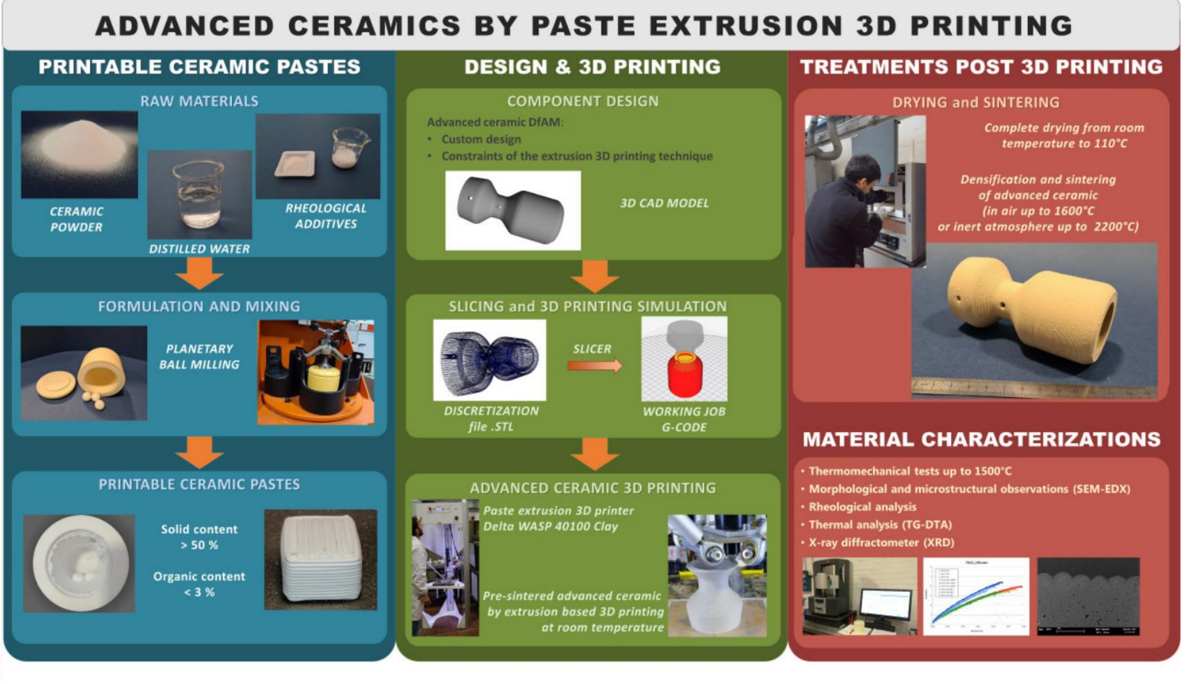
3D Printing techniques for monolithic ceramics: aerospace applications

3D printing (Additive Manufacturing (AM)) is promising both in terms of productivity and versatility and constitutes a real revolution in the sector of technical ceramic materials. 3D printing allows to "form" net-shape components, and hence opens the doors of the market for technical ceramics, thanks to the reduced manufacturing costs.
The AM of ceramic components is proposed as a winning manufacturing methodology, which is convenient from both an economic and environmental sustainability point of view.

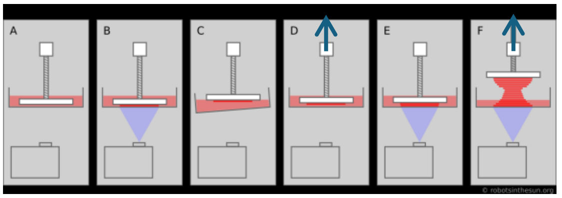
3D printing of ceramics combines the high customization level of the product with the possibility of directly obtaining the desired shape without additional mechanical machining, limited processing waste also using low-cost technologies.

LDM - Liquid Deposition Modeling

Liquid Deposition Modeling (LDM) technology requires low investment costs, allowing large series production. The aqueous and high-solids-content pastes developed by ENEA-TEMAF lab 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.
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: the ceramic pastes, during the printing process, is extruded through a nozzle, which is moved on the 3 axis by a delta robot. The geometry of the printed object is defined starting from the CAD drawing of the component, taking into account the constraints of the printing technology; the G-CODE file obtained by the slicing of the CAD, is used by the printer to obtain the green component, layer by layer.
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. ENEA-TEMAF developed new formulations of ceramic pastes, based on oxide (alumina, zirconia, aluminium titanate, etc.) and non oxide ceramics (silicon carbide, molybdenum silicides, etc.).



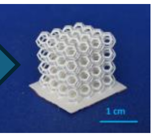
DLP - Digital Light Processing



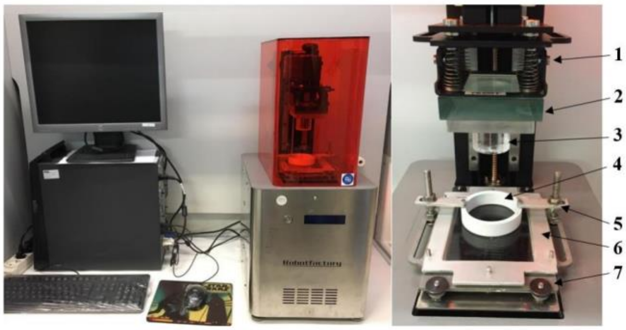
DLP printing steps

Ceramic resin

Trabecular structure during DLP printing



Printed Object



DLP Printer in ENEA-TEMAF (left). Printer components (right): Step summarization of DLP: 1-3 construction base for the printed object, 4-5 reduced vat for the resin, 6-7 glass support for the vat.

The most suitable AM techniques for dense technical ceramics are Stereolithography (SLA) and its variant "Digital Light Processing" (DLP), in which the component is obtained by polymerization of successive layers of a photo polymeric resin.

The idea of "forming" ceramic materials using the stereolithographic 3D printing approach is based on the possibility of loading a photosensitive liquid resin with ceramic powder and polymerizing layers of resin containing the powder, by means of laser sources (SLA) or the light of a projector (DLP). The CAD drawing of the component is transformed into STL format and processed by the printing software, which allows building the component layer by layer (additive technique).

The layer hit by the light polymerizes, while the rest of the material remains fluid. The build platform lifts and allows the next layer to be cured. At the end of the printing process, the solid object is extracted from the liquid resin bath and constitutes the ceramic "green", which is a component not yet sintered. After subsequent post-curing steps with a special UV lamp and heat treatment to eliminate the resin, the component is sintered at high temperature, as in the normal ceramic production cycle, to obtain the finished product with the final shape, without the need for demanding and expensive mechanical machining.

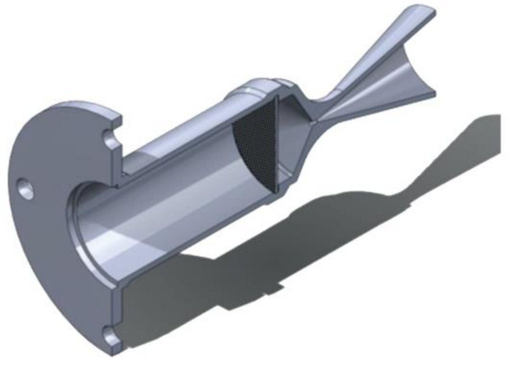
The ENEA-TEMAF Laboratory in Faenza has the know-how necessary to develop photopolymer slurries loaded with ceramic powders, constituted by zirconia, alumina, zinc oxide or silicon nitride, and their composites for the production of prototype components for multiple sectors. ENEA-TEMAF also owns the instruments for the characterization and qualification of these components.

Potential Application

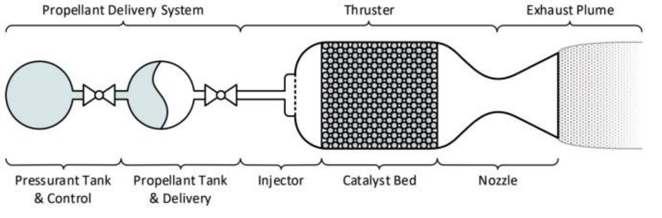
Liquid Deposition Modelling. The service offered ENEA-TEMAF is addressed to both 3D printer users and manufacturers and also to end-users interested in custom and/or limited series production of advanced technical ceramic components for applications where chemical inertia, high resistance/specific weight 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.

Digital Light Processing. The technique allows producing dense ceramic components, with a high degree of detail and surface finishing, which can be advantageously applied in the biomedical field (bone scaffolds) and in the sector of metal-free dental restoration (endosseous implants and dental crowns), in electrotechnics and microelectronics (sensors), in the field of watchmaking, jewelry, and luxury goods, in the energy production and aeronautics sectors (for the production of cores for the investment casting of turbine blades).

AEROSPACE APPLICATION (Ongoing Project)



Monopropellant thruster schematization



Monopropellant thruster system based on hydrogen peroxide.

Concept from SMAL–SAT project (Sistema di Monitoraggio AmbientaLe nano-SATellitare) Funded by Emilia-Romagna region PR FESR 2021-2027 with EU contribution.

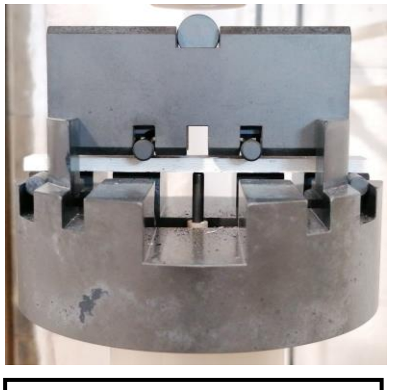
The **SMAL-SAT project** has the aim of developing three qualifying technologies (up to TRL 6) for a nano-satellite mission, for the environmental monitoring of the Emilia-Romagna region.
The project requires the implementation, among the other technologies, of a ‘green’ propulsion system for the orbital control of the nano-satellite.
ENEA-TEMAF is in charge for the realization of the thruster. The object, still in the modelling phase, will be obtained by additive manufacturing of ceramic material.

ENEA-TEMAF skills linked to ceramic Additive Manufacturing

Microstructural and physico-chemical characterization:

- Rheology and Photo-Reology of liquid and pastes
- X-Ray Diffraction of powders and bulk material
- UV-Vis and FTIR Spectroscopy for photo-polymerizable resin development
- Scanning Electron Microscopy with Energy Dispersive X-ray Spectrometry of bulk and powder materials
- Thermogravimetric analysis for thermal treatment studies (e.g. dewaxing and sintering).

Thermomechanical characterization of material and components up to 1500 °C



High temperature 4 point bending test

Thermo Fischer UV-Vis and FTIR Spectroscopy

Malvern Panalytical Rheometer

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