

A Brief Review on Materials and Printing Processes in 3D Fiber Reinforced Concrete for Environmental Sustainability

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Abstract:

Three-dimensional concrete printing (3DCP) has emerged as a transformative technology in the construction industry due to its ability to reduce material waste, eliminate formwork, and improve construction efficiency. However, the absence of conventional reinforcement in printed concrete limits its tensile and flexural performance. Fibre reinforcement has therefore become an effective strategy to enhance the mechanical and durability properties of 3D printed concrete. This review examines various printing methods, including extrusion-based printing, binder jetting, and spray-based systems, along with the influence of different fibre types such as steel, polypropylene, basalt, carbon, and natural fibres. The study highlights the role of fibres in improving tensile strength, ductility, crack resistance, and interlayer bonding. In addition, the incorporation of supplementary cementitious materials and recycled materials contributes to environmental sustainability by reducing cement consumption and carbon emissions. The review also discusses fresh state properties, mechanical behaviour, durability characteristics, and sustainability aspects of fibre-reinforced 3D printed concrete. Finally, key research gaps related to standardization, long-term durability, interlayer bonding, and large-scale structural applications are identified. The findings indicate that fibre-reinforced 3D concrete printing has significant potential for sustainable and high-performance construction applications.

1.0 INTRODUCTION

Three-dimensional concrete printing (3DCP) has become one of the most innovative technologies in the construction industry because of its ability to automate construction processes, reduce labour dependency, and eliminate conventional formwork[1],[14]. Compared with traditional construction practices, 3DCP minimizes material waste, reduces carbon emissions, and provides greater architectural flexibility[5],[15]. The technology has evolved from small-scale prototyping to large-scale structural applications through the integration of robotics and additive manufacturing techniques[6],[13].

Extrusion-based printing is the most widely adopted technique in 3D concrete printing due to its compatibility with cementitious materials and ease of fabrication. Successful printing requires a balance between pumpability, extrudability, and buildability. The material should possess sufficient flowability for smooth extrusion while maintaining adequate structural build-up to support subsequent layers[5-8].

Despite its advantages, 3D printed concrete suffers from poor tensile strength and weak interlayer bonding because conventional steel reinforcement is difficult to incorporate during printing. Fibre reinforcement has therefore emerged as a promising solution to improve ductility, tensile strength, crack resistance, and post-crack behaviour. Different fibres such as steel, polypropylene, basalt, carbon, and natural fibres have been investigated for enhancing the performance of 3D printed concrete.

In addition, sustainability has become an important research focus in 3DCP. The incorporation of supplementary cementitious materials (SCMs), recycled aggregates, and waste materials helps reduce cement consumption and environmental impact[37],[68]. This paper reviews the printing techniques, fibre types, mechanical behaviour, durability characteristics, and sustainability aspects of fibre-reinforced 3D printed concrete (3DCP-FRC).

2.0 DATA AND METHODS

The present study is based on an extensive review of journal articles, conference proceedings, theses, and review papers related to fibre-reinforced 3D concrete printing[40],[41],[44].. The collected literature primarily focuses on:

- Printing techniques used in 3DCP

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- Fresh and hardened properties of fibre-reinforced printable concrete
- Mechanical and durability performance
- Sustainability and life cycle considerations
- Structural applications and future challenges

The reviewed studies include investigations on extrusion-based printing, binder jetting, and spray-based printing systems. Different fibre types such as steel, polypropylene, basalt, carbon, and natural fibres were analysed based on their influence on rheology, printability, strength, and durability properties[4],[66].

The collected data from previous studies were comparatively analysed to identify the advantages, limitations, and research gaps in the development of sustainable fibre-reinforced 3D printed concrete.

3.0 RESULTS AND DISCUSSION

3.1 Printing Methods for Fibre-Reinforced Concrete

3.1.1 Extrusion-Based Printing

Extrusion-based printing is the most commonly used technique in 3DCP. In this process, cementitious material is pumped through a nozzle and deposited layer by layer. The addition of fibres improves tensile and flexural properties but also increases yield stress and viscosity. Superplasticizers and viscosity-modifying agents are therefore often required to maintain printability.[29],[34],[38].

Fibre alignment during extrusion significantly affects the anisotropic behaviour of printed concrete[33]. Although aligned fibres improve strength along the printing direction, interlayer bonding may become weak if sufficient bridging between layers is not achieved[53-56].

3.1.2 Binder Jetting

Binder jetting involves selective deposition of a liquid binder onto a powder bed. This technique enables the fabrication of complex geometries and improves surface finish[2],[5]. Studies reported that basalt fibre incorporation significantly enhanced flexural strength. However, the printed components often exhibit lower density and require post-processing for improved strength.

3.1.3 Spray-Based Printing

Spray-based systems utilize high-velocity deposition of cementitious materials. Carbon fibre-reinforced mortars printed using spray techniques demonstrated improved fibre alignment and enhanced flexural strength. This method is suitable for complex structural applications where conventional extrusion becomes difficult.

3.2 Influence of Fibre Types

Steel Fibres

Steel fibres improve tensile strength, flexural strength, ductility, and toughness. However, their higher density and stiffness create challenges such as nozzle clogging, fibre settlement, and equipment wear[6],[20],[38],[63].

Polypropylene Fibres

Polypropylene fibres are widely used because of their low density, good dispersion, and crack control ability. They improve printability and reduce shrinkage cracking, although their mechanical enhancement is lower than steel or carbon fibres[5],[6],[57],[58],[61].

Basalt Fibres

Basalt fibres provide excellent durability in aggressive environments such as seawater and cold climates. They improve flexural performance and reduce brittle failure. However, higher fibre dosages may reduce flowability and extrudability[21],[25-30].

Carbon Fibres

Carbon fibres provide superior mechanical performance and significantly improve tensile and flexural strength. Hybrid fibre systems containing carbon and basalt fibres also enhance interlayer bonding. However, carbon fibres are expensive and require careful rheological control [22],[24],[32].

Natural Fibres

Natural fibres such as jute, coconut, and wool offer sustainable alternatives with lower environmental impact. Although they improve crack resistance and flexural behaviour, their long-term durability and water absorption characteristics require further investigation [3], [7], [23], [26], [59], [64].

3.3 Mechanical Properties

The incorporation of fibres improves the overall mechanical performance of 3D printed concrete [50], [51], [65].

Compressive Strength

The increase in compressive strength due to fibre addition is generally moderate and depends on fibre type, content, orientation, and loading direction. Studies reported that printed specimens loaded perpendicular to the layers often exhibit lower strength compared to specimens loaded parallel to the layers [42], [48], [52].

Most studies indicate that compressive strength varies with loading direction, with specimens loaded perpendicular to the layers exhibiting 10–30% lower strength compared to those loaded parallel to the layers.

Tensile and Flexural Strength

Fibres significantly improve tensile and flexural strength through crack-bridging mechanisms and enhanced energy absorption. Strain-hardening behaviour with multiple fine cracks instead of catastrophic failure has been reported in fibre-reinforced mixes. Studies by Figueiredo et al., Sun et al., and Li et al. demonstrated that fibres enable strain-hardening behavior, with tensile strain capacities exceeding 2–3%, indicating significant improvement in tensile performance [47], [60].

Figures 4 and 5 indicate that the incorporation of fibres significantly enhances the mechanical properties and interlayer bonding characteristics of 3D printed concrete, depending on the fibre type and dosage used.

Interlayer Bonding

Interlayer bonding is a critical factor in 3DCP because weak interfaces can reduce structural integrity. Fibre reinforcement improves interlayer strength by bridging adjacent layers and providing mechanical interlocking [36].

3.4 Durability Properties

Fibre incorporation improves several durability characteristics of 3D printed concrete [50], [51].

- Fibres reduce shrinkage cracking by controlling crack propagation.
- Freeze–thaw resistance is enhanced due to reduced permeability and improved crack control.
- Fire resistance improves because fibres reduce thermal cracking and spalling.
- Long-term durability in aggressive environmental conditions remains an active area of research.

Table 1 synthesizes the reported effects of different fiber types on 3DCP-FRC based on the reviewed literature.

3.5 Sustainability Considerations

Sustainability is one of the major advantages of 3D concrete printing. The elimination of formwork reduces material waste and labour requirements. The use of SCMs such as fly ash, silica fume, GGBS, and calcined clay further decreases cement consumption and carbon emissions [10], [12], [17], [18], [43], [64]. The usage of recycled materials like natural sand with recycled glass powder, recycled sand or recycled concrete aggregates, waste tire rubber as aggregate, copper tailings or copper slag in printable mortars is a major trend [5], [10], [11], [16], [20].

Life cycle assessment studies indicate that 3DCP can provide considerable environmental benefits compared with conventional construction methods. However, higher cement contents and the use of steel reinforcement may offset some sustainability gains. Comprehensive building-scale life cycle assessments are still limited and require further investigation [4], [9], [10], [19].

4.0 CONCLUSION AND SUGGESTIONS

Fibre-reinforced 3D concrete printing has emerged as a promising technology for sustainable and automated construction. Different fibre types contribute to improvements in tensile strength, flexural strength, ductility, crack resistance, and durability performance.

Steel and carbon fibres provide superior mechanical performance, while basalt fibres offer excellent durability in harsh environments. Polypropylene fibres improve printability and shrinkage resistance, whereas natural fibres provide sustainable alternatives with lower environmental impact.

Although significant advancements have been achieved, several challenges remain. Standardized testing methods for printability, interlayer bonding, and anisotropic behaviour are still lacking. Long-term durability studies under field conditions are limited, and large-scale structural applications require further validation.

Future research should focus on:

- Development of standardized evaluation methods
- Improvement of interlayer bonding mechanisms
- Optimization of hybrid fibre systems
- Large-scale life cycle assessment studies
- Development of sustainable low-carbon printable materials

Overall, the integration of fibre reinforcement, sustainable materials, and advanced printing technologies can significantly enhance the performance and environmental sustainability of future construction practices.

5.0 REFERENCES

1. Tabassum, A., et al. (2023). A review of 3D printing technology—the future of sustainable construction. *Materials Today: Proceedings*. <https://doi.org/10.1016/j.matpr.2023.08.013>
2. Wang, M., et al. (2024). Concrete 3D printing technology in sustainable construction: A review on raw materials, concrete types and performances. *Developments in the Built Environment*, 17, 100378. <https://doi.org/10.1016/j.dibe.2024.100378>
3. Spalding, M. (2023). Biobased fiber reinforced composite materials for construction 3D-printing. In *RILEM Bookseries* (Vol. 40). Springer. https://doi.org/10.1007/978-3-031-33465-8_40
4. Nicholas, R. (2023). Sustainability and 3D concrete printing: Identifying a need for a more holistic approach to assessing environmental impacts. *Architectural Intelligence*, 2(1). <https://doi.org/10.1007/s44223-023-00030-3>
5. Shakor, P., et al. (2019). Review of emerging additive manufacturing technologies in 3D printing of cementitious materials in the construction industry. *Frontiers in Built Environment*, 4, Article 85. <https://doi.org/10.3389/fbuil.2018.00085>
6. Formiga, J., et al. (2020). *Impressão 3D em concreto: Revisão da literatura e desafios*. ENEGEP. https://doi.org/10.14488/ENEGEP2020_TN_WPG_346_1779_41448
7. Lu, Y., et al. (2024). 3D printing recycled concrete incorporating plant fibres: A comprehensive review. *Construction and Building Materials*, 447, 135951. <https://doi.org/10.1016/j.conbuildmat.2024.135951>
8. Madake, S. (2022). Additive manufacturing of sustainable construction materials and form-finding structures: A review on recent progresses. *3D Printing and Additive Manufacturing*, 9(5), 337–356. <https://doi.org/10.1089/3dp.2020.0331>
9. El-Wafa, A. (2024). Integrating fiber with new cement trends to create a greener future for sustainable concrete. *Global Journal of Engineering and Technology Advances*, 21(2), 193–208. <https://doi.org/10.30574/gjeta.2024.21.2.0203>
10. Fonseca, L., et al. (2023). 3D construction printing standing for sustainability and circularity: Material-level opportunities. *Materials*, 16(6), 2458. <https://doi.org/10.3390/ma16062458>
11. Prodhan, M., et al. (2024). Integrating recycled and alternative materials in 3D concrete printing for sustainable development. *European Journal of Theoretical and Applied Sciences*, 2(6), 566–579. [https://doi.org/10.59324/ejtas.2024.2\(6\).38](https://doi.org/10.59324/ejtas.2024.2(6).38)

12. Bbosa, D., et al. (2024). A review of sustainable concrete construction: Strategies, advancements, and future directions. *European Journal of Theoretical and Applied Sciences*, 2(3), 440–454. [https://doi.org/10.59324/ejtas.2024.2\(3\).28](https://doi.org/10.59324/ejtas.2024.2(3).28)
13. Zhou, X., et al. (2023). An overview of recent advancements in fibre-reinforced 3D printing concrete. *Frontiers in Materials*, 10, 1289340. <https://doi.org/10.3389/fmats.2023.1289340>
14. Li, Y. (2024). From concept to reality: Transforming architectural visions with 3D printed concrete. *Academic Journal of Science and Technology*. <https://doi.org/10.54097/jbc6ff42>
15. Capeto, A., et al. (2024). Building a greener future: Advancing concrete production sustainability and the thermal properties of 3D-printed mortars. *Buildings*, 14(5), 1323. <https://doi.org/10.3390/buildings14051323>
16. Sambucci, M., et al. (2023). Life cycle assessment (LCA) of 3D concrete printing and casting processes for cementitious materials incorporating ground waste tire rubber. *Recycling*, 8(1), 15. <https://doi.org/10.3390/recycling8010015>
17. Gamage, R., et al. (2024). Advancement in sustainable 3D concrete printing: A review on materials, challenges, and current progress in Australia. *Buildings*, 14(2), 494. <https://doi.org/10.3390/buildings14020494>
18. Meng, W. (2022). A review of printing strategies, sustainable cementitious materials and characterization methods in the context of extrusion-based 3D concrete printing. *Journal of Building Engineering*, 45, 103599. <https://doi.org/10.1016/j.jobbe.2021.103599>
19. Mohammad, A., et al. (2020). 3D concrete printing sustainability: A comparative life cycle assessment of four construction method scenarios. *Buildings*, 10(12), 245. <https://doi.org/10.3390/buildings10120245>
20. Cao, J., et al. (2022). 3D printing devices and reinforcing techniques for extruded cement-based materials: A review. *Buildings*, 12(4), 453. <https://doi.org/10.3390/buildings12040453>
21. Basalt and carbon 3DCP insights: Internal synthesis report. (2026). Unpublished internal report.
22. Yao, Y., et al. (2025). Enhancing mechanical properties of three-dimensional cementitious composites through 3 mm short fibre systems: Single and hybrid types. *Buildings*, 15(14), 2519. <https://doi.org/10.3390/buildings15142519>
23. Liu, X., et al. (2022). Review on the developments of structure, construction automation, and monitoring of intelligent construction. *Buildings*, 12(11), 1890. <https://doi.org/10.3390/buildings12111890>
24. Li, Y., et al. (2023). Mechanical properties of 3D-printed carbon fiber-reinforced cement mortar. *Fibers*, 11(12), 109. <https://doi.org/10.3390/fib11120109>
25. Wang, M., et al. (2026). Printability, mechanical properties and microstructural analysis of 3D-printed basalt fiber-reinforced concrete in freshwater and seawater environments. Manuscript under review.
26. Rudziewicz, K., et al. (2025). 3D-printed lightweight foamed concrete with dispersed reinforcement. *Applied Sciences*, 15(8), 4527. <https://doi.org/10.3390/app15084527>
27. Aljuwayhel, A. (2024). Evaluation of fiber-reinforced mixtures for 3D concrete printing in cold regions (Doctoral dissertation).
28. Shang, Y., et al. (2025). Research on 3D printing materials and printing parameters of basalt fiber reinforced concrete. In *Conference Proceedings*.
29. Alonso-Cañón, A., et al. (2025). Selection of the best 3D printing high-performance mortars using multi-criteria analysis. *Buildings*, 15(18), 3307. <https://doi.org/10.3390/buildings15183307>
30. Shoaie, P., et al. (2024). Characterization of 3D-printable geopolymers: Effect of binder composition and basalt fiber reinforcement. *Case Studies in Construction Materials*, 21, e03335. <https://doi.org/10.1016/j.cscm.2024.e03335>
31. Ma, X., et al. (2025). Mechanical improvement of basalt fiber reinforced cementitious material for binder jetting 3D printing. *Additive Manufacturing*, 104, 104688. <https://doi.org/10.1016/j.addma.2025.104688>
32. Liu, Y., et al. (2023). Mechanical performance optimization in spray-based three-dimensional-printed mortar using carbon fiber. *Journal of Materials in Civil Engineering*, 35(5). [https://doi.org/10.1061/\(ASCE\)MT.1943-5533.0004587](https://doi.org/10.1061/(ASCE)MT.1943-5533.0004587)
33. Yang, X., et al. (2024). Materials, performance studies, and application progress of fiber-reinforced 3D-printed concrete. *Journal of Testing and Evaluation*. <https://doi.org/10.1520/JTE20240057>

34. Huang, Y., et al. (2026). *Research on the workability of 3D printed fiber-reinforced concrete materials*. Preprint manuscript.
35. Duan, X., et al. (2024). *Effect of process parameters on forming quality and flexural strength of continuous fiber reinforced cement-based 3D printed composites*. *Construction and Building Materials*, 448, 137241. <https://doi.org/10.1016/j.conbuildmat.2024.137241>
36. Ramesh, P., et al. (2024). *Bond-slip behaviour of textile-reinforcement in 3D printed concrete*. *Journal of Building Engineering*, 89, 108873. <https://doi.org/10.1016/j.jobe.2024.108873>
37. Sukontasukkul, P., et al. (2024). *Eco-friendly 3D printing mortar with low cement content: Investigation on printability and mechanical properties*. *Civil Engineering Journal*, 10(3), 1086–1104. <https://doi.org/10.28991/cej-2024-010-03-010>
38. Kuchem, B. (2019). *Development of test methods for characterizing extrudability of cement-based materials for use in 3D printing* (Master's thesis).
39. Xia, Y., et al. (2025). *Comparative analysis of polypropylene, basalt, and steel fibers in 3D printed concrete: Effects on flowability, printability, rheology, and mechanical performance*. *Construction and Building Materials*, 474, 140098. <https://doi.org/10.1016/j.conbuildmat.2025.140098>
40. Tretmans, H. (2022). *3D concrete printing technology current progress and future perspective: A state-of-the-art review*. In *Advances in Construction Materials and Systems* (pp. xx–xx). Springer. https://doi.org/10.1007/978-981-19-0189-8_3
41. Rehman, A. U., et al. (2021). *3D concrete printing: A systematic review of rheology, mix designs, mechanical, microstructural, and durability characteristics*. *Materials*, 14(14), 3800. <https://doi.org/10.3390/MA14143800>
42. Van der Heever, M., et al. (2021). *Mechanical characterisation for numerical simulation of extrusion-based 3D concrete printing*. *Journal of Building Engineering*, 44, 102944. <https://doi.org/10.1016/J.JOBE.2021.102944>
43. Du, Y., et al. (2024). *Bio-inspired innovations in 3D concrete printing: Structures, materials and applications*. *Applied Materials Today*, 39, 102459. <https://doi.org/10.1016/j.apmt.2024.102459>
44. Ahmed, G. H. (2023). *A review of 3D concrete printing: Materials and process characterization, economic considerations and environmental sustainability*. *Journal of Building Engineering*, 66, 105863. <https://doi.org/10.1016/j.jobe.2023.105863>
45. Figueiredo, S. C., et al. (2020). *Quality assessment of printable strain hardening cementitious composites manufactured in two different printing facilities*. In *Second RILEM International Conference on Concrete and Digital Fabrication* (pp. xx–xx). Springer. https://doi.org/10.1007/978-3-030-49916-7_81
46. Li, Z., et al. (2024). *Methodology to design eco-friendly fiber-reinforced concrete for 3D printing*. *Cement and Concrete Composites*, 147, 105415. <https://doi.org/10.1016/j.cemconcomp.2023.105415>
47. Pan, T., et al. (2019). *Fiber reinforced cement-based material for 3D printing, preparation, performance evaluation and application*.
48. Varghese, L., et al. (2025). *Strength, structure, and sustainability in 3D-printed concrete using different types of fibre reinforcements*. *U.Porto Journal of Engineering*, 11(2). https://doi.org/10.24840/2183-6493_011-002_003270
49. Farina, I., et al. (2016). *Surface roughness effects on the reinforcement of cement mortars through 3D printed metallic fibers*. *Composites Part B: Engineering*, 99, 305–313. <https://doi.org/10.1016/J.COMPOSITESB.2016.05.055>
50. Arunothayan, A. R., et al. (2022). *Digital fabrication of eco-friendly ultra-high performance fiber-reinforced concrete*. *Cement and Concrete Composites*, 125, 104281. <https://doi.org/10.1016/J.CEMCONCOMP.2021.104281>
51. Sun, X., et al. (2021). *PVA fibre reinforced high-strength cementitious composite for 3D printing: Mechanical properties and durability*. *Additive Manufacturing*, 49, 102500. <https://doi.org/10.1016/J.ADDMA.2021.102500>
52. Surehali, A., et al. (2023). *Anisotropy in additively manufactured concrete specimens under compressive loading—Quantification of the effects of layer height and fiber reinforcement*. *Materials*, 16(15), 5488. <https://doi.org/10.3390/ma16155488>
53. Weng, Y., et al. (2019). *Printability and fire performance of a developed 3D printable fibre reinforced cementitious composites under elevated temperatures*. *Virtual and Physical Prototyping*, 14(3), 284–292. <https://doi.org/10.1080/17452759.2018.155504>

54. Chu, S. H., et al. (2021). *Development of extrudable high strength fiber reinforced concrete incorporating nano calcium carbonate*. *Additive Manufacturing*, 37, 101617. <https://doi.org/10.1016/J.ADDMA.2020.101617>
55. Ungureanu, D., et al. (2023). *Microstructure and mechanical properties of cost-efficient 3D printed concrete reinforced with polypropylene fibers*. *Buildings*, 13(11), 2813. <https://doi.org/10.3390/buildings13112813>
56. Singh, A., et al. (2022). *Mechanical and macrostructural properties of 3D printed concrete dosed with steel fibers under different loading direction*. *Construction and Building Materials*, 323, 126616. <https://doi.org/10.1016/j.conbuildmat.2022.126616>
57. Janani, G., et al. (2025). *Synergistic effects of polypropylene fibers on the strength and durability properties of 3D printed concrete*. *Structural Concrete*. <https://doi.org/10.1002/suco.70387>
58. Uddin, M. N., et al. (2023). *Prediction of rheological parameters of 3D printed polypropylene fiber-reinforced concrete (3DP-PPRC) by machine learning*. *Materials Today: Proceedings*. <https://doi.org/10.1016/j.matpr.2023.03.191>
59. Pérez, G. (n.d.). *Assessment of fresh and hardened state properties in medium-scale 3D printing of earth-cement mixtures with and without jute fibers*.
60. Şahin, H. G., et al. (2024). *Mechanical and rheological properties of fiber-reinforced 3D printable concrete in terms of fiber content and aspect ratio*. *Structural Concrete*. <https://doi.org/10.1002/suco.202400030>
61. Pham, L., et al. (2025). *Experimental study on anisotropic mechanical properties of 3D reinforced concrete with discrete polyethylene fibers*. *Research on Engineering Structures and Materials*. <https://doi.org/10.17515/resm2025-785me0326rs>
62. Pham, L., et al. (2020). *Steel fibres reinforced 3D printed concrete: Influence of fibre sizes on mechanical performance*. *Construction and Building Materials*, 250, 118785. <https://doi.org/10.1016/J.CONBUILDMAT.2020.118785>
63. Paritala, S., Raj, S., Singh, P. R., & Subramaniam, K. V. (2025). *Designing 3D printable concrete by integrating the influence of aggregate characteristics*. *Materials and Structures*, 58(8), 267.
64. Rahul, A. V., Santhanam, M., Meena, H., & Ghani, Z. (2019). *Mechanical characterization of 3D printable concrete*. *Construction and Building Materials*, 227, 116710. <https://doi.org/10.1016/j.conbuildmat.2019.116710>
65. Rahul, A. V., Santhanam, M., Meena, H., & Ghani, Z. (2019). *3D printable concrete: Mixture design and test methods*. *Cement and Concrete Composites*, 97, 13–23. <https://doi.org/10.1016/j.cemconcomp.2018.12.014>

Table 1: Comparative analysis of Fiber performance

Type of Fibre	Process of printability	Improved mechanical behaviour	Durability and environmental sustainability	Limitations
Carbon	Requires rheology tuning (SP/accelerators).	Maximum compressive and bending strength	Enhanced performance and suitability for hybrid systems	High cost; high environmental footprint.
Steel	High nozzle wear; clogging risk.	Toughness High durability	General FRC durability; no 3DCP LCA.	Anisotropy, high density
Synthetic (PP)	Compatibility is better; easy to extrude.	Control crack effectively.	Polymer aging concerns; limited 3DCP LCA.	Lower strength than steel/carbon.
Natural	Variable dispersion; water absorption issues.	Lower strength; good environmental profile.	Potential degradation; high moisture uptake.	Material variability.

Basalt	Reduces fluidity at >1 wt%.	Quasi-brittle transition; good flexural gains.	Excellent in seawater & cold regions.	Potential for nozzle abrasion.
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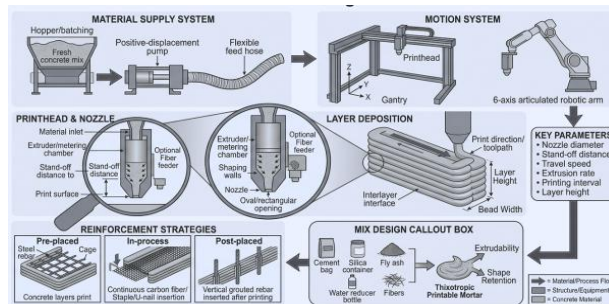


Fig.1. Printing process of 3D Concrete

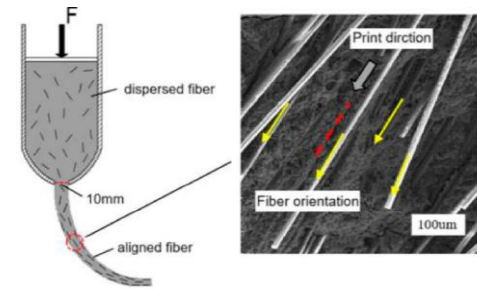


Fig.2.Orientation of fibres during mixing

Source: Reproduced from [Zhang, et.al,2021].

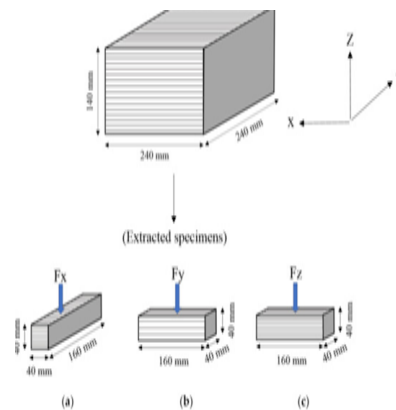


Fig. 3. Effect of 3D printing tests

Source: Reproduced from Hao Zhang,et.al,material journal (2023).

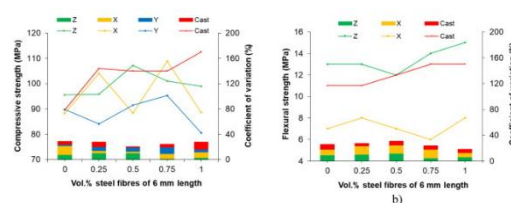


Fig. 4. Compressive strengths of printed and cast specimens at different fibre contents

Source: Reproduced from Pham, L. et al. (2020).

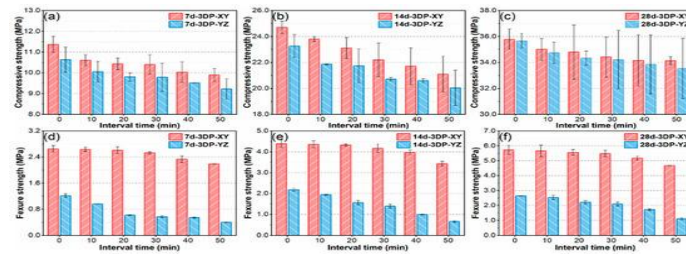


Fig.5. Interlayer bonding characteristics of 3D printed fibre reinforced geopolymers

Source: Reproduced from Liu, X. et al. (2024).