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Additive Manufacturing Integrated Technologies Applied to Human Machine Interfaces: An Industry 5.0 Overview

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Abstract

The industry 5.0 revolution prioritizes digital transformation and automation, while also focusing on improving human-machine interface (HMI), improving production and reducing work-related injuries. On the other hand, to tackle the challenge of designing lightweight and complicated structures, new high-tech materials have been developed using combined additive manufacturing (AM) and powder metallurgy (PM) techniques. The futuristic subsections of additive manufacturing (AM) produce composite materials that incorporate both metallic and ceramic components, suitable for a range of applications from art to industrial use. This brief overview examines the key features of the fifth industrial revolution, with particular attention to the selective laser melting (SLM) process. Two specific areas of study include the exploration of an antiviral metal-ceramic composite and also reflective metal fabrication using integrated AM-PM technologies.

Introduction

The world is rapidly moving towards the 5th industrial revolution which is characterized by a technology-driven approach towards automation and a smarter connection between operator-device and human-machine interface (HMI). This revolution is more focused on automation and reducing the impact of professional diseases and injuries. With the increasing degree of automation, the integration of workers into the changing industrial processes is becoming essential for better acceptance and adaptation. One of the common challenges in the 4th and 5th industrial revolutions is fast design and prototyping, along with reliable connection of human-robot [1,2].
Combination of methods, software and devices are inevitable to bring the technology to the new level. For an example, to address the challenge of keeping frequently touched surfaces disinfected, compact design of components, and lightweight design of complicated structures, new high-tech materials are being developed through additive manufacturing (powder bed fusion, PBF) and powder metallurgy (spark plasma sintering, SPS) techniques. In this paper, the authors describe the fabrication of porous structures of copper and titanium alloys using laser powder bed fusion, followed by filling the base material with Ag/TiO_2 for virucidal material using plasma sintering or isostatic pressing (SPS or HIP) for biomedical applications. These metal-ceramic composites are expected to have antiviral, antibacterial, and antiadhesive properties, which aim to reduce deposition of bacteria and viruses on various applications. The effectiveness of these materials can be tested against the Covid19 for a wide range of in-vitro applications. The outcomes of this work are self-cleaning parts, such as laboratory equipment surfaces. The application of combined PBF-SPS techniques, along with interdisciplinary design-fabrication software and AM-PM integrated technology, yields a medical/antiviral output. Once the results are validated, human-machine communication can facilitate the transition to mass production and automation for rapid fabrication [3,4,5,6].
HMI in the context of Industry 5.0. with its ability to produce intricate geometries and lightweight designs, AM offers a practical solution for the fast design and prototyping of HMIs that are essential in the automation-driven Industry 5.0. as an application, to impact such COVID pandemic situation, the current overview has highlighted the importance of developing antiviral HMIs to ensure the safety of human-

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machine interactions. In this regard, AM, combined with Powder Metallurgy (PM) technologies and HMI interface, can be used to create cermet composites that have virucidal properties, making them ideal for use in industries where frequently touched surfaces need to be disinfected. The integration of AM and PM technologies in the creation of antiviral HMIs can significantly improve the safety and reliability of human-machine interactions in Industry 5.0. For example, the use of copper and titanium alloys with antiviral and antibacterial properties, combined with silver or titanium dioxide filling for virucidal material, can help reduce the deposition of bacteria and viruses on various applications, such as laboratory surfaces, doorknobs, and elevator panels and finally, can lead to the creation of self-cleaning HMIs that are durable and have a desired design. These developments will help industries to address the challenges of Industry 5.0, particularly in the automation and connection of human-machine interfaces, and the safety of human-machine interactions [7,8,9,10].

Industry 5.0; human-centered technologies

With the recent COVID-19 pandemic, keeping frequently touched surfaces disinfected has become a major concern for industries. To address these challenges, AM and PM integrated technologies can be applied to develop antiviral human-machine interfaces for Industry 5.0. The AM technology, particularly PBF, enables the fabrication of porous structures with intricate geometries that cannot be produced using traditional manufacturing methods. These structures have a high surface area to volume ratio, which is crucial for effective virucidal properties. In addition, PM can enhance the mechanical properties of the parts while maintaining their lightweight design, making them ideal for applications in industries where lightweight components are desired. To create antiviral human-machine interfaces, copper and titanium alloys are often used due to their excellent virucidal properties. Specifically, CuNi2SiCr or Cu15Ni8Sn alloys have been shown to have antiviral, antibacterial, and anti-adhesive properties, while Ti6Al4V or Ti22Al25Nb alloys have high mechanical strength and are lightweight. These alloys can be fabricated into porous structures using PBF and then filled with Ag/TiO_2 for virucidal material using SPS for biomedical applications. The Ag/TiO_2 filled structure can help reduce the deposition of bacteria and viruses on various applications, such as laboratory surfaces, doorknobs, elevator panels, and other frequently touched surfaces. The effectiveness of these materials can be tested against the bacteriophage Phi6, which is a known model system for RNA-enveloped viruses, or against Covid19 for a wide range of in-vitro applications. The outcomes of this work can lead to the creation of self-cleaning human-machine interfaces that are durable and have the favorable design [11,12,13].
The relation of industry 5.0 and its elements regarding the AM technology is shown in Figure 1. Industry 5.0 emphasizes human-centered approaches in manufacturing and aims to create a more sustainable, efficient, and collaborative work environment. This is achieved through the use of advanced technologies, such as additive manufacturing, human-centered technologies, environmental sustainability practices, digitalization and automation, artificial intelligence, combination of technologies, waste minimization, and collaborative software and robots. Additive manufacturing enables the production of complex and customized parts while reducing waste and transportation costs. Human-centered technologies like augmented and virtual reality improve worker safety and enhance worker skills. Digitalization and automation streamline production processes and improve quality control, while artificial intelligence helps machines to make decisions and reduce human intervention. The combination of technologies creates more advanced and flexible manufacturing systems that can adapt to changing conditions and customer needs. Waste minimization and pollution prevention practices reduce the environmental impact of manufacturing processes and ensure worker safety. Collaborative software and robots enable humans and machines to work together, improving productivity and reducing errors. Overall, Industry 5.0 represents a shift towards a more sustainable, efficient, and collaborative manufacturing industry [14,15,16,17].

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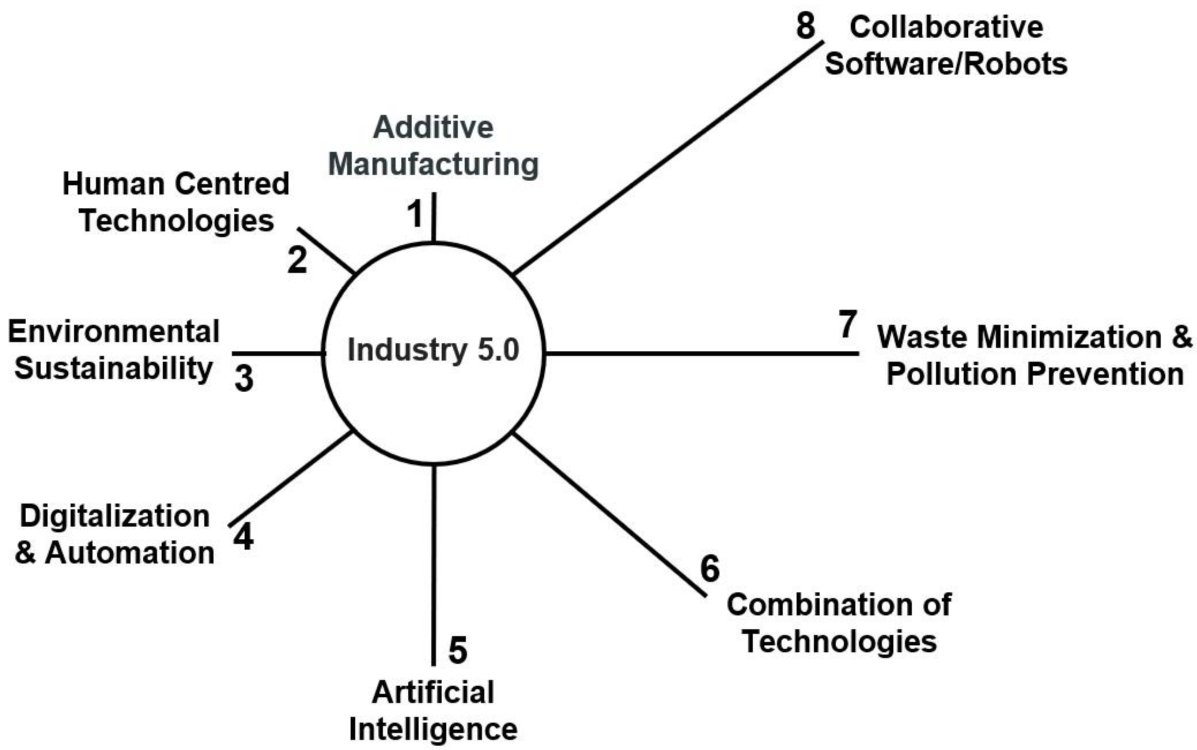

Figure 1. Main elements of Industry 5.0 regarding the additive manufacturing technology

Additive manufacturing (AM) of copper (as a reflective metal) and its alloys (e.g., CuNi2SiCr and Cu15Ni8Sn alloys) can offer several benefits and disadvantages, which the benefits are outlined below:

- Design Flexibility: One of the significant benefits of additive manufacturing of copper and its alloys is the design flexibility it offers. AM enables the production of complex shapes that are not possible with traditional manufacturing methods.
- Reduced Material Waste: AM is a "build-to-order" process, which means that only the required amount of material is used, reducing material waste and cost.
- Time Efficiency: AM can reduce the time it takes to produce parts, as the process is automated and can run 24/7. This can lead to faster lead times and shorter production runs.
- Customization: AM allows for the production of highly customized parts, which can be tailored to the specific needs of the end-user.
- Improved Material Properties: The AM process can create a finer grain structure in copper and its alloys, leading to improved material properties such as increased strength and ductility.

On the other hand, main disadvantages can be listed as:

- High Initial Investment: The cost of AM equipment and materials can be significantly higher than traditional manufacturing methods, which can be a barrier to entry for some companies.
- Limited Material Availability: The range of copper and copper alloys available for AM is currently limited, which can restrict the ability to produce certain parts.
- Post-Processing Requirements: Some AM processes may require additional post-processing, such as sintering, which can add time and cost to the production process.
- Surface Roughness: The surface finish of parts produced by AM can be rougher than those produced by traditional manufacturing methods, which may require additional finishing steps.
- Quality Control: AM can be prone to defects such as porosity, which can affect the mechanical properties of the parts produced. Quality control and testing are critical to ensure the parts meet the required standards.

Overall, additive manufacturing of copper and its alloys can offer several benefits, including design flexibility, reduced material waste, time efficiency, customization, and improved material properties.

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However, there are also some disadvantages, such as high initial investment, limited material availability, post-processing requirements, surface roughness, and quality control challenges.

Industry 5.0; additive manufacturing progress

Industry 5.0 is the latest evolution of the manufacturing industry that aims to combine the benefits of both Industry 4.0 (automation and data exchange) and human intelligence and creativity. Additive manufacturing of copper and its alloys can play a significant role in Industry 5.0 by enabling the production of highly customized and complex parts that are tailored to the specific needs of the end-user. Industry 5.0 places a strong emphasis on human creativity and innovation, and additive manufacturing of copper and its alloys can provide the tools to unleash this creativity. The ability to produce highly customized parts with complex geometries and improved material properties can open up new possibilities for product design and development. Moreover, additive manufacturing of copper and its alloys can support the trend towards localized production and on-demand manufacturing. As the manufacturing process is automated, it can be easily set up and run in small batches or even as a one-off production, which can lead to faster lead times, reduced inventory costs, and less waste. Overall, additive manufacturing of copper and its alloys can be a powerful tool in the industry 5.0 manufacturing ecosystem, enabling new levels of customization, flexibility, and innovation while maintaining the benefits of automation and data exchange [18,19,20].

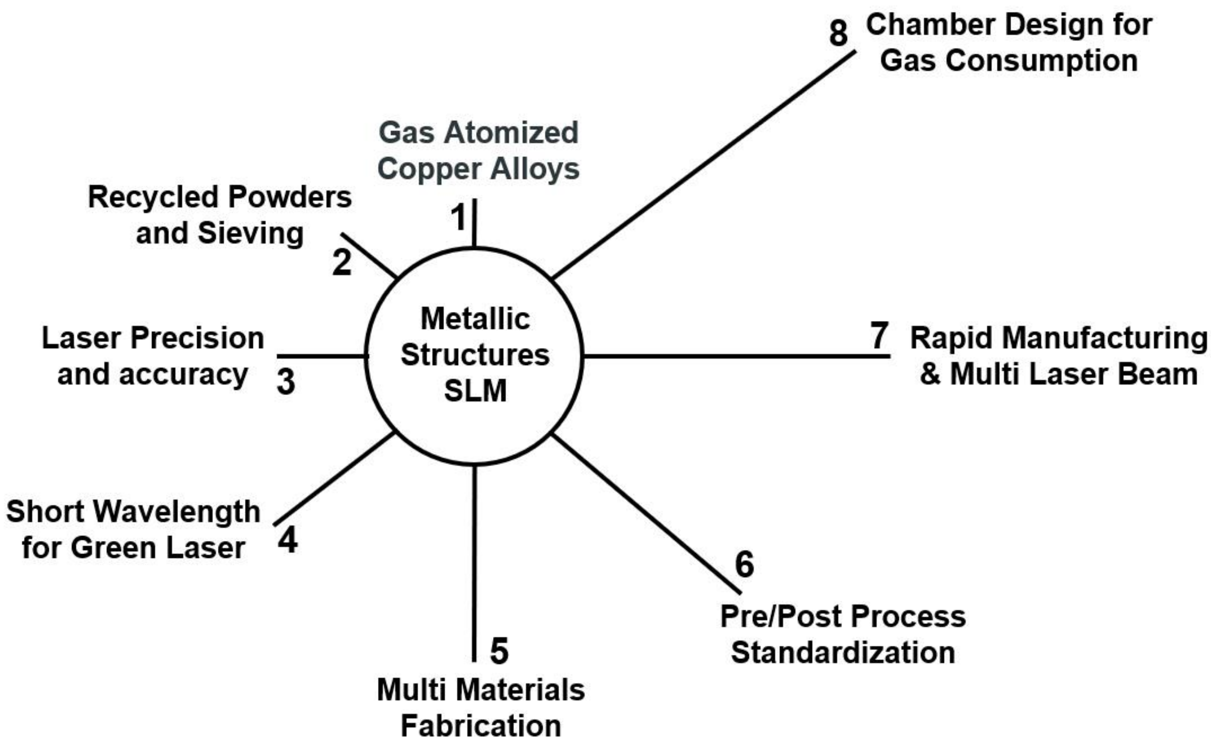

Figure 2. Expected advances in SLM process of metallic structures

The future of SLM of metallic structures in Industry 5.0 is promising, with several technological advancements that will shape its evolution. It is illustrated in Figure 2. Gas atomized copper alloys are an innovative material that can be used in SLM for their excellent mechanical properties, making them suitable for applications in various industries. Recycled powders and sieving are expected to be integrated into the SLM process, reducing material waste and costs. Laser precision and accuracy are critical in SLM, and Industry 5.0 will see further advancements in laser technology to enhance these features. Short wavelength green lasers will become more prevalent, enabling high-speed printing and the production of small and intricate parts. Multi-materials fabrication will become more accessible through the development of new materials and better control over the SLM process. Pre/post-process standardization will increase efficiency and quality control, making SLM more predictable and consistent. Rapid manufacturing will become a reality, thanks to the improvements in laser technology and materials. Multi-laser beam systems will also increase productivity and reduce printing time. Chamber design for gas consumption will improve efficiency and reduce the environmental impact of SLM. Overall, Industry 5.0 will bring significant changes to SLM of metallic structures, enabling faster, more efficient, and sustainable production of complex and customized parts. These advancements will be critical in the aerospace, medical, and automotive industries, among others, where SLM has the potential to transform manufacturing processes and supply chains [21,22].

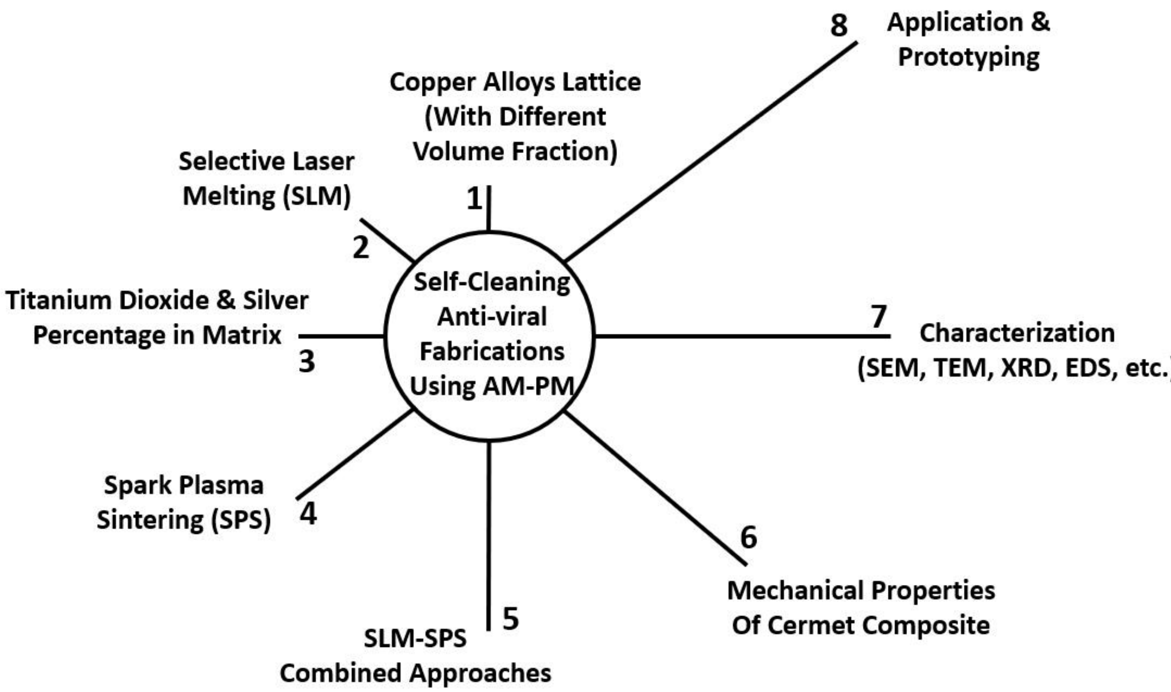

Figure 3. Schematic of combined SLM-SPS processes for antiviral prototyping

Figure 3 illustrates the sequential arrangement of SLM and SPS, either independently or in combination. SLM enables the determination of the composition and creation of metallic components, such as copper or titanium alloys in various forms like bulk, lattice, scaffold, or triply periodic minimal surface. On the other hand, the production of ceramic parts, including titanium dioxide, zirconium dioxide, hydroxyapatite, or wollastonite, can be accomplished directly using SPS or SLM-SPS methods, depending on the flowability of the powder or its suitability for printing. These metal-ceramic hybrids, known as cermet composites, exhibit potential for diverse applications in the realm of antiviral and antibacterial measures.

Conclusion

In this study, we provide an overview of the integration of additive manufacturing (AM), powder metallurgy (PM), and human-machine interface (HMI) techniques for the production of a diverse array of metal-ceramic applications. These innovative methods enable the fabrication of various functional structures, including antiviral self-cleaning surfaces, among others. The 5th industrial revolution seeks for digital transformation, smarter and valuable connection of operator-device and human machine interface (HMI). Compared to Industry 4.0, the 5th industrial revolution is more technology-driven and more focused on automation approach. The human collaborators also have their focus increased, as a higher degree of automation usually requires the integration of the worker on the changing industrial processes, for better acceptance and adaptation. This approach through the 5th industrial revolution focuses on reducing weight of structures, increase the speed of processes, prevent diseases/injuries, rapid prototyping, and reliable connection of human-robot.

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