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Editorial

Metal Additive Manufacturing—State of the Art 2020

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1. Introduction and Scope

Additive manufacturing (AM), more popularly known as 3D printing, comprises a group of technologies used to produce objects through the addition (rather than the removal) of material. AM is now transforming the industry and this transformation is expected to become more comprehensive and reach a higher pace during the coming years.

The AM of metal components with virtually no geometric limitations has enabled new product design options and opportunities, increased product performance, shortened the cycle time in part production, reduced total costs, shortened lead time, improved material efficiency, created more sustainable products and processes, enabled full circularity in the economy, and developed new revenue streams.

This Special Issue of *Metals* provides a 2020 account of metal AM, primarily with respect to product design (generative design, topology optimization, and lattice and surface optimization), material and process design and engineering, new materials, process control and optimization and quality assurance, post-processing, and industrial applications (aerospace, defense, automotive, consumer, medical, and industrial products).

2. Contributions

In this Special Issue, eleven contributions address the topics mentioned above. The topics of material design and new materials are subject to an investigation in [1], where the authors report the development of a Mg-Al-Zn-Ca-rare earth alloy for wire arc additive manufacturing (WAAM). Compared to parts made of commercially available filler wire, the newly developed alloy achieves a higher strength in WAAM. Especially for large dimensional parts, this processing route can be faster and easier to implement than traditional routes such as milling and casting [1].

WAAM is also the AM method used and studied in [2]. This method provides a promising alternative to conventional machining for the production of large structures with a complex geometry, as well as individualized low quantity components using cost-efficient production resources. The experimental study in [2] describes the effects of thermal cycling on the geometrical and material properties of a WAAM-ed Al-5356 aluminum alloy.

Process design and engineering and quality assurance are addressed in several contributions [3–5].

Focused on the electron beam melting (EBM) of the stainless steel alloy 316LN, the area energy (AE) input and beam deflection rate were varied in [3] to produce a wide array of samples. Tensile and microstructural analysis showed that increasing the beam deflection rate, and consequently lowering the AE, results in a smaller grain size, a lower ductility, a lower yield strength, and a narrower window for producing material that is neither porous nor swelling [3].

Large components are often manufactured via directed energy deposition (DED) instead of using powder bed fusion (PBF) processes. The advantages of the DED process are a high build-up rate with values up to 300 cm^3/h and a nearly limitless build-up volume. The DED processed EN AW-7075 shows comparable mechanical properties to the PBF processed EN AW-7075 [4].

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The grain structure of parts made using selective electron beam melting (SEBM) can be influenced strongly by the processing parameters. This was studied in [5], where trapezoidal prism samples from IN718 were produced using SEBM with different processing strategies. Based on numerical simulation, the authors demonstrate how technical single crystals develop in IN718 by forcing the temperature gradient along a μ-helix. The slope of the μ-helix, i.e., the deviation of the thermal gradient from the build direction, determines the effectiveness of grain selection right up to single crystals [5].

Post-processing in combination with process control and optimization (and quality assurance) are addressed from different perspectives and for different materials and AM methods in [6–8].

While structures bearing insufficient support result in defective overhangs, structures with excessive support result in higher material and time consumption, and post-processing costs. The results of [6] show that appropriate design and process parameters in the EBM of Ti6Al4V overhang parts led to a significant reduction in the support removal time and protection of the part's surface quality.

The research novelty in [7] is the aggregation of all kinds of data from the last 20 years of investigating the Ti–6Al–4V parts manufactured via selective laser melting (SLM) and EBM. Throughout the report, it can be seen that the expected microstructure of the Ti–6Al–4V alloy is different in SLM and EBM, mainly due to the distinct cooling rates. However, heat treatments can modify the microstructure, reduce the residual stresses, and increase the ductility, fatigue life, and hardness of the components. Furthermore, distinct post-treatments can induce compressive residual stresses on the part's surface, consequently enhancing the fatigue life [7].

In very demanding corrosive atmospheres, the question is whether AM lowers or eliminates the risk of stress corrosion cracking (SCC) compared to welded 316L components. The authors of [8] concentrate on post-processing and its influence on the microstructure, and surface and subsurface residual stresses. The immersion tests with four-point-bending in an 80 °C magnesium chloride solution for SCC showed no difference between the AM and reference samples, even after a 674-h immersion [8].

The applications are addressed in [9–11].

3D printing is now viewed as a highly appealing approach for the manufacturing of personalized implants. The most important functional request of such devices should be their capacity to stimulate fast bone regeneration. Thereby, the materials of choice would be bioceramics that highly resemble the composition and structure of the mineral bone phase. Unfortunately, such stand-alone bioceramics lack the suitable mechanical properties, thus risking implant failure. Furthermore, they are difficult to use in 3D printing. Therefore, the compromise solution is the fabrication of customized implants using 3D printing with metallic materials, before coating them with bioactive ceramic thin films, closely mimicking the fine and intricate features of the metallic biomedical device. 3D cranial meshes of Ti6Al4V were successfully manufactured using SLM and coated using radio-frequency magnetron sputtering with a ~600-nanometer layer of hydroxyapatite that was derived from biogenic sustainable resources (i.e., calcined cortical bovine bones). The Bio-HA sputtered films elicited promising biological performances [9].

The fabrication of microwave slot array antennas, and waveguide bandpass and notch filters using 3D printing has significant advantages in terms of speed and cost, even for the parts with a high mechanical complexity. One disadvantage of Stereolithography (SLA) 3D printed, copper plated microwave components is that some SLA resins have a high coefficient of thermal expansion. Resonant structures experience significant frequency drift, with temperature changes in the order of 10–50 °C. The issue of the frequency characteristics of 3D printed microwave structures changing significantly with a temperature shift has not been addressed or reviewed in the current literature [10]. The authors of [10] measured and simulated the effect of temperature change on a slot array, cavity notch filters, and post loaded waveguide bandpass filters. They tested several types of SLA resin, different plating techniques, and also direct metal laser sintering (DMLS) and binder infusion metal 3D printing. The performance as a function of temperature is presented for these alternatives in [10].

The author of [11] focused on the laser-based PBF (L-PBF) of production tools used in cold working, hot working, and injection molding. Examples of the production tools designed for and made using L-PBF are described. It is shown in [11] that efficient design, i.e., high tooling efficiency and performance in operation, should be the primary target of tool design. Topology and lattice structure optimization provide additional benefits. Using efficient design, L-PBF exhibits the greatest potential for tooling in hot working and injection molding [11].

3. Conclusions and Outlook

This Special Issue of *Metals* provides a comprehensive and stimulating insight into the current state of the art of metal AM, the technology maturity index, and the industrialization index of different metal AM processes, and future research needs. As Guest Editor, I hope that this special issue attracts interest and will be useful for future work within academia and the industry.

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