OPEN ACCESS
International Journal of Applied Research in Social Sciences
P-ISSN: 2706-9176, E-ISSN: 2706-9184
Volume 6, Issue 3, P.No. 279-291, March 2024
DOI: 10.51594/ijarss.v6i3.886
Fair East Publishers
Journal Homepage: www.fepbl.com/index.php/ijarss

INNOVATIVE MATERIAL PROCESSING TECHNIQUES IN PRECISION MANUFACTURING: A REVIEW

Kehinde Andrew Olu-lawal[1], Oladiran Kayode Olajiga[2], Adeniyi Kehinde Adeleke[3], Emmanuel Chigozie Ani[4], & Danny Jose Portillo Montero[5]

[1]Niger Delta Power Holding Compnay, Akure, Nigeria
[2]Independent Researcher, UK
[3]Centre for Precision Metrology Department of Mechanical Engineering and Engineering Science, University of North Carolina, USA
[4]Department of Electrical Engineering, The University of Nebraska-Lincoln, USA
[5]Department of Metallurgical and Materials Engineering, The University of Alabama, USA

Corresponding Author: Kehinde Andrew Olu-lawal
Corresponding Author Email: nwakamma@ge.com

Article Received: 15-01-24 **Accepted:** 02-03-24 **Published:** 17-03-24

ABSTRACT

Precision manufacturing plays a pivotal role in various industries, demanding high accuracy, efficiency, and quality in the production process. The continual pursuit of innovation in material processing techniques is essential to meet evolving demands and challenges. This review explores the latest advancements and innovations in material processing methods within precision manufacturing. The review encompasses a comprehensive analysis of various innovative material processing techniques, including additive manufacturing, subtractive manufacturing, and hybrid approaches. Additive manufacturing, often referred to as 3D printing, has gained significant attention for its capability to produce complex geometries with high precision. The exploration of novel materials, such as metal alloys, polymers, and composites, expands the applicability of additive manufacturing in diverse industrial sectors. Subtractive manufacturing techniques, such as milling, turning, and grinding, are also undergoing transformative advancements to enhance precision and efficiency. Emerging technologies like abrasive waterjet machining, electrical discharge machining (EDM), and laser machining offer improved accuracy and surface finish while enabling the processing of a wide range of materials, including hard-to-machine alloys and composites. Hybrid manufacturing approaches, combining additive and subtractive techniques, are revolutionizing precision manufacturing by leveraging the strengths of both methods. These hybrid systems enable the production of intricate components with high precision, reduced lead times, and minimized material waste, addressing the challenges of traditional manufacturing processes. Furthermore, the review highlights advancements in process monitoring and control technologies, such as in-process sensing, real-time feedback systems, and adaptive control algorithms, facilitating enhanced quality assurance and productivity in precision manufacturing. The integration of advanced computational tools, simulation techniques, and artificial intelligence further augments the optimization and customization capabilities of material processing techniques, driving efficiency and innovation in precision manufacturing. Overall, this review provides valuable insights into the latest developments and trends in innovative material processing techniques, offering a roadmap for future research directions and applications in precision manufacturing industries.

Keywords: Material, Processing, Techniques, Precision, Manufacturing, Review.

INTRODUCTION

Precision manufacturing involves the use of advanced techniques to create highly accurate and intricate components, often at a micro or nano scale (Shore & Morantz, 2012). These techniques are crucial in various industries such as aerospace, automotive, and electronics, where the demand for high precision and quality is paramount. The importance of innovative material processing techniques in precision manufacturing cannot be overstated. These techniques, such as additive manufacturing, nanocatalysis, and hybrid manufacturing processes, enable the production of complex geometries, improved material properties, and enhanced efficiency in manufacturing processes (Ribeiro et al., 2021; Zhu et al., 2013; Schneider et al., 2019). They also contribute to the development of sustainable products, mass customization, and on-demand production, aligning with the evolving needs of modern manufacturing (Ramakrishna et al., 2018; Guan & Zhao, 2022; Schneider et al., 2019).

The scope of this review encompasses an in-depth analysis of various innovative material processing techniques and their applications in precision manufacturing. It aims to explore the advancements in manufacturing processes, such as topology optimization, mesostructural design, and ultra-precision machining, and their impact on the quality and efficiency of precision manufacturing (Ribeiro et al., 2021; Schneider et al., 2019; Matz et al., 2014). Furthermore, the review seeks to provide insights into the integration of sustainability principles in ultra-precision and micro machining, aligning with the growing emphasis on sustainable manufacturing practices (Schneider et al., 2019). By synthesizing the latest research and developments in the field, this review aims to offer a comprehensive overview of innovative material processing techniques in precision manufacturing and their implications for the future of manufacturing industries.

Additive Manufacturing (AM)

Additive Manufacturing (AM) encompasses a group of technologies capable of translating virtual solid model data into physical models (Gibson et al., 2010). This technology, also known as direct digital manufacturing, free form fabrication, or 3D printing, has rapidly emerged as a disruptive force in manufacturing, with implications for various industries and supply chains (Bogers et al., 2016; Welz et al., 2022; Frazier, 2014). AM has opened up new opportunities for precision manufacturing, enabling the production of complex and functionally sophisticated parts with fewer machining processes (Cao et al., 2023). Additionally, AM has facilitated the development of "green" alternatives, reducing the environmental impact of manufacturing processes (Voet et al., 2020).

AM has revolutionized the materials used in manufacturing. For instance, Wire + Arc Additive Manufacturing has made it possible to deposit large components in metals such as titanium, aluminum, and steel (Williams et al., 2016). Additionally, there has been a focus on sustainable photopolymers and biobased, biodegradable, and recyclable alternatives in 3D printing, aiming to reduce the environmental impact of AM materials (Voet et al., 2020; Odeyemi et al., 2024). Furthermore, the technology has enabled the integration of carbon fibers into thermosetting resins, expanding the potential applications of AM materials (Tamez & Taha, 2021).

The applications of AM in precision manufacturing are diverse, ranging from the production of tissues and organs to the fabrication of 3D structural electronics (Melchels et al., 2012; Lopes et al., 2012). AM has also been utilized in maxillofacial reconstruction, highlighting its benefits in the medical field (Dincă et al., 2017; Ajayi-Nifise et al., 2024). Moreover, the technology has been combined with finishing processes such as turning, demonstrating its versatility in manufacturing a wide range of parts (Negrău et al., 2021).

However, along with its advancements and applications, AM also presents challenges. These include the need for a framework to reduce the environmental impact through design optimization, as well as the comparative environmental impacts of additive and subtractive manufacturing technologies (Paris et al., 2016; Tang et al., 2016). Additionally, there is a need for a comprehensive life cycle sustainability assessment of AM to understand its overall impact (Ribeiro et al., 2020; Ohalete et al., 2023). Furthermore, there are challenges related to the dimensional modeling of single pass welding in wire and arc additive manufacturing, highlighting the multi-disciplinary nature of AM technology (Cao et al., 2023; Righettini & Strada, 2021).

In conclusion, Additive Manufacturing has significantly impacted precision manufacturing through its technological advancements, diverse material applications, and wide-ranging uses. While it presents opportunities for innovation and sustainability, it also poses challenges that require comprehensive assessments and solutions.

Subtractive Manufacturing Techniques

Subtractive manufacturing techniques encompass traditional methods such as milling, turning, and grinding, as well as emerging techniques like abrasive waterjet machining, EDM, and laser machining. Traditional subtractive manufacturing involves fabricating parts by removing excess material from a block, while emerging techniques offer exciting possibilities for complex designs and material utilization (Olubusola et al., 2024; Hsu et al., 2019). The integration of advanced tooling and machining strategies is crucial for achieving high precision in subtractive manufacturing processes (Liu et al., 2019). However, challenges persist in achieving simple, scalable, low-cost, and rapid fabrication, especially for high-temperature structural materials like ceramics due to their high melting points and the complexity of building intricate architectures (Guo et al., 2023; Odeyemi et al., 2024).

The advantages of subtractive manufacturing include the ability to work with a wide range of materials, high precision, and surface finish. However, traditional subtractive methods may not be feasible for materials with extreme hardness and brittleness, necessitating the exploration of emerging techniques (Luitz et al., 2023; Anamu et al., 2023). Additive manufacturing, on the other hand, offers one-step production, maximum material utilization, and minimum expense, making it an attractive alternative to traditional subtractive methods (Hsu et al., 2019). Furthermore, hybrid manufacturing processes, which combine varied manufacturing operations, are emerging as a potential evolution for current manufacturing technologies, offering the potential to overcome the limitations of traditional subtractive methods (Zhu et al., 2013; Aderibigbe et al., 2023).

In conclusion, while traditional subtractive manufacturing methods have their advantages in terms of material compatibility, precision, and surface finish, emerging subtractive techniques and additive manufacturing offer exciting possibilities for complex designs, material utilization, and cost-effectiveness. The integration of advanced tooling and machining strategies is essential for achieving high precision in subtractive manufacturing processes. However, challenges remain in achieving simple, scalable, low-cost, and rapid fabrication, especially for high-temperature structural materials like ceramics. Therefore, a combination of traditional subtractive methods and emerging techniques, along with the exploration of hybrid manufacturing processes, presents a promising path for the future of subtractive manufacturing.

Hybrid Manufacturing Approaches

Hybrid manufacturing is an advanced approach that integrates additive and subtractive manufacturing processes to create intricate and high-precision components. This innovative technique involves the combination of various manufacturing methods to achieve superior results. The concept of hybrid manufacturing has gained significant attention due to its potential to revolutionize the production of complex parts and components (Flynn et al., 2016). It is characterized by the combination of additive and subtractive operations within a single manufacturing system, allowing for enhanced material utilization, intricate part complexity, and improved quality management (Flynn et al., 2016). The integration of these processes presents substantial opportunities for advancing material utilization, part complexity, and quality management in functional parts (Flynn et al., 2016). Furthermore, hybrid manufacturing systems have been shown to offer a flexible and sustainable approach for producing cost-effective small batches of metal parts (Mehmeti et al., 2021).

The benefits of hybrid manufacturing in precision applications are evident in its ability to produce parts more efficiently and productively by combining two or more technologies (Avram et al., 2021). This approach has been widely applied across multiple manufacturing industries to enhance productivity and efficiency. Additionally, the advancement of hybrid approaches requires a comprehensive understanding of the fundamental properties of these new technologies, their restrictions, and requirements (Sommer et al., 2022). The combination of additive and subtractive manufacturing processes enables the creation of complex and topologically optimized geometries with internal cavities that were previously impossible to produce using traditional manufacturing processes (Jiménez et al., 2021). Moreover, the accuracy of additive manufacturing in precision applications has significantly improved, although further exploration is still needed to enhance its capabilities (Tang et al., 2022).

Several examples of hybrid systems that combine additive and subtractive manufacturing processes have been documented in the literature. These systems have been applied in various contexts, such as the manufacture of nanoscale integrated circuits, reclaimed carbon and flax fiber composites, and high-precision prismatic parts (Le et al., 2004; Longana et al., 2018; Zhu et al., 2014). The integration of additive and subtractive operations within these hybrid systems has demonstrated the potential to achieve high precision and intricate geometries, making them suitable for a wide range of applications.

In conclusion, hybrid manufacturing represents a transformative approach that combines additive and subtractive manufacturing processes to achieve enhanced precision, intricate geometries, and improved material utilization. The integration of these processes offers significant opportunities for advancing manufacturing capabilities and has been widely applied across diverse industries to enhance productivity and efficiency.

Advanced Process Monitoring and Control Technologies

The significance of process monitoring in precision manufacturing cannot be overstated. In precision manufacturing, the ability to monitor and control the manufacturing process in real-time is crucial for ensuring high-quality output and minimizing defects (Li et al., 2017). Advanced process monitoring technologies, such as in-process sensing technologies, provide real-time feedback on the manufacturing process, enabling quick detection and correction of any deviations from the desired parameters (Zou et al., 2017). These technologies are essential for maintaining tight tolerances and ensuring the consistency and quality of the manufactured products.

In-process sensing technologies, such as tactile sensors, have been developed to enhance the monitoring of manufacturing processes. These sensors, along with smart tactile sensing systems, enable the development of realistic and useful prosthetics, contributing to advancements in precision manufacturing (Zou et al., 2017). Additionally, the integration of artificial intelligence and machine learning has further optimized the manufacturing process by enabling adaptive control algorithms and real-time feedback systems (Kocsis, 2019). These technologies have the capability to learn from the process data and make autonomous adjustments to optimize the manufacturing process.

The integration of artificial intelligence and machine learning in process monitoring and control has opened new frontiers in precision manufacturing. These technologies have the potential to revolutionize the industry by enabling predictive maintenance, autonomous optimization, and adaptive control algorithms (Kocsis, 2019). Furthermore, the use of advanced sensing and communication technologies, such as reconfigurable intelligent surfaces, presents opportunities for intelligent manipulation of the wireless propagation environment, contributing to the advancement of process monitoring and control in precision manufacturing (Liu et al., 2022).

In conclusion, the integration of advanced process monitoring and control technologies, such as in-process sensing, real-time feedback systems, and artificial intelligence, is paramount for achieving precision manufacturing. These technologies not only ensure the quality and consistency of the manufactured products but also pave the way for autonomous and optimized manufacturing processes.

Computational Tools and Simulation Techniques

The role of computational tools in material processing is crucial for the concurrent design of materials, processes, and products (El-Azab, 2017). These tools integrate simulation at various scales, aiding in the development of new materials and processes (El-Azab, 2017). Additionally, computational manufacturing is a low-cost tool for choosing optimal solutions, with the theory of probability predicting reliable production yield estimations (Trubetskov et al., 2011). Furthermore, computational manufacturing significantly reduces the development time for new materials and processes in various industrial sectors (Rodgers, 2009).

Simulation techniques play a vital role in predicting manufacturing outcomes. For instance, simulation results are used to determine search directions or to select tool types, contributing to decision-making in flexible manufacturing systems (Kim et al., 2001). Moreover, the powerful computational capacity of software guarantees the optimality of the machining process, demonstrating the significance of simulation techniques in achieving desired manufacturing outcomes (Lu et al., 2020).

Virtual prototyping and design optimization are facilitated by computational tools, enabling the early use of deep simulation models at various manufacturing stages (Urbikain et al., 2016). This early use of simulation models is essential for achieving the required productivity, accuracy, and reliability in machine tools (Urbikain et al., 2016). Additionally, computational validation is performed to evaluate the mechanical properties of tools, emphasizing the role of virtual prototyping in ensuring the quality and performance of manufacturing tools (Evans et al., 2020).

Artificial intelligence (AI) finds applications in computational manufacturing, particularly in the context of machine tools. During the manufacturing process, machine tools accumulate a large amount of data, which can be leveraged by intelligent machine tools based on edge-cloud collaboration (Lou et al., 2020). Furthermore, AI contributes to tool requirements planning in flexible manufacturing systems, aiding in decision-making processes (Kim et al., 2001).

In conclusion, computational tools and simulation techniques play pivotal roles in material processing, manufacturing outcome prediction, virtual prototyping, design optimization, and the application of artificial intelligence in computational manufacturing. These tools and techniques are essential for concurrent design, decision-making, and ensuring the quality and reliability of manufacturing processes and products.

Future Directions and Challenges

The future of precision manufacturing presents several emerging trends and potential areas for further research and development. These trends include the use of advanced manufacturing technologies such as additive manufacturing (AM) or 3D printing, micro- and nano-manufacturing, and precision automated manufacture of living materials for regenerative medicines (Williams et al., 2012; , Guan & Zhao, 2022; , Yip et al., 2021). Additionally, the development of precision manufacturing is influenced by the need to address challenges such as scalability, sustainability, and cost-effectiveness (Yip et al., 2021; , Qudeiri et al., 2020; , Xie, 2023). For instance, there is a growing focus on sustainable ultra-precision manufacturing to meet the increasing demand for highly technological products (Thompson et al., 2016). Furthermore, the implications for industrial practice and academia are significant, as precision manufacturing technologies have the potential to impact various industries, including biomedical engineering, electronics, and aerospace engineering (Guan & Zhao, 2022; , Qudeiri et al., 2020; , Yang et al., 2018).

The use of advanced manufacturing technologies, such as additive manufacturing, is expected to evolve towards higher precision, convenience, safety, standardization, and networking (Wang et al., 2019). This aligns with the increasing demands for replication precision and quality in precision manufacturing (Luo et al., 2018). Moreover, the integration of precise engineering technologies, including material development and die fabrication, is crucial for manufacturing micro metallic devices (Lin et al., 2019). These advancements in manufacturing technologies are essential for achieving high precision in the production of components and products.

In addressing challenges such as scalability, sustainability, and cost-effectiveness, the role of sustainable precision manufacturing becomes crucial. The development of sustainable precision manufacturing is influenced by the need to improve innovation efficiency and green strategies in manufacturing, . Additionally, the assessment of sustainable product manufacturing involves ergonomics-based factors and criteria, highlighting the multidimensional nature of sustainability in precision manufacturing.

In conclusion, the future of precision manufacturing is shaped by emerging trends in advanced manufacturing technologies, the need to address challenges such as scalability and sustainability, and the implications for industrial practice and academia. These trends and challenges underscore the importance of continued research and development in precision manufacturing to meet the evolving demands of various industries.

RECOMMENDATION AND CONCLUSION

Throughout our study, we delved into the realm of material processing techniques within precision manufacturing. We uncovered several key findings and gained valuable insights into the significance of innovation in this field. Firstly, we observed that traditional material processing methods often pose limitations in terms of efficiency, precision, and environmental impact. However, through the adoption of innovative techniques such as additive manufacturing, laser cutting, and advanced machining, manufacturers can overcome these challenges and achieve enhanced outcomes. Moreover, we noted the pivotal role of advanced materials in enabling novel manufacturing processes, thereby facilitating the production of complex components with superior properties.

The importance of innovative material processing techniques cannot be overstated. These techniques not only enhance the efficiency and precision of manufacturing processes but also enable the production of highly customized and intricate components. Furthermore, they offer significant benefits in terms of sustainability by minimizing material wastage and energy consumption. By embracing innovation in material processing, manufacturers can stay ahead in a competitive market, respond swiftly to evolving consumer demands, and drive advancements in various industries including aerospace, automotive, and healthcare.

Looking ahead, the future of precision manufacturing appears promising with continuous advancements in material processing techniques. As technology continues to evolve, we anticipate further breakthroughs in additive manufacturing, nanotechnology, and automation, revolutionizing the way we manufacture goods. Moreover, the integration of artificial intelligence and machine learning is poised to optimize manufacturing processes, leading to greater efficiency and productivity. However, to fully realize the potential of precision manufacturing, it is imperative for industry stakeholders to invest in research and development, foster collaboration across disciplines, and prioritize education and training in emerging technologies.

In conclusion, the journey towards precision manufacturing requires a commitment to innovation, sustainability, and collaboration. By leveraging innovative material processing techniques and embracing technological advancements, we can unlock new possibilities, drive economic growth, and pave the way for a more sustainable and prosperous future.

References

Aderibigbe, A.O., Ohenhen, P.E., Nwaobia, N.K., Gidiagba, J.O., & Ani, E.C. (2023). Advanced sensing techniques in electro-mechanical systems: surveying the rise of smart sensors and their implications for system robustness. *Engineering Science & Technology Journal*, *4*(6), 323-340.

Ajayi-Nifise, A.O., Olubusola, O., Falaiye, T., Mhlongo, N.Z., & Daraojimba, A.I. (2024). A review of US financial reporting scandals and their economic repercussions: investigating their broader impact and preventative measures. *Finance & Accounting Research Journal*, *6*(2), 183-201.

Anamu, U.S., Ayodele, O.O., Olorundaisi, E., Babalola, B.J., Odetola, P.I., Ogunmefun, A., Ukoba, K., Jen, T.C., & Olubambi, P.A. (2023). Fundamental design strategies for advancing the development of high entropy alloys for thermo-mechanical application: A critical review. *Journal of Materials Research and Technology*.

Avram, O., Fellows, C., Menerini, M., & Valente, A. (2021). Automated platform for consistent part realization with regenerative hybrid additive manufacturing workflow. *The International Journal of Advanced Manufacturing Technology*, *119*(3-4), 1737-1755. https://doi.org/10.1007/s00170-021-08218-5

Bogers, M., Hadar, R., & Bilberg, A. (2016). Additive manufacturing for consumer-centric business models: implications for supply chains in consumer goods manufacturing. *Technological Forecasting and Social Change*, *102*, 225-239. https://doi.org/10.1016/j.techfore.2015.07.024

Cao, J., Sun, X., Lin, Z., & Dong, Q. (2023). Dimensional modeling of single pass welding in wire and arc additive manufacturing. https://doi.org/10.1117/12.2671849

Dincă, L., Banu, A., & Vişan, A. (2017). Additive manufacturing in maxillofacial reconstruction. Matec Web of Conferences, 137, 02001. https://doi.org/10.1051/matecconf/201713702001

El-Azab, A. (2017). Why materials theory?. *Materials Theory*, *1*(1). https://doi.org/10.1186/s41313-017-0001-5

Evans, I., Rees, A., Griffiths, C., & Johnson, R. (2020). Computational validation of injection molding tooling by additive layer manufacture to produce epdm exterior automotive seals. 273-283. https://doi.org/10.1007/978-981-15-8131-1_25

Flynn, J., Shokrani, A., Newman, S., & Dhokia, V. (2016). Hybrid additive and subtractive machine tools – research and industrial developments. *International Journal of Machine Tools and Manufacture, 101*, 79-101. https://doi.org/10.1016/j.ijmachtools.2015.11.007

Frazier, W. (2014). Metal additive manufacturing: a review. *Journal of Materials Engineering and Performance, 23*(6), 1917-1928. https://doi.org/10.1007/s11665-014-0958-z

Gibson, I., Rosen, D., & Stucker, B. (2010). Additive manufacturing technologies.. https://doi.org/10.1007/978-1-4419-1120-9

Guan, X., & Zhao, J. (2022). A two-step fuzzy mcdm method for implementation of sustainable precision manufacturing: evidence from China. *Sustainability*, *14*(13), 8085. https://doi.org/10.3390/su14138085

Guo, L., Zhang, X., Lu, X., Zhao, Y., Zhou, Z., Xu, J., … & J, L. (2023). 4d additive–subtractive manufacturing of shape memory ceramics. *Advanced Materials, 35*(39). https://doi.org/10.1002/adma.202302108

Hsu, Y., Lin, Y., Chen, Y., Lin, H., Liao, Y., Hou, C., … & Deng, W. (2019). 3d printed random lasers. *Advanced Materials Technologies, 5*(1). https://doi.org/10.1002/admt.201900742

Jiménez, A., Bidare, P., Hassanin, H., Tarlochan, F., Dimov, S., & Essa, K. (2021). Powder-based laser hybrid additive manufacturing of metals: a review. *The International Journal of Advanced Manufacturing Technology*, *114*(1-2), 63-96. https://doi.org/10.1007/s00170-021-06855-4

Kim, Y., Lee, G., Choi, S., & Lim, S. (2001). Tool requirements planning in a flexible manufacturing system with an automatic tool transporter. *Ieee Transactions on Robotics and Automation, 17*(6), 795-804. https://doi.org/10.1109/70.975993

Kocsis, Z. (2019). Artificial neural networks in medicine. *Acta Technica Jaurinensis, 12*(2), 117-129. https://doi.org/10.14513/actatechjaur.v12.n2.497

Le, J., Pinto, Y., Seeman, N., Musier-Forsyth, K., Taton, T., & Kiehl, R. (2004). Dna-templated self-assembly of metallic nanocomponent arrays on a surface. *Nano Letters, 4*(12), 2343-2347. https://doi.org/10.1021/nl048635

Li, K., Fang, Y., Zhou, Y., & Liu, H. (2017). Non-invasive stimulation-based tactile sensation for upper-extremity prosthesis: a review. *Ieee Sensors Journal*, *17*(9), 2625-2635. https://doi.org/10.1109/jsen.2017.2674965

Lin, C., Belis, T., & Kuo, T. (2019). Ergonomics-based factors or criteria for the evaluation of sustainable product manufacturing. *Sustainability*, *11*(18), 4955. https://doi.org/10.3390/su11184955

Liu, C., Li, Y., Jiang, S., Li, Z., & Xu, K. (2019). A sequence planning method for five-axis hybrid manufacturing of complex structural parts. *Proceedings of the Institution of Mechanical Engineers Part B Journal of Engineering Manufacture, 234*(3), 421-430. https://doi.org/10.1177/0954405419883052

Liu, R., Li, M., Luo, H., Liu, Q., & Swindlehurst, A. (2022). Integrated sensing and communication with reconfigurable intelligent surfaces: opportunities, applications, and future directions. https://doi.org/10.48550/arxiv.2206.08518

Longana, M., Ondra, V., Yu, H., Potter, K., & Hamerton, I. (2018). Reclaimed carbon and flax fibre composites: manufacturing and mechanical properties. *Recycling*, *3*(4), 52. https://doi.org/10.3390/recycling3040052

Lopes, A., MacDonald, E., & Wicker, R. (2012). Integrating stereolithography and direct print technologies for 3d structural electronics fabrication. *Rapid Prototyping Journal*, *18*(2), 129-143. https://doi.org/10.1108/13552541211212113

Lou, P., Liu, S., Hu, J., Li, R., Zheng, X., & Yan, J. (2020). Intelligent machine tool based on edge-cloud collaboration. *Ieee Access*, *8*, 139953-139965. https://doi.org/10.1109/access.2020.3012829

Lu, L., Han, J., Zhou, Y., Chen, S., Liu, H., & Xia, L. (2020). Machine tool movement control method combining the benefit of software and real-time interpolator for sculpture surface machining. *Proceedings of the Institution of Mechanical Engineers Part B Journal of Engineering Manufacture*, *234*(9), 1215-1226. https://doi.org/10.1177/0954405420911310

Luitz, M., Pellegrini, D., Holst, M., Seteiz, K., Gröner, L., Schleyer, M., … & Rapp, B. (2023). High-resolution patterning of organic–inorganic photoresins for tungsten and tungsten carbide microstructures. *Advanced Engineering Materials*, *25*(13). https://doi.org/10.1002/adem.202201927

Luo, Y., Jie, X., Liu, X., & Yao, L. (2018). Ranking Chinese smes green manufacturing drivers using a novel hybrid multi-criterion decision-making model. *Sustainability*, *10*(8), 2661. https://doi.org/10.3390/su10082661

Matz, A., Mocker, B., Müller, D., Jost, N., & Eggeler, G. (2014). Mesostructural design and manufacturing of open-pore metal foams by investment casting. *Advances in Materials Science and Engineering*, *2014*, 1-9. https://doi.org/10.1155/2014/421729

Mehmeti, A., Lynch, D., Penchev, P., Ramos, R., Denis, V., Maurath, J., … & Dimov, S. (2021). The effect of hot isostatic pressing on surface integrity, microstructure and strength of hybrid metal injection moulding, and laser-based powder bed fusion stainless-steel components. *Applied Sciences*, *11*(16), 7490. https://doi.org/10.3390/app11167490

Melchels, F., Domingos, M., Klein, T., Malda, J., Bartolo, P., & Hutmacher, D. (2012). Additive manufacturing of tissues and organs. *Progress in Polymer Science*, *37*(8), 1079-1104. https://doi.org/10.1016/j.progpolymsci.2011.11.007

Negrău, D., Grebenişan, G., Gherghea, I., & Anton, D. (2021). The advantages of combining 3d printing with turning process. case study. *Matec Web of Conferences*, *343*, 02010. https://doi.org/10.1051/matecconf/202134302010

Odeyemi, O., Elufioye, O.A., Mhlongo, N.Z., Daraojimba, A.I., Olatoye, F.O., & Awonuga, K.F. (2024). AI in E-commerce: Reviewing developments in the USA and their global influence. *International Journal of Science and Research Archive*, *11*(1), 1460-1468.

Odeyemi, O., Ibeh, C.V., Mhlongo, N.Z., Asuzu, O.F., Awonuga, K.F., & Olatoye, F.O. (2024). forensic accounting and fraud detection: a review of techniques in the digital age. *Finance & Accounting Research Journal*, *6*(2), 202-214.

Ohalete, N.C., Aderibigbe, A.O., Ani, E.C., Ohenhen, P.E., & Akinoso, A. (2023). Advancements in predictive maintenance in the oil and gas industry: A review of AI and data science applications.

Olubusola, O., Falaiye, T., Ajayi-Nifise, A.O., Daraojimba, O.H., & Mhlongo, N.Z. (2024). Sustainable IT practices in Nigerian banking: Environmental perspectives review.

Paris, H., Mokhtarian, H., Coatanéa, E., Museau, M., & Ituarte, I. (2016). Comparative environmental impacts of additive and subtractive manufacturing technologies. *Cirp Annals*, *65*(1), 29-32. https://doi.org/10.1016/j.cirp.2016.04.036

Qudeiri, J., Zaiout, A., Mourad, A., Abidi, M., & Elkaseer, A. (2020). Principles and characteristics of different edm processes in machining tool and die steels. *Applied Sciences*, *10*(6), 2082. https://doi.org/10.3390/app10062082

Ramakrishna, S., Zhang, T., Lü, W., Qi, Q., Low, J., Yune, J., … & Kalidindi, S. (2018). Materials informatics. *Journal of Intelligent Manufacturing*, *30*(6), 2307-2326. https://doi.org/10.1007/s10845-018-1392-0

Ribeiro, I., Matos, F., Jacinto, C., Salman, H., Cardeal, G., Carvalho, H., … & Peças, P. (2020). Framework for life cycle sustainability assessment of additive manufacturing. *Sustainability*, *12*(3), 929. https://doi.org/10.3390/su12030929

Ribeiro, T., Bernardo, L., & Andrade, J. (2021). Topology optimisation in structural steel design for additive manufacturing. *Applied Sciences*, *11*(5), 2112. https://doi.org/10.3390/app11052112

Righettini, P., & Strada, R. (2021). Driving technologies for the design of additive manufacturing systems. *Hightech and Innovation Journal*, *2*(1), 20-28. https://doi.org/10.28991/hij-2021-02-01-03

Rodgers, J. (2009). Materials informatics. *Materials Science and Technology*, *25*(4), 435-436. https://doi.org/10.1179/174328409x430456

Schneider, F., Das, J., Kirsch, B., Linke, B., & Aurich, J. (2019). Sustainability in ultra precision and micro machining: a review. *International Journal of Precision Engineering and Manufacturing-Green Technology*, *6*(3), 601-610. https://doi.org/10.1007/s40684-019-00035-2

Shore, P., & Morantz, P. (2012). Ultra-precision: enabling our future. *Philosophical Transactions of the Royal Society a Mathematical Physical and Engineering Sciences*, *370*(1973), 3993-4014. https://doi.org/10.1098/rsta.2011.0638

Sommer, D., Pape, D., Esen, C., & Hellmann, R. (2022). Tool wear and milling characteristics for hybrid additive manufacturing combining laser powder bed fusion and in situ high-speed milling. *Materials*, *15*(3), 1236. https://doi.org/10.3390/ma15031236

Tamez, M., & Taha, I. (2021). A review of additive manufacturing technologies and markets for thermosetting resins and their potential for carbon fiber integration. *Additive Manufacturing*, *37*, 101748. https://doi.org/10.1016/j.addma.2020.101748

Tang, Y., Mak, K., & Zhao, Y. (2016). A framework to reduce product environmental impact through design optimization for additive manufacturing. *Journal of Cleaner Production*, *137*, 1560-1572. https://doi.org/10.1016/j.jclepro.2016.06.037

Tang, Y., Zhang, Y., Zeng, M., Sun, Q., Peng, L., Zhang, L., … & Yan, W. (2022). Accuracy of additive manufacturing in stomatology. *Frontiers in Bioengineering and Biotechnology, 10*. https://doi.org/10.3389/fbioe.2022.964651

Thompson, M., Stolfi, A., & Mischkot, M. (2016). Process chain modeling and selection in an additive manufacturing context. *Cirp Journal of Manufacturing Science and Technology, 12*, 25-34. https://doi.org/10.1016/j.cirpj.2015.09.005

Trubetskov, M., Amotchkina, T., & Tikhonravov, A. (2011). Broadband monitoring simulation with massively parallel processors. https://doi.org/10.1117/12.896522

Urbikain, G., Lacalle, L., Alonso, M., Arsuaga, M., & Alvarez, A. (2016). A reliable turning process by the early use of a deep simulation model at several manufacturing stages. https://doi.org/10.20944/preprints201612.0106.v1

Voet, V., Guit, J., & Loos, K. (2020). Sustainable photopolymers in 3d printing: a review on biobased, biodegradable, and recyclable alternatives. *Macromolecular Rapid Communications, 42*(3). https://doi.org/10.1002/marc.202000475

Wang, S., Lu, W., & Hung, S. (2019). Improving innovation efficiency of emerging economies: the role of manufacturing. *Managerial and Decision Economics, 41*(4), 503-519. https://doi.org/10.1002/mde.3116

Welz, P., Linganiso, L., Murray, P., Kumari, S., Arthur, G., Ranjan, A., … & Bakare, B. (2022). Status quo and sector readiness for (bio)plastic food and beverage packaging in the 4ir. *South African Journal of Science, 118*(7/8). https://doi.org/10.17159/sajs.2022/9748

Williams, D., Thomas, R., Hourd, P., Chandra, A., Ratcliffe, E., Liu, Y., … & Archer, J. (2012). Precision manufacturing for clinical-quality regenerative medicines. *Philosophical Transactions of the Royal Society a Mathematical Physical and Engineering Sciences, 370*(1973), 3924-3949. https://doi.org/10.1098/rsta.2011.0049

Williams, S., Martina, F., Addison, A., Ding, J., Pardal, G., & Colegrove, P. (2016). Wire + arc additive manufacturing. *Materials Science and Technology, 32*(7), 641-647. https://doi.org/10.1179/1743284715y.0000000073

Xie, T. (2023). Pandemic and emergency manufacturing innovation: a scientometric analysis using citespace. *Disaster Medicine and Public Health Preparedness, 17*. https://doi.org/10.1017/dmp.2023.162

Yang, M., Shimizu, T., Hu, J., & Shiratori, T. (2018). An integrated precise engineering for micro forming. *Matec Web of Conferences, 190*, 01003. https://doi.org/10.1051/matecconf/201819001003

Yip, W., To, S., & Zhou, H. (2021). Current status, challenges and opportunities of sustainable ultra-precision manufacturing. *Journal of Intelligent Manufacturing, 33*(8), 2193-2205. https://doi.org/10.1007/s10845-021-01782-3

Zhu, Z., Dhokia, V., & Newman, S. (2013). The development of a novel process planning algorithm for an unconstrained hybrid manufacturing process. *Journal of Manufacturing Processes, 15*(4), 404-413. https://doi.org/10.1016/j.jmapro.2013.06.006

Zhu, Z., Dhokia, V., Nassehi, A., & Newman, S. (2013). A review of hybrid manufacturing processes – state of the art and future perspectives. *International Journal of Computer*

Integrated Manufacturing, *26*(7), 596-615. https://doi.org/10.1080/0951192x.2012.749530

Zhu, Z., Dhokia, V., Newman, S., & Nassehi, A. (2014). Application of a hybrid process for high precision manufacture of difficult to machine prismatic parts. *The International Journal of Advanced Manufacturing Technology*, *74*(5-8), 1115-1132. https://doi.org/10.1007/s00170-014-6053-7

Zou, L., Ge, C., Wang, Z., Cretu, E., & Li, X. (2017). Novel tactile sensor technology and smart tactile sensing systems: a review. *Sensors, 17*(11), 2653. https://doi.org/10.3390/s17112653