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FUTURE MATERIALS
OCTOBER 03-07, 2022 | ROME, ITALY | HYBRID

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The construction industry is at the same time one of the biggest economic factors, but also one of the biggest polluters of the environment, which is why new "green" building materials have to be developed quickly. One of the hopefuls are alkaline activated materials or geopolymers. These two classes of materials are based on the same manufacturing process, alkaline activation, but differ slightly in their chemistry and resulting properties. Therefore, our work investigated blends of fly ash-based geopolymers and alkaline-activated concrete rubble-based materials. Geopolymers form well cross-linked sodium silicate hydrates and alkaline activated materials form less well cross-linked calcium alumosilicate hydrates. These studies will help to better understand the interactions of the two different setting processes on each other, to elucidate the material properties resulting from mixing and thus to open up new raw material sources for alkaline activation. The setting behavior and the forming structures will be investigated by infrared spectroscopy, X-ray diffraction analysis and scanning electron microscopy. In the course of the investigations, the manufactured geopolymer samples are examined for the material parameters relevant to building materials, namely compressive strength, bulk density and thermal conductivity. Thus, the highest compressive strengths measured were σ_d = 113 MPa, the lowest density was ρ_{roh} = 1.69 gcm^{-3}, and the lowest thermal conductivity was $\lambda_{10,dr.}$ = 0.354 $Wm^{-1}K^{-1}$.

The research leading to these results was funded by the European Union through the LIFE Program 2014-2020 for Environment and Climate Action under project number LIFE18 CCM/ES/001114.

Investigation of Ceramics Matrix Composite Material Suitability for an Aeronautical Application

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In the aerospace field the introduction of innovative materials has been of crucial importance to reduce weight and to increase performances and safety. Ceramics Matrix Composites (CMC), which over the years they have become more commonly used due to the implementation of more cost-effective production methods, allowed to design and produce lightweight structures with load carrying capabilities at extremely high temperatures. This work aims to redesign an aeronautical exhaust muffler, currently produced using metallic materials, employing CMC material, which will improve the thermal and noise abatement performances while complying to stringent requirements in terms of weight and fire resistance. The material was subjected to different mechanical tests aiming to characterize its properties and to define design values for the verification of the structure. Moreover, due to the projected application the tests were performed both on virgin and on oxidated specimens. The tests highlighted a particular response of the material, which is characterized by a pseudo-plastic behavior, and demonstrated that the material is capable of resisting to high temperature in an oxidizing atmosphere for long times. Finally, the component was not designed from scratch, but part of the solutions adopted followed the current design philosophy, thus leading to the need to laminate complex shapes. The technological trials performed on these shapes showed undesirable distortion in the element associated to the production process and a possible approach to numerically predict this phenomenon is outlined, aiming to implement solutions tocompensate the undesired effects.

INVESTIGATION OF CERAMICS MATRIX COMPOSITE MATERIAL SUITABILITY FOR AN AERONAUTICAL APPLICATION

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Objective of the EU-funded CHRZASZCZ project:

- Develop new material construction concepts for aircraft auxiliary power unit (APU).
- Requirements of weight reduction, noise attenuation, thermal and fire protection.
- Design full-scale components and manufacture ground demonstrators.

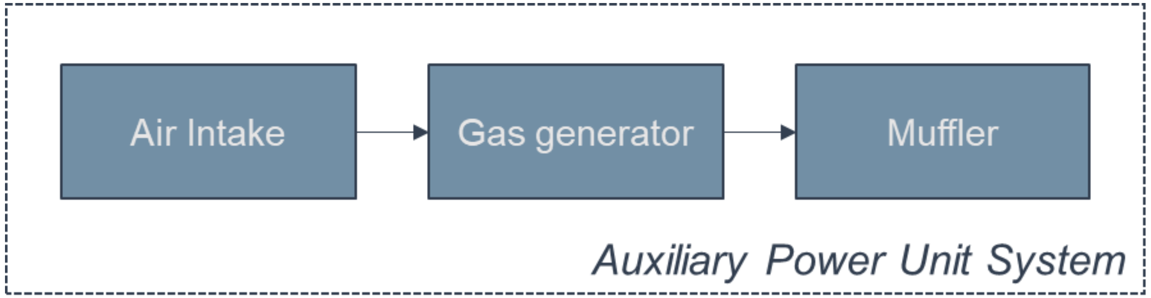
Project consortium:

1. Łukasiewicz Research Network – Institute of Aviation, Warsaw, Poland
2. Petroceramics S.p.A., Stezzano, Italy
3. Dept. of Aerospace Science and Technology, Politecnico di Milano, Milano, Italy
4. LA Composite, s.r.o., Prague 9, Czech Republic

CHRZASZCZ Project

Parts studied in the project:

- Air Intake: inertial and pressure loads.
- Muffler: inertial, pressure and thermal loads.



Current solution:

- Metal for air intake and muffler.

Proposed solution:

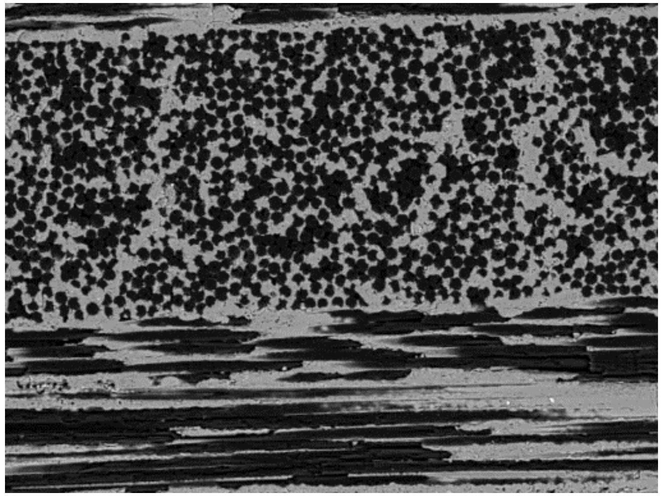
- Polymeric matrix composite for air intake.
- Ceramics matrix composite for muffler.

Subject of the presentation

Table of contents

Material under study:

- C/SiC composite manufactured via LSI Technique, with a plain weave fabric reinforcement.
- Intrinsic ability and coating to withstand oxidizing atmospheres.
- Commercially known as OxyComp and manufactured by Petroceramics S.p.A.



LSI technique:

Allows a significant cost reduction with respect to other methods to produce CMC

Pre-preg → Lamination and curing of the precursor → Pyrolysis in Nitrogen → Silicon infiltration → Finite piece

1 Characterization tests campaign

Testing campaign objectives:

1. Define design values for the material
2. Verify the resistance to oxidation

Tests performed:

- Tensile tests on 0° specimens
- Tensile tests on 45° specimens
- Compression tests on 0° specimens
- Short Beam Test on 0° specimens
- Double Cantilever Beam tests on 0° specimens

In plane properties (tensile tests on 0° and 45° specimens, compression tests on 0° specimens)

Out of plane properties (Short Beam Test and Double Cantilever Beam tests on 0° specimens)

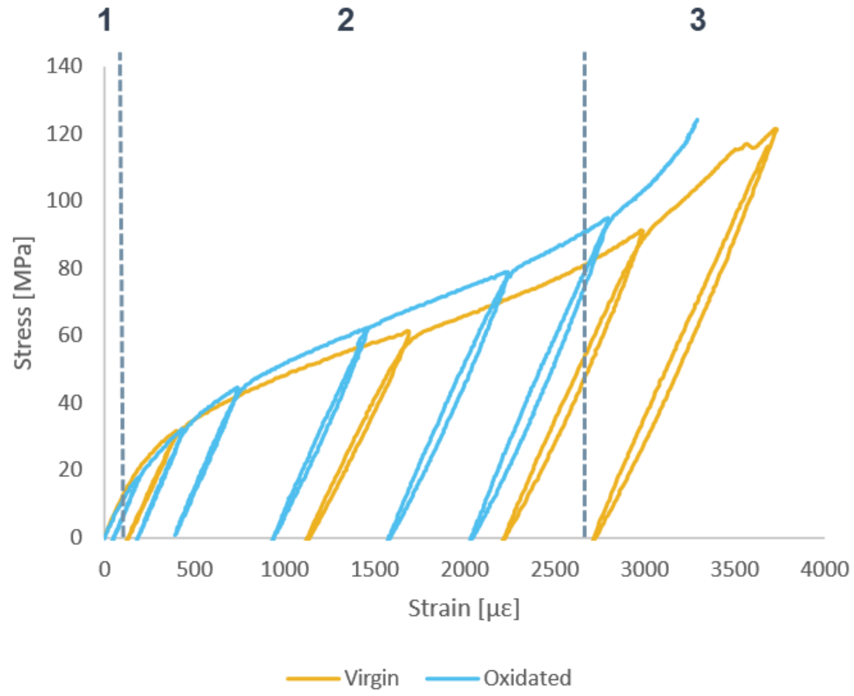
Each test type was performed on:

- 5 virgin specimens
- 5 oxidated specimens (250 *h* at 650°C in oxidizing atmosphere)

Tensile tests of 0° layup

- Low scattering between same family specimens and between virgin and oxidated specimens.
- Pseudoplastic response.

	Virgin	Oxidated
Young's Modulus	117.75 GPa	106.98 GPa
Failure Strength	113.96 MPa	107.98 MPa
Failure Strain	3617.10 με	3361.27 με



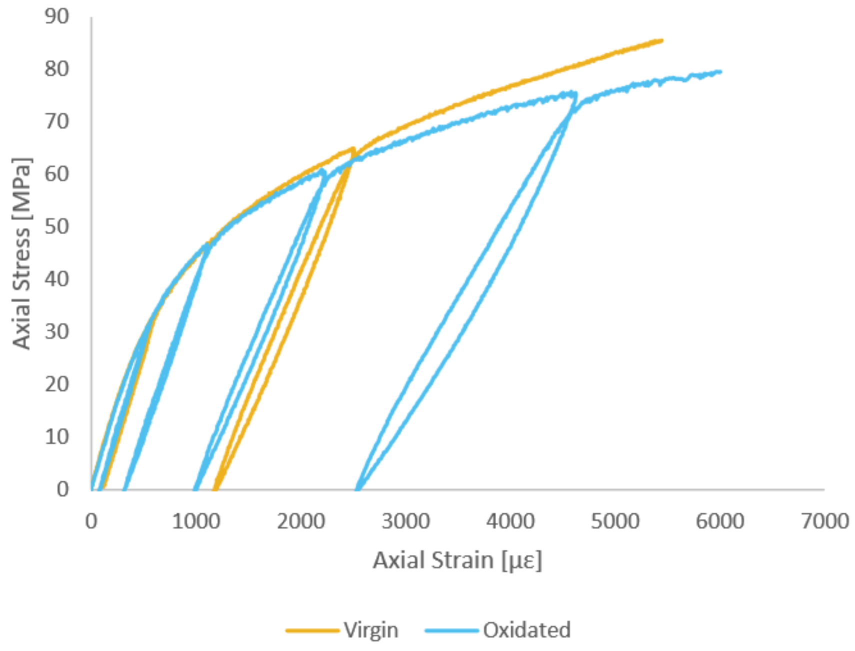
In the response three regions can be identified:

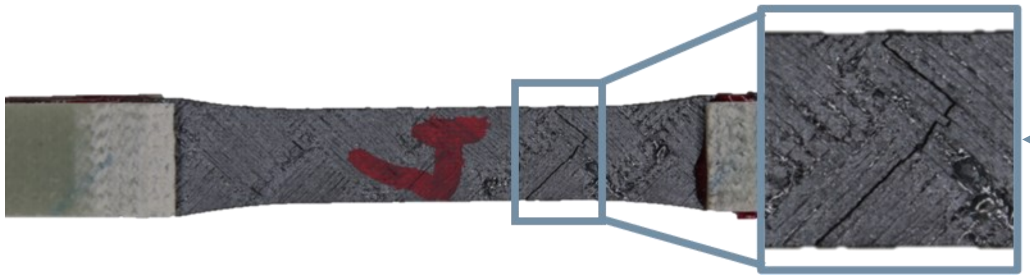
1. **Elastic**
2. **First pseudo plastic**
3. **Second pseudo plastic**

Tensile tests of 45° layup

- Characterized by damages, pseudo plasticity and failure in shear.
- Small scattering between specimens and virgin and oxidates specimens.

	Virgin	Oxidated
Failure Shear (τ)	37.02 MPa	37.74 MPa
Failure Axial Strain	4765.16 με	5145.46 με



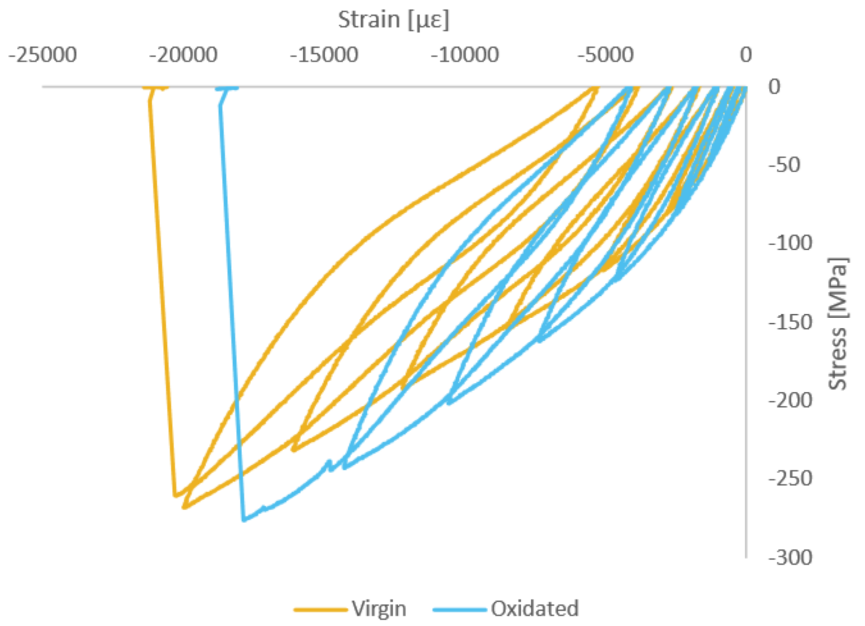


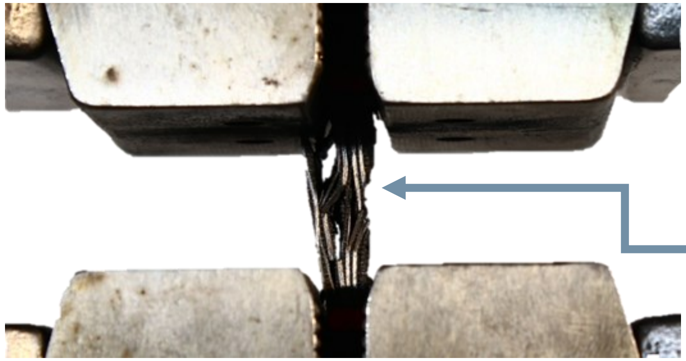
Shear failure with cracks at 45°

Compression tests

- Hysteresis in loading unloading cycles.
- Reduction in stiffness and increase in failure stress and strain with respect to tensile tests.

	Virgin	Oxidated
Young's Modulus	40.04 GPa	51.24 GPa
Failure Strength	-250.77 MPa	-263.25 MPa
Failure Strain	-20586.93 με	-17571.12 με



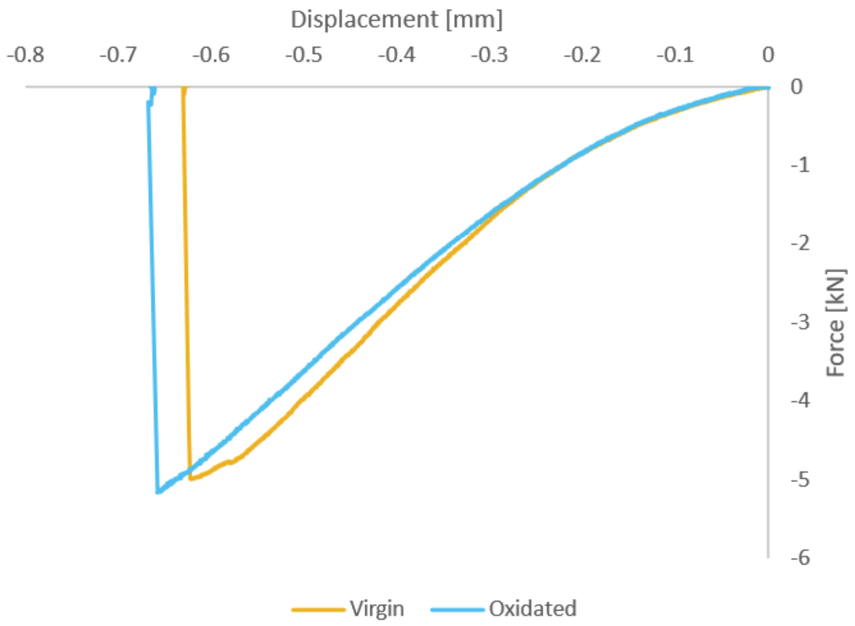


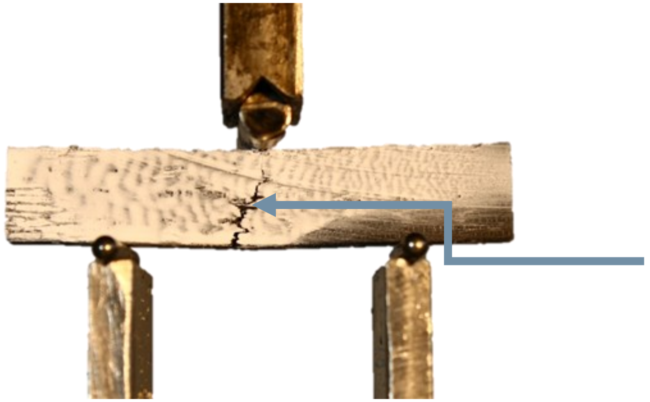
Local buckling of the plies was typical failure of the compression tests.

Short beam test

- The specimens failed in bending
- The ratio between interlaminar toughness and tensile strength is higher than typical polymeric matrix materials

	Virgin	Oxidated
Shear Strength	30.974 MPa	29.522 MPa

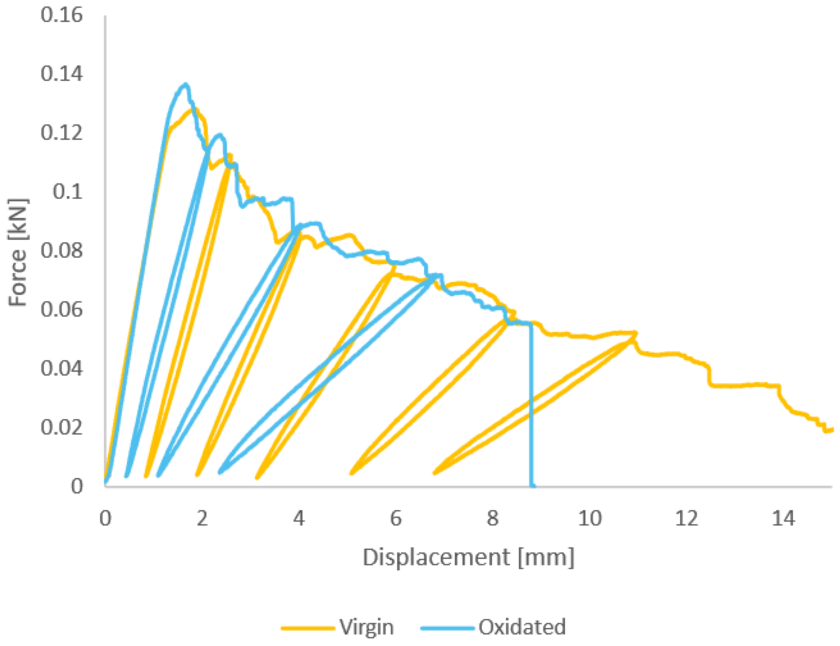




Bending failure

Double cantilever beam test

- Two methods to produce the pre-crack:
  1. Machined for virgin
  2. In manufacturing for oxidated
- The oxidated specimens had sharper crack limited to one interlaminar layer.



The two methods resulted in:

- similar toughness
- different pseudo plasticity and failure

Observations on the testing campaign

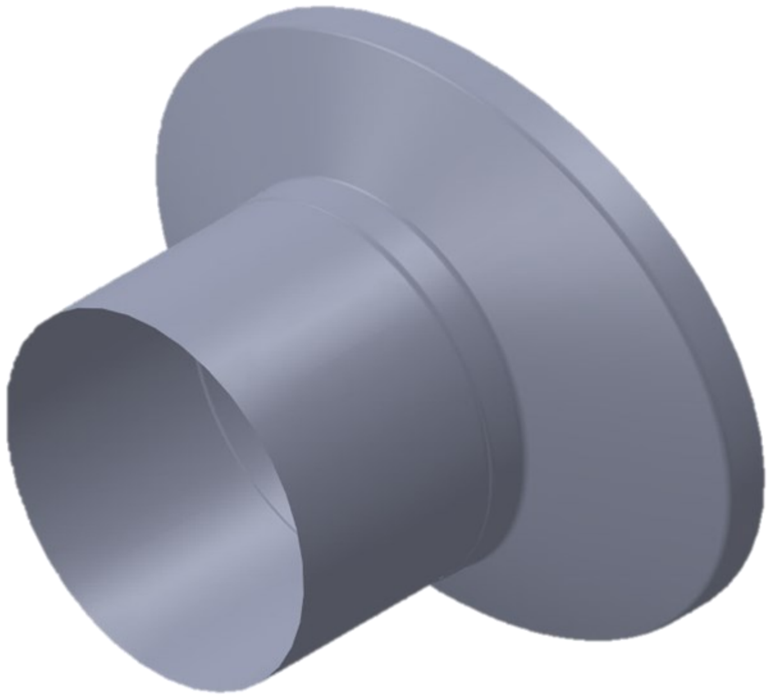
- The material demonstrate to be able to resist in oxidizing atmosphere
- The pseudo-plastic response with three regions can be associated to Thermal Residual Stresses which arise during manufacturing process and to the fiber-matrix interaction
- The phenomena which regulate the response of the material is different between traction and compression
- The ratio between interlaminar properties and in plane properties is high compared to the ones typically obtained for polymeric matrix composites
- The interlaminar properties coming from DCB tests require numerical methods to be evaluated due to the high pseudo plasticity

Demonstrator manufacturing

- Lamination of a double curvature component
- Ply junctions arrangement to avoid weak areas
- High temperature processing which led to deformations
- Require a dismountable mold

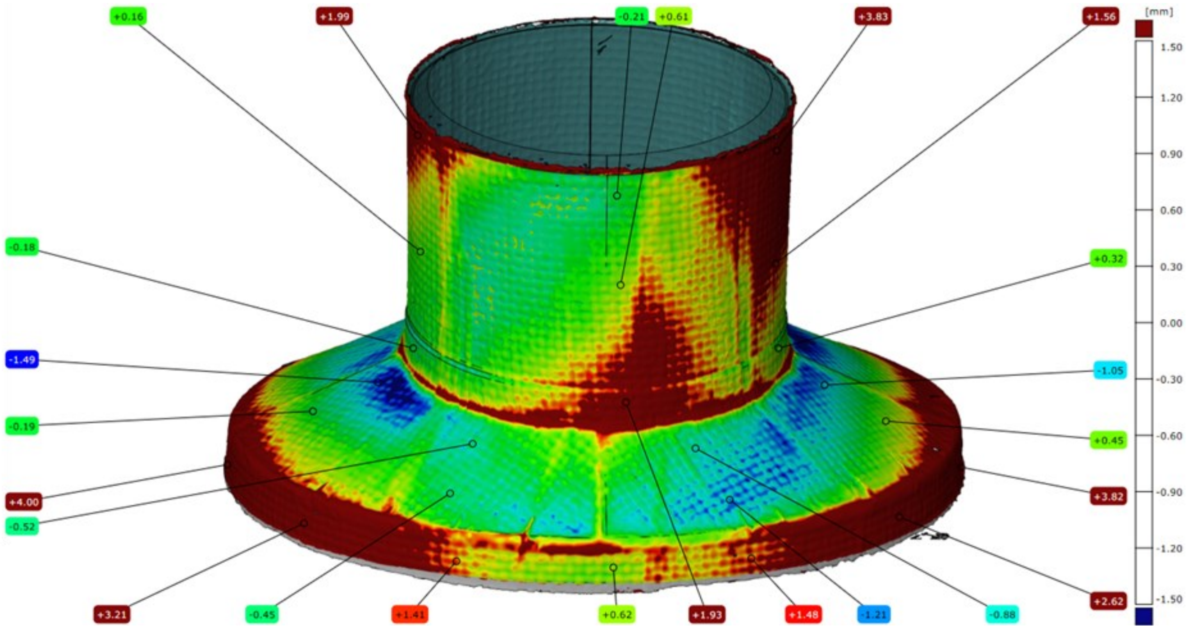
Mold characteristics

- Obtained via 3D printing techniques
- PA12 polymeric material



Results of the trials

- The pyrolyzed and infiltrated component quality was good.
- The manufacturing process led to noticeable deformations in the final piece (up to 4 mm).



To study this deformation and to evaluate the thermal residual stress a numerical model of the process can be implemented based on the finite element technique.

New trials using metallic mold reduced the deformations due to lower CTE mismatch between the mold and the material.

Numerical modeling of the process

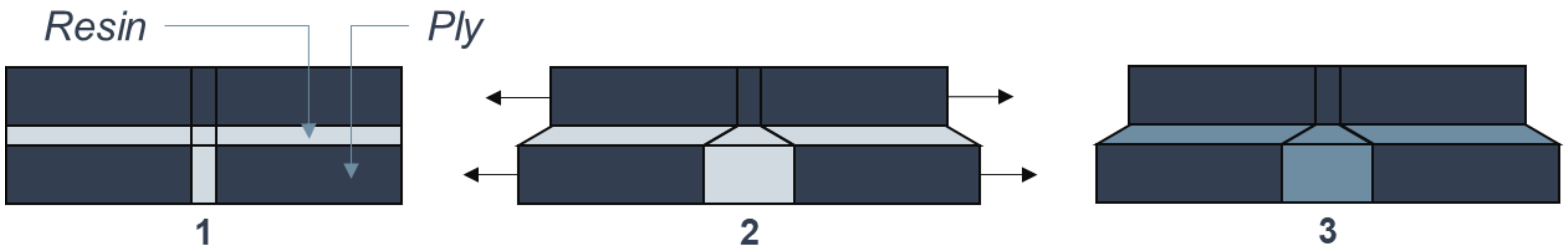
- Requires materials properties changes during the simulation
- The simulation for the curing of the precursor showed promising results

The future steps include the simulation of the pyrolysis and infiltration process

Precursor curing simulation

The ply wise model represents the whole component, and it includes the mold and a layer of resin in the junctions and between the plies.

1. **Starting configuration:** the resin properties are 100 times lower than the nominal.
2. **Heating:** the mold expansion due to heat move the plies.
3. **"Curing" and cooldown:** the resin properties are set to nominal and the temperature lowered leading to freeze the configuration and to TRS.



3 | *Conclusions*

Characterization tests

Demonstrated the ability to resist to oxidation of the material. The found strengths are higher than the expected load in operating conditions.

Technological trials

Showed the feasibility of manufacturing of a complex shape in CMC. The undesired deformation were reduced by using a metallic mold.

Numerical modelling

The first results were promising, but more studies are required. The capability to model the process for complex shapes is fundamental to enhance the quality of the pieces.

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