$COMPASsCO_2$

RECEIVER TECHNOLOGY INNOVATION: LESSONS LEARNT IN THE DEVELOPMENT AND TESTING OF NEW PARTICLES

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COMPASsCO2 Final Workshop

Back to the Future: A Forward-Thinking Approach to Concentrating Solar Technologies - Key Takeaways from the $COMPASsCO_2$ Project

April 24th, 2025

9h30 – 14h30 CEST

Husinec u Řeže, Czech Republic & Online lifesize

Structure

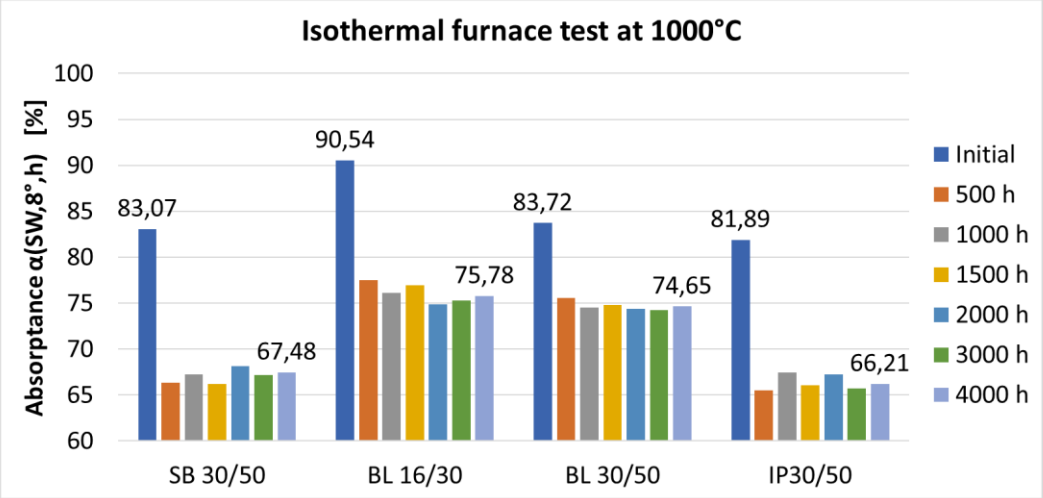
- Review of the state-of-the-art proppants
- Innovations & contributions of the COMPASsCO2 Project
  - The new particles FerOx
  - Coating for particles
  - Testing the particles
  - Simulating the particles
- Lessons learned & challenges
- Future research & innovation directions
- Questions and answers

Review of the state-of-the-art proppants

- Technology developed in fracking
- Generally made of different materials
- Advantage using particles for CST
  - High chemical stability
  - High temperature resistance
  - Can be used for Heat Energy Storage
- Inconvenience: Solar absorptance degradation

Initial

After 1500 h



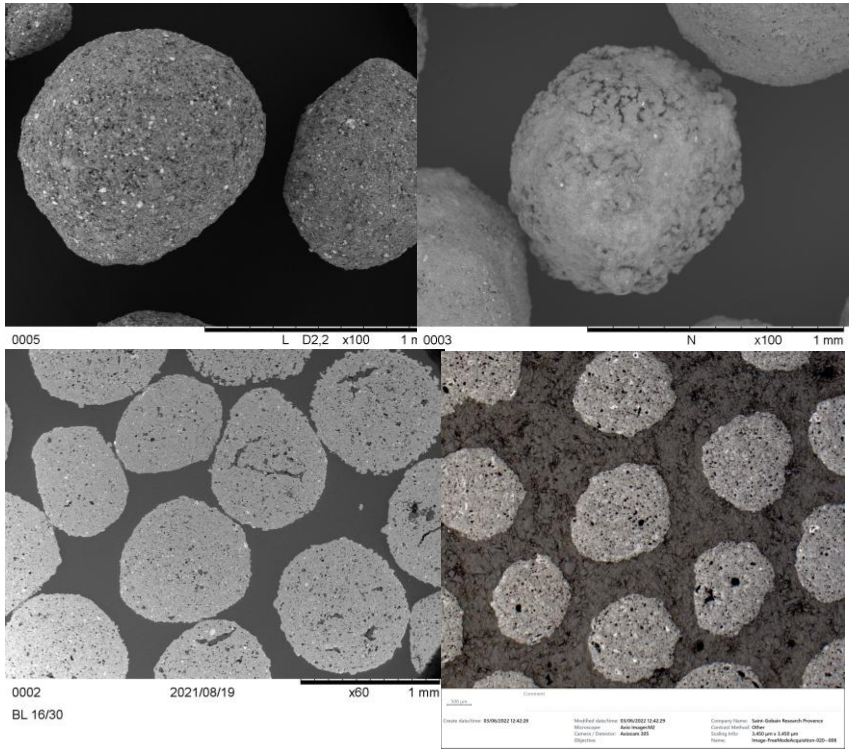
The new particles FerOx

- Development of new particles by Saint-Gobain
  - **FerOx particles** made with recycled raw materials (refractory bricks + iron)
  - Size :0.6 -1.2 mm
  - Cost ≈1€/kg for large volume production

Particle type	State-of-the-art particles BL 16 /30	New developement FerOX particles
Color		
Color After TT 1000°C / 24 h		
Chemistry	Al_2O_3 based composition	Mix of different oxides
Bulk Density [g/cc]	1.85	2.00
ρ.Cp [kJ/m^3.K]	2146	2200
Softening temperature [°C]	857	**940**

State-of-the-art BL 16/30

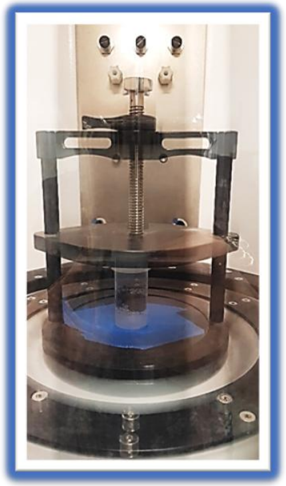
FerOx particles



- New FerOX particles :
  - Unique mix of oxides
  - Higher density
  - Higher thermal stability
  - Limited color change after heat treatment

Coating for particles (DLR/CIEMAT/DFI)

Black commercial pigment

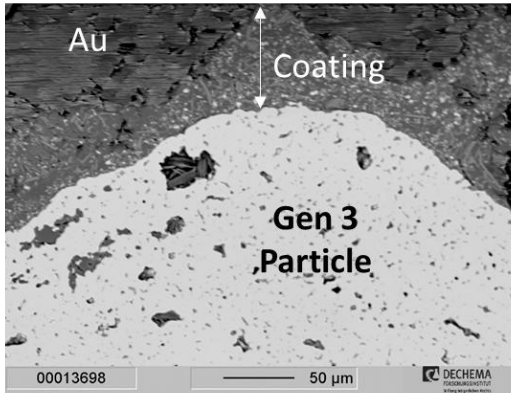


RAM mixing

- Cu-Mn-Fe-O spinel applied in 2 layers with Resonance Acoustic Mixer
- Sintering at 1200°C
- Solar absorptance of 93%

- Preparation of spinels from metal salt solutions (Cu-Mn-Co-O spinel)
- Application on particles
- Thermal treatment at 1000°C (removing of solvent and additives, spinel formation)
- Solar absorptance of 97%

[SATA]



- Air-sprayed suspension onto particles
- Ethanol-based suspensions → resin, additives, hardening agent and **$CuCr_2O_4$** black pigments
- Coating thickness: 15-40 µm
- Cured at room temperature
- Solar absorptance of 97%

Testing the particles

Test applied to particles

Characterization test

- Particle density
- Softening temperature
- Microstructures
- Optical properties
  - Solar absorptance
  - Emitance
- Mechanical properties
  - Crushing test (SGCREE)

Enviromental testing

- Humidity
  - Condesation (DLR/CIEMAT)
  - Freezing (DLR/CIEMAT)
- Temperature
  - Isothermal (DLR/CIEMAT)
  - Thermocyclic exposure (DFI)

Mechanical test

- Room temperature
  - Resonance Acoustic Mixer (DLR)
  - Particle-to-particle abrasion (CIEMAT)
- Operational temperature
  - Rotary furnace (DLR)
  - Particle impact (DLR/CIEMAT)

Testing the particles

Relevance

		State of the art proppants SAINT-GOBAIN				new developments SAINT-GOBAIN					Coatings on FerOx		
Property	**Target values**	**Sintered Bauxite SB 30/50**	**BauxLite BL 16/30**	**BauxLite BL 30/50**	**InterProp IP 30/50**	**Fused Gen 1**	**Fused Gen 2**	**Granulated Gen 2**	**Granulated Gen 3**	**Granulated FerOx**	**CIEMAT Coating on FerOx**	**DECH coating on FerOx**	**DLR coating on FerOx**
Size distribution [µm]		297-590	590-1190	297-590	297-590	800-1200	600-1200	600-1250	600-1200	600-1200	Same as Gen 4	Same as Gen 4	Same as Gen 4
Cost [€/kg]	<1	1.5	<1.5	<1.5	<1.5	5	3	3	~1.3 -1.5	~1	~0.5 - 0.75	~0.5 - 0.75	0.54
c_p at 1000°C [J/g·K]	>1.5	1.28	1.16	1.11	1.07	1.20		0.88	Similar to Gen2	1.1	Same as Gen 4	Same as Gen 4	Same as Gen 4
Bulk density ρ_b [g/cm³]	>2	1.85	1.74	1.61	1.73	2.08	2.08	2.8	2.83	2.0	Same as Gen 4	Same as Gen 4	Same as Gen 4
Material density ρ_m [g/cm³] specific /absolute	>3.5	3.3/3.45	3.06/3.42	3.12/3.26	3.16/3.34	3.47/3.53	3.32/3.39	4.71/5.07	4.92/5.04	3.56/3.76	Same as Gen 4	Same as Gen 4	Same as Gen 4
Softening temperature T_s [°C]	>900	882	857	850	856	1110	1080	1010	1080	940	Same as Gen 4	Same as Gen 4	Same as Gen 4
Vickers Hardness *HV 0.1*	>900	911	833	623	723	1110	988	636	704	926	Same as Gen 4	Same as Gen 4	Same as Gen 4
Breaking force *F* [N] 0.8-1.0mm	>140		141			63	98	70	90	120-140	Same as Gen 4	Same as Gen 4	Same as Gen 4
Sphericity [-] B/L (Q3=50.0 %)	as good as proppants	0.87	0.87	0.86	0.86	0.94	0.95	0.91	0.86	0.89	Same as Gen 4	Same as Gen 4	Same as Gen 4
Roundness [-]	as good as proppants	0.75	0.72	0.71	0.76	0.79	0.81	0.79	0.81	0.82	Same as Gen 4	Same as Gen 4	Same as Gen 4
Solar absorptance α [-]	>0.9	0.845	0.914	0.851	0.834	0.964	0.974	0.928	0.882	0.833	0.967	0.970	0.926
Thermal emittance ε at **900**°C [-]	?	0.757	0.845	0.767	0.737	0.951	0.941	0.829	0.772	0.614	0.809	0.931	0.708
Degradation after 4000h at 1000°C													
Δα	<0.02	-0.156	-0.148	-0.091	-0.157	-0.030	-0.023	-0.002	+0.003	-0.012	-0.010	-0.016	-0.000
Δε(**900°C**)	<0.02	-0.293	-0.305	-0.182	-0.249	-0.104	-0.086	+0.001	-0.004	-0.106	-0.040	-0.117	+0.014

Testing the particles

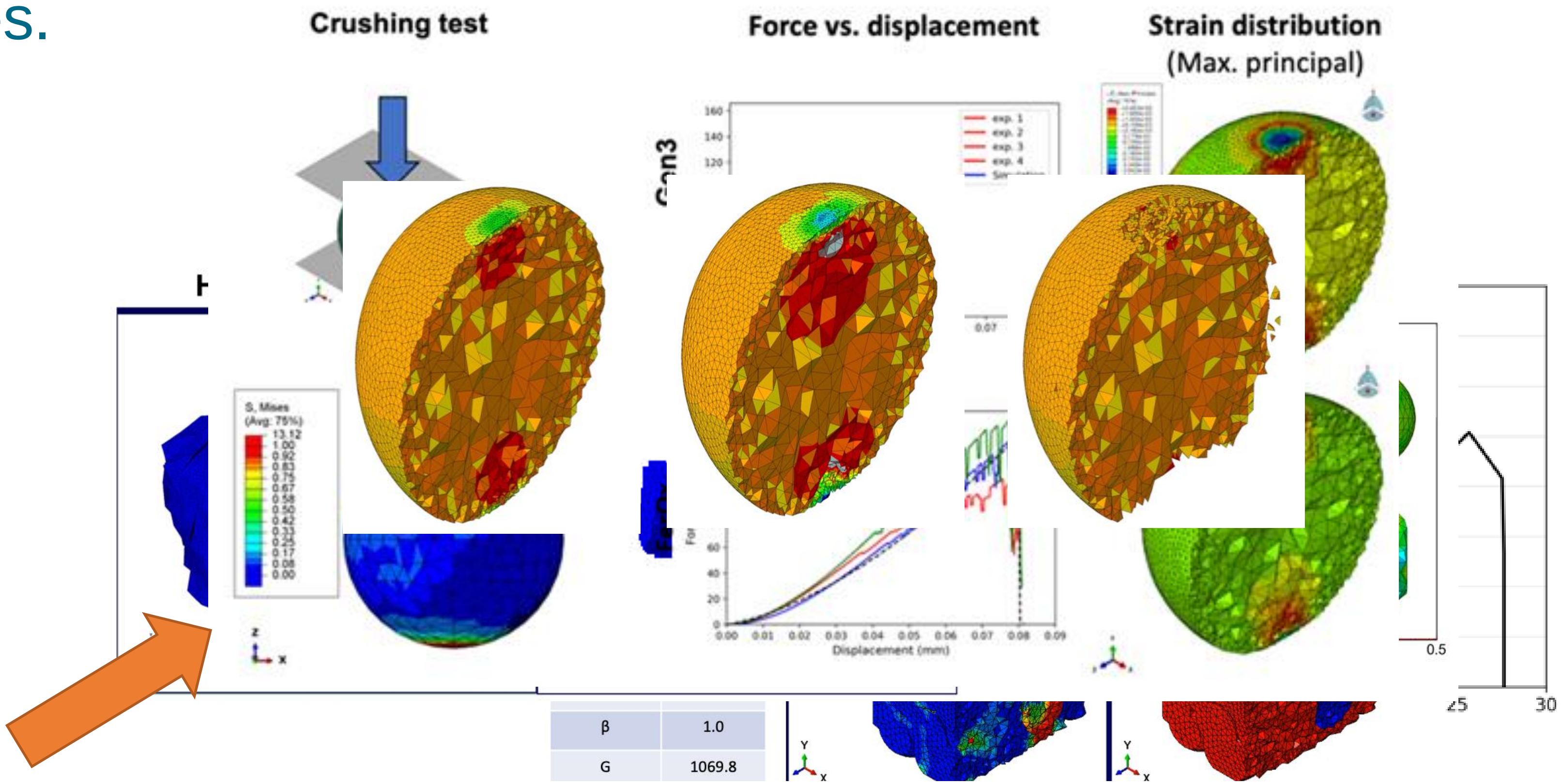
FerOx particles have no changes on their solar absorptance

Test	DLR	CIEMAT	DFI
After coated	93.0 %	97.0 %	97.0 %
Condesation (DLR)	-0.3 %	+0.3 %	+0.5 %
Freezing (DLR)	-0.5 %	+0.4 %	+0.6 %
Isothermal (DLR)	0.0 %	**-1.0 %**	**-1.6 %**
Thermocyclic exposure (DFI)	**+2.0 %**	-0.5 %	-0.3 %
Resonance Acoustic Mixer (RAM) (DLR)	-1.1 %	-1.5 %	+0.3 %
Particle-to-particle abrasion (CIEMAT)	**-1.1 %**	**-1.9 %**	**-1.5 %**
Rotary furnace (DLR)	+0.1 %	-0.4 %	**-1.8 %**
Particle impact (DLR/CIEMAT)	**-1.1 %**	**-2.0 %**	**-4.9 %**

- Humidity does not affect the coatings
- DLR solar absorptance increase with temperature. CIEMAT and DFI are stable
- DFI has the highest solar absorptance at room temperature.
- DLR resists the mechanical interacion.
- CIEMAT has the highest solar absorptance at operational temperature.

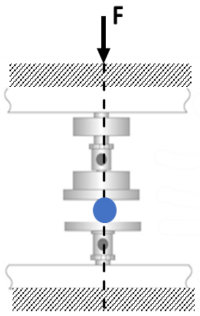
Simulating the particles (VTT)

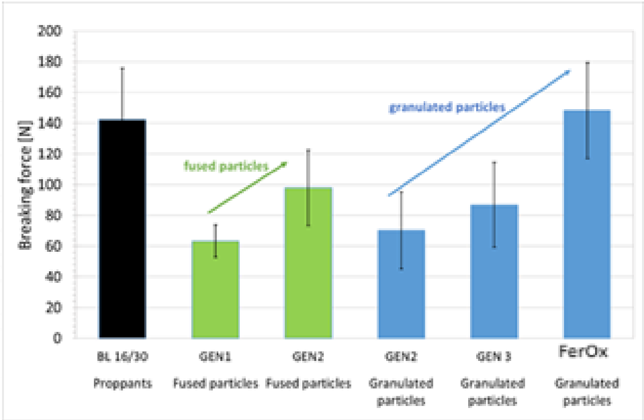
- Comparison between particles.
- Study of fragmentation.
- Influence of temperature.
- Influence of sphericity.
- Microstructure simulations.

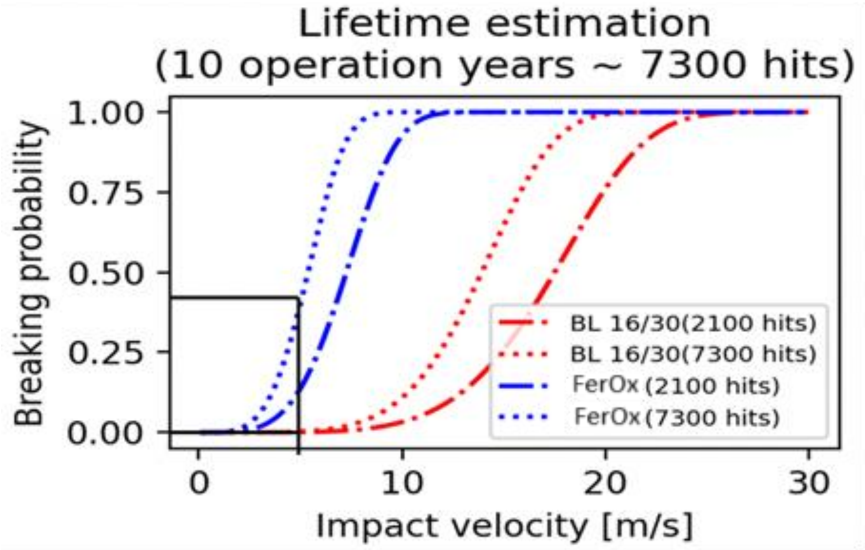


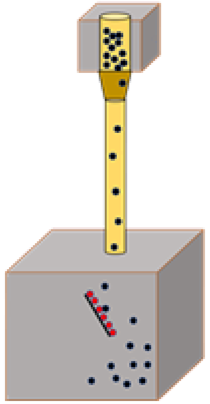
Simulating the particles (VTT)

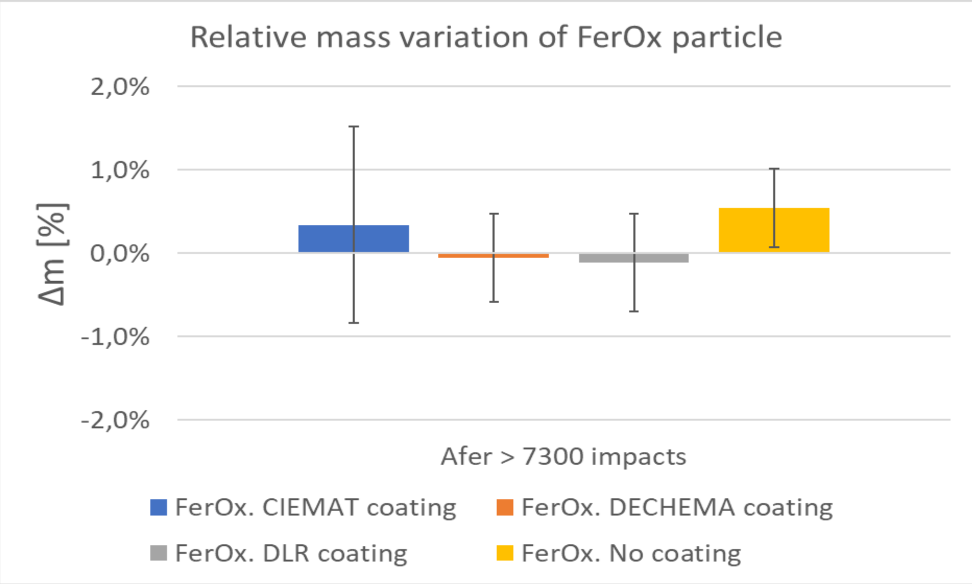
- Lifetime predictions done base on Particle Crushing Test.
- Lifetime calculated for the receiver’s worst conditions.
- Results:
  - Lifetime shows better results for BL 16/30.
  - FerOx lifetime predicted to be lower than what is found in experimental impact tests











Simulating the particles

- Particle bulk simulation does not take into account roundness. Important factor.
- BL 16/30 at high temperature have softer areas surrounded by hard areas → Stress concentrations.
- FerOx at high temperature have hard areas surrounded by soft areas → Better stress distribution.

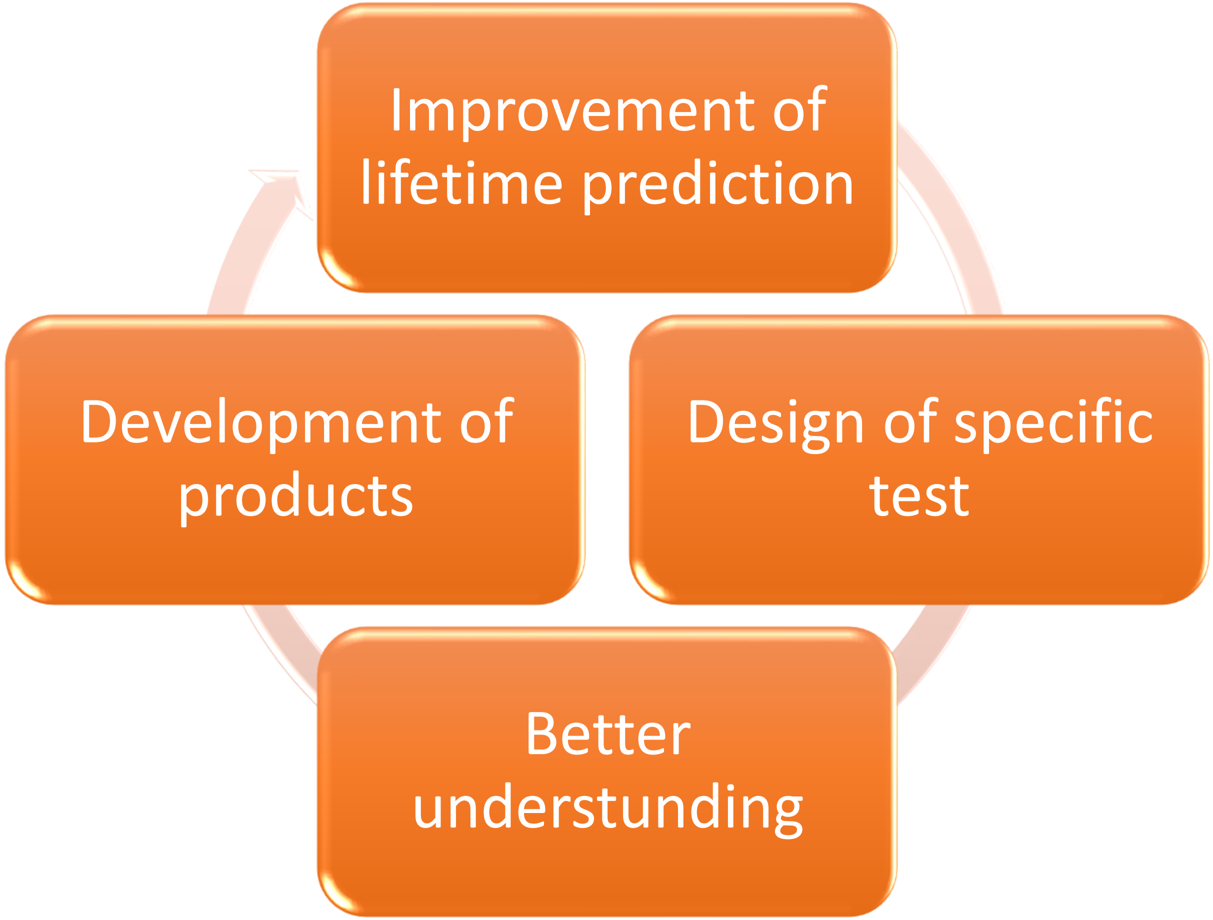
- The particle bulk model assumes homogeneously smooth and spherical particles.
- Improvement: better microstructural simulation & take into account sphericity

To improve the lifetime estimation, new specific test are required.

Lessons learned & challenges

- State-of-the-art particles do not have a constant solar absorptance after the thermal test, therefore they are not optimal for application in CSP.
- FerOx particles have been selected as the best option due to their increased hardness compared to other granulated particle generations, despite the relatively lower solar absorptance.
- To improve solar absorptance, three coatings were developed by CIEMAT, DLR, and DFI. These have been proven by different tests.

Future research & innovation directions



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