New solar setup with acoustic diagnostic techniques for CSP materials

Comparison of the proposed behavior model with the experimental results from the developed test bed

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Executive Summary

The EU-funded research project SFERA II – grant agreement 312643 – aims to boost scientific collaboration among the leading European research institutions in solar concentrating systems, offering European research and industry access to the best research and test infrastructures and creating a virtual European laboratory.

This deliverable is part of the results of the task 3 of the workpackage 13 *Determination of physical properties of CSP materials under concentrated solar irradiation* within the Joint Research Activities.

This workpackage 13 aims to provide a better evaluation of the material behavior for CSP applications and other fields with similar thermal stress, such as high temperature steels or SiC ceramics, thanks to better or new experimental tests bed and associated theoretical models. These results will lead to help users developing higher performance materials for higher process efficiency.

The task 1 of workpackage 13 is focused on two principal targets:

- Define and validate new methodologies for comparative evaluation of the ability of key CSP components to sustain cyclic thermal gradient.
- Improve CSP test facilities by developing news instruments and methods for in-situ thermo-mechanical investigation using acoustic methods.

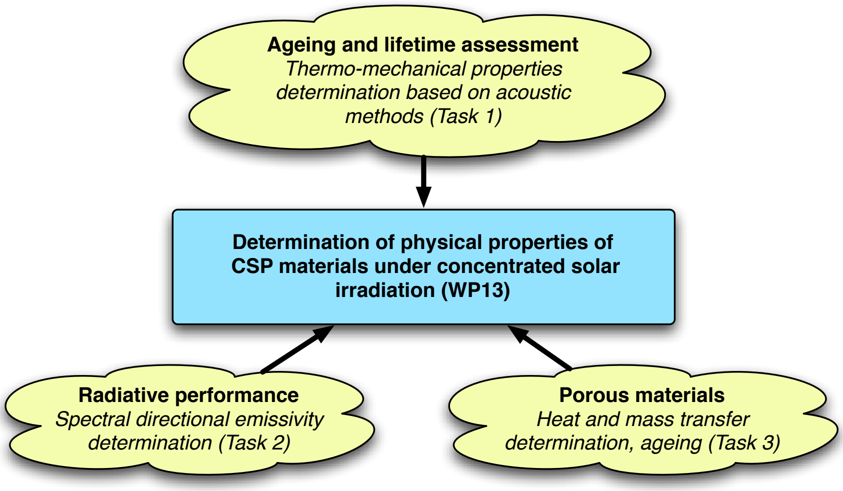
The work presented here relates the development and achievement of the experimental device "IMPACT": A novel device for in-situ thermo-mechanical investigation of materials under concentrated sunlight. The detailed text has been published in J. Solar Energy Materials and Solar Cells, vol. 172, Dec. 2017, pp 59-65.

https://doi.org/10.1016/j.solmat.2017.07.002.

Please refer also to:

- SFERA2 deliverable D13.1 about the initial sample selection.
- « Impact: A New Device for Thermo-Mechanical Investigation on Central Receiver Materials », oral presentation at SolarPACES 2017, Santiago, Chili. A paper will be included in the conference proceedings.
- PhD thesis by Yasmine Lalau (expected 2017), U. Perpignan, France.

Workpackage 13 overview



SFERA2 Joint Research Activities : WP13

For completeness, the reader should refer to the other work delivered within the workpackage 13, but also the rest of the project such as WP12 (temperature measurements), WP14 (component qualification) and also the previous project SFERA GA n°228296 such as WP12 task 1 (standardization activities). http://sfera.sollab.eu/index.php

List of deliverables for SFERA II WP13:

- Task 1, thermo-mechanical properties
  - D13.1: Selected test samples: materials and geometries selected, modeled behavior.
  - ➢ D13.2: Comparison of the modeled behavior and experimental results from the developed test bed.
- Task 2, radiative properties
  - D13.3: Comparison of experimental determination of emissivity measurements for selected materials between the techniques used by the partners.
  - D13.4: Assessment of experimental measurements of spectral directional emissivity at high temperature.
- Task 3, porous materials properties
  - D13.5: Heat and Mass transport properties of reticulated porous ceramic structures.
  - D13.6: Characterization of the physical and chemical properties of the surface cavities of porous materials.
  - D13.7: Comparison of experimental determination of transport properties to predicted characterization.

1. IMPACT: A novel device for in-situ thermo-mechanical investigation of materials under concentrated sunlight

Refer to https://doi.org/10.1016/j.solmat.2017.07.002 for the full text highlighted here and for proper citation of the corresponding work.

A poster presented at the 15th International IUPAC Conference on High Temperature Materials Chemistry (HTMC XV), Orleans, 2016, is also joined for additional information. https://htmc15.sciencesconf.org/

1.1. Abstract

A promising route toward affordable and efficient solar energy conversion lies in the development of the high temperature Concentrated Solar Power (CSP) tower. The extreme thermal stress conditions to which the tower receivers may be submitted raise the question of the ability of these components to efficiently perform over extended periods of time. Conventional methods commonly used to assess the mechanical stability and lifetime of these components involve laboratory testing, which suffers from the fundamental inability of these methods to effectively reproduce the real operating conditions. In this work, we suggest an original set-up based upon the use of acoustic emission for in-situ thermo-mechanical investigation of receiver materials exposed to concentrated solar irradiation, named IMPACT (In-situ thermo-Mechanical Probe by ACoustic Tracking). The ability of this set-up to precisely track the nature, the location and the dynamics of mechanical defects in the receiver material is assessed. Implications for future characterization tools aimed at obtaining an in-depth understanding of the thermo-mechanical behavior of a wide range of materials in real-working operation is also discussed.

1.2. Introduction

Solar towers appear promising candidates in the quest for highly efficient, affordable and disposable solar electricity because of 1) their high concentration levels (up to 1000) allowing an efficient conversion of sunlight into electricity 2) their flexibility (easy and low-cost storage and integration) [1]. However, this technology suffers from a lack of standardization as well as challenging scalability issues, which undoubtedly impede its large scale deployment [2–4].

The receiver is a key component intended to absorb the concentrated solar radiation and transmit the heat to the working fluid. Since the transfer fluid must reach temperatures above 1000 °C for an optimal energy conversion, the receiver should in fact be designed to withstand higher temperatures. In real-working operation, solar receivers are likely to be exposed to cyclic service associated with night and day alternation (long duration standard cycles) and with cloud obstruction or daily start up and shut down (short-timescale critical cycles). This cyclic service may progressively lead to accumulated damage in both low cycle fatigue (i.e. when the nominal operating conditions are largely exceeded) and polycyclic fatigue (i.e. when nominal operating conditions are fulfilled), finally resulting in failure of the system. It is thus fundamental to diagnose ability of the materials to perform efficiently over extended periods of time. Whilst the study of the thermo-physical properties of the materials under accelerated conditions has instigated significant research effort [5–10], the literature dealing with thermo-mechanical behavior appears to be very scarce [11,12].

The ability of materials to accommodate such extreme thermo-mechanical conditions is usually evaluated with classical mechanical laboratory tests, which are fundamentally unable to replicate the real operating conditions. A better comprehension of the damage occurring in the materials under harsh thermo-mechanical stress would require the implementation of in-situ and non-destructive techniques (NDT). These techniques are able to detect the occurrence of sudden faults before their dramatic propagation, and provide valuable information leading to a better understanding of the damage history of a sample under thermo-mechanical stress, by studying its fracture or fatigue behavior [13]. These techniques are also widely used in several industries such as the oil or aerospace industry, to improve maintenance by monitoring structures [14]. Recently, the CSP field considered these techniques to implement a preventive maintenance program [15].

Acoustic emission is an in-situ technique for detecting and tracking the onset and spread of defects induced by internal mechanisms. It has been identified as the most suitable method to detect the initiation of defects with a high sensitivity [15]. A major benefit of this technique lies in the possibility for the operator to follow the real-time damage evolution of the sample under test during solar irradiation cycling, and to classify the observed mechanisms with a suitable post-treatment analysis.

This paper deals with the design of IMPACT (In-situ thermo-Mechanical Probe by ACoustic Tracking), an original experimental set-up based on acoustic emission, for in-situ thermo-mechanical investigation on plate or tubular receiver materials submitted to concentrated solar radiation.

Acoustic emission and the underlying physical phenomenon are first presented, and the set-up developed for in-situ characterization of receiver materials under harsh thermo-mechanical stress is described in detail. The ability of this technique to precisely portray the thermo-mechanical behavior of solar receiver components under severe conditions of illumination and temperature will finally be discussed.

1.3. Technique and measurement principle

1.4. IMPACT design

1.5. IMPACT validation

1.6. Conclusion

In this paper, a new original device for in-situ thermo-mechanical investigation on CSP receiver materials has been presented. The strength and the novelty of this method, based on acoustic emission, lie in its ability to detect microstructural changes and defects at an early stage in real operating conditions.

We identified several key parameters which were optimized to achieve a high location accuracy: 1) hexagonal sensor meshing, 2) no coupling contact between sample and waveguide 3) high pressure spring, and 4) combined time arrival and zonal location.

We experimentally demonstrated, using the IMPACT experimental set-up developed in the framework of this study, the ability of this method to better understand the thermo-mechanical behavior of solar receiver materials in real operating conditions.

An accurate detection of the degradation mechanisms occurring in the sample under test will necessarily require the optimal cycling strategy to be determined, which will be addressed in a future work. In addition, the acoustic activity will have to be precisely correlated to these cycles, to better grasp the material behavior under extreme thermo-mechanical stress and to assess their durability in real operating conditions.

1.7. Acknowledgements

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1.8. References

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15th International IUPAC Conference on High Temperature Materials Chemistry HTMC XV, March 29 - April 1, 2016, Orléans - France

IN SITU THERMO-MECHANICAL DIAGNOSTICS OF MATERIALS SUBJECTED TO HIGH SOLAR FLUX: TEST DEVICE DEVELOPMENT

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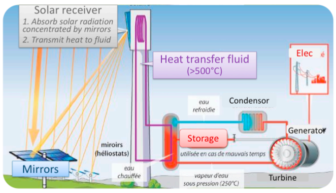
Context & Objectives

Solar power tower plant principle



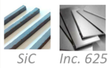
Challenge on the receiver

High T (°C) & gradients → THERMO-MECANIC STRESS

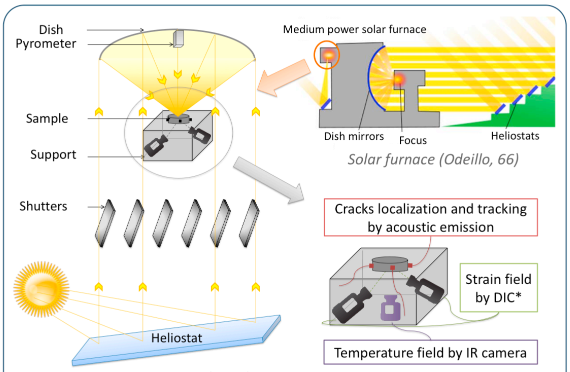
ISSUE: Study receiver materials in-situ behaviour to compare their performance under cycling and define aging indicators

Function of test bed

THERMAL STRESS → Solar flux → SAMPLES → THERMO-MECANIC BEHAVIOUR: → Temperatures, → Crackc tracking, → Strain field



Experimental means



Paraboloc dish (2 kW)

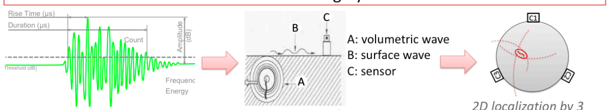
Solar furnace (Odeillo, 66)

Test bed to develop

**Digital Image Correlation*

In situ and non destructive measurement methods

Cracks localization and tracking by acoustic emission



Burst from an acoustic event — *Detection by a sensor* — *2D localization by 3 sensors (triangulation)*

Strain field by DIC*

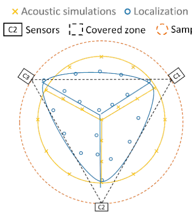
Comparison between 2 pictures: reference / deformed → Strain field estimation

Design for a reliable localization

Hsu-Nielsen tests on Ø76mm steel sample

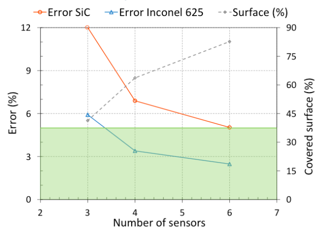
Hsu-Nielsen test principle

Experimental accuracy
t = ± 0.5 µs
↓
Spatial accuracy
$d = v_{sample} \times t$



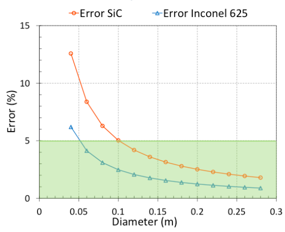
Localization of acoustic event

How many acoustic sensors ?



✓ 6 sensors: Error < 5%

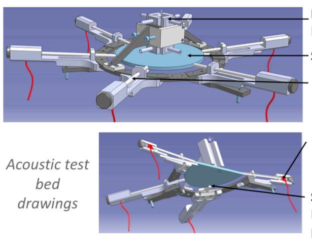
What sample diameter ?



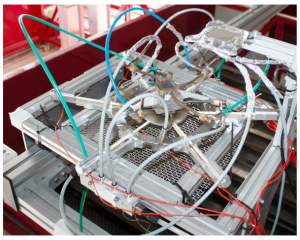
✓ Diameter>100mm: Error < 5%

Test bed production and validation

Production: drawings and pictures

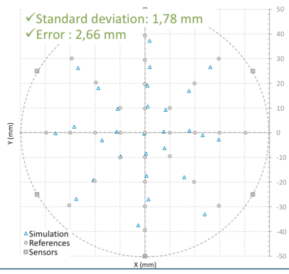


Acoustic test bed drawings



Test bed picture

Localization validation test



Conclusions

- ✓ Choice of two in situ and non destructive complementary methods to study damage
- ✓ Localization feasibility by the designed test bed validate (error<5%)

Perspectives

- ➢ Study acoustic behaviour under cycling
- ➢ Photo-mechanic test bed completion and test
- ➢ Aging indicators identification

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