**ABSTRACT – Ph.D. Thesis Contest**

# Additive manufacturing of functionally graded ceramic materials

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Multi-material structures offer the unique ability to combine distinct material properties, enabling the design of components with tailored functionalities that cannot be achieved with single-homogeneous material systems. In the context of biomedical implants, this approach provides a means to overcome the limitations of single-material implants. By combining a high-hardness, low-temperature degradation (LTD) resistant alumina-toughened zirconia (ATZ) surface with a tough and strong 3 mol% yttria-stabilized zirconia (3Y-TZP) core, the drawbacks of each material can be effectively addressed. Additionally, multi-material parts allow for generating and strategically manipulating thermal residual stresses. During cooling from the sintering temperature, the differences in the constituent materials' thermal expansion coefficients and elastic moduli induce residual thermal stresses. When carefully controlled, these stresses can significantly enhance the toughness and strength of the final product, offering a pathway to high-performance, durable implant designs.

This study investigates the potential of additive manufacturing (AM), particularly direct ink writing (DIW), for fabricating advanced multi-material ceramic components. DIW, an extrusion-based AM technique, offers several advantages, including the ability to produce multi-material parts and the potential for cost-effective, environmentally friendly production. This research focuses on developing multi-material parts featuring an ATZ shell and a 3Y-TZP core, aiming to address the challenges posed by conventional manufacturing techniques.

To achieve this goal, the powder dispersion was initially optimized to ensure the preparation of a high solid loading, homogeneous paste free of agglomerates. Extensive rheological testing identified optimal ink formulations for fabricating high-density, single-material components, enabling the production of parts with minimal sintering shrinkage and high density. The DIW parameters were optimized and applied to ATZ and 3Y-TZP pastes, resulting in dense monolithic parts with enhanced mechanical properties. Building on these advancements, multi-material disks with an ATZ shell and a 3Y-TZP core were successfully fabricated. The optimal relative thickness ratio between ATZ and 3Y-TZP was determined to maximize the distribution of thermal residual stresses, enhancing mechanical performance through increased compressive surface stresses.

In summary, this study successfully demonstrates the feasibility of DIW for producing high-density, defect-free single and multi-material ceramic components with tailored properties. This work highlights the potential of DIW as a manufacturing approach that addresses the limitations of conventional techniques while expanding the design possibilities for high-performance ceramics.