fiber:

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

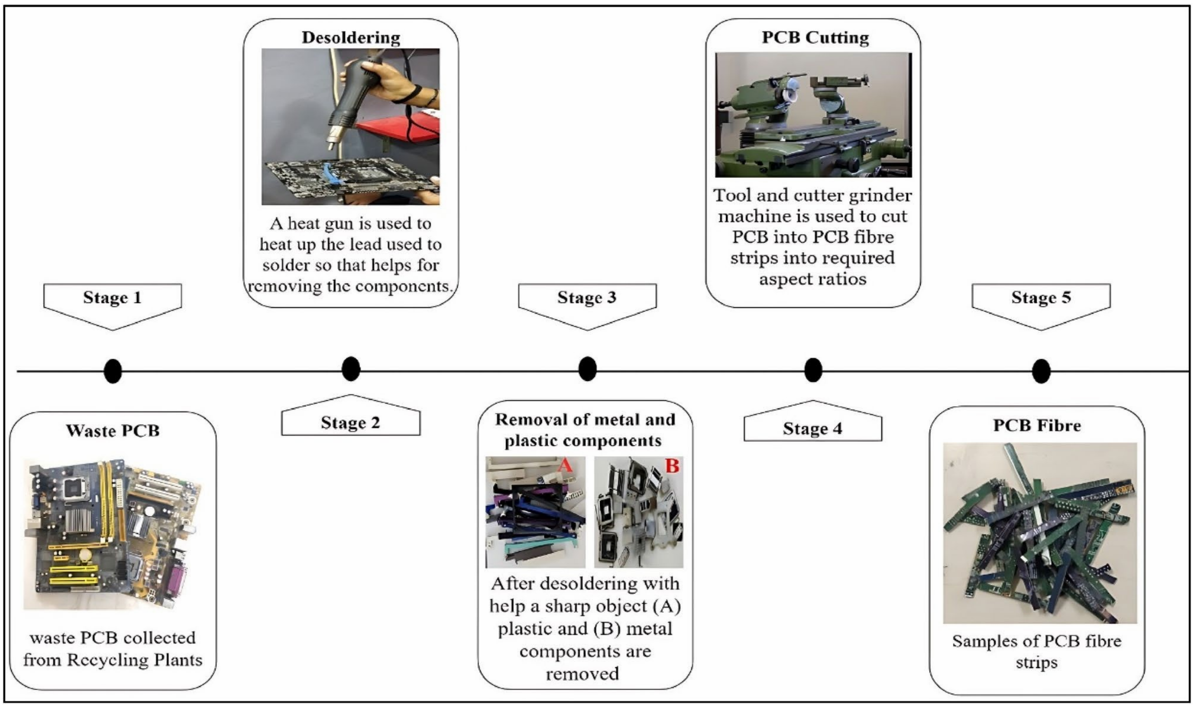


Figure 5: Process of making PCB Fiber *[15]*

3. Survey of Literature Antecedent to Experimental Analysis:

According to research conducted by **Kennedy C. Onyelowe et al. (2023)**, for an aspect ratio of 30, the PCB fiber measures 40 mm in length, 1.5 mm in width, and 1.6 mm in thickness. [15] In contrast, for an aspect ratio of 40, the dimensions change to 45 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.

Table 4: Mix Specification:

Mix Specification	**Cement (kg/m3)**	**WPCB Fiber**	**WPCB fiber (%)**
Conventional Concrete	412.5	0	0
PCB (AR 30)	412.5	4.13	1
PCB (AR 30)	412.5	8.25	2
PCB (AR 30)	412.5	12.38	3
PCB (AR 30)	412.5	16.5	4
PCB (AR 30)	412.5	20.63	5

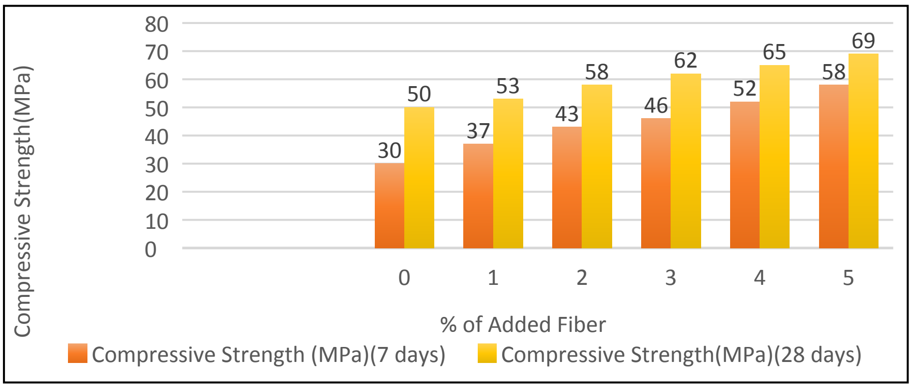


Fig 6: Compressive Strength Test Result on Cubic Specimens (**Kennedy C. Onyelowe et al., 2023)**

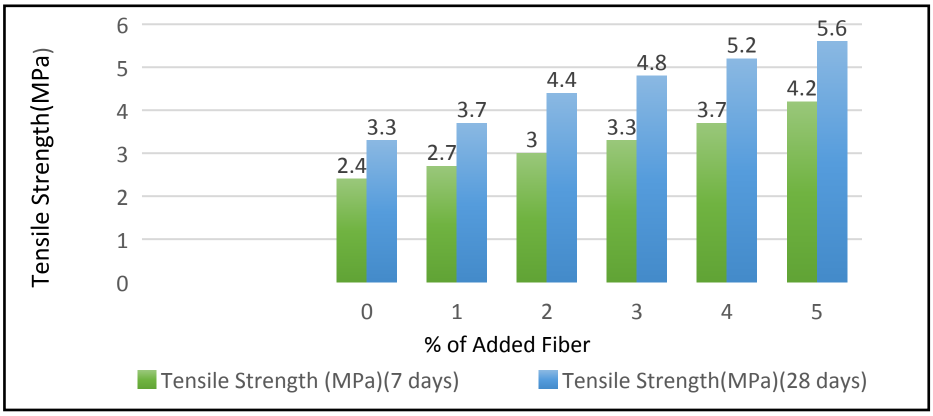


Fig 7: Split Tensile Strength Result Test on Cylindrical Specimens (**Kennedy C. Onyelowe et al., 2023)**

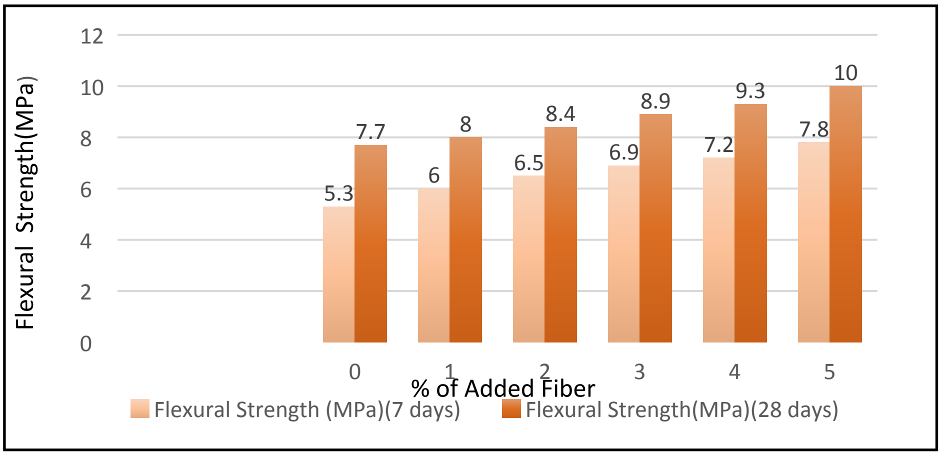


Fig 8: Flexural Strength Test Result on Beam Specimens (**Kennedy C. Onyelowe et al., 2023)**

At 28 days, the compressive strength of all aspect ratio (AR) 30 fiber mixes was higher than that of the conventional concrete. In comparison to ordinary concrete, the compressive strength of the AR 30 mix jumped by 6.43%, 12.45%, and 20.48%, respectively, with the use of 1%, 2%, and 3% of WPCB fibers. Similarly, compressive strength improved by 24.50% and 32.53%, when 4% and 5% of WPCB fibers were added respectively. The concrete reinforced with 5% AR 30 fibres visualised the highest compressive strength which is 66 MPa. The concrete reinforced with 5% AR 30 fibers visualized the highest tensile strength which is around 5.6 MPa and increased by 69.70% relative to the conventional concrete. Similarly, the concrete reinforced with 5% AR 30 fibres showed the highest Flexural strength which is around 10 MPa. From the experimental data analysis of AR40 **(Kennedy C. Onyelowe et al., 2023) the** mechanical properties of concrete specimens demonstrate variability depending on the percentage of PCB fiber present.[14]

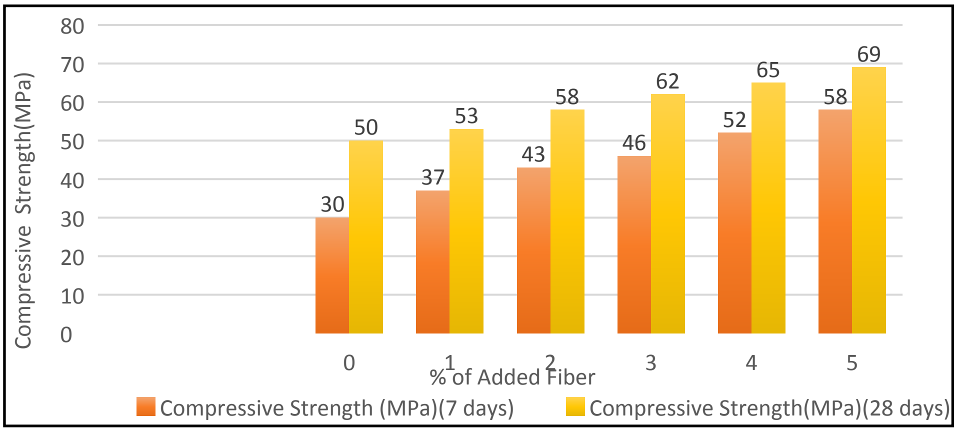


Figure 9: Compressive Strength of Cube Graphs (AR 40)

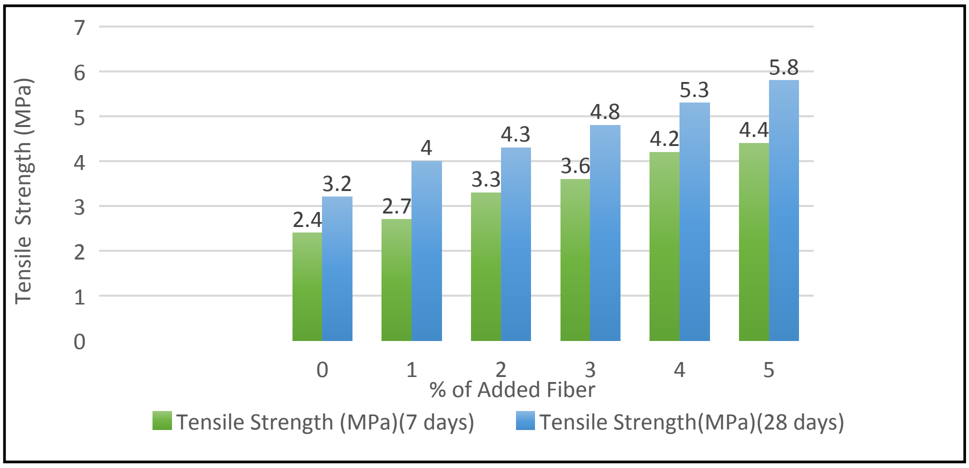


Figure 10: Tensile strength of Cylinder Graphs (AR 40)

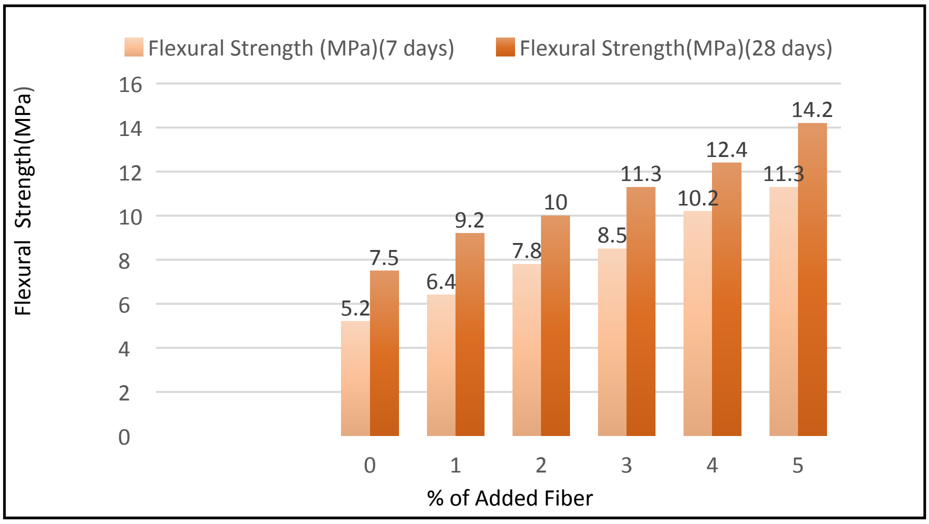


Fig 11: Flexural strength of beam Graphs (AR 40)

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. When more than 5% fiber is added to the mix, a balling phenomenon occurs with the WPCB fiber, which reduces both the workability and the mechanical properties of the concrete.[15]

In the research carried out by **R. 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. [14] 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. [14] The outcomes from **R. Annadurai et al., 2023** are shown in figure-

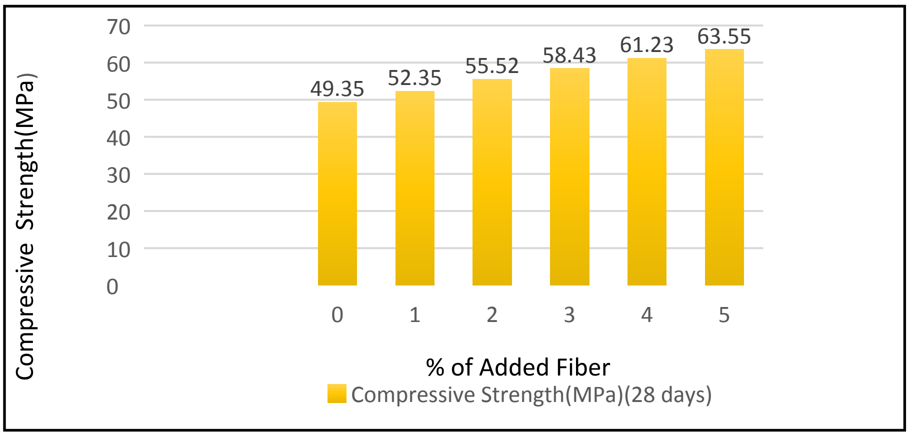


Figure 12: Compressive Strength of Cube Graphs (AR 10)

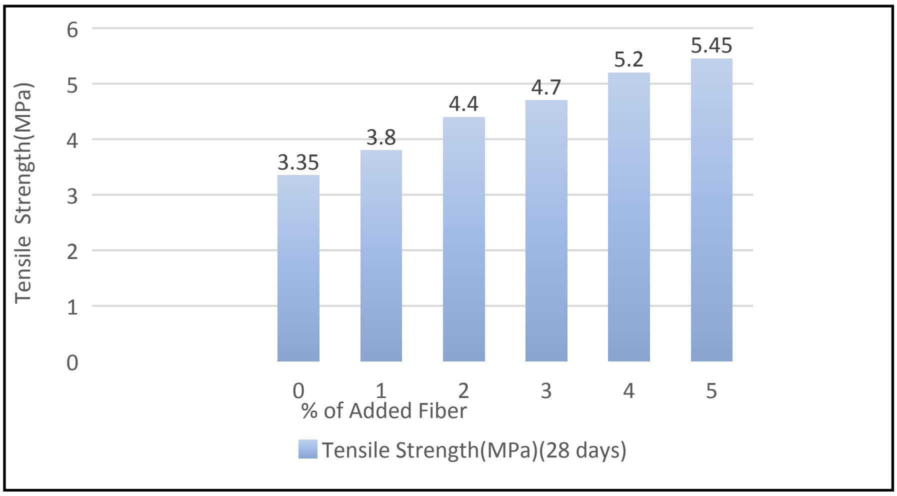


Figure 13: Tensile strength of Cylinder Graph (AR 10)

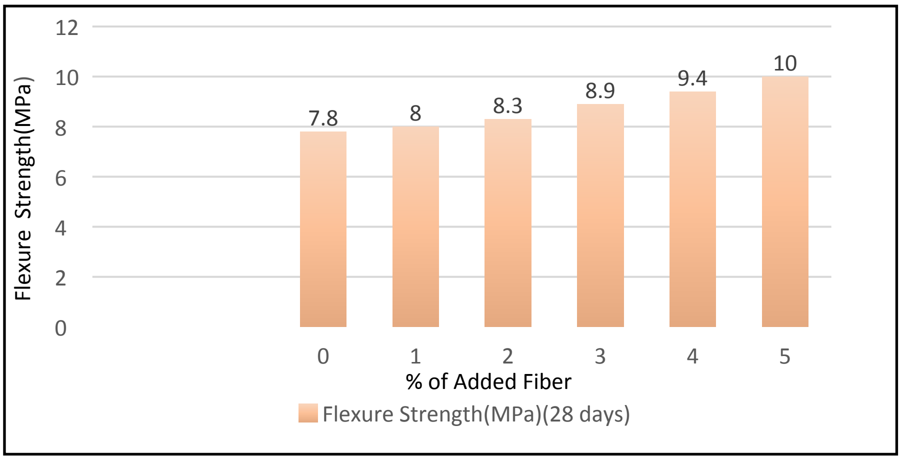


Figure 14: Flexural Strength of Beam Graphs (AR10)

After observing the experimental results, it was observed that the fiber concrete with PCB demonstrated higher compression, split tension, and flexural strengths compared to conventional concrete. After 28 days, the compressive strength of the control mix reached 49.35 MPa. When comparing the control concrete to the PCB fiber mix, the compressive strength increased by 6.07%, 12.5%, and 18.4% when PCB fibers were added at 1%, 2%, and 3%, respectively. Similarly, introducing 4% and 5% PCB fibers raised the compressive strength by 24.11% and 28.77%, respectively. The concrete reinforced with 5% AR 10 fibers visualized the highest tensile strength which is around 5.45 MPa (28 days) and increased by 62.69% relative to the conventional concrete. The highest flexural strength is found at 28 days (10 MPa) which is 28.21% greater than the conventional.[14]

Vishnupriyan Marimuthu et al., 2022, 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 behaviour after 7 days and 28 days of curing are observed and demonstrated in a graphical representation-

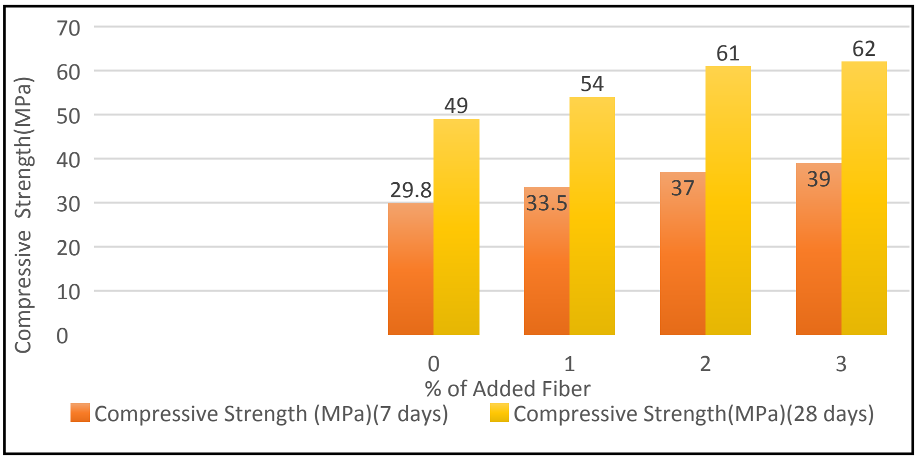


Figure 15: Compressive Strength of Cube Graphs (AR 20)

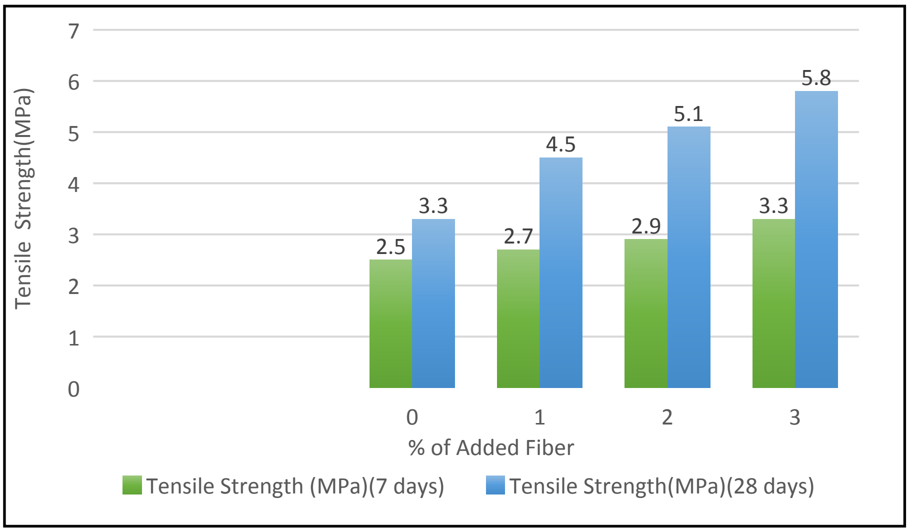


Figure 16: Tensile strength of Cylinder Graph (AR 20)

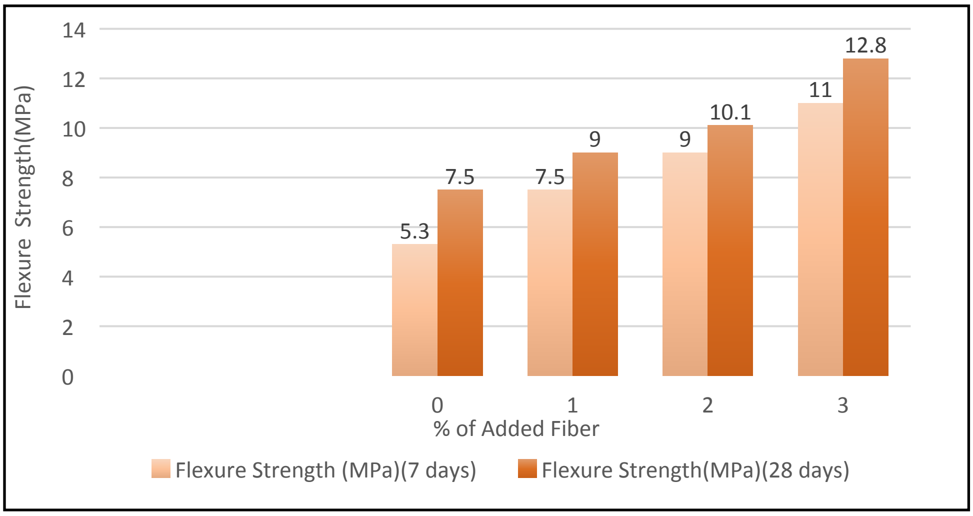
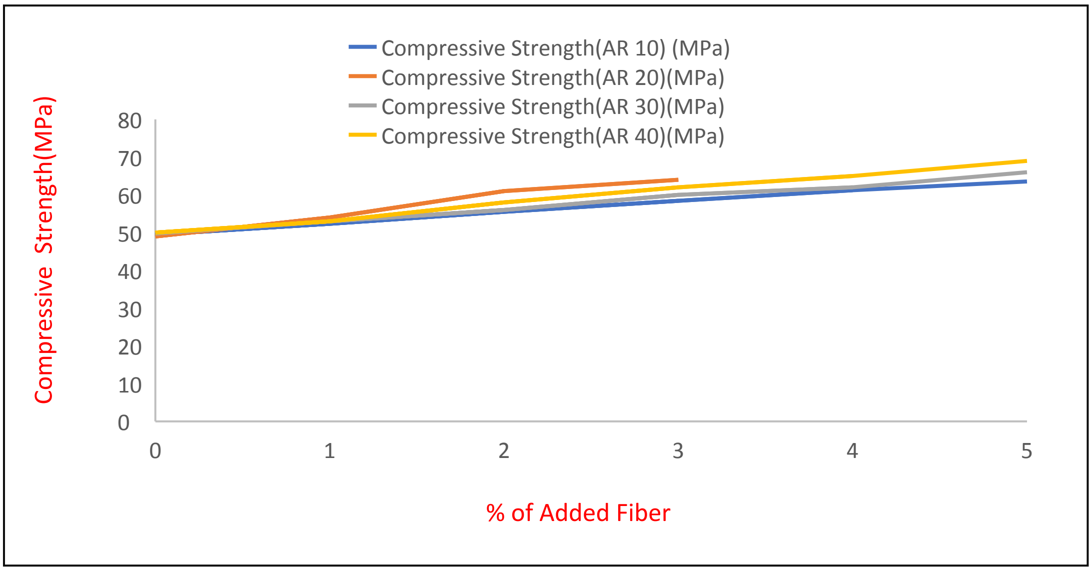
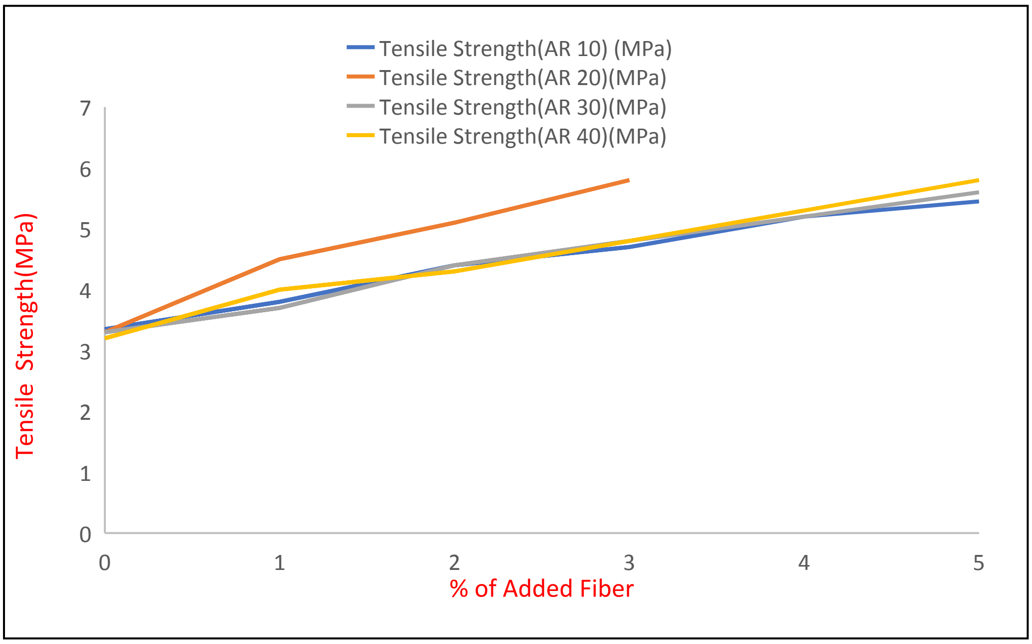


Figure 17: Flexural strength of Beam Graph (AR 20)

It was obvious from this experimental study that the PCB fiber concrete's compressive strength (CS) was raised by the proportion of PCB e-fiber waste (at 1%, 2%, and 3%). 1% increase in PCB fiber and an aspect ratio of 20 resulted in a 10.20% improvement in compressive strength (CS). Similarly, with 2% and 3% fiber additions, the CS demonstrate improvements of up to 24.49% and 26.53% for an aspect ratio of 20. The addition of fiber was thought to be responsible for the progressive improvement in compressive strength. In comparison to conventional concrete, the incorporation of 3% fiber enhances the tensile strength of concrete specimens when PCB fiber is included.

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





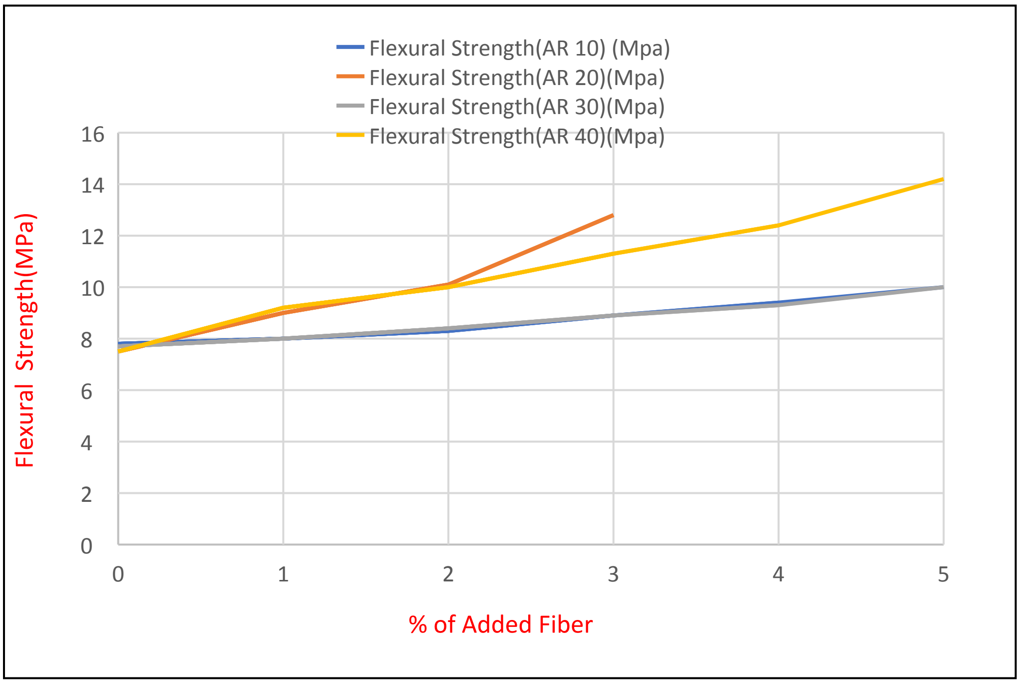


Figure 18: Combined Graph for different Aspect Ratios

From the combined graph for different aspect ratios (AR), it can be said 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. By using different percentages of PCB fiber with concrete specimens, mechanical behavior was improved by obtaining more strength when compared to conventional concrete.

II. Conclusion:

The incorporation of PCB fiber in concrete mixes has demonstrated significant improvements in strength characteristics, particularly notable when percentages of PCB fiber are optimized. [2] 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.

- In the case of AR 10, AR 20, AR 30, and AR 40, ultimate tensile strength for 28 days was found 5.45 MPa, 5.8 MPa, 5.6 MPa and 5.8 MPa respectively. So, AR 40 for a length of 50 mm and width of 5 mm is more considerable in concrete application.
- Beyond 5% addition of WPCB fibre 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.
- Optimal PCB fiber content is 5%, the maximum strength obtained.

Environmental Policy Impact:
Incorporating waste PCB fibers into concrete supports environmental goals by reducing the volume of electronic waste sent to landfills. It aligns with sustainability policies that encourage recycling and reuse of industrial waste, helping to lower the environmental footprint of construction materials.

Cost Efficiency:
Using PCB waste as a fiber additive can reduce the need for conventional reinforcement materials, cutting down material costs. It also helps manufacturers save on e-waste disposal fees. However, costs may rise due to the need for careful handling and treatment of hazardous substances in PCBs.

Recommendation:
Due to some limitations, future research need to be taken because of the inability to perform shrinkage tests and durability test 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 as creep, fatigue, shear strength should also be studied.

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