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Editorial

Special Issue on Materials Development by Additive Manufacturing Techniques

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Abstract: Additive manufacturing (AM) processes are steadily gaining attention from many industrial fields, as they are revolutionizing components' designs and production lines. However, the full application of these technologies to industrial manufacturing has to be supported by the study of the AM materials' properties and their correlations with the feedstock and the building conditions. Furthermore, nowadays, only a limited number of materials processable by AM are available on the market. It is, therefore, fundamental to widen the materials' portfolio and to study and develop new materials that can take advantage of these unique building processes. The present special issue collects recent research activities on these topics.

Keywords: additive manufacturing; materials development; mechanical properties; polymers; metals; ceramics

1. Introduction

Additive manufacturing (AM) is an innovative class of production technologies, which is often considered to have a large impact in all manufacturing activities, as it allows for the production of complex-shaped components without the need of dedicated tools [1]. This family of production techniques had a large success in recent years, not only thanks to the design freedom that it is possible to achieve, but also thanks to the possibility to produce customized components and to reduce time to market and costs of some production lines [2].

2. Materials for Additive Manufacturing

The countless advantages and challenges of AM processes from a design and from a productivity point of view have been widely discussed in recent years, but, recently, many research studies pointed out that these innovative processing technologies also bring many advantages and challenges from a material perspective [3]. From a materials point of view, in fact, the main issues to be solved are related to the study of the AM parts' properties and to the limited amount of processable materials available on the market.

On the basis of these considerations, many universities, research centers, and industries started studying the correlations between feedstock properties, AM process parameters, and materials properties and are seeking to expand the portfolio of materials available for AM processes [3]. This special issue was, therefore, introduced to summarize the recent research activities on these topics. The main recent advances in AM materials development are described below per each material class.

2.1. Polymers

Polymers are by far the most-used materials in AM due to their simple processes, easy availability and low cost. The most-used polymer AM techniques are stereolithography, selective laser sintering

(SLS), fused deposition modelling (FDM), laminated object manufacturing (LOM), and 3D bioprinting. Each type of technology can process only specific polymers. Photopolymer resins for stereolithography, for example, are the most-used ones in the industrial field, mainly thanks to the excellent accuracy it is possible to achieve through this building process [4]. Polystyrene, polyamide, and thermoplastic elastomers are also widely used and generally processed by SLS. As the mechanical properties of printed polymers seemed to be a major concern, large efforts were carried out to process composites using various AM technologies [5].

Recently, much research was carried out on the development of polymers for the FDM technology. The most common thermoplastic polymers face in fact have many issues, mainly related to their physical properties. In this frame, several studies recently investigated the processability and the properties of Ultem 9085, which is a thermoplastic polymer especially designed by Stratasys for the FDM process [6]. The main advantages of this composition are related to its high glass transition temperature, good flame retardancy, and high mechanical properties. Recent works, reported in this special issue, demonstrated that, due to the layer by layer process, the Ultem tensile properties are strongly anisotropic and heavily related to the building parameters [6,7]. Similarly, Solorio et al. investigated the FDM processability and properties of an innovative amorphous poly(lactide acid) (PLA) blend with poly(styrene-co-methyl methacrylate) (poly(S-co-MMA)) [8]. The study, published in this special issue, demonstrated how the introduction of MMA allowed for an improvement of the processability of the PLA filaments.

2.2. Metals

Nowadays mainly steels, titanium, aluminum, and nickel alloys are successfully processed by AM and used in disparate applications [9]. However, not all alloys belonging to these families can be successfully processed by the most common metal-AM techniques, such as laser powder bed fusion (LPBF), electron beam melting (EBM), and directed energy deposition (DED).

Steel has been by far the first alloy class to be processed and has, therefore, been used in several industries, such as the automotive and aerospace ones [10]. Among AM processable steels, the most studied ones are stainless steel, such as 316L and 304L, precipitation hardening (PH) steels, such as 17-4 PH, tool steels, such as H13 and M2, and maraging steels, such as 18Ni-300. Large efforts have been made in previous works in order to understand the microstructure of steels' built components and their correlation with the building parameters together with the effect that they have on mechanical properties [11]. Saboori et al. summarized the main data and results obtained on DED 316L samples in a review published in the present special issue [11].

Titanium alloys are the most-used alloys in AM thanks to the wide range of applications they have in the biomedical and aerospace fields. Many of these applications can take advantage of the possibility to produce complex and customized parts. Furthermore, the vacuum EBM process of Ti6Al4V Gd23 alloy allows the control of the interstitial content and the consequent respect of the standards.

Aluminum alloys also had large success in the AM field mainly thanks to the strong interest of aerospace companies that need the production of complex, lightweight components [12]. Currently, however, mainly Al–Si alloys, with a near eutectic composition, are processable by AM while most of the Al high-strength alloys strongly suffer from solidification cracking during AM processing. There is, therefore, a limited amount of aluminum alloys processable by AM and, recently, universities, research centers, and companies are investing in the development of new compositions specifically designed for AM, such as the Scalmalloy® or the A20X™ [3].

Nickel alloys, such as In625, In718, and HastelloyX, have been widely used for the AM production of parts that need high-creep and corrosion resistance, such as engine turbine blades, turbochargers, heat exchangers, and petrochemical equipment [13]. The strong interest in this alloy class has pushed the research in the understanding of the microstructure–properties correlation of these materials. Recently other alloys belonging to the Ni family have been successfully processed by AM. As an example, in this special issue, results about the Monel Ni–Cu alloy are reported [14]. This alloy, which has been recently processed by LPBF, showed good processability within specific parameters. High-mechanical properties were measured thanks to fine microstructure and high residual stresses [14].

2.3. Ceramics

Ceramic AM processes are generally classified into direct (or single-step) and indirect (or multistep) methods [15]. In the first class of technologies, the material is fabricated in a single process in which both the final shape and the materials' properties are obtained. These direct methods allow a larger design freedom and are generally, therefore, preferred when complex geometries have to be built. The disadvantage of these processes is that the manufactured parts are usually porous and characterized by a high surface roughness. The processes belonging to the second class, on the contrary, need several steps to reach the final component's consolidation. In the first step, the shape is provided, and the green body is obtained through binding. The subsequent steps are needed to consolidate the part and reach the desired properties. The main advantages of these processes are mainly associated with reduced delamination and anisotropy issues.

The ceramic AM processes have rapidly evolved in recent years, however, in many cases, the mechanical properties of manufactured parts do not reach the desired values [16]. Because of this reason, lately, large efforts have been made to improve the ceramic AM processes' capabilities and to enlarge the palette of processable materials, also involving high-performance ceramics (HPCs) [16,17].

Altun et al., for example, demonstrated, in a paper published in this special issue, the applicability of the indirect AM lithography-based ceramic manufacturing (LCM) method to the production of precise and complex silicon nitride (Si_3N_4) parts. This nonoxide ceramic has attracted large interest thanks to its unique properties, such as high toughness, strength, and thermal shock resistance together with an outstanding biocompatibility that makes it an excellent candidate for dental applications [18].

3. Conclusions

The studies reported in this special issue clearly highlight the importance of the materials' development in AM applications. It is striking that, in most of the cases, a strong correlation between building conditions and materials' properties exist. Furthermore, these studies make it apparent that AM processes open large possibilities in the development of new materials having specific properties and distinct functionalities.

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