AddH$_2$ – SP1: Fused pellet fabrication of ceramics resistant to thermal shock and hydrogen combustion

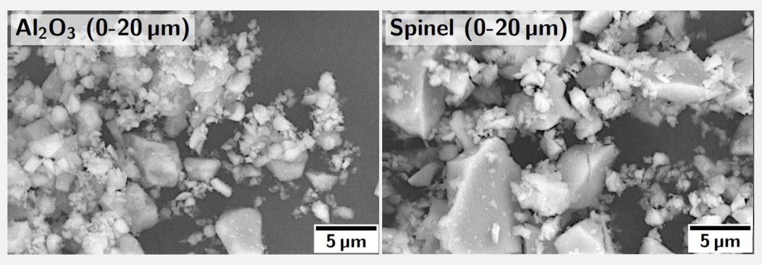
Florian Kerber, Jana Hubálková, and Christos G. Aneziris
Institute of Ceramics, Refractories and Composite Materials

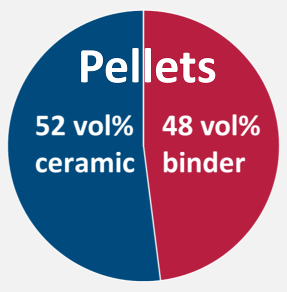
Aims / Objectives

- **Primary Aim:** Development of advanced additive-manufactured burner components based on alumina with superior resistance to high-temperature corrosion and chemical attacks, especially in hydrogen-fueled environments [1,2].
- **Design:** Engineering of the burner nozzle to withstand extreme chemical, thermal, and mechanical stresses, ensuring enhanced durability in challenging industrial conditions.
- **Structural Development :** Leverage additive manufacturing to create optimized internal geometries featuring tailored hollow structures, which improve thermal shock resistance and reduce the likelihood of structural failure [3].
- **Surface Refinement:** Utilization of inline post-processing techniques with CNC-assisted milling to smooth the nozzle's surface, minimizing interactions with hydrogen fuel gas. Additionally, custom-designed wall profiles will enhance fuel flow dynamics, further optimizing the burner's performance and efficiency.

Materials / Methods

Ceramic powder



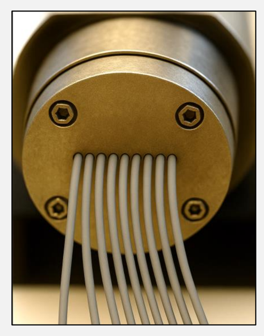


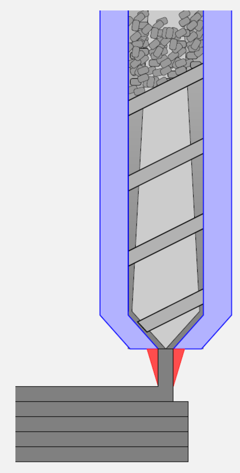
Binder composition

	vol%
Polyethylene	69.0
Cellulose	20.5
Stearic acid	10.0
Lignin sulfonate	0.5

Experimental procedure

Kneeding ➔ Extrusion ➔ Pellets ➔ 3D-Printing

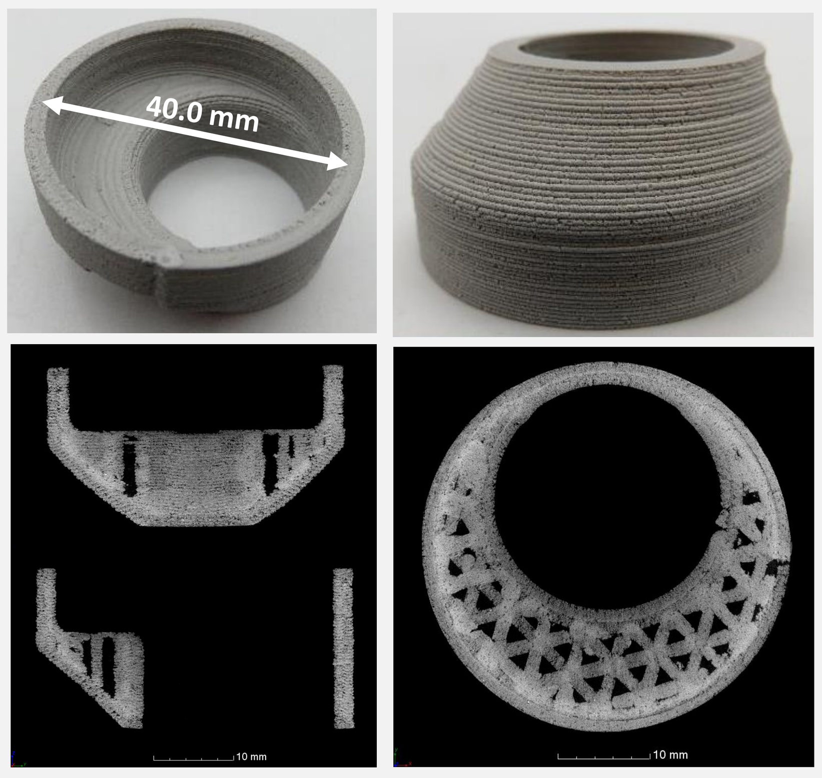




H$_2$ corrosion test ⬅ Sintering ⬅ Debinding ⬅

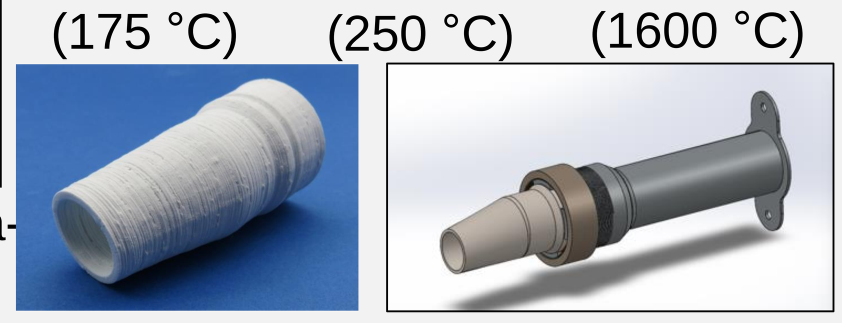
Characterization: Microstructure, chemical alteration, mechanical properties

Results

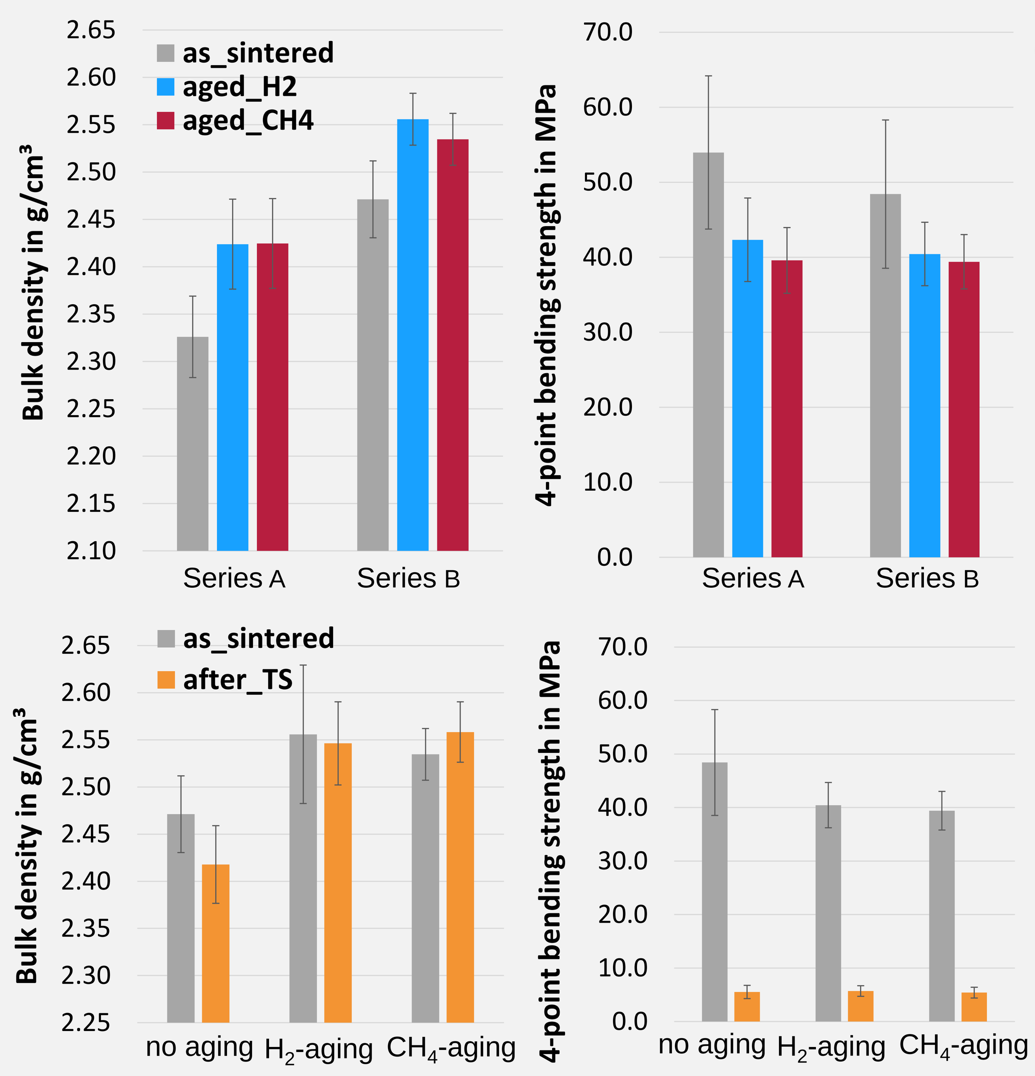


Photographs and computer tomography images of a prototype burner nozzle after 3D printing with infill structure for improved thermal shock resistance.

As-printed (175 °C) Debound (250 °C) Sintered (1600 °C)



Fabricated pilot burner nozzle and corresponding 3D model illustrating the assembly.



600 h aging in synthetic H$_2$ or CH$_4$ combustion atmosphere at **1500 °C**

➔ Increasing bulk density
➔ Decreasing strength

Thermal shock (TS) by quenching in water (950 °C)

➔ Comparable strength
➔ Higher rel. residual strength after aging

Conclusions

- **Feasibility of 3D printing** for complex, high-temperature components validated.
- **Impact of combustion atmosphere:** Aging for 600 h in H$_2$ or CH$_4$ combustion atmospheres increased bulk density and reduced strength of 3D-printed alumina, while thermal shock resistance remained unchanged.
- **Future Developments** focusing on refinement of the burner's inner and outer geometries, enhancing surface post-processing, followed by testing in extreme thermal and chemical conditions, particularly in high-temperature hydrogen-fueled environments.

References

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[2] Gomes, M. R., Leber, T., Tillmann, T., Kenn, D., Gavagnin, D., Tonnesen, T., Gonzalez-Julian, J.: Towards H$_2$ implementation in the iron-and steelmaking industry: State of the art, requirements, and challenges for refractory materials. J Eur. Ceram. Soc., 44(3), 2024, 1307-1334. https://doi.org/10.1016/j.jeurceramsoc.2023.10.044

[3] Yaroshevskyi, S., Malczyk, P., Weigelt, C., Hubalkova, J., Dudczig, S., Lohse, U.; Aneziris, C.G.: Fused Filament Fabrication of Thermal-Shock-Resistant Fine-Grained Refractories for Steel-Casting Applications. Ceramics, 6, 2023, 475-491. https://doi.org/10.3390/ceramics6010027

Contact

Dr.-Ing. Florian Kerber florian.kerber@ikfvw.tu-freiberg.de
Dr.-Ing. Jana Hubálková jana.hubalkova@ikfvw.tu-freiberg.de
Prof. Dr.-Ing. Christos G. Aneziris christos.aneziris@ikfvw.tu-freiberg.de

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