

Innovative Development and Application Exploration of Additive Manufacturing Technology under the Background of Intelligent Manufacturing

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Abstract: Intelligent manufacturing, characterized by digitalization, networking, and intelligence, empowers the development of additive manufacturing. Additive manufacturing breaks through the limitations of traditional manufacturing and offers advantages such as flexibility and personalization. This paper explores the synergistic development mechanism between intelligent manufacturing and additive manufacturing. From the perspectives of technological integration, breakthroughs in materials and processes, and equipment upgrading, it analyzes innovations in additive manufacturing technology and examines its applications across multiple scenarios, including high-end equipment and healthcare. The study demonstrates the significant role of additive manufacturing in promoting the transformation and upgrading of the manufacturing industry as well as the development of multiple fields.

Keywords: Intelligent manufacturing; Additive manufacturing; Technological integration; Multi-scenario applications

Introduction

In the context of rapid technological advancement, intelligent manufacturing has become a key direction for the transformation and upgrading of the manufacturing industry, while additive manufacturing, as an emerging manufacturing technology, has also attracted widespread attention. Relying on a new generation of information technologies, intelligent manufacturing enables efficient and precise control throughout the entire production process. Additive manufacturing, based on the principle of “layer-by-layer deposition,” overcomes

the constraints of traditional manufacturing methods. The synergistic development of the two brings new opportunities to the manufacturing sector. An in-depth investigation into their collaborative mechanisms, innovative development, and application practices is of great significance for promoting industrial progress.

1. Synergistic Development Mechanism between Intelligent Manufacturing and Additive Manufacturing

1.1 Core Characteristics of Intelligent Manufacturing

Intelligent manufacturing is supported by digitalization, networking, and intelligence, running through the entire



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production process and exhibiting multidimensional core characteristics. Its essence lies in the deep integration of a new generation of information technologies with the manufacturing industry, aiming to achieve efficient allocation of production factors and precise control of production processes. Digitalization serves as the foundation: through digital twin technology, virtual production scenarios are constructed to realize real-time mapping between physical entities and virtual models, thereby providing data support for production optimization. Networking relies on the industrial Internet to build collaborative platforms, breaking geographical and departmental barriers and enabling interconnection and coordinated operation among equipment, personnel, and resources. Intelligence is reflected in autonomous decision-making and adaptive regulation capabilities. By means of artificial intelligence and big data analytics, production systems are endowed with functions such as fault prediction, dynamic scheduling, and self-optimization ^[1]. Meanwhile, intelligent manufacturing emphasizes full life-cycle management, covering design, production, sales, and service, and pursuing efficient, low-carbon, and flexible production. It provides core driving forces for the transformation and upgrading of the manufacturing industry and lays a technological foundation for synergy with additive manufacturing.

1.2 Technological Essence of Additive Manufacturing

Additive manufacturing, also known as 3D printing, is essentially a breakthrough beyond the limitations of traditional subtractive and formative manufacturing, with “layer-by-layer deposition” as its core principle for rapid component fabrication. Unlike conventional manufacturing, which removes excess material from raw stock to form finished products, additive manufacturing builds three-dimensional entities by stacking materials layer by layer based on digital models, offering high flexibility and strong customization advantages. Its technological core lies in digitally driven precision forming: through a discrete-deposition process logic, design schemes can be directly transformed into physical components without the need for complex molds, significantly shortening R&D and production cycles. Additive manufacturing enables the integrated fabrication of complex structures, addressing challenges in traditional manufacturing where intricate cavities and hollow structures are difficult or costly

to process, while also reducing material waste and improving resource utilization efficiency. Furthermore, its technological essence is reflected in the potential for multi-material integrated fabrication. According to functional requirements, materials with different properties can be precisely deposited, endowing products with superior comprehensive performance and providing a novel technological pathway for high-end manufacturing fields.

1.3 Pathways through Which Intelligent Manufacturing Empowers Additive Manufacturing

Intelligent manufacturing provides comprehensive empowerment for the large-scale and precision-oriented development of additive manufacturing, constructing an efficient and collaborative development pathway. In the design stage, parametric design and simulation optimization technologies in intelligent manufacturing are deeply integrated with additive manufacturing. Through digital twin-based simulation of the forming process, potential issues such as stress concentration and deformation can be predicted in advance, enabling design optimization and improving component forming quality. In the production stage, the industrial Internet and intelligent sensing technologies enable real-time monitoring of additive manufacturing equipment. Key parameters such as temperature, printing speed, and material consumption are accurately collected and dynamically adjusted through big data analysis, ensuring stability and consistency in the production process. In the supply chain stage, the full-process traceability system of intelligent manufacturing runs through material procurement, manufacturing, and finished-product inspection in additive manufacturing, achieving full life-cycle management from raw materials to final products and enhancing product reliability. Artificial intelligence algorithms further empower production scheduling by dynamically allocating equipment resources and optimizing production plans based on order demands, promoting the transition of additive manufacturing from single-piece customization to batch production and breaking through bottlenecks in large-scale application.

2. Dimensions of Innovative Development in Additive Manufacturing Technology

2.1 Technological Integration and Innovation

Technological integration and innovation in additive

manufacturing constitute the core driving force for its breakthrough development and exhibit prominent characteristics of multi-technology convergence. At present, additive manufacturing is being deeply integrated with a new generation of information technologies, such as artificial intelligence, digital twins, and the industrial Internet, to build intelligent forming systems. Artificial intelligence empowers path planning and parameter optimization by autonomously generating optimal forming paths and precisely regulating process parameters, significantly improving component accuracy and production efficiency. Digital twin technology enables full-process virtual simulation of the forming process and provides real-time feedback on deviations between physical forming and virtual models, offering accurate support for process optimization. Meanwhile, the integration of additive manufacturing with traditional manufacturing technologies has become increasingly evident, forming composite processes such as “additive+subtractive” and “additive+casting.” These hybrid approaches combine the flexibility advantages of additive manufacturing with the precision advantages of conventional manufacturing, thereby expanding application scenarios. In addition, interdisciplinary technological integration continues to deepen, with technologies from materials science, computer science, and mechanical engineering mutually penetrating and reinforcing each other. This trend drives additive manufacturing toward breakthroughs in high precision, high efficiency, multi-material capability, and large-scale forming, and fosters a diversified technological innovation ecosystem^[2].

2.2 Breakthroughs in Materials and Processes

Continuous breakthroughs in materials and processes constitute the core support for the iterative upgrading of additive manufacturing technology, driving its extension from basic applications to high-end manufacturing fields. In terms of materials, additive manufacturing has expanded from traditional resins and plastics to diversified categories, including high-performance metal materials, ceramic materials, composite materials, and biomedical materials. Additive manufacturing technologies for high-performance metals, such as titanium alloys and superalloys, have become increasingly mature, addressing challenges related to lightweight and integrated manufacturing of key components in

high-end equipment. Meanwhile, the development and application of biomedical materials—such as biodegradable polylactic acid and bioceramics—have made personalized manufacturing of medical implants feasible. From the perspective of processes, various forming technologies have been continuously optimized. Processes such as selective laser melting, electron beam melting, and stereolithography have achieved significant improvements in precision, efficiency, and stability, while the range of achievable forming dimensions has been steadily expanded. At the same time, novel forming processes are constantly emerging, including directed energy deposition and cold spray additive manufacturing. These processes break through the temperature limitations and material adaptability bottlenecks of traditional techniques, enabling efficient forming of difficult-to-process materials. The synergistic innovation of materials and processes not only enhances the forming capabilities of additive manufacturing but also endows products with superior mechanical properties, corrosion resistance, and functional characteristics, thereby broadening its application boundaries.

2.3 Intelligent Upgrading of Equipment

The intelligent upgrading of equipment is an important guarantee for the large-scale and precision-oriented application of additive manufacturing, showing development trends toward integration, intelligence, and high efficiency. At present, additive manufacturing equipment is evolving from single-function forming devices toward multi-process integrated systems that combine forming, inspection, and post-processing. This integration reduces process transfers, improves production efficiency, and enhances component consistency. The level of intelligence has been significantly improved, with equipment increasingly equipped with intelligent sensing systems, automatic calibration devices, and AI-based control systems. These systems can collect multidimensional data during the forming process in real time, enabling accurate monitoring of equipment status, automatic fault warning, and adaptive parameter adjustment, thereby reducing risks associated with human intervention. Meanwhile, equipment efficiency and scale have been notably enhanced. Through optimization of laser sources, scanning systems, and material feeding mechanisms, forming speed and component size have

been increased to meet the demand for large-scale, high-precision components in fields such as high-end equipment manufacturing and construction. In addition, the acceleration of standardization and modularization in equipment development has improved the universality of key components—such as laser heads and control systems—reducing equipment development and maintenance costs. This trend promotes the widespread adoption of additive manufacturing equipment and lays a solid foundation for the large-scale development of the industry.

3. Exploration of Multi-Scenario Applications of Additive Manufacturing

3.1 High-End Equipment Sector

The application of additive manufacturing in the high-end equipment sector has become an important breakthrough for industrial upgrading, widely covering key fields such as aerospace, rail transit, and marine engineering. In the aerospace field, additive manufacturing enables the integrated fabrication of core components including engine blades, combustion chambers, and airframe structural parts. This significantly reduces component weight, enhances structural strength, shortens R&D cycles, and lowers manufacturing costs, while addressing the challenges of processing complex structural components in traditional manufacturing, thereby supporting aircraft lightweight design and performance improvement^[3]. In the rail transit sector, additive manufacturing is used for the customized production of train components, such as bogie parts and interior structural elements, enabling rapid replenishment and personalized optimization of components, and improving operational safety and passenger comfort. In the field of marine engineering, in response to the requirements of corrosion resistance and high strength for deep-sea equipment, additive manufacturing is applied to produce underwater structural components and valve parts. This approach optimizes structural design and enhances resistance to seawater corrosion and service life. Owing to its flexibility advantages, additive manufacturing can rapidly respond to the customized and small-batch production demands of the high-end equipment sector, promoting the transformation of equipment manufacturing toward high-end and intelligent development.

3.2 Healthcare Sector

Additive manufacturing has brought revolutionary changes to the healthcare sector. With its core advantages of personalization and precision, it has been widely applied across diagnosis, treatment, and rehabilitation. In the manufacturing of implants, patient-specific orthopedic implants—such as artificial joints and spinal supports—as well as dental implants, including dentures and implants, can be customized based on patients' CT and MRI data. This ensures precise matching between implants and human tissues, improves therapeutic outcomes and patient comfort, and reduces postoperative complications. In the field of tissue engineering, additive manufacturing technology can be used to construct three-dimensional biological scaffolds loaded with cells and bioactive substances, providing structural support for tissue regeneration. This approach shows promise for the *in vitro* cultivation and transplantation of tissues such as cartilage, bone, and skin, potentially alleviating the shortage of organ donors. In the domain of medical devices and rehabilitation equipment, additive manufacturing enables the rapid production of customized surgical instruments, rehabilitation braces, and prosthetics to meet the individualized needs of different patients, while also shortening production cycles and reducing manufacturing costs. With the synergistic development of biomedical materials and additive manufacturing technologies, its application potential in areas such as precision medicine and regenerative medicine will continue to be released.

3.3 Consumer and Cultural & Creative Sectors

The application of additive manufacturing in the consumer and cultural & creative sectors is akin to a wave of innovation that fundamentally breaks through the limitations of traditional production models and strongly promotes diversified expressions of personalized consumption and cultural creativity. In the consumer sector, additive manufacturing makes customized production a reality. Taking fashion accessories as an example, consumers are no longer satisfied with homogeneous styles. Additive manufacturing enables the creation of unique necklaces and bracelets tailored to individual preferences, from distinctive design forms to precise material selection, fully meeting personalized needs. Customized electronic product housings are also achievable,

allowing consumers to participate in the design process and create casings that align with their aesthetic tastes and usage habits. The same applies to household products: whether uniquely shaped table lamps or personalized storage boxes, additive manufacturing can easily bring them to life. In the cultural and creative sector, additive manufacturing opens up new pathways for cultural heritage preservation and the realization of creative design. It enables precise replication of cultural relics and components of ancient architecture, preserving original appearances to the greatest extent and providing accurate references for restoration, thereby supporting cultural inheritance. For designers, additive manufacturing allows abstract ideas to be rapidly transformed into physical works—such as exquisite sculptures, collectible figurines, and artistic decorative objects—significantly reducing the threshold and cost of creative realization and stimulating innovation vitality within the cultural and creative industries. In addition, in the food manufacturing sector, additive manufacturing can design and print personalized foods with unique shapes and precise ingredient compositions based on consumers' nutritional needs and taste preferences, driving the food industry toward personalization and precision, and greatly enriching consumption scenarios and experiences.

3.4 Construction and Infrastructure Sector

Additive manufacturing injects new momentum into the construction and infrastructure sector. With its advantages of high efficiency, environmental friendliness, and flexibility, it is gradually transforming traditional construction modes. In building construction, 3D printing technologies can use materials such as concrete, mortar, and polymer composites to achieve automated fabrication of walls, floor slabs, and even entire buildings. This significantly shortens construction periods and reduces labor costs and material waste, making it particularly suitable for rapid construction in remote areas and emergency or disaster-relief scenarios^[4]. At the same time, it enables precise construction of complex architectural forms, breaking through the design constraints of conventional construction techniques and creating distinctive buildings that combine aesthetic value with structural stability. In the field of infrastructure, additive manufacturing can be applied to produce customized components such as

manhole covers, drainage channels, and bridge bearings, improving compatibility with specific engineering contexts and extending service life. In scenarios such as road repair and pipeline installation, additive manufacturing technologies enable rapid maintenance and personalized construction, enhancing the efficiency of infrastructure operation and maintenance. With continuous upgrades in construction materials and printing equipment, additive manufacturing is driving the construction industry toward greener, more intelligent, and modular development.

Conclusion

The integrated development of intelligent manufacturing and additive manufacturing has opened up new pathways for the manufacturing industry. Driven by technological innovation, additive manufacturing has continuously upgraded its materials, processes, and equipment, while its application scenarios have expanded steadily, demonstrating great potential across multiple fields such as high-end equipment manufacturing and healthcare. Looking ahead, with further technological breakthroughs, deeper synergy between intelligent manufacturing and additive manufacturing will inject sustained momentum into high-quality manufacturing development and create broader possibilities.

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