EPFL MIDDLE EAST

Innovation Program:	**Built Environment**
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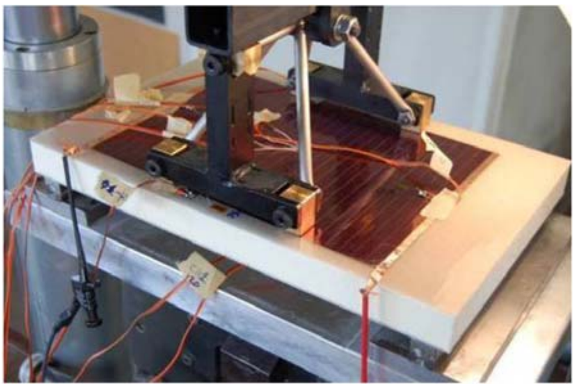
Main Laboratory:	Composite Construction Laboratory (CCLAB)
Project time line:	09.2010– 08.2013
Research project:	**Thermomechanical long-term behavior of composite sandwich structures with encapsulated photovoltaic cells.**

Abstract

The objective of the research is the investigation of the long-term behavior of multifunctional glass fiber reinforced polymer (GFRP) sandwich structures with encapsulated photovoltaic (PV) cells. The sandwiches are intended for use in multifunctional envelope or roof structures of low-energy buildings in tropical climates. The energy supply provided by the encapsulated PV cells presents a further step in function integration, in addition to the structural, building physics and architectural functions already provided by GFRP sandwich structures.

Topics of investigation are the extent to which structural integrity and operational reliability can be maintained if subjected to long-term hot and humid climates, such as in the United Arab Emirates. The following parameters will be investigated: sandwich skin and core materials, type of PV cells, temperature cycles (simulating sun radiation), humidity (including salt), mechanical loading (e.g. walking on the sandwich surface), and abrasion (due to wind-borne sand particles).

Multifunctional GRFP sandwich roof (Novartis campus main entrance building, 2006)



Mechanical loading set-up of GFRP sandwich structure with encapsulated photovoltaic cells.

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1. Motivation

Today, in the midst of the information age and globalization, our society can be characterized by the growing complexity and acceleration of all kinds of processes. To speed up production and lower cost, almost all types of industry have adopted automated processes, with the exception of one: the construction industry. Bridges and buildings are still cast on-site using scaffolding and employing complicated and cumbersome processes – as has been done for 100 years – with increasingly unacceptable consequences regarding cost, quality and safety. The construction industry is therefore now confronted with a challenge: the transition from pure on-site prototype production to fully industrialized and modularized made-to-measure prefabrication. This transition is required in order to shorten construction times, improve quality and increase overall flexibility and economy.

This challenge coincides with the arrival of new materials in the field of construction: fiber-reinforced polymer (FRP) composites. These are lightweight and high-strength materials that are compatible with industrialized prefabrication and rapid installation. FRP composites may also exhibit advantageous environmental characteristics, particularly if glass fibers are used (GFRP), such as low grey energy consumption and low carbon dioxide emissions. Furthermore, properties such as the low thermal conductivity and optional translucency of GFRP offer promising new options, e.g. the integration of building physics and architectural functions into structural components of buildings (Keller et al. 2004). Function integration allows a reduction in the number of building components, thus shortening construction time and mitigating higher material costs, as shown in Fig. 1. Multifunctional FRP composites can therefore contribute significantly to profound innovations in the construction industry on the environmental and economic levels.

Fig. 1. Prefabricated multifunctional GFRP sandwich roof of Novartis Campus Main Entrance Building, (Keller et al. 2008)

Within the EPFL Solar Impulse project (Rion 2008), CCLab performed a feasibility study to integrate energy supply into multifunctional sandwich construction through the encapsulation of photovoltaic (PV) cells into transparent GFRP sandwich skins (Keller et al. 2010). Integration of energy supply (in addition to building physics functions) into load-bearing FRP sandwich structures constitutes the basis for self-sustaining buildings, such as ″minergy″ or zero-energy buildings, which, however – in contrast to traditional low-energy buildings – are lightweight and flexible and therefore offer many advantages.

The basic feasibility of the encapsulation has been proved, since stresses of less than 20% arose in the sandwich skins due to thermal and mechanical loading up to structural failure. Composite action through the skins with encapsulated cells was maintained and no debonding between skins and foam core was observed. However, such important aspects as thermal fatigue and optimization of the manufacturing process still need to be addressed. Furthermore, in view of potential applications in hot climates, e.g. on the new EPFL Campus in Ras Al Khaimah (United Arab Emirates), impacts of high and salty humidity and abrasion through sand particles transported by wind need to be taken into account.

2. Objectives

The objective of the proposed research is the investigation of the long-term behavior of multifunctional GFRP sandwich structures with encapsulated photovoltaic cells. It will be investigated to which extent structural integrity and operational reliability can be maintained if subjected to long-term hot and humid climates, such as present in the United Arab Emirates.

Parameters investigated will comprise: sandwich skin and core materials, type of PV cells, temperature cycles (simulating radiation), humidity (including salt), mechanical loading (e.g. walking on the sandwich surface), and abrasion (due to wind sand particles).

3. Methodology

Thermomechanical analytical and numerical models will be developed to predict the short- and long-term deformation, strength and durability behavior of the function-integrated GFRP sandwich structures. The established models will be experimentally validated on specimens as shown in Fig. 2. Answers must be found to three basic fields of questions:

1) Sandwich integrity: PV-cells produce heat during operation (see Fig. 2), which further increases the sandwich temperature (in addition to the temperature increase produced by sunlight). In a first step, this cell-type dependent thermal loading needs to be characterized (no such data exists). Furthermore, the total thermal loading throughout the building service life (up to about 50 years) needs to be described (in particular peak temperatures, their frequency and number). The effects of this thermal loading history on the long-term structural sandwich integrity and performance can then be investigated. Sandwich materials such as GFRP skins and different types of core materials (e.g. polyurethane and PET foams) will be used (similar to those used in the Novartis roof, shown in Fig. 1). Models to describe the thermal fatigue and degradation behavior of the sandwich structure will be established and experimentally validated. In particular the degree of recovery of mechanical properties and resin post-curing subsequent to possible short-term exceeding of the resin glass transition temperature need to be investigated.

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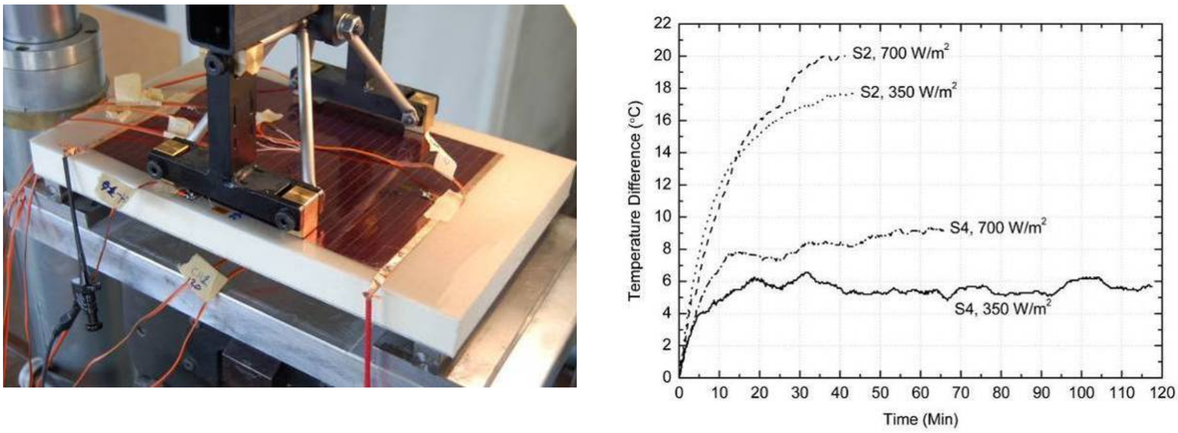

Fig. 2. Mechanical loading of thin-film silicon PV-cell sandwich and temperature increase below cells for polycrystalline (S2) and thin-film silicon (S4) cells at two radiation intensities (Keller et al. 2010)

2) Solar system operation: the integrated solar systems will be subjected to mechanical loading due to composite action. The system endurances, particularly of the connections, need to be investigated. Flexible thin-film cells may offer several advantages compared to brittle polycrystalline cells, such as possible arrangements in curved shapes and far fewer connections due to almost unlimited size, which may both compensate for their lower efficiency.

3) Solar skin integrity: the interfaces between the PV cells and the sandwich skin material needs particular investigation to prevent debonding and assure long-term durability. In particular the thin GFRP skin, which covers the PV-cells, needs to fulfill high requirements regarding transparency, resistance to environmental impact (temperature, humidity, UV radiation, abrasion). Appropriate material selection and the application of protective layers will be crucial.

4. References

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