ANALYSIS OF THE STRESS FIELD IN PHOTOVOLTAIC MODULES DUE TO IMPACT LOADINGS

Mauro Corrado\(^*(1)\), Andrea Infuso\(^2\), Marco Paggi\(^3\)

\(^1\)Civil Engineering Institute, École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland
\(^2\)Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Torino, Italy
\(^3\)IMT Institute for Advanced Studies Lucca, Lucca, Italy
\(^*\)Email: mauro.corrado@epfl.ch

ABSTRACT

In the present work the stress field due to hail impacts on semi-flexible photovoltaic (PV) modules is analysed. Experimental tests and finite element simulations have been performed by considering different arrangements for the stack of layers of the panels and different kind of substrates in order to identify the type of support that minimizes the extension of the solar cell region where high tensile stresses take place under impacts. Practical hints for production and installation of the modules are derived from the obtained results.

Keywords: composites, photovoltaics, impacts, contact mechanics, implicit FEM.

INTRODUCTION

Photovoltaic (PV) modules are complex composite systems constituted by layers having very different mechanical properties and fulfilling different functions. Two main typologies are available on the market: rigid panels with a glass layer on top of the stack of layers which gives rigidity and protection against mechanical loads, and semi-flexible panels, entirely constituted by soft polymeric layers. The former typology is usually installed on roofs or on the ground, whereas the latter one is used on curved supports (typical applications regard sailing boats, motorhomes and mountain refuges). Since they are installed outdoor, the main sources of damage are related to environmental conditions: cyclic thermal loads, wind gusts, snow, and impact loadings due to hail (Meyer and van Dyk, 2004). Among the others, the impact of hailstone is particularly severe for the semi-flexible panels, lacking of the protective glass layer.

EXPERIMENTAL TESTS AND NUMERICAL SIMULATIONS

Low-velocity impact tests have been performed in order to analyse the problem of impact of hailstones on semi-flexible modules with monocrystalline Si cells. A compressed-air apparatus has been used to project a polyamide sphere having a radius of 2 cm at different velocities, up to a maximum value of 20 m/s. As regards the substrate stiffness, two different cases have been considered: a rigid one, in which the PV module is directly laid on a wooden board, and a soft one, for which a cellular plastic layer is interposed between the PV module and the wooden board. The effects of the impact load on the Si cell, invisible by the naked eye, are analysed through electroluminescence (EL) images (Paggi et al., 2014), as shown in Fig. 1. In the case of rigid substrate, the Si cell is completely destroyed in a localized area (dark circle in Fig. 1a). A very different damage pattern is obtained with a soft substrate, characterized by several concentric cracks developing around the point of impact (Fig. 1b).
The problem of the impact of the sphere on the PV module has been also analysed by means of a FE approach. An axisymmetric model has been developed, and the interaction in the dynamic regime between sphere and PV module and between PV module and substrate has been modelled by means of contact mechanics, with a penalty parameter approach (Wriggers, 2006). A fully implicit scheme has been adopted for time integration and for the solution of the nonlinearities. A linear elastic behaviour has been assumed for the materials constituent the layers of the PV module. As an example of the obtained results, the contour plot of the radial normal stress, $\sigma_r$, on the vertical cross-section of the panel at the instant of maximum indentation is shown in Fig. 2. Such results are in agreement with the experimental observation of a more diffused damage in case of soft substrate.

![Electroluminescence images of Si cells after an impact at a velocity of 6 m/s: (a) rigid substrate and (b) soft substrate.](image1)

![Finite element model results. Extension of the damaged zone in the Si cell by varying the substrate stiffness: (a) rigid substrate, (b) soft substrate.](image2)

**ACKNOWLEDGMENTS**

M.C and M.P. gratefully acknowledge the support from the European Union’s FP7 under contract numbers PEOPLE-2013-IEF-628921 and ERC StG 2012 GA 306622, respectively. M.C. and A.I. acknowledge the support of the Italian Ministry of Education, University and Research to the FIRB project 2010 “Structural mechanics models for renewable energy applications”.

**REFERENCES**

