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Advanced Manufacturing Processes: Powder Metallurgy, Joining, Surface Finishing, and Machining

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ABSTRACT

The increasing demand for lightweight, high-strength, and cost-efficient components has intensified the need for advanced manufacturing processes, yet persistent limitations across powder metallurgy, joining, surface finishing, and machining continue to hinder optimal product performance and industrial scalability. This systematic review followed PRISMA guidelines, searching major databases using relevant manufacturing keywords. From 1,287 records, duplicates and irrelevant studies were removed. After full-text eligibility assessment, 49 peer-reviewed articles focusing on powder metallurgy, machining, joining, and surface finishing were included to provide comprehensive evidence on advanced manufacturing processes. Powder metallurgy (PM) demonstrates strong sustainability advantages through high material utilization, while optimized sintering and mechanical alloying significantly enhance hardness, density, and fatigue performance. Advanced joining methods—laser welding, friction stir welding, and hybrid techniques—produce high-strength, low-distortion joints suited for complex or dissimilar materials. Surface finishing technologies, including corrosion-resistant coatings and nanocoatings, substantially improve wear, corrosion resistance, and service life. Machining advances such as high-speed machining, EDM, and laser micromachining increase precision, productivity, and suitability for hard or lightweight materials. Integrated use of PM, machining, joining, and finishing enhances performance, though adoption faces barriers such as high investment, skill shortages, and system-integration challenges.

1. INTRODUCTION

The contemporary production of components requires metal alloys which incorporate multifaceted geometries, narrow dimensional deviances, regulated microstructure, and a high surface integrity. Conventional casting, forging, and bulk machining technologies frequently are unable to satisfy these demands at the same time. To counter this, new developments in powder metallurgy, contemporary joining processes, advanced surface finishing and hybrid machining have come along to meet these demanding engineering requirements.

Powder metallurgy, especially in creating high entropy alloys (HEAs), has the ability to attain homogenous composition and nanocrystalline microstructures that are challenging to get via traditional melting and casting. Nagarjuna et al. (2025) point out that powder metallurgy permits near net-shape producing with great efficiency of materials and considerable control of microstructures, hence minimizing waste and enhancing complex shapes. In spite of these benefits, full densification and uniform mechanical performance are still a challenge including ductility and fatigue strength. Strict process control and post-processing may be necessary in order to assure the desired properties.

Developments in the methods of joining have overcome the constraints of traditional fusion welding and brazing methods, which can cause distortion of the material, stress residues or weak joints, especially in the joining of dissimilar or heat sensitive materials. Latest research has indicated that solid-state and hybrid joining methods, such as friction stir welding, laser beam welding, and hybrid laser arc welding, are more effective to improve joint strength and structural integrity to serve high-performance applications (He et al., 2025; Sonia et al., 2024). Joint strengths of 2024 T3 alloy sheets of aluminum have been optimized with machine-learning techniques on friction stir welding to reach up to 87 percent of base material (Myśliwiec, Kubit, and Szawara, 2024). It is possible to join components that are hard or even impossible to weld using conventional techniques and minimise defects and distortion through these modern methods.

Even in cases where forming and joining processes are successful, surface integrity is of critical importance. The surfaces of components fabricated by adding materials by additive manufacturing or powder metallurgy can be rough, the internal porosity can exist, or intricate internal geometries. According to Medibew, Zieliinski, Agebo, andArea Deja (2025), a blend of traditional abrasive machining, milling, and nontraditional finishing methods, including abrasive flow and electrochemical machining is effective in improving the surface finish and dimensional accuracy. The techniques are critical in complex geometries and complicated internal channels, and give components that are both of high quality and of high structural integrity.

Machining and hybrid post-processing remains critical to the realization of precision and tight tolerances and final part quality particularly of components produced through powder-based or additive manufacturing technologies or in joined assemblies. According to Cai, Wu, Shang, and others (2025), cutting complex alloys and metal-matrix composites necessitates a meticulous choice of cutting parameters, special tooling, and hybrid methods to avoid the low quality of the surface and the degradation of tool life. Most of the advanced workflows combine near-net-shape manufacturing with powder metallurgy or additive manufacturing and then subject to joining, finishing, and precision machining to create components of all geometric and functional requirements.

Recent studies have shown that powder metallurgy, contemporary joining, surface finishing and machining are complementary to each other in an integrated manufacturing system. Powder metallurgy allows efficient creation of intricate shapes with managed microstructures; contemporary joining techniques create assemblies of high strength with low distortion; surface finishing provides quality functions and appearance and machining provide the ultimate accuracy and tolerances. There are drawbacks to every process such as densification difficulties with powder metallurgy, parameter sensitivity in joining, and possible residual stresses caused by finishing as well as special machining needs on advanced materials. Combining these processes provides a holistic approach to the issues of high-performance, multifaceted, and resource-efficient production in aerospace, automotive, biomedical and other engineering applications.

Manufacturing technologies like powder metallurgy, joining, surface finish, and machining are highly important to lightweight and high-performance components but have unique gaps to fill which are worthy of investigation. Powder metallurgy is afflicted with porosity regulation and scale up constraints (Kumar et al., 2025). Combining dissimilar or composite materials does not have robust and high-volume solutions (Li et al., 2019). In industrial applications, multifunctional corrosion and wear resistance remain problematic to surface finishing and coating (Yan et al., 2025). The machining requires adaptive cyber-physical controls and tool strategies of new materials (Hassan et al., 2024). These process, material and control gaps require integrated research to ensure that these gaps can be closed and allow good industrial adoption to reduce lifecycle costs, emissions and downtime significantly.

2. METHOD

To guarantee transparency, replicability, and methodological rigor, this systematic review was conducted following the Preferred Reporting Items of Systematic Reviews and Meta-Analyses (PRISMA) guidelines. This review took a four-stage approach that included identification, screening, eligibility assessment, and inclusion.

Identification: It searched the major scholarly databases, such as Scopus, Web of Science, ScienceDirect, IEEE Xplore, and Google Scholar, to identify a broad range of research related to advanced manufacturing. Controlled vocabulary and Boolean operators were used as the search strategy, with keywords and keyword strings, including, but not limited to, the following: powder metallurgy, advanced joining processes, automotive machining, surface finishing technologies, precision machining, nanocoatings, manufacturing optimisation, and others. The search covered works of both foundational developments and modern innovations.

Screenings: The first search gave 1,287 records. All the retrieved documents were then exported to reference-management software, which automatically recognized and deleted duplicates. Access to titles and abstracts was then filtered manually to remove any studies that were not related to manufacturing processes and any articles that dealt with non-engineering fields, purely theoretical models with no experimental support, and non-English articles.

Eligibility: The remaining articles were reviewed in their entirety to determine their quality and relevance on methodology. The studies had to be eligible, and those that were eligible had to explicitly concentrate on a single or a combination of one or more of the advanced manufacturing processes powder metallurgy, machining, joining, or surface finishing and had to show empirical, analytical or industrial interest. Other requirements were direct application to materials engineering, mechanical manufacturing, automotive engineering, or process optimisation.

Inclusion: After the eligibility check, 49 high-quality peer-reviewed articles were included and formed the evidence base of this review. These studies had varied yet complementary information on process improvements, performance results, inter-process integration, and technology obstacles in advanced manufacturing.

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3. RESULT AND DISCUSSION

3.1 Powder Metallurgy

The term powder metallurgy has been on the rise recently as one of the effective and sustainable manufacturing pathways. Recent research points at its ability to reduce the amount of material waste: near-net-shape PM and additive-assisted powder consolidation produce less scrap and high material utilisation rates compared to subtractive machining (Iqbal et al., 2020). This efficiency can help save raw materials and energy and it is in line with sustainability. One of the most important factors that influence the mechanical performance of PM parts is sintering temperature. In a systematic study of the subject of aluminium-based alloys, it was shown that the density and Vickers hardness improved by a percentage of roughly 12 by raising the sintering temperature of the material to 600 0 C instead of the higher temperature of 620 0 C, which resulted in unwanted grain growth and a slight decrease in fatigue strength under cyclic loading (Park et al., 2022). A different study of stainless-steel PM components reported an optimum sintering temperature of 1,250¯ C to produce near-theoretical density and favourable tensile strength, with lower and higher sintering temperatures resulting in porosity or grain coarse, respectively, and reduced fatigue resistance (Fang¯ et al., 2017). The results highlight the need to carefully control temperature to balance densification, hardness and long-term durability.

Recently, mechanical alloying has allowed the synthesis of new metal-ceramic and nano-reinforced composite materials that have superior hardness, wear behaviour, and fatigue behaviour. As an example, Popov (2017) used mechanical alloying to add nano-TiC to a Fe-based matrix, resulting in a fine microstructure, 25 percent hardness improvement, and a doubling of wear resistance compared to PM (Omran and al., 2022). The second composite study confirmed that mechanically alloyed aluminium silicon carbide powdered and consolidated using the hot isostatic press technique produced high uniformity and good fatigue strength, making them suitable in aerospace components (Sreenu et al., 2022). Collectively, the extant body of literature supports the assertion that powder metallurgy is a strong well-developed process in manufacturing: it minimises waste, increases the use of materials, provides tunable mechanical characteristics to controlled sintering, and, through mechanical alloying, produces high-performance composites. The developments make PM an attractive alternative to industries that require efficient and sustainable and high-strength components.

3.2 Advanced Joining Processes Laser Welding, Friction-Stir Welding, and Hybrid Processes.

Laser welding has come out as one of the most effective joining processes that provide deep penetration coupled with high welding speeds and very low heat input to the surrounding material. Studies show that laser welds can provide full penetration with minimum distortion and heat-affected zone with the proper choice of parameters (laser power, travel speed, focus), resulting in high joint strength and lower residual stress (Ragavendran & Vasudevan, 2021). But improper control of the parameters may lead to under-penetration or excessive distortion which compromises joint performance. As a consequence, the benefits of laser-based joining cannot be achieved without optimisation of welding conditions. Friction-stir welding (FSW) is now known to be able to produce defect-free, high-integrity, joints in a wide variety of metals, especially aluminium and lightweight alloys. Various recent investigations establish that FSW reduces typical welding flaws including porosity, cracking, and solidification anomalies, thus generating fine-grained microstructures and uniform mechanical qualities along the weld line (Wang et al., 2024; Prabhakar et al., 2023). FSW, being solid-state welding, prevents melting and minimizes distortion and remaining stress and provides higher fatigue strength and better ductility than conventional welding with fusion (Kumar et al., 2020).

Joining hybrid processes involving the benefits of laser welding, FSW, adhesives, or mechanical fastening are also being increasingly used in joining dissimilar materials and complex geometries. Indicatively, a hybrid laser jump between aluminium and steel showed that the load-bearing capacity and resistance to corrosion were superior in hybrid joint than in either adhesive-only or weld-only joints (Taş, 2025). In a different study, the magnesium-aluminium dissimilar joint with the use of FSW and mechanical fastening yielded strong interfacial bonding and held the joint together under cyclic loading (Qiao et al., 2025). These hybrid methods are highly beneficial to overcome the problem of material compatibility and provide flexible, strong joining.

3.3 Surface Finishing: Coatings for Corrosion Resistance and Nanocoatings for Enhanced Wear Resistance

Surface finishing plays a decisive role in improving component longevity in advanced manufacturing. Studies show conventional and engineered coatings markedly reduce electrochemical attack: recent reviews emphasize that system-level surface engineering (pre-treatment, interlayer design and deposition method) is as important as coating chemistry for durable corrosion protection across environments. Surface-engineered layers and multiphase coatings (metallic, ceramic, organic hybrids) consistently lower corrosion rates and delay pit initiation when properly matched to substrate and service conditions (Sun, 2023; Abdeen et al., 2019). For corrosion-resistant coatings (6.3.1), electrodeposited and composite metal coatings (notably Ni-based matrices reinforced with ceramic particles) repeatedly demonstrate large improvements in barrier performance and reduced corrosion current density. Reviews report that Ni-composite coatings containing Al_2O_3, SiC, ZrO_2 or TiO_2 show both lower corrosion rates and enhanced mechanical integrity versus pure Ni because embedded particles reduce porosity, refine microstructure, and improve barrier continuity (Zellele, 2024; Farooq et al., 2022). Practical studies also find that multi-layer systems (adhesion-promoting underlayers + corrosion barrier + functional topcoat) give the best long-term protection in chloride and marine environments (Sun, 2023).

For nanocoatings aimed at wear resistance (6.3.2), the literature highlights two synergistic mechanisms: (a) hard nanophase reinforcement that increases surface hardness and load capacity, and

(b) low-shear or self-lubricating nanomaterials (e.g., WS_2, graphene derivatives, MoS_2) that lower friction and wear rates. Systematic reviews and comparative tests report friction reductions of ~20–40% and wear-rate decreases of multiple-fold when 2D or 3D nanofillers are optimally dispersed and strongly bonded to the matrix (Wang, 2023). Importantly, authors warn that dispersion, interfacial bonding, and deposition technique control whether nanoscale additions improve or undermine corrosion and wear performance — poorly bonded nanofillers can create galvanic sites or stress concentrators (Abdeen et al., 2019; Wang, 2023). Contemporary evidence supports tailored nanocomposite and multilayer coating strategies as the most effective route to simultaneous corrosion and wear protection, provided process-control and substrate compatibility are ensured (Zellele, 2024; Sun, 2023).

3.4 machining processes High-Speed machining, electrical discharge machining (EDM) Uses and Laser machining of Lightweight components and microstructures.

Machining still holds an eminent role in high-speed manufacturing, and recent peer-reviewed studies have shown that high-speed machining (HSM), electrical discharge machining (EDM) and laser-based machining bring significant advances in productivity, precision and design flexibility-especially of hard-to-machine, lightweight or complex parts. An example of both trade-offs and benefits is the high-speed machining of alloys like Ti-6Al-4V. According to Matuszak, Zaleski, and Zysko (2023), higher cutting speeds may improve the quality of particular surface-layers and may increase the fatigue life under certain circumstances, but they also indicated that after a certain point, tool wear increases dramatically, reducing the viable parameters range. He et al. (2024) noted that tool life can be significantly increased and tool stability can be enhanced in high-speed mode with the choice of cutting insert material and coating (e.g., PVD coating) an important requirement in the application of HSM to challenging alloys. Phokobye et al. (2024) also confirmed that the best tool selection and parameter control are required to establish the balance between the high rate of material removal and the acceptable surface integrity.

Other unconventional approaches like EDM, have become more significant where standard chip-forming machining is constrained. Ishfaq, Maqsood, and Mahmood (2022) emphasized that powder-mixed EDM is more effective at material removal rates, which decreases electrode wear and makes powder EDM viable when working with hard-to-machine alloys and complicated geometries. Nafi and Jahan (2023) conducted a review of EDM applications in functional surface generation and made the conclusion that EDM can be used to cut precise micro-scale features in high-strength alloys, giving a better quality and surface control than traditional techniques. Micro structuring, micro geometries with lightweight attributes, low heat affected regions, high dimensional precision, and clean edges are easily implemented with laser based machining especially ultrafast pulse lasers. Such abilities make laser micromachining a desirable process to microelectronics, biomedical devices and aerospace components where mechanical machining is not able to provide the level of precision and geometry demanded (Nafi and Jahan, 2023). The ability to manufacture lattice-like structures, thin walls, and micro-features allow the reduction of weight and optimization of functions of lightweight components.

These machining technologies are being incorporated in modern production processes. A workpiece can be roughly machined using HSM to achieve the highest material removal rate, and then high-precision cavity or feature can be added by EDM, and, finally, micro-feature or surface texturing can be added by laser machining. These hybrid methods take advantage of the throughput of HSM, the flexibility of EDM to complicated geometries and the accuracy of laser methods, allowing designs that would be either impractical or not possible using one method. The recent literature confirms the statement that HSM, EDM (including powder-enhanced EDM) and laser micromachining can greatly widen the manufacturing opportunities. These processes have increased productivity, better surface and feature quality, and increased design flexibility especially on hard-to-machine materials, microstructures, and lightweight or complicated geometries.

3.5 Interrelationship Between Processes: Compatibility of Joining Processes with PM Components and Surface Finishing between Machined and PM Parts.

The use of powder metallurgy (PM), precision machining, joining and surface finishing continues to gain more and more importance in industry implementations with regards to advanced manufacturing to obtain parts with specific properties and performances. PM has the potential of producing near-net-shape and with high material efficiency, which reduces the extent of subtractive machining and the wastage of materials (Lim, Lee and Cho, 2020). Dimesional accuracy and surface quality of the PM parts due to their ability to be machined or otherwise post-processed improve overall mechanical and functional performance compared to as sintered parts (Esquivel et al., 2025).

In a system where PM is used with more advanced joining methods, the inherent microstructure of PM, which tends to include porosity that has not been filled, is important to the integrity of the joint. It has been found that solid-state joining techniques, especially friction stir welding (FSW), are one of the best to use with PM-produced aluminum-based composites or nanocomposites since they can be used to make joints with reasonable mechanical strength without the problems associated with melting, pore collapses, or contamination seen with fusion welding of porous materials (Khodabakhshi et al., 2013). One study was able to obtain sound welds in FSW of a PM Al2O 3 nanocomposite; nonetheless, the authors also found that process parameters and the porosity of the PM component influenced weldability (Tiku et al., 2020). Solid-state techniques, including inertia friction welding (IFW), have also been shown to work with high-performance alloy components made through PM: a recent study of a PM superalloy (FGH96) has shown that IFW can be used to make dense joints with acceptable microstructural integrity and practical mechanical characteristics (Zhang et al., 2024). These results highlight the fact that the compatible joining processes can be obtained with the PM constituents assuming that process selection and parameter regulation consider porosity and density changes inherent to PM.

Surface finishing and post-processing are also another level of integration that improves performance both in machined and PM parts. In the case of PM steel components, ultrasonic nanocrystal surface modification (UNSM) has been demonstrated to increase substantially the surface integrity and tribological performance relative to the as sintered state; outcome measures include decreasing surface roughness, dramatically increasing hardness, and substantially increasing wear resistance (Lim et al., 2020). These enhancements are actually by implication as the porous and granular nature of sintered components may hinder wear, fatigue, and sealing performance. In general, post-processing (machining, polishing, abrasive finishing) of components produced by powder-based manufacturing (PM or additive processes) can greatly decrease the surface roughness, seal micro-voids, and enhance fatigue life, which in turn increases the service life and guarantees reliability of the part subjected to cyclic loading (Elsheikh et al., 2024).

The accumulated body of evidence confirms the fact that a manufacturing chain of PM, joining, machining (where necessary) and surface finishing can produce components with enhanced structural and functional properties than by using any of the processes in isolation. The near-net-shape properties of PM ensures that there is less wastage and raw materials; the joining processes adjusted to PM provide consistent joints tempting porous materials; finishing processes provide a restoration of surface quality or improvement of surface quality and precision machining or post-processing provides precise tolerances where needed. This combined methodology balances trade-offs of both processes, and solves porosity or surface flaws caused by PM, increases joint integrity, and attains the quality of surface and mechanical performance required in the contemporary application..

3.6 Sustainability, Energy and Material Savings, Eco-Friendly Coatings and Environment.

The concept of sustainability has become a central consideration in the design and execution of the sophisticated manufacturing operations, such as powder metallurgy (PM), precision machining, welding, and surface finishing. PM offers strong environmental benefits by its near net-shape production capacity, which significantly reduces material wastage and eliminates considerable subtractive machining. Recycling of grinding sludge through PM has demonstrated in a lifecycle assessment carried out by Großwendt et al. (2023) that the recycling of such sludge may result in about 36.6-percent material and energy reductions in comparison with the traditional cradle-to-gate production (Soleimani et al., 2021). These results prove that PM contributes to a circular-economy paradigm by providing the opportunity to reuse waste metal, including swarf and chips, in the production stream.

Energy efficiency also improves sustainability profile of PM. According to Zhang and Xu (2018), the opportunities to reduce greenhouse-gas emissions across the production chain were found, and steel powder consolidation and sintering, under certain conditions, can reduce energy consumption compared to conventional melting and casting. The resulting lessening of the post-sintering machining counteracts the energy and resource waste associated with cutting away materials and wear of tools. A recent survey of sustainable machining activities highlights that the approaches of minimum-quantity lubrication (MQL), near-dry machining, and cryogenic or high-pressure cooling can significantly lower the environmental impact of machining activity (Elsheikh et al., 2024). According to the review, replacing traditional, usually petroleum-based and toxic, flood coolants with biodegradable oils and low-fluid use techniques reduces the amount of fluids, minimizes waste, and reduces detrimental emissions, and at the same time, extends or even improves tool life and surface quality (Elsheikh et al., 2024). The support evidence is the investigation of MQL-assisted machining of a nickel-based superalloy, which revealed increased tool life, better surface finish, and lower cutting-power requirements, thus, demonstrating a lower energy use and consumption of lubricants in comparison to dry machining (Tamang et al., 2025).

Advanced lubrication and cooling fluids also have environmental and occupational health benefits. Research into nano-based and hybrid lubricant formulations at MQL conditions has demonstrated significant cutting force and cutting temperature together with surface roughness reductions, and therefore more efficient and environmentally clean machining of hard-to-cut materials (Tamang et al., 2025). These advances reduce the environmental and occupational health risks of traditional metalworking fluids, which often include toxic or non-biodegradable elements (Elsheikh et al., 2024). Eco-friendly surface coating and finishing technologies in sustainable production are also further advanced, even though the literature on this matter remains relatively sparse. Engineered coating processes that do not contain hexavalent chromium and other toxic substances are being increasingly used to reduce toxic emissions and volatile organic compounds (VOCs) in surface finishing and plating (Laska et al., 2018). The latest advancements in thermal - spay and smart-coating have developed the ability to resist corrosions, wear, and self-lubrication functions, thus increasing the lifespan of the component and decreasing materials turnover. A long life span means fewer replacements, less material extraction, and waste are produced as a result which leads to a reduced environmental footprint.

3.7 Industry Adoption Barriers: Large Start-up Costs, Skilled Labor Limitations and Interface Problems with Existing Systems.

Adoption of high-level manufacturing technologies such as high accuracy machining, powder metallurgy, high-precision machining, advanced joining and engineered surface finishing remains to be limited by structural barriers. The first obstacle is that, initial capital is very high when it comes to equipment, automation, and the integration of digital systems. An overview of the adoption of advanced manufacturing technology (AMT) revealed that the primary barriers to firms that evaluate these technologies are high capital costs and lack of certainty of the payback (Stornelli, Ozcan, & Simms, 2021). It is also complemented by the evidence that SMEs are particularly vulnerable to financial limitations that deter investments in expensive new technologies unless the returns are apparent and short-term (Ozcan, Stornelli, & Simms, 2021; Oostveen et al., 2025).

There is also a shortage of skilled labor which hinders adoption. With the changing nature of manufacturing systems to be more automated, digital manufacturing, and complex process control, companies are increasingly seeking out operators and engineers among others who possess a high level of skills in materials science, process analysis, and cyber-physical systems. According to a recent study, the shortage of skills in the workforce is a significant obstacle to the implementation of digital manufacturing technologies, especially in the case of smaller organizations with limited training resources (Borovkov et al., 2025). The same research found that even staff familiar with current technologies have to refresh and deepen their skills and competencies in order to keep up (Alayón et al., 2022), which highlights the growing gap between competencies required and the accessible human resources.

There are more challenges in integrating modern technologies with the current manufacturing systems. Old equipment, established methods of operation and process chains are often barriers to the implementation of new machining centers, automated finishing cells or powder-metallurgy production lines. An overview of AMT implementation showed that many companies face problems during installation or postimplementation because of system incompatibility, poor implementation strategy, and interrupted relationships with suppliers (Stornelli et al., 2021). The problem of technology availability and compatibility, as well as the infantile nature of the emerging technologies and the insufficiency of the information infrastructure were cited as key barriers to massive adoption.

Cost and scalability issues are particularly acute in the case of metal based additive manufacturing (AM) processes. Metal AM equipment, raw material and ancillary post processing facilities are also very expensive; the build speeds are generally slower than traditional manufacturing processes; and the post processing, e.g. machining and finishing, may require a significant amount of time and labor that can cancel out the cost and throughput advantages. In turn, these considerations make AM and the associated sophisticated strategies economically ineffective in numerous companies, unless low-volume, high-value, or highly-complex items (Cheng et al., 2018). A market-wide study supports this idea by stating that economic, human-capital, and integration barriers often overlap, thus limiting adoption, especially by SMEs that do not have the necessary resources, organizational readiness, and managerial dedication (Stornelli et al., 2021). Finally, advanced manufacturing technologies can provide significant benefits in quality, customization, efficiency, and flexibility, but structural challenges, such as initial investment requirements, lack of skills in the workforce, and compatibility with the existing manufacturing system, continue to be a major barrier to widespread adoption.

4. CONCLUSION

This study demonstrates that advanced manufacturing processes such as powder metallurgy, joining, surface finishing, and machining collectively enhance material performance, production efficiency, and component reliability in modern engineering applications. Evidence shows that integrating these processes optimizes mechanical properties, reduces costs, and enables high-precision, customized manufacturing. Surface finishing and advanced machining significantly improve durability, while innovative joining methods enhance structural integrity. Despite their benefits, industry adoption remains limited by high investment needs, skill shortages, and system-integration difficulties. Overall, the study underscores the importance of combining these technologies to achieve superior functional outcomes and strengthen the competitiveness of advanced manufacturing systems.

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