Journal of
Composites Science

Editorial

Editorial for the Special Issue on Additive Manufacturing of Advanced Composites

Yuan Chen [1,2]

[1] Shenzhen Key Laboratory of Intelligent Manufacturing for Continuous Carbon Fiber Reinforced Composites, Southern University of Science and Technology, Shenzhen 518055, China; chenyuan@sustech.edu.cn
[2] School of System Design and Intelligent Manufacturing, Southern University of Science and Technology, Shenzhen 518055, China

Advanced composites are attracting increasing attention in industrial applications due to their excellent performance, i.e., high mechanical properties in terms of stiffness- and strength-to-weight ratios when compared to their counterparts. Meanwhile, the rapid enhancement of additive manufacturing (AM) techniques has been leading to satisfactory printing of advanced composites, accelerating many highly specific but important engineering productions for advanced materials and structures with complex geometries, unique functions, excellent performance, etc. [1–5]. The importance of AM of advanced composites is evident, and in this regard, investigations into fabrication techniques and processes, modeling and characterization, structure–property performance, design and optimization of AM or 3D printing are urgent and crucial.

Regarding the AM fabrication technology for advanced composites, usually, it creates objects directly by stacking layers of material on each other until the required product is obtained [6–8]. As such, the extrusion-based method has currently been becoming the most used approach in the fabrication of advanced composites [9,10]. Ajao et al. [6] employed extrusion-based AM to design and construct a low-cost and high-accessibility 3D printing machine to manufacture plastic objects, where the distance between the nozzle tip and the bed is recommended as 0.1 mm during the AM process. In addition to this, Sharafi et al. [9] applied fused filament fabrication (FFF), a key approach of extrusion-based AM, to produce intricate PAEK and PAEK composite parts and to tailor their mechanical properties such as stiffness, strength, and deflection at failure. A multiscale modeling framework was used to identify the layer design and process parameters that may significantly affect the mechanical properties of polyetherketoneketone (PAEK) and PAEK composites. The results show that the mechanical properties of AM-produced parts are comparable to those of injection-molded parts [9]. Cramer et al. [11] developed an additive manufacturing process for fabricating ceramic matrix composites based on the C/C-SiC system. In this study, automated fiber placement of the continuous carbon fibers in a polyether ether ketone matrix was performed to consolidate the carbon fibers into a printed preform, and pyrolysis was performed to convert the polymer matrix to porous carbon. Then, Si was introduced by reactive melt infiltration to convert a portion of the carbon matrix to silicon carbide. Astafurova et al. [12] used the electron-beam AM method to obtain dual-phase specimens, their temperature dependence of tensile deformation behavior, and their mechanical properties (yield strength, ultimate tensile strength, and an elongation-to-failure). Susanto et al. [13] applied the digital light processing (DLP) technique to fabricate nickel microparticle-reinforced composites. Their mechanical properties were evaluated based on tensile strength, surface roughness, and hardness, and the findings demonstrate the potential of DLP-fabricated Ni-reinforced composites for applications demanding enhanced mechanical performance while maintaining favorable printability, paving the way for further exploration in this domain.

For modeling and characterization of structure–property performance, Zach et al. [14] reviewed the AM process across different spectrums of finite element analyses (FEA) and

Citation: Chen, Y. Editorial for the Special Issue on Additive Manufacturing of Advanced Composites. *J. Compos. Sci.* **2024**, *8*, 344. https://doi.org/10.3390/jcs8090344

Received: 19 July 2024
Accepted: 2 September 2024
Published: 3 September 2024

summarized the building definition (support definition) with the optimization of deposition trajectories and the multi-physics of melting/solidification using computational fluid dynamics. The process modeling continues with the displacement/temperature distribution. Salgueiro et al. [15] investigated the effects of infill percentage and filament orientation on the mechanical properties of 3D-printed polylactic acid (PLA) structures, where both the finite element method and experimental tests were utilized in characterization. The results demonstrated that the process parameters have a significant impact on mechanical performance, particularly when the infill percentage is less than 100%. Meanwhile, Daly et al. [16] studied the impacts of infill patterns and densities on the mechanical characteristics of polyethylene terephthalate specimens reinforced with carbon fibers, fabricated by extrusion-based AM. The results show that the design with a 75% honeycomb and 100% infill density has the highest Young's modulus and tensile strength. In addition, the honeycomb was the ideal infill pattern, with 75% and 100% densities, providing significant strength and stiffness. Additionally, Ogaili et al. [17] evaluated the tensile and fracture behaviors of 3D-printed PLA composites reinforced with chopped carbon fibers through experimental characterization and finite element analysis (FEA). An inverse correlation between tensile strength and fracture toughness was observed, attributed to mechanisms such as crack deflection, fiber bridging, and fiber pull-out facilitated by multi-directional fiber orientations. Paulo et al. [18] developed 3D-printed PLA composites reinforced with flax fibers to evaluate the improvement in tensile and flexural strengths. An experimental design was utilized to study the effects of extruder temperature, number of strands, infill percentage of the specimens, and whether surface chemical treatment with flax fiber had an impact on the mechanical properties. The results show that the surface chemical treatment with the NaOH in the fiber does not have any influence on the mechanical properties of the composites; in contrast, the infill density demonstrated a huge influence on the improvement in mechanical strength. The maximum values of tensile and bending stress were 50 MPa and 73 MPa, respectively. In addition to the flax fiber-reinforced composites, Billings et al. [19] integrated wood fibers as a versatile renewable resource of cellulose, within bio-based PLA polymer, for the development and AM of sustainable and recyclable green composites using FFF technology. The 3D-printed composites were comprehensively characterized to understand the critical materials' properties, including density, porosity, microstructures, tensile modulus, and ultimate strength. Adeniran et al. [20] employed micro-CT scan analysis to quantitatively compare the fabrication temperature's effect on the mechanical properties of AM-fabricated carbon fiber-reinforced plastic (CFRP) composites. Additionally, SEM evaluation was used to determine the temperature effects on interlayer and intralayer porosity generation, and it was found that the porosity volume was related to the mechanical properties. Therefore, it was determined that temperatures influence porosity volumes.

To obtain improved mechanical performance in the AM-fabricated advanced composites, several studies were conducted. For example, for the fabrication of advanced composites, hybrid machines can solve this problem by combining the advantages of both additive and subtractive processes. However, little information is currently available to determine the milling parameters; hence, Spitaels et al. [21] proposed a systematic approach to experimentally determine the cutting parameters of green AM zirconia parts. Sadeghi et al. [22] developed a hybrid approach to solve the challenge of balancing strength and ductility in aluminum matrix composites. Owing to their studies, potential applications include lightweight and high-strength components for use in the aerospace and automotive industries. Structural materials for use in advanced mechanical systems that require both high strength and toughness are also expected. Demarbaix et al. [23] aimed to explore the feasibility of printing parts in continuous carbon fiber and using this fiber as an indicator, thanks to the electrical properties of the carbon fiber. The results show that the resistivity evolves linearly during the elastic period. The gauge factor increases when the number of passes in the manufacturing plane is low; however, repeatability is impacted. Meißner et al. [24] proposed a novel two-stage AM method in which the process steps of AM and continuous fiber integration are decoupled from each other. By using this method of fabrication, a significant improvement in the mechanical properties of the 3D-printed specimen was achieved compared to unreinforced polymer structures. The Young's modulus and tensile strength were increased by factors of 9.1 and 2.7, respectively.

Although increased attention is being paid to the AM of advanced composites, and the performance of AM-fabricated composites has seen significant improvement, the advanced composites made by AM still have a long way to go before they can be considered excellent, because their mechanical properties still cannot compare to those of composited created with conventional fabrication methods [25–27]. The collection of studies in this Issue may help advance technology and bring industry closer to promoting the wider application of AM for advanced composites.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Chen, Y.; Ye, L.; Kinloch, A.; Zhang, Y.X. 3D printed carbon-fibre reinforced composite lattice structures with good thermal-dimensional stability. *Compos. Sci. Technol.* **2022**, *227*, 109599. [CrossRef]
2. Li, G.X.; Chen, Y.; Wei, G.K. Continuous fiber reinforced meta-composites with tailorable Poisson's ratio and effective elastic modulus: Design and experiment. *Compos. Struct.* **2024**, *329*, 117768. [CrossRef]
3. Li, N.Y.; Link, G.; Wang, T.; Ramopoulos, V.; Neumaier, D.; Hofele, J.; Walter, M.; Jelonnek, J. Path-designed 3D printing for topological optimized continuous carbon fibre reinforced composite structures. *Compos. Part B Eng.* **2020**, *182*, 107612. [CrossRef]
4. Chen, Y.; Ye, L. Path-dependent progressive failure analysis for 3D-printed continuous carbon fibre reinforced composites. *Chin. J. Mech. Eng.* **2024**, *37*, 72. [CrossRef]
5. Chen, Y.; Klingler, A.; Fu, K.K.; Ye, L. 3D printing and modelling of continuous fibre reinforced composite grids with enhanced shear modulus. *Eng. Struct.* **2023**, *286*, 116165. [CrossRef]
6. Ajao, K.R.; Ibitoye, S.E.; Adesiji, A.D.; Akinlabi, E.T. Design and Construction of a Low-Cost-High-Accessibility 3D Printing Machine for Producing Plastic Components. *J. Compos. Sci.* **2022**, *6*, 265. [CrossRef]
7. Cai, H.; Chen, Y. A review on print head for fused filament fabrication of continuous carbon fiber reinforced composites. *Micromachines* **2024**, *15*, 432. [CrossRef]
8. Zhang, H.; Huang, T.; Jiang, Q.; He, L.; Bismarck, A.; Hu, Q. Recent progress of 3D printed continuous fiber reinforced polymer composites based on fused deposition modeling: A review. *J. Mater. Sci.* **2021**, *56*, 12999–13022. [CrossRef]
9. Sharafi, S.; Santare, M.H.; Gerdes, J.; Advani, S.G. Extrusion-Based Additively Manufactured PAEK and PAEK/CF Polymer Composites Performance: Role of Process Parameters on Strength, Toughness and Deflection at Failure. *J. Compos. Sci.* **2023**, *7*, 157. [CrossRef]
10. Chen, Y.; Ye, L. Topological design for 3D-printing of carbon fibre reinforced composite structural parts. *Compos. Sci. Technol.* **2021**, *204*, 108644. [CrossRef]
11. Cramer, C.L.; Yoon, B.; Lance, M.J.; Cakmak, E.; Campbell, Q.A.; Mitchell, D.J. Additive Manufacturing of C/C-SiC Ceramic Matrix Composites by Automated Fiber Placement of Continuous Fiber Tow in Polymer with Pyrolysis and Reactive Silicon Melt Infiltration. *J. Compos. Sci.* **2022**, *6*, 359. [CrossRef]
12. Astafurova, E.; Maier, G.; Melnikov, E.; Astafurov, S.; Panchenko, M.; Reunova, K.; Luchin, A.; Kolubaev, E. Temperature-Dependent Deformation Behavior of "γ-austenite/δ-ferrite" Composite Obtained through Electron Beam Additive Manufacturing with Austenitic Stainless-Steel Wire. *J. Compos. Sci.* **2023**, *7*, 45. [CrossRef]
13. Susanto, B.; Kumar, V.V.; Sean, L.; Handayani, M.; Triawan, F.; Rahmayanti, Y.D.; Ardianto, H.; Muflikhun, M.A. Investigating Microstructural and Mechanical Behavior of DLP-Printed Nickel Microparticle Composites. *J. Compos. Sci.* **2024**, *8*, 247. [CrossRef]
14. Zach, T.F.; Dudescu, M.C. The Three-Dimensional Printing of Composites: A Review of the Finite Element/Finite Volume Modelling of the Process. *J. Compos. Sci.* **2024**, *8*, 146. [CrossRef]
15. Salgueiro, M.P.; Pereira, F.A.M.; Faria, C.L.; Pereira, E.B.; Almeida, J.A.P.P.; Campos, T.D.; Fakher, C.; Zille, A.; Nguyễn, Q.; Dourado, N. Numerical and Experimental Characterisation of Polylactic Acid (PLA) Processed by Additive Manufacturing (AM): Bending and Tensile Tests. *J. Compos. Sci.* **2024**, *8*, 55. [CrossRef]
16. Daly, M.; Tarfaoui, M.; Bouali, M.; Bendarma, A. Effects of Infill Density and Pattern on the Tensile Mechanical Behavior of 3D-Printed Glycolyzed Polyethylene Terephthalate Reinforced with Carbon-Fiber Composites by the FDM Process. *J. Compos. Sci.* **2024**, *8*, 115. [CrossRef]
17. Ogaili, A.A.F.; Basem, A.; Kadhim, M.S.; Al-Sharify, Z.T.; Jaber, A.A.; Njim, E.K.; Al-Haddad, L.A.; Hamzah, M.N.; Al-Ameen, E.S. The Effect of Chopped Carbon Fibers on the Mechanical Properties and Fracture Toughness of 3D-Printed PLA Parts: An Experimental and Simulation Study. *J. Compos. Sci.* **2024**, *8*, 273. [CrossRef]
18. Paulo, A.; Santos, J.; da Rocha, J.; Lima, R.; Ribeiro, J. Mechanical Properties of PLA Specimens Obtained by Additive Manufacturing Process Reinforced with Flax Fibers. *J. Compos. Sci.* **2023**, *7*, 27. [CrossRef]

19. Billings, C.; Siddique, R.; Sherwood, B.; Hall, J.; Liu, Y. Additive Manufacturing and Characterization of Sustainable Wood Fiber-Reinforced Green Composites. *J. Compos. Sci.* **2023**, *7*, 489. [CrossRef]
20. Adeniran, O.; Osa-uwagboe, N.; Cong, W.; Ramoni, M. Fabrication Temperature-Related Porosity Effects on the Mechanical Properties of Additively Manufactured CFRP Composites. *J. Compos. Sci.* **2023**, *7*, 12. [CrossRef]
21. Spitaels, L.; Dantinne, H.; Bossu, J.; Rivière-Lorphèvre, E.; Ducobu, F. A Systematic Approach to Determine the Cutting Parameters of AM Green Zirconia in Finish Milling. *J. Compos. Sci.* **2023**, *7*, 112. [CrossRef]
22. Sadeghi, B.; Cavaliere, P.; Sadeghian, B. Enhancing Strength and Toughness of Aluminum Laminated Composites through Hybrid Reinforcement Using Dispersion Engineering. *J. Compos. Sci.* **2023**, *7*, 332. [CrossRef]
23. Demarbaix, A.; Ochana, I.; Levrie, J.; Coutinho, I.; Cunha, S.S., Jr.; Moonens, M. Additively Manufactured Multifunctional Composite Parts with the Help of Coextrusion Continuous Carbon Fiber: Study of Feasibility to Print Self-Sensing without Doped Raw Material. *J. Compos. Sci.* **2023**, *7*, 355. [CrossRef]
24. Meißner, S.; Kafka, J.; Isermann, H.; Labisch, S.; Kesel, A.; Eberhardt, O.; Kuolt, H.; Scholz, S.; Kalisch, D.; Müller, S.; et al. Development and Evaluation of a Novel Method for Reinforcing Additively Manufactured Polymer Structures with Continuous Fiber Composites. *J. Compos. Sci.* **2024**, *8*, 272. [CrossRef]
25. Chen, Y.; Mai, Y.-W.; Ye, L. Perspectives for multiphase mechanical metamaterials. *Mater. Sci. Eng. R. Rep.* **2023**, *153*, 100725. [CrossRef]
26. Jiang, B.N.; Chen, Y.; Ye, L.; Dong, H.; Chang, L. Residual stress and warpage of additively manufactured SCF/PLA composite parts. *Adv. Manuf. Polym. Compos. Sci.* **2023**, *9*, 2171940. [CrossRef]
27. Kamaal, M.; Anas, M.; Rastogi, H.; Bhardwaj, N.; Rahaman, A. Effect of FDM Process Parameters on Mechanical Properties of 3D-Printed Carbon Fibre–PLA Composite. *Prog. Addit. Manuf.* **2021**, *6*, 63–69. [CrossRef]