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Editorial: Advances in additive manufacturing of ceramics

Recently, additive manufacturing of ceramics has achieved the maturity to be transferred from scientific laboratories to industrial applications. At the same time, research is progressing to expand the boundaries of this field into the territory of novel materials and applications.

This feature issue addresses current progress in all aspects of additive manufacturing of ceramics, from parts design to feedstock selection, from technological development to characterization of printed components. It includes comprehensive reviews on the state of the art and future perspectives of additive manufacturing processes comprising thermoplastic feedstocks [1] as well as following the laser powder bed fusion route [2]. Technological developments that help expand the capabilities of current processes are also presented, such as a device that allows for top-down vat-photopolymerization with viscous slurries [3] or a building platform actuated by an anthropomorphic robot that helps counteract gravity during the fabrication of cylindrical lattice structures by direct ink writing [4]. The advent of robotic arms into the additive manufacturing field expands the design space and can also lead to the development of hybrid additive-subtractive processes for complex components, such as ceramic parts with internal channel networks [5]. Machine development forms the basis for the multi-material vat-photopolymerization process featured in this issue, whose capabilities are demonstrated with the fabrication of a zirconia-alumina sandwich composite with outstanding biaxial strength [6].

Current technologies can also highly benefit from innovation in their feedstock materials that enhance their processability and final properties. The addition of metal oxide nanoparticles to selective laser sintering powder beds, for example, results in higher heat absorbance and improved densification of alumina parts [7]. For processes employing liquid feedstocks, the high particles' dispersion and the stability of the ceramic suspensions are key aspects, which can be predicted by correlation to the zeta potential [8]; when such requirements are achieved for nanosized particles suspensions, they can be employed in volumetric additive manufacturing processed such as 2-photon-polymerization to produce ceramic structures with resolution in the sub-micrometer scale [9].

A proper combination of feedstock and process can be taken advantage of to produce unique properties and features: for instance, textured alumina ceramics with superior mechanical properties are fabricated by employing a platelet-based suspension that benefits from the stresses induced by the doctor blade and the immersing platform in a vat-photopolymerization process [10].

This feature issue also showcases some of the latest additions to the family of printable materials, including cermets [11] and ceramic-matrix-composites embedding metal-organic-frameworks [12]. The renewed interest in human space exploration fosters research on in situ resource utilization to support astronauts over the long term and reduce spacecraft payloads; in this framework, examples of additive manufacturing processes employing extraterrestrial material simulants, namely lunar and Mars regolith, are here included, with particular focus on the sintering process in simulated extraterrestrial atmosphere [13,14].

The assessment of the relationship between process, structure and properties finds space in several works featured in this issue. Process parameters need to be linked precisely to the material properties and geometry of choice; for instance, modelling the material extrusion of a reactive geopolymer composite opens up to the process of upscaling and employment in the construction field [15]. In the case of sintered ceramics, the object's topology influences its final properties and the printing, debinding and sintering stages [16]. The digital design can be improved by models and simulations of the chosen process; for vat-photopolymerization, custom supports are added, and part orientation is optimized to minimize and counteract the scraping loads generated during the spreading of individual layers [17]. Custom functional geometries, such as fluctuating surface features and graded porosity profiles, can be systematically designed through numerical simulations of specific properties such as optimized fluid flow propagation [18].

The industry's adoption of additive manufacturing processes runs through their incorporation into established post-processing protocols. The additive manufacturing of SiC parts provides an example: their fabrication has to be accompanied by specific sintering procedures, including liquid phase sintering, precursor infiltration, pyrolysis, and liquid silicon infiltration. The final density and strength of a part rely on successful processing after printing; thus, the whole process chain needs to be accounted for starting from the component design [19,20].

Validation of ceramic additive manufacturing processes for industrial applications has to be accompanied by a thorough characterization of their physical and functional properties. Different defect determination methods are presented and compared here, from x-ray microtomography to less expensive mass and volume determinations that could be integrated into process chains [21]. The complexity of printed structures demands novel characterization methods and models; this issue features a novel approach for thermal conductivity estimation based on high resolution infrared thermography, which avoids using thermocouples that would be difficult to attach to 3D porous structures [22].

In summary, this collection encompasses research work that aims to improve the acceptance of existing technologies and develop novel technologies and materials for future applications.

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