CEM-WAVE

Novel Ceramic Matrix Composites produced with Microwave-assited Chemical Vapour Infiltration process for energy-intensive industries

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Novel high performance materials and components (RIA)

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SUMMARY

In the CEM-WAVE project non-oxide and oxide-based CMCs will be manufactured by an innovative MW-CVI process developing then a prototype to be validated in radiant tube furnaces for steelmaking applications ending up in a TRL5. A dedicated manufacturing chain has been developed to achieve tailored CMC preforms to ease the subsequent matrix infiltration process. The latest microwave solid-state sources have been implemented within the MW-CVI plants to maximise both the energy and chemical process efficiency and looking for strategies to automate this technology. New

joining and coating materials have been developed to manufacture complex shaped components with high corrosion resistance in the expected use-case environment. All the activities have been flanked by micro- and macro-scale modelling of the MW-CVI process to estimate the impact of the process parameters on the final CMC quality.

PROJECT SCOPE

The CEM-WAVE project will result in the development and validation of innovative Ceramic Matrix Composites (CMCs) production process, based on Microwave-assisted Chemical Vapour Infiltration (MW-CVI) technologies. The proposed **novel process**, while maintaining the optimal features usual of CMCs (high toughness, low density, high temperature, wear and corrosion resistance) will significantly reduce the costs for making components, thus making CMCs sustainable for process industries in energy-intensive sectors such as steelmaking.

The project has a huge **innovation potential**, since CMCs represent very **promising solutions for high temperature applications in strategic industrial sectors**, such as transport (e.g. for elements of combustion engines of aircrafts, valve-trains, turbine blades, exhaust systems, cars braking systems) and energy sector (e.g. refractory materials for silicon foundry furnaces, energy reactors, gas burners and high pressure heat exchangers). Additionally, the increased efficiency and lifetime of CMCs compared to currently employed metallic alloys in radiant tube furnaces, will open new possibilities in steelmaking (i.e. use of higher annealing temperatures, new chemistries to process) making further more competitive CMC-based components cost enabling their wider deployment to almost all industrial lines, **which will be the main deliverable.**

PROJECT TECHNICAL DESCRIPTION & IMPLEMENTATION

As a part of the project use-case, innovative CMCs will have to be validated in radiant tube furnaces for steelmaking applications evaluating in particular their resistance in view of the expected transition from fossil to renewable based fuels (i.e. hydrogen/biogas mixtures). Advanced tools for the online monitoring of the structural health and performance analysis of the CMC prototype will be also developed.

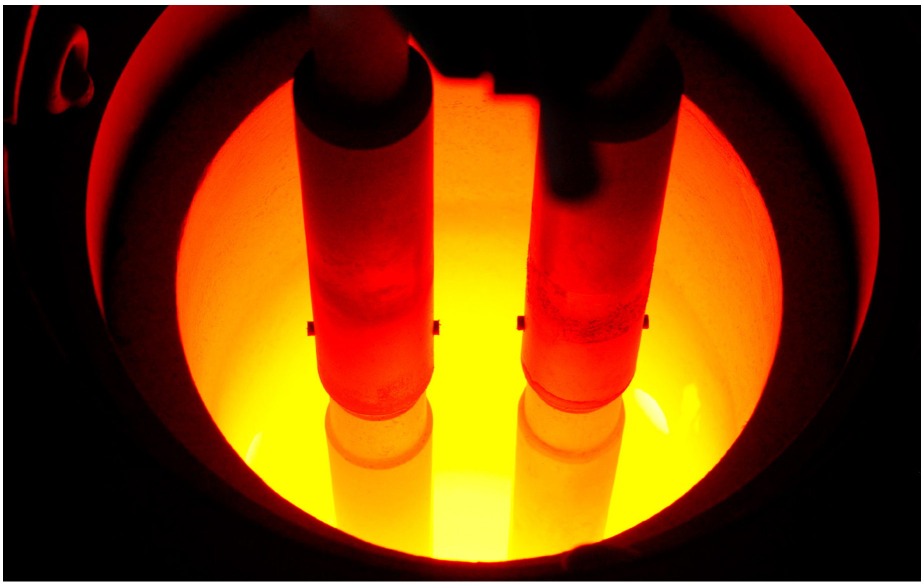
Past experience showed that an upgrade of the MW-CVI process (TRL 3-4) demanded for a replacement of the MW sources technology. Therefore, a first step in this project, has been the passage from the low spectral purity MW magnetron sources to coherent solid-state sources overcoming the main drawbacks associated to the lack of frequency control as well as minimizing the heterogeneous hotspots formation on the sample and plasma phenomena. The MW heating of the CMC sample with these sources is expected to improve the uniformity of the sample temperature, with the additional possibility to dynamically adjust the electromagnetic field in the reactor without involving any moving metal part. The latter opportunity has been exploited for the development of dedicated program routines to automate the tuning of the optimal operating frequency, ensuring the highest energy efficiency during the MW-CVI process (TRL 3).

Furthermore, the tailoring of the temperature distribution is being investigated to optimize the densification mechanism since, a crucial parameter to achieve a fully infiltrated material, is the temperature gradient within the CMC preform. In this framework, AI image-based numerical modelling can indicate the directions to improve the MW-CVI process efficiency while preserving or even improving the material quality by a deep understanding of the interplay of the physicochemical phenomena at several scales.

The manufacturing of CMC preforms with selected geometries, tailored reinforcing architectures and high starting levels of open porosity has been investigated as well. A dedicated process chain has been developed, based on various steps from the interphase coating of the ceramic fibres (TRL 3-4), and the fabrication of the porous CMC preforms by filament winding technique (TRL 3) up to the thermal treatment and the final non-destructive inspection of the samples.

Another critical issue for the wider use of CMCs is the development of inexpensive, reliable and user-friendly joining methods to assemble large components into more complex structures (TRL 3-4). The combination of advanced surface and innovative joining materials/ techniques has been exploited to maximise the interfacial strength of the joints. Dedicated EBC multilayer systems (TRL 3), to be deposited by slurry coating technique, have been also developed to protect the underlying CMC from corrosion during use.

All these approaches will be combined to obtain MW-CVI manufactured CMC tubes to determine their application in future radiant tubes by validation in a specific pilot-plant furnace, designed and developed as a part of the CEM-WAVE project activities. The latter outcome aims at a closer exploitation of the project results in current furnaces where our CMC materials can be introduced bringing immediate advantages in terms of heat transfer efficiency and product lifetime.



RESULTS ACHIEVED

The main results achieved so far within the CEM-WAVE project involve:

1 Uniform interphase coating deposition of oxide and non-oxide ceramic fibres and manufacturing of square and tubular-shaped CMC preforms.

2 Design and development of high-power (≥ 1 kW) MW solid-state sources covering the whole 2.4-2.5 GHz ISM frequency band.

3 Integration of the MW solid-state sources system to the MW-CVI plants by means of a high coupling system (≤ -10 dB).
First MW-CVI trials on 10x10x0,3 cm3 SiCf/SiC samples resulted in localized matrix deposition at the borders due to the high residual carbon content (high relative permittivity). Future work is oriented to the usage of SiC-based preceramic polymers during the preforms manufacturing process.

4 Development of advanced monitoring tools with program routines to acquire, store and process the data obtained along the MW-CVI process to automatically optimize the operating parameters.

5 Acquisition of realistic numerical simulation domains from μCT scans and SEM micrographs and definition of laws providing the evolution of geometrical and transfer properties as a function of the fiber volume fraction and porosity degree.

6 Development, characterization and testing of joining materials for both oxide-oxide (glass-ceramics – Y2Ti2O7 main cristallyne phase) and non-oxide (YAS, Yttria-Alumina-Silica) CMCs. The joining materials satisfied the expected KPI, as the max joint in-service temperature in relevant environment, respectively of 900°C and 1200°C.

7 Design and development of a radiant tube pilot furnace, equipped with a new Coke Oven/Hydrogen gas network, for validation of the CMC prototype.

IMPACT

CEM-WAVE project is expected to make measurable contributions along with all the expected impacts listed in the SPIRE-08-2020 topic.

Energy efficiency improvement of the target production and/or operation processes of at least 30%, and reduction of CO_2 emissions and resource utilization by 20%.

CMCs will contribute to the sustainability of the CMCs production processes, and the validation of the materials developed on steelmaking industry through the development of a section for a radiant tube furnace is highly relevant in medium-term towards CO_2 emissions reduction; Steel is a CO_2 and energy intensive, but highly competitive industry that also enables the uptake of major CO_2 mitigation measures in other sectors. Due to the improved thermal efficiency and thermo-mechanical properties the use of CMC materials in a radiant tube furnace while contributing to significantly increase the energy efficiency of both the production and operation process by at least 30%, will consequently reduce CO_2 emissions by at least 20%.

Increased lifetime of the equipment by at least 20%.

CEM-WAVE components target several Key Performance Indicators, addressed in different tasks: lifetime, heat transfer efficiency, high temperature impact, corrosion resistance. Health condition monitoring in real environment will be performed as part of the activities, and different joining and integration technologies are being studied to produce complex shapes and for easier maintenance and repair in service.

CONTRIBUTION TO EU POLICIES

Contribution in relation to the “Strengthening EU’s open strategic autonomy” EU policy:

Improving the production processes for the development of advanced materials as CMCs would contribute to reduce the dependence on foreign suppliers for critical materials or components, strengthening the EU’s strategic autonomy while enhancing the competitiveness of the European industries, helping EU to maintain a strong position in the global market.

Contribution in relation to the “Circular Economy Action Plan” EU policy:

It is expected that the use of CMCs allows to extend the service life of radiant tube furnace components in steelmaking plants, which would reduce the need of frequent replacements, lowering the environmental impact associated with production, transport and disposal of materials.

2050 long-term strategy for climate neutrality:

CMCs used on the radiant tube furnaces in the steelmaking industry, due to their properties can enhance the energy efficiency of these furnaces, reducing losses and minimizing the energy required to maintain high temperatures.

Improving the efficiency of the steelmaking processes, CMCs can help reducing carbon emissions, contributing to the EU decarbonization efforts.

Contribution to “Renewable Energy Directive” and “REPower EU” EU policies:

Greener fuels containing hydrogen/biogas mixtures, that will be used to replace current fuels, can cause harmful phenomena such as hydrogen embrittlement for metals and hydrothermal attack for ceramics, which suppose a burden for several production processes, as in the steelmaking industry. The use of CMCs components on the steelmaking industry plants would contribute to accelerate the adoption of hydrogen as a fuel.

CONTRIBUTION TO KEY PERFORMANCE INDICATORS

Climate neutrality

- CO_2 emission reduction by integration of renewable energy & energy efficiency.
- CO_2 emission reduction through CO_2 Capture and/or Use.

In view of the transition from current fossil fuels to hydrogen/biogas mixtures, CEM-WAVE proposed the application of high-performance CMCs manufactured by an innovative MW-CVI process, characterized by lower CO_2 emissions of about 20%, to allow their sustainable use in sectors with significant environmental and productivity impact.

Circularity

- Minimising the amount of wastes and by-products in industrial processes.
- Recycling and upcycling of secondary raw material.
- Water reused/recycled through energy and solute recovery.
- Impact on environmental performance of Process Industry, beyond circularity and climate neutrality.
- Foster circularity through Hubs for Circularity (H4Cs), industrial and industrial-urban symbiosis.

The CEM-WAVE project proposes the use of CMCs in harsh-conditions manufacturing settings improving energy efficiencies in future steelmaking production of up to 30% and enlarging the lifetime of radiant tube furnaces of up to 20% compared to the current average.

Competitiveness

- Drive the demonstrator portfolio towards TRL 8 and first of a kind (TRL 9).
- CAPEX and OPEX reduction through innovation.
- Foster new framework conditions to generate markets for climate neutral and circular solutions.
- Foster new skills, jobs and business models.

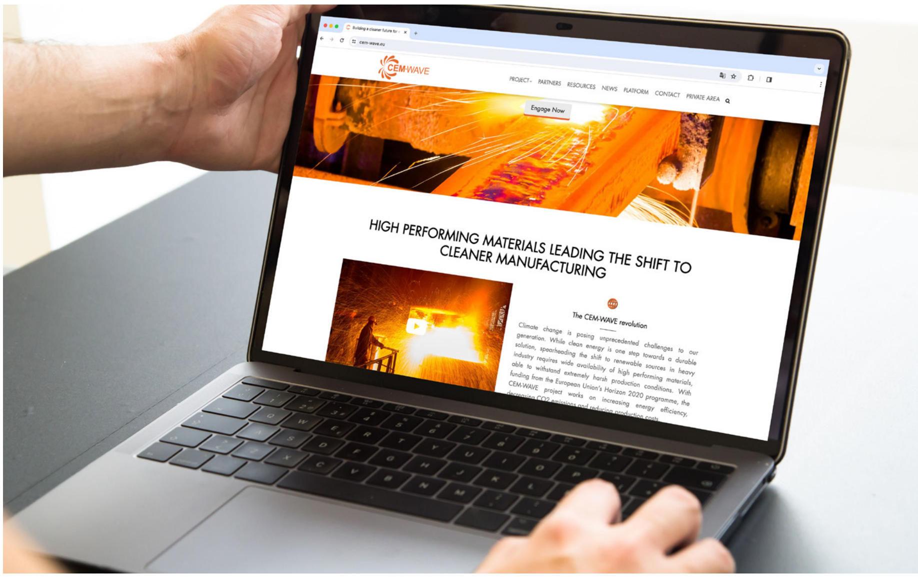
ADDITIONAL INFORMATION

Ceramic Matrix Composites (CMCs) have been so far extensively used as main materials in the transport sector, for example to produce elements in aircraft combustion engines, turbine blades, exhaust systems and automotive braking systems (brake discs and clutches), and in the energy sector, where they have been employed as refractory materials in silicon foundry furnaces, energy reactors, gas burners and high-pressure heat exchangers.

The adoption of lightweight composites by the electrical vehicle manufacturers is increasing and expected to further boost the market for CMCs in the near future. Given the increased efficiency and lifetime of CMCs compared to currently employed metallic alloys in radiant tube furnaces, new possibilities will open within the steelmaking industry, such as chances to use higher annealing temperatures and new processing chemistries.

CEM-WAVE newly established cost-opportunities for CMCs will enhance the competitiveness of CMC-based components, eventually enabling their wider deployment to almost all industrial lines and furthering both environmental and economic gains, in a win-win situation.

COMMUNICATION MATERIAL



The project website:

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