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Editorial: Additive manufacturing of advanced ceramic materials and its applications

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Editorial on the Research Topic
Additive manufacturing of advanced ceramic materials and its applications

Additive manufacturing (AM or 3D printing) holds the potential to revolutionize the ceramic industry by offering fresh avenues for manufacturing complicated ceramic components directly from digital models without the need for costly tooling. This advancement can lead to decreased production costs and lead times, while also enhancing design flexibility and tolerance for imperfections. Thus, there is an increasing interest in utilizing AM techniques to produce advanced ceramic components and explore their wide-ranging applications. This Research Topic consists of several articles from renowned groups worldwide, presenting their insights and recent progress in AM of advanced ceramic materials and applications. These articles discuss advances across various Research Topic including novel materials, innovative techniques, and emerging applications, which broaden the understanding of the capabilities, challenges, future perspectives and implementation of AM of advanced ceramic materials.

The collections in this Research Topic have attracted review and research articles addressing diverse aspects of the AM-fabricated advanced ceramic materials and applications. Fiume et al. discussed the vat-photopolymerization of ceramic materials and explored the state-of-the-art of the applications in advanced multidisciplinary fields including biomedicine, energy, environment, space and aerospace, with a special focus on current trends and project-specific requirements. Pan et al. formed high-resolution, defect-free alumina ceramics using stereolithography-based 3D printing technology, which provides a rapid and cost-effective manner to produce ceramic cores used in astronautics engineering and material engineering fields related to high-temperature environments. Yan et al. introduced a hybrid approach methodology that combines experimental rheology with Finite Element simulations to determine the printability of ceramic-polymer ink formulations which aids in optimizing low-temperature extrusion 3D printing of novel inks for bone tissue engineering. Heise et al. presented the design and use of an inline mid-infrared optical coherence tomography (MIR-OCT) system combined with deep learning for classification and in-process feedback as a versatile tool for at-line and inline quality control in lithography-based ceramic manufacturing.

This Research Topic has a strong focus on AM-fabricated advanced ceramic materials and their applications. The exceptional dimensional/chemical stability over a wide temperature range, along with high corrosion resistance and lower density in comparison to metal-based components, have made ceramic materials highly intriguing for space and aerospace applications, thus have becoming a fascinating research area. Fiume et al. summarized relevant outcomes and final considerations of various classes of AM-fabricated advanced ceramics used in space and aerospace industry, including both oxide- and non-oxide ceramics and ceramic composites. Pan et al. discussed the influence of high-temperature sintering conditions on microstructure and properties of 3D-printed alumina ceramics and obtained high-performance intricate alumina ceramic cores essential for crafting high-temperature hollow turbine blades.

Tissue engineering applications are another subfield where AM of bioceramics finds tremendous potential. Fiume et al. highlighted how the scientific community is devoting considerable efforts to the transfer of stereolithography-based 3D printing technology of bioceramic materials into clinical practice in various fields of application, such as orthopedics and dentistry. Yan et al. established a framework for streamlining the design of inks for extrusion 3D printing of ceramic-polymer scaffolds for bone tissue engineering. They evaluated the compressive properties of printed hydroxyapatite-polycaprolactone scaffolds and characterized the effects of ceramic content and component ratio on the hyperelasticity observed in response to compressive deformations.

In recent years, artificial intelligence (AI) has emerged as one of the most active subfields of AM. This is also reflected in AM of advanced ceramic materials. AI has been suggested in AM of ceramics for classification between accurately 3D-printed and ceramics specimens with failures at the micron scale. Specifically, deep learning methods involving convolutional neural networks or residual neural networks that have enabled easy training and model generation for image data are chosen. Deep learning plays a crucial role in advancing AM by enabling more efficient processes, better quality control, and innovative material and design solutions. Heise et al. highlighted the potential of MIR-OCT coupled with AI-based identification methods for inline process monitoring and quality control in additive ceramic manufacturing machinery. They integrated the OCT measurement head in a 3D ceramic printer that enables direct layer growth monitoring, geometry verification, and real-time defect development monitoring, providing immediate user alerts when misprints are produced. Such monitoring enhances production efficiency by promptly detecting potential defects, reducing the time and cost commitments, and minimizing resource consumption.

As mentioned earlier, AM of advanced ceramic materials and its applications constitute a vibrant and rapidly evolving field. While the contents of this Research Topic may encompass just a fraction of the outstanding research efforts in progress, our aspiration is to offer fellow researchers a glimpse into the dynamic and swiftly evolving landscape of this field.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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