# Advanced ceramics by 3D extrusion based printing: from the development of ceramic raw materials to the creation of prototypes.

ENEA-TEMAF offers a complete service for the development of advanced ceramic components obtained by 3D printing with the technique based on paste extrusion. The printable ceramic pastes are water-based and characterized by a low organic content (<3%), with low environmental impact, good green densities and low sintering shrinkage. The rheological behaviour of the pastes leads to the printing at room temperature without deformation of the object.
The printer set-up is implemented and the work job is optimized by slicing software chosen on the basis of the component design, which can also reach large dimensions.
Thanks to the experience gained in the sector, the DfAM is applied to advanced ceramic components and the complete characterization is performed, starting from the development of the printable ceramic pastes up to the qualification of the sintered component. The explored applications include the heat and power production also from renewable sources.

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| **Laboratory** | ENEA-TEMAF |
| **Specialization Area** | Energy and Sustainability, Mechatronics and Materials |
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| **Keyword** | Ceramic additive manufacturnig , Extrusion based 3D printing, Printable ceramic pastes, Net-shape advanced ceramic |

***"Low cost and sustainable 3D printing of advanced ceramics."***

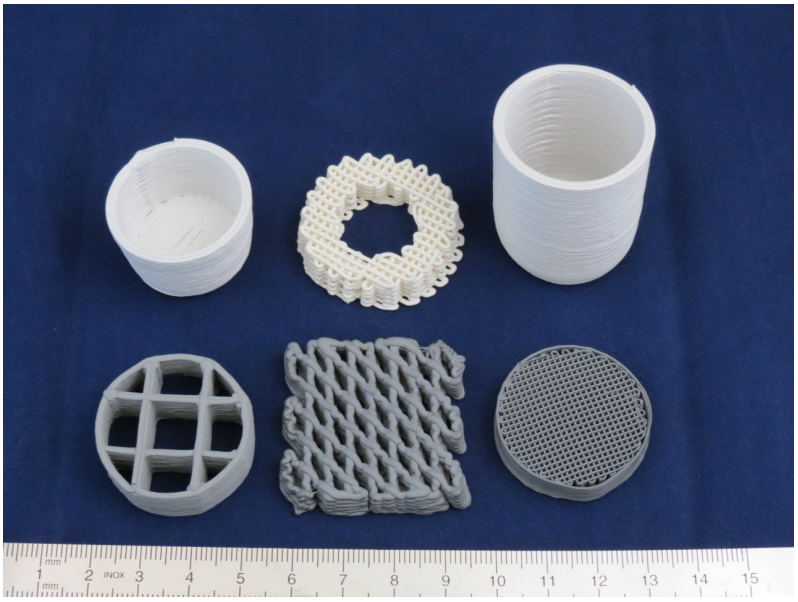


*Fig. 1: 3D printed advanced ceramics (alumina, aluminium titanate and silicon carbide) by extrusion of new paste formulations after sintering.*

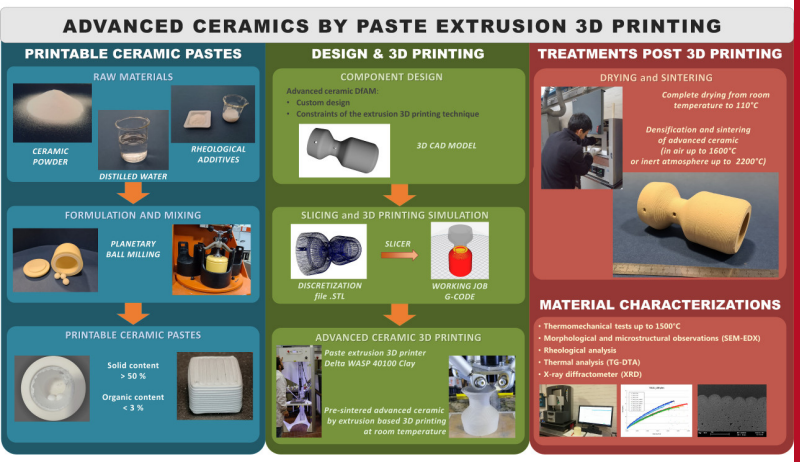



*Fig. 2: Skill and service of the Industrial research laboratory ENEA-TEMAF for the development of feedstock and components for extrusion based 3D printing of advanced ceramics*

## Description

3D printing of advanced ceramics allows to explore their use even in applications previously excluded from the limits of design and costs of conventional manufacturing processes. In particular, it is possible to realize complex geometries, more and more required in the optimization of fluid dynamics, lightweighting and for the coupling of components, offering also custom solutions. One of the 3D printing techniques used at ENEA-TEMAF is the LDM (Liquid Deposition Modeling), a low cost technique based on the extrusion of ceramic pastes.
New formulations of ceramic pastes, based on oxide (alumina, zirconia, aluminium titanate, etc.) and non oxide ceramics (silicon carbide, molybdenum silicides, etc.), are developed including composite formulations. The paste is prepared by mixing ceramic powders with suitable rheological additives in an aqueous medium, until the rheological behaviour suitable for printing is reached.
The components are then printed, starting from the CAD drawing of the designed component, taking into account the constraints of the printing technology; the G-CODE file obtained by the slicing of the CAD, is used by printer to make the green component, layer by layer. The component printed at room temperature is then sintered in furnaces also available at pilot scale. Prototypes and small series are realized and the characterization is carried out up to the thermomechanical qualification of materials and components.

## Innovative aspects

The 3D printing of advanced ceramics is a promising net-shape forming method, aimed at greatly reducing the high costs of mechanical grinding, typical of pressing processes, and the limits of shape by mould processes, barriers for a wide use despite the well-known performance advantages of advanced ceramics. The development of AM for advanced ceramics is a potential answer to the demand of more competitive and sustainable materials, characterized by high performance, but at the same time with low density. The market needs for new and sustainable solutions in the production of advanced ceramics, alongside conventional manufacturing processes, could be also satisfied by extrusion based 3D printing. Liquid Deposition Modeling (LDM) technology requires low investment costs, allowing large series production. The aqueous and high-solids pastes developed by ENEA-TEMAF involve a sustainable process with the printing at room temperature and thermal cycle up to sintering with low emissions (organic content < 3%) and low energy consumption.

## Potential applications

The offered service is addressed to both 3D printer users and manufacturers and also to end-users interested in custom and/or limited series production of advanced technical ceramic components for applications where chemical inertia, high resistance/specific weight ratio or thermal shock resistance are required. Potential applications cover various industrial sectors such as power production (e.g. burners, braziers, turbines), lightweight solutions for automotive and aerospace, filters or catalytic media for industry.

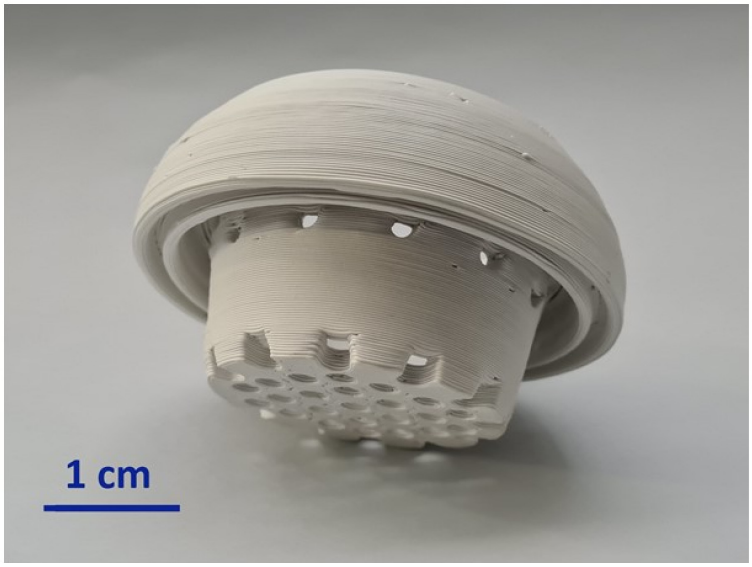



*Fig. 3: 3D printed aluminium titanate crucible for pellets stove made of by extrusion of ceramic paste after sintering*

**Involved partners**

The collaboration with a company leader in household heating based on woody biomass, has allowed to develop and co-design the new advanced ceramic brazier and to test both materials and 3D printed prototypes within their labs equipped to reproduce the real working conditions.

**Implementation Time**

Raw materials and prototypes realized in 12 months

**Technology Readiness Level**

TRL6 - Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)

**Exploitation**

New collaborations with other partners to explore the potential of advanced ceramics obtained by extrusion-based 3D printing are expected:

• end-users of different application fields (e.g. power production, automotive, aerospace, chemical industry, etc.);

• producers of ceramic pastes for 3D printing;

• co-designers to implement the DfAM of advanced technical ceramics.

# Application example

**Advanced ceramic components extrusion based 3D printing to improve the sustainability of household heating.**

**Development of ceramic pastes for extrusion 3D printing, DfAM co-design, 3D printing and sintering of advanced ceramic brazier and testing for pellet stoves.**

**Producers looking for solutions to improve efficiency and reduce emissions from household and industrial plants based on biomass.**

The braziers are the "core" of pellet stoves where the combustion takes place and the conditions are heavier. The conventional braziers are made of cast iron, a low cost material and with good technical properties, but the production by casting in mould limits the design for the combustion optimization. Advanced ceramics, more refractory and with better thermal properties, obtained by low cost 3D printing technique were proposed. A new aluminium titanate (tialite) ceramic paste with rheological behaviour suitable for 3D printing was produced. The design of the brazier with fluid dynamics optimized for combustion was developed, by applying DfAM for advanced ceramics and taking into account both the needs of the end user and the constraints of 3D printing. The job file was obtained with the slicer Cure from the CAD project. 3D printing of the green brazier was carried out at room temperature followed by drying at 60 ° C and sintering in air up to 1500°C. Laboratory tests showed that the tialite obtained by 3D printing, compared with to the same pressed material, shown a moderate reduction of Young's modulus and bending strength. The tialite based brazier got through the preliminary tests in real conditions in pellet stove.

# ENEA-TEMAF

**ENEA - Laboratorio Tecnologie dei Materiali Faenza**



Il Laboratorio accreditato ENEA-TEMAF (Tecnologie dei Materiali Faenza) comprende due unità operative: TEMAF e SAFE.
TEMAF, con sede a Faenza dal 1994, si occupa di R&D di materiali avanzati. Svolge ricerca, sviluppo e trasferimento tecnologico per la sostenibilità e la competitività dei prodotti e dei processi, e innovazione nei settori dei trasporti, della produzione e recupero di energia, della meccanica avanzata, dell'aerospazio, dell'edilizia, del biomedicale e del manifatturiero. In particolare si occupa di:
• R&D di ceramici strutturali e funzionali (monolitici, compositi e rivestimenti) e dei processi di produzione, fino alla fabbricazione di prototipi
• R&D di materiali e tecnologie per l'Additive Manufacturing
• Ingegnerizzazione e trasferimento tecnologico di componenti e processi innovativi
• Caratterizzazione termomeccanica di materiali e qualifica di componenti in condizioni standard e simulanti l'esercizio
SAFE, con sede a Bologna, svolge attività di ricerca e sviluppo per materiali e metodi per la sicurezza sismica:
• Protezione sismica di edifici, patrimonio culturale, edifici strategici e impianti industriali a rischio di incidente rilevante
• Prevenzione dei rischi naturali
• Strategie per l'incremento della resilienza
• Diagnostica non distruttiva
• Telerilevamento e analisi di immagini satellitari
Le attività sono svolte all'interno di progetti di ricerca e le specifiche competenze e l'ampia dotazione strumentale rendono possibili servizi altamente qualificati per le imprese e la PA.

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