NEWSLETTER

COMPASsCO$_2$

Contents

NOVEMBER 30, 2024

Issue : VIII

This project has received funding from the European Union’s Horizon 2020 Research and Innovation Action (RIA) under grant agreement No. 958418

Team: 12 partners from 7 countries

Research focus: New particles, metal alloys and heat exchanger

Duration: 1 November 2020 – 30 April 2025

Status of Implementation

20 Deliverables

21 Milestones

7 GA Meetings

74 Papers & Presentations

6 Workshops & Webinars

This COMPASsCO$_2$ newsletter (8th issue) highlights significant progress across its work packages as the project nears completion (by April 2025). Key achievements include advancements in particle testing and coating durability, development of high-performance metal alloys for extreme conditions, and insights from modeling and evaluation of material interactions in supercritical CO$_2$ environments. The outcomes have been widely shared through publications, conferences, and collaborative dissemination activities.

DEVELOPMENT AND TESTING OF PARTICLES

The Gen 3 particles with the DECHEMA coating and the Gen 4 particles with the coatings developed by CIEMAT, DLR, and DECHEMA, as well as a control group without coating, have been tested to characterize attrition. Two methods have been developed for this purpose. The particles have been tested for around 7,300 impacts on each other at 5 m/s, simulating 10 years of operating conditions (assuming that a particle passes through the receiver twice per day).

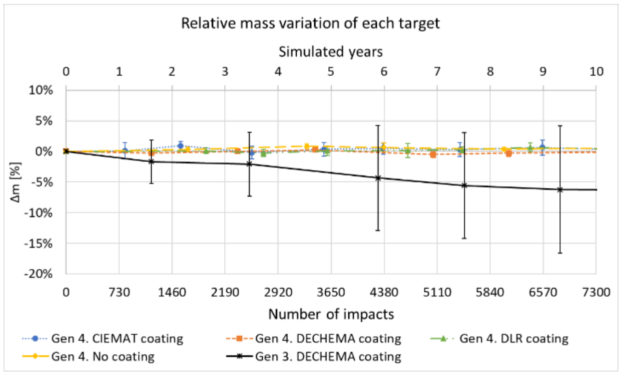


Figure 1. Relative mass loss as a function of the number of impacts received

The first characterization method is based on the measurement of alterations in shape. By comparing the height of each point after a number of impacts against the initial state of that point, the relative mass variation can be measured. The results, presented in Figure 1, represent the mean mass loss of the particles with its standard deviation. For Gen 3 particles, the standard deviation is high due to the partial cracking of particles. There are particles that have lost almost 80% of their mass, and others that have experienced almost no change.

Comparing images after each cycle at selected points of the target, partial breakage of Gen 3 particles was observed, as evidenced in Figure 2. The degradation of Gen 3 can be attributed to the propagation of the cracks, which resulted in the partial breakage observed. These observations indicate an increase in brightness compared to the initial state of the tests. The partial breakage was predominantly observed in particles with a diameter below 500 µm. Nevertheless, particles with comparable diameters to Gen 4 particles, which are approximately 1000 µm, exhibited less damage or no damage at all.

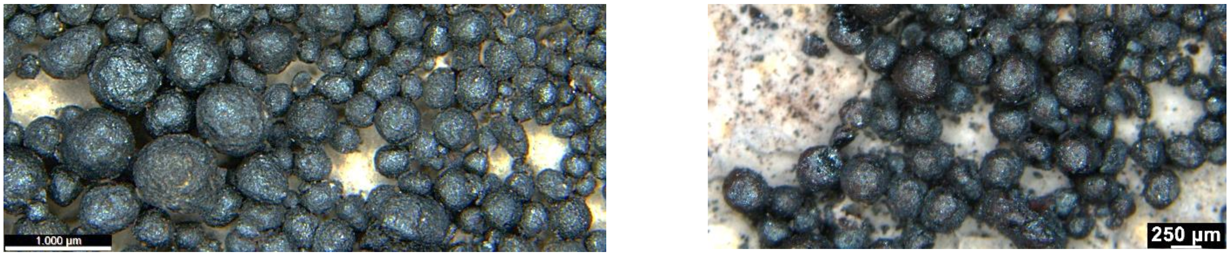


Figure 2. Initial state of Gen 3 particles (left). Gen 3 particles after more than 10 years simulated or more than 7300 impacts (right).

The images of the Gen 4, Figure 3 (left) represent the initial state, while the other, taken after more than 10 simulated years, shows that no visible damage has occurred. However, a change in colour is evident when comparing both images. This change has been quantified using the second method.

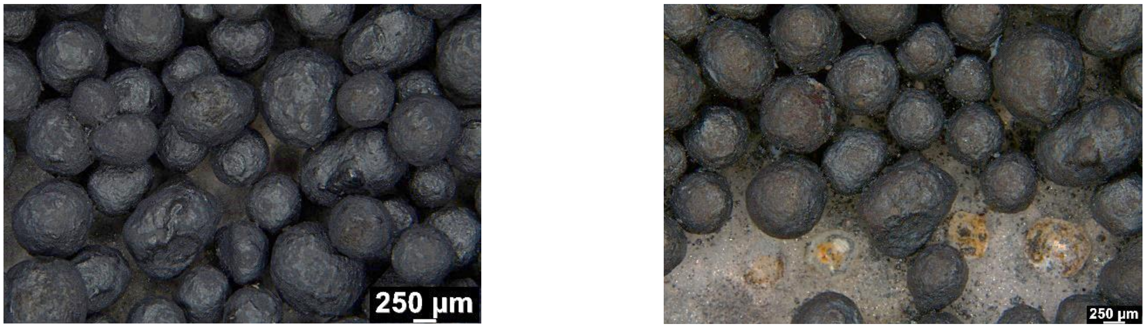


Figure 3. Initial state of Gen 4 particles with the DECHEMA coating (left). Gen 4 particles with the DECHEMA coating after more than 10 years simulated or more than 7300 impacts (right)

The second method measures the solar absorptance degradation due to loss of coating from the impacts. In order to eliminate the degradation caused by temperature, the initial state is measured after the test on an area, which was exposed to temperature but where no impacts do occur. Figure 4 illustrates the solar absorptance of the Gen 4 with coatings at the initial state and after approx. 10 simulated years of impacts. The coating developed by DECHEMA decays by approx. 5%, the CIEMAT coating shows a decay of approximately 2%, while the DLR coating decays by 1%. Based on these results, the DLR coating can be considered the most stable, while the CIEMAT coating exhibits the highest solar absorptance after the impacts.

To conclude, the results demonstrate that Gen 4 minimizes attrition and that the coatings may lose up to 5% of solar absorptance after ten years of operation due to impacts at the exit of the receiver. Additional losses may be caused by abrasion with metallic walls or sliding movements between particles.

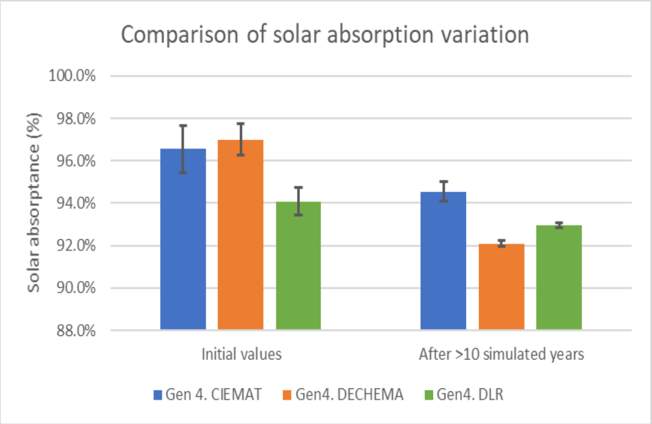


Figure 4. Comparison of the different coatings after more than 10 simulated years

A lifetime estimation model using Discrete Element Method (DEM) simulations is being developed. These simulations describe the flow of particles through heat exchanger tube system, where we get information about particle collisions: both the particle-particle and particle-tube collisions, and the related contact forces the particles experience, which helps us better understand the mechanical loads the particles experience under realistic operating conditions, as shown in Figure 5.

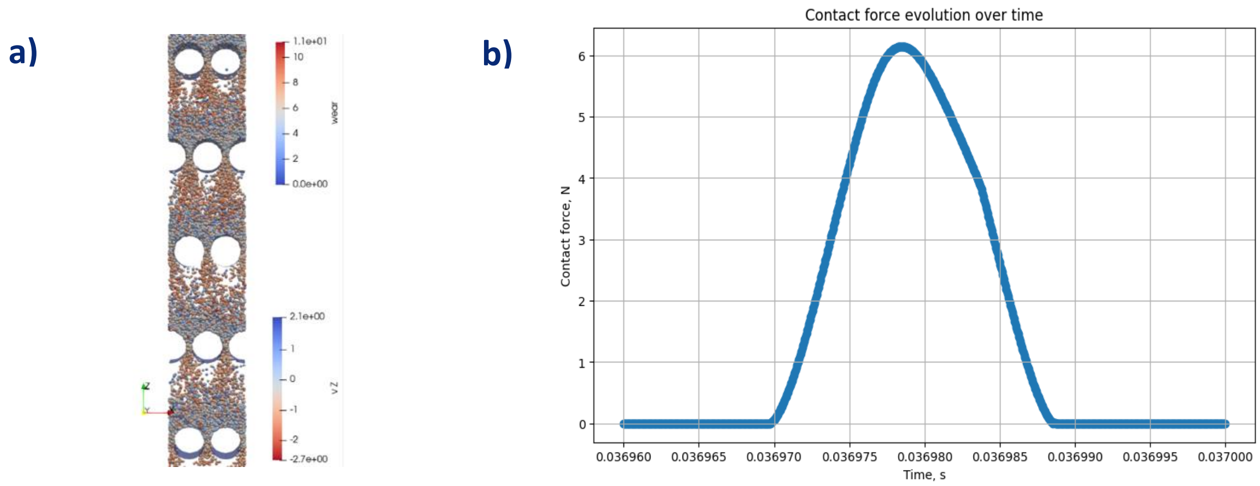


Figure 5: Simulations to predict the mechanical response of particles, where a) shows the particle vertical velocity (m/s) in heat exchanger tubes and b) shows the contact force history of an individual particle collision event.

Experimental parameters from the "Cold Test" experiments were obtained, where an optimal vertical pitch between the tubes has been identified as the best trade-off for thermal resistance. This arrangement was used for simulations. The particle properties (density, Young's modulus, hardness) correspond to Gen 3 particles.

Based on these collision simulations and the resulting contact force evolution, the mechanical response of the particles can be evaluated. Based on the contact force experienced by the particles, the loading inside the particles can be evaluated in high-fidelity finite element simulations of individual particles, shown in Figure 6.

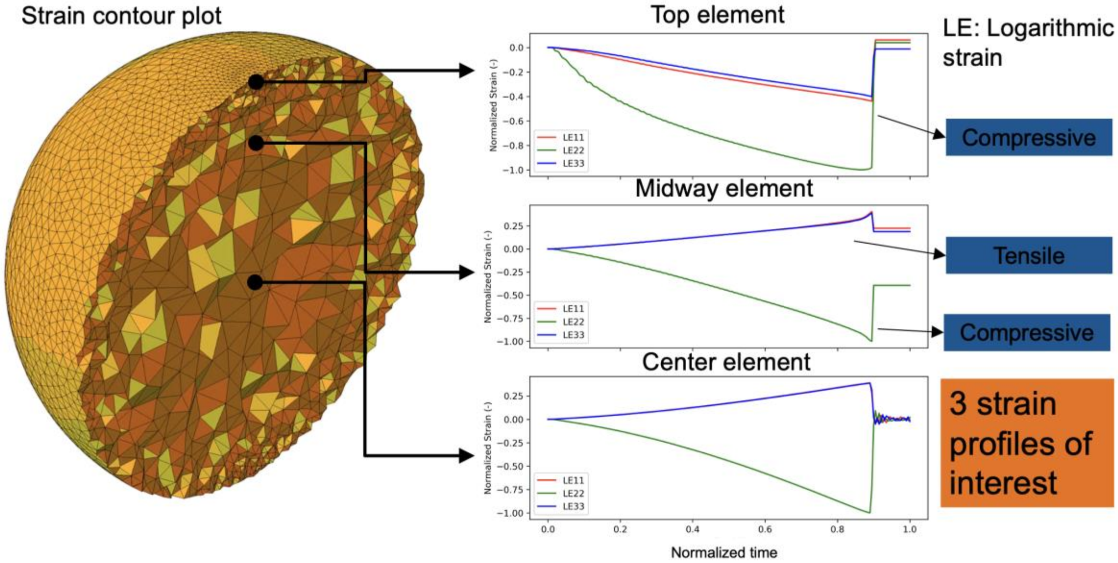


Figure 6: Strain distribution inside an individual particle in a high-fidelity single particle finite element simulation: elements close to the top surface are under compressive strain conditions (unlikely to crack), whereas the elements further away from the particle surface are under tensile loading condition, which can lead to catastrophic fracture events inside the particles.

Finally, the loading can be linked to the particle microstructure through microstructure scale finite element simulations, as shown in Figure 7.

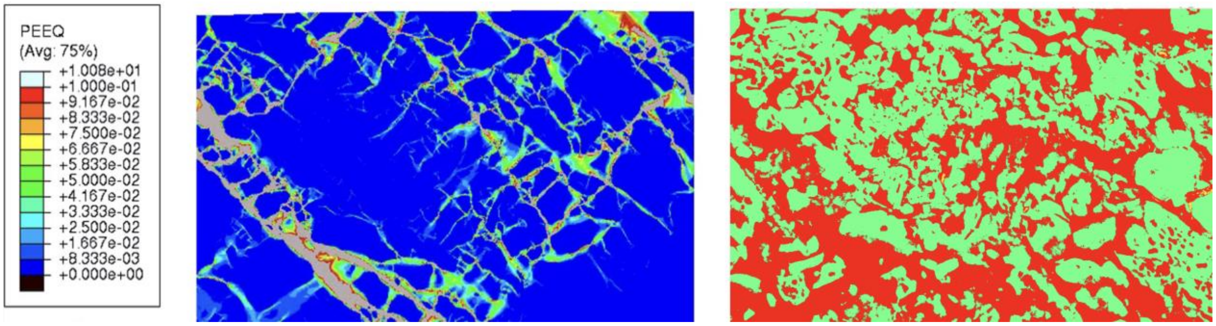


Figure 7: Simulated tensile loading test of the particle microstructures, where left) shows a measure of "plastic" deformation and right) shows the segmented phase distribution.

DEVELOPMENT OF METALS

Work Package 3 (WP3) focused on improved materials by developing high-performance metals capable of withstanding extreme temperatures and abrasive environments. WP3 has targeted the testing of state-of-the-art (SOTA) materials, including nickel-based superalloys and high-temperature steels, as well as producing novel chromium-based alloys that hold the potential to outperform current SOTA alloys, including (i) chromium(Cr)-based bcc-superalloys and (ii) chromium-silicide alloys.

Task 3.1 has developed and advanced Cr bcc-superalloys incorporating NiAl-type aluminide precipitates, enhancing thermal stability and strength at elevated temperatures. Task 3.2 has focused on Cr alloys strengthened by Cr3Si silicide intermetallics, yielding materials with excellent high-temperature resistance and durability. In addition to developing these bulk materials, WP3 has explored the potential of Cr aluminides and silicides as protective coatings for traditional steel and nickel substrates (Task 3.3), allowing existing materials to benefit from increased resilience. Material coupons, including these new alloys and coated materials, have been produced for environmental testing in WP4 and WP5, where they undergo particle abrasion and CO_2 exposure trials. Tasks 3.4 through 3.6 have involved comprehensive microstructural, mechanical, and modelling efforts. Characterization has confirmed that the target precipitates and reinforcements are effectively embedded, while mechanical testing highlights the high-temperature strength and abrasion resistance of the materials. Modelling predicts the long-term performance of these structures, guiding continued optimization.

The outcomes of WP3 have been widely shared with the scientific community, resulting in three peer-reviewed journal publications and presentations at over 10 international conferences across Europe, the US, China, and Mexico, including a recent talk at Eurocorr2024. This exposure has allowed the work package to receive valuable feedback and raise awareness of the advancements in CSP materials. Results from WP3 will contribute to abrasion and coolant interaction studies in WP4, moving these materials closer to CSP operational conditions. With WP3's contributions, COMPASsCO$_2$ is set to enhance CSP durability and efficiency, paving the way for advanced, resilient solar technology.

EVALUATION AND MODELING OF METAL/MEDIUM INTERACTION

The state-of-the-art and new materials have been tested in the COMPASsCO$_2$ heat exchanger aggressive environments. The influence of load on the material degradation and oxidation at high temperatures has been compared between the state-of-the-art alloys. Long term 3,000h oxidation tests at 700°C and 900°C of the Cr-Si coated alloys and the new bulk Cr-Ni-Al alloys have been completed. The new materials and coatings have shown improved behavior when compared to their baseline or uncoated counterparts in terms of cyclic oxidation performance in air and CO_2 and isothermal exposures in CO_2. The in-depth characterization of the various degradation mechanisms and underlying microstructural changes have been compiled amongst the project partners, with several manuscripts in preparation before the project end. This data has informed the lifetime modeling efforts with the goal of a model to describe the degradation mechanisms and give a lifetime estimate of the HEX tubes. The model geometries include the cold test layout and the planned demonstrator HEX as shown in Figure 8. The initial results indicate the wear loss is higher on the tubes towards the top of the HEX and on the sides of the HEX tubes.

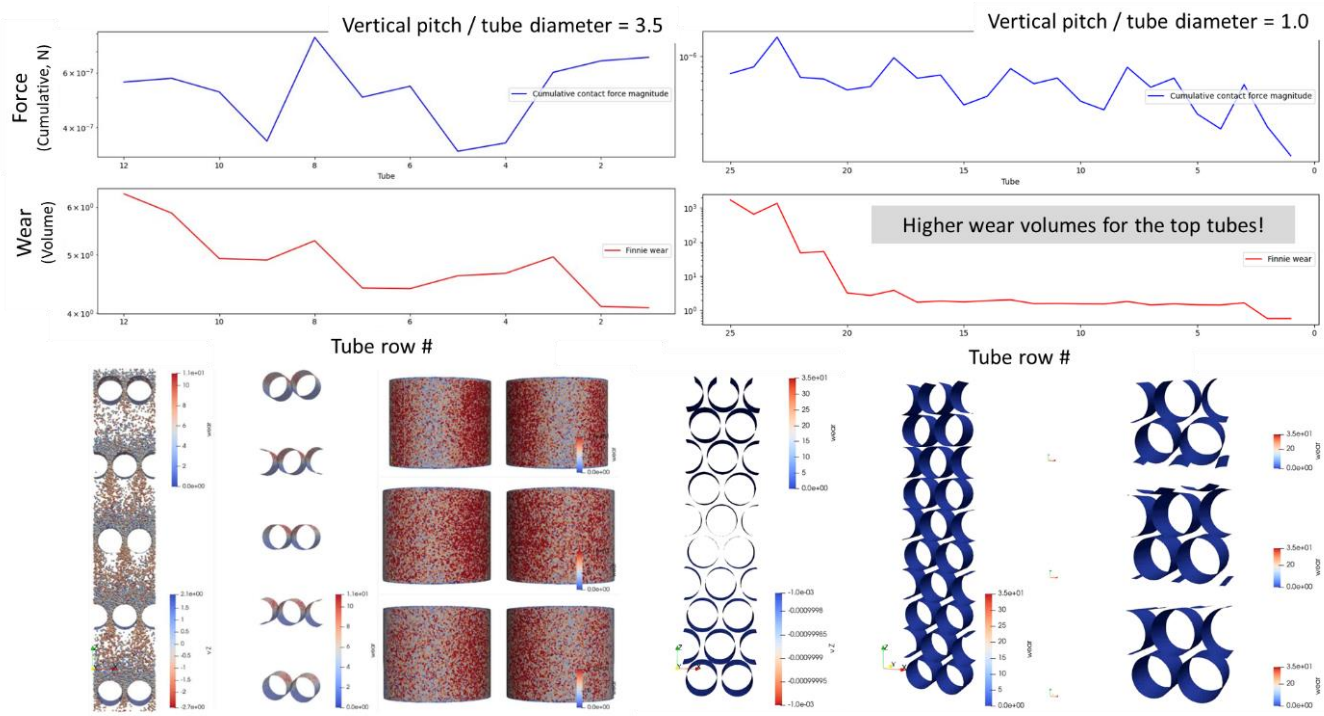


Figure 8. Wear prediction as a function of force and tube position for two HEX geometries. Courtesy of VTT.

TECHNOLOGY VALIDATION

The unique testing loop for granular particles, developed in COMPASsCO_2, is yielding its first results. Creep conditions were achieved within tubes made of standard stainless steel, preloaded with an internal pressure of 78 bar, after approximately 200 hours at 750°C. Deformation was captured using the 3D laser scanning method, as shown in Figure 9. The first tube from the left plastically deformed and ruptured, causing the escaping argon gas to create a small depression in the neighboring tube.

Additional results from the impact test are also presented. Samples were exposed to a stream of particles at temperatures up to 670°C and velocities up to 15 m/s. It was demonstrated that the reference sample made of stainless steel could not withstand these conditions, losing approximately 0.25 g/h. In contrast, the sample made of alumina oxide showed exceptionally good performance, losing only 0.002 g/h. The comparison of these two samples is shown in Figure 10.

Currently the exposition experiments are ongoing until the end of the year 2024, aiming to reach a total of 1000 hours.

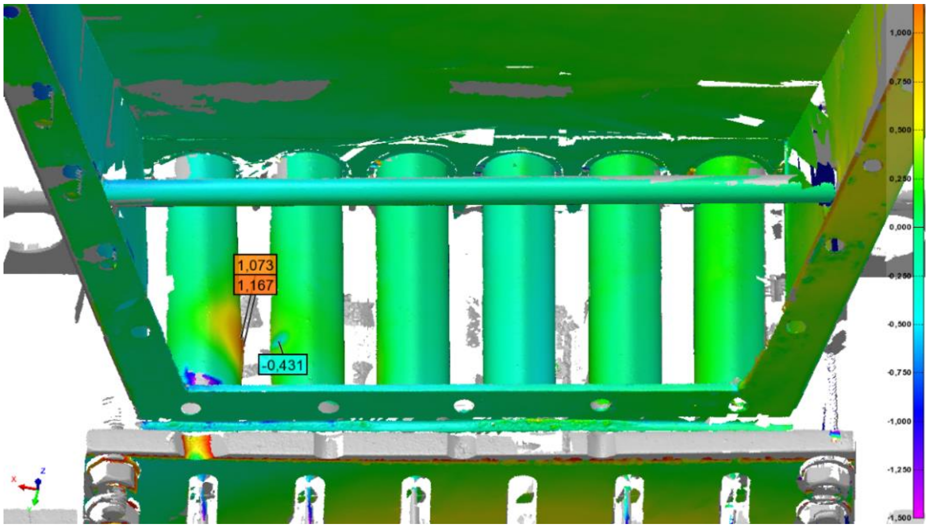


Figure 9: 3D scan of the test section preloaded with internal pressure.

Figure 10: Comparison of the impact test samples. Left side reference sample from stainless steel. Right sample made of Alumina oxide ceramics.

PROJECT MANAGEMENT & COORDINATION

Meetings

Quarterly Phone Call - The call was organized on 22 July 2024 to discuss the overall progress of the project. It highlighted progress across work packages, including dissemination activities, while addressing delays and adjustments for ongoing experiments and deliverables.

Seventh General Assembly Meeting - The Seventh GA Meeting took place on 24 October 2024 online. The COMPASsCO$_2$ team discussed the overall progress, including a 6-month extension, the preparation for the final events (last GA meeting, Review Meeting for the third reporting period of the project and final workshop) to be organized in April 2025, on-going activities, challenges, and next steps.

COMMUNICATION, DISSEMINATION & EXPLOITATION ACTIVITIES

The COMPASsCO$_2$ project successfully disseminated its findings across a range of prestigious international and interdisciplinary platforms, including papers in scientific journals as detailed below.

Papers produced by COMPASsCO_2 Team

Kerbstadt, M.; Ma, K.; White, E.M.H.; Knowles, A.J.; & Galetz, M.C. (2024). Novel Chromium-Silicon Slurry Coatings for Hot Corrosion Environments. *High Temperature Corrosion of Materials*. Link to PDF.

Grimme, C.; Ma, K.; Kupec, R.; Oskay, C.; White, E.M.H.; Knowles, A.J.; & Galetz, M.C. (2024). Nanocrystalline Y_2O_3-modified metal matrix composite coatings with improved resistance to thermocyclic oxidation and V_2O_5-induced type II hot corrosion. *Surface & Coatings Technology*, 485, 130891. Link to PDF

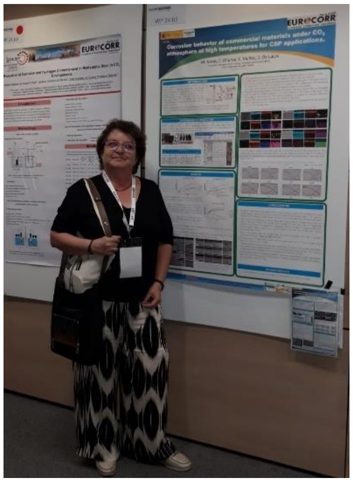
Sutter, F.; Montecchi, M.; Morales Sabio, A.; San Vicente, G.; Fernández-García, A.; Pernpeintner, J.; Reche-Navarro, T., et al. (2022). Round Robin Test of Absorptance and Emittance of Particles for CSP. *SolarPACES 2022: 28th International Conference on Concentrating Solar Power and Chemical Energy Systems – Measurement Systems, Devices, and Procedures*. Link to PDF

COMPASsCO_2 Participation at Conferences

Through presentations at conferences, the project showcased significant advancements in sustainable energy systems, including CSP and s-CO2 technologies. Key topics such as high-temperature corrosion, erosion resistance, and innovative coatings were shared with the scientific community, reflecting strong collaboration among leading research institutions. Below is a summary table of the presentations delivered by the consortium team during the last 6 months.

LEAD PARTNER (S)	EVENT VENUE DATE	TITLE OF THE PRESENTATION
FZJ	HTCPM 2024 Île des Embiez, France 9 -14 June 2024	High temperature oxidation-erosion behaviour of candidate materials for concentrated solar power plants with ceramic particle receivers
FZJ		Effect of Ni-base alloy chemistry on the growth rate and adherence of oxide scales formed at high temperatures in a CO2 environment
DFI		High temperature oxidation and corrosion behavior of nickel-based alloys at 900°C – comparison of pack and slurry
DLR, SGCREE	Sonnenkolloquium 2024 Jülich, Germany 24 June 2024	Improved particles for solid heat transfer and storage technology
UoB	IMRC2024 Cancun, Mexico 13 -18 August 2024	High Performance Materials for Sustainable Energy Applications
CIEMAT	EUROCORR 2024 Paris, France 2-5 September 2024	Corrosion behavior of commercial materials under CO2 atmosphere at high temperatures for CSP applications
DFI		*High temperature oxidation and corrosion behavior of chromized Ni-based superalloys – by pack cementation and slurry coating*
CVR	Image analysis in nuclear research Prague, CZ 9 September 2024	General information of the COMPASsCO2 project
UoB	MSE 2024 Darmstadt, Germany 24-26 September 2024	Chromium-based bcc-superalloys strengthened by iron supplements
UoB		Bcc-superalloy microstructure template for nuclear, aerospace and solar applications
DFI		Creep performance of Sanicro25, IN617B, IN740 and Haynes282 in CO2 at 700°C

CIEMAT, DLR, DFI, SGCREE	SolarPACES 2024 Rome, Italy 8-11 October 2024	Abrasion Testing Methodologies for CSP Particles
CIEMAT		Spinel Composition Optimisation for Improving Absorptance of Solar Particle Receivers
CIEMAT, UoB		Application of the small punch test techniques to the investigation of the mechanical behaviour of candidate materials for particle/s-CO2 heat exchangers
DFI, DLR, CIEMAT, SGCREE		Development of high solar absorptance coatings for particle based CSP systems and their performance in isothermal and thermocyclic conditions
DFI, DLR, CIEMAT, SGCREE		High Temperature Attrition Testing of Novel Coated Particles for Solar Tower Receivers
DFI		Corrosion mechanisms of Fe- and Ni-based alloys in solar salt and mitigation strategies
DFI		PVD MAX-Phase Coatings for CSP applications
DFI		Development of high solar absorptance coatings for particle based CSP systems and their performance in isothermal and thermocyclic conditions

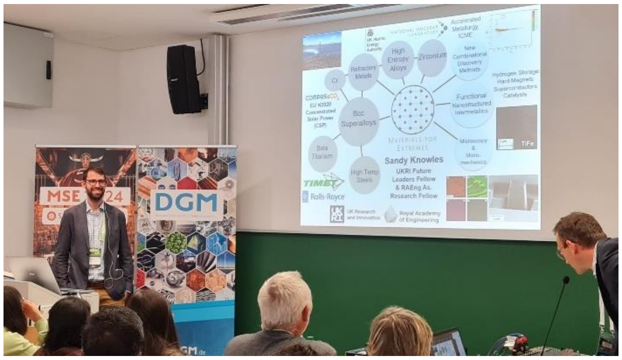


Marta Navas from CIEMAT at EUROCORR 2024 conference, Paris, France, 2-5 September 2024

Florian Lebendig from FZJ Wins Best Poster Award at HTCPM 2024 Symposium, Île des Embiez, France, 9 -14 June 2024

Joint Dissemination Activity at MSE2024

In collaboration with other research consortia (ACHIEF, HIPERMAT, topAM), COMPASsCO$_2$ organized a joint session at MSE 2024 (24-26 September 2024, Hybrid (Darmstadt & online) - *F02 Session: High Performance Materials for Sustainable Energy Applications*. This symposium addressed recent advances in the field of novel high performance materials and components (according to aims of projects under the Horizon 2020 framework under, call LC-SPIRE-08-2020) by addressing materials design concepts, new materials as bulk materials or as coatings (metallic and ceramic), and technologies for their development, with the final aim of manufacturing components for the industrial applications.



Alexander Knowles from UoB at MSE 2024, Darmstadt, Germany, 24-26 September 2024

How to Get Involved in COMPASsCO$_2$ Activities

Become a member of the project's stakeholders' network

Whether you want to learn more about specific WP activities, collaborate with the consortium or act as an external expert, kindly contact us at contact@compassco2.eu. We will keep you updated about project activities, invite you to attend the project's public events and ask your feedback on the progress and main outcomes of the project.

Check our website and follow us on social media networks

twitter LinkedIn

https://www.compassco2.eu/

For more information

Check the project's website: www.compassco2.eu

Contact us: contact@compassco2.eu

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