

INFLUENCE OF MECHANICAL LOAD AT LOW TEMPERATURES ON CELL DEFECTS AND POWER DEGRADATION AT FULL SCALE PV MODULES

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ABSTRACT: The scope of this work is the application and evaluation of mechanical load tests on photovoltaic modules for the simulation of wind and snow loads at -20 and -40 °C. This behavior is not taken into account in the existing standards for module certification. For most PV modules, EVA is taken as encapsulation material, which has a low Young's modulus at room temperature absorbing mechanical strain transferred from the top layer to the cells. This Young's modulus rises by several orders of magnitude when the temperature is reduced to -40 °C accompanied by increasing forces on the cells and subsequently cell breakage. Cyclic and static mechanical load tests at three temperatures (25, -20, -40 °C) were carried out at Fraunhofer ISE. The tests have unveiled a correlation between occurrence of cell cracks and the temperature at which the mechanical load was applied. Compared to the applied cyclic load profiles, the profile according to IEC 61215 – 10.16 caused more failures at all temperatures.

Keywords: mechanical load, snow load, wind load, low temperature, dynamic mechanical load, cell breakage, IEC 61215

1 INTRODUCTION

For European design approval, PV modules are certified according to international standards IEC 61215:2005 Ed. 2 (for crystalline modules), IEC 61646:2008 Ed.2 (for thin film modules) and IEC 61730:2004 Ed.1. The mechanical load test included in these standards consists of three cycles of a static load applied to the PV module at room temperature. [1]. Also the mechanical load test in the US standard is performed at room temperature [2].

All these standardized tests aim at testing the stability of the modules against wind and snow loads. As snow loads appear at low temperature, the test conditions represent only partly the reality.

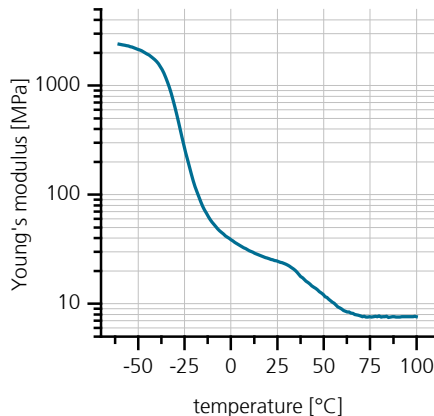


Figure 1: Temperature dependent Young's modulus of EVA from DMA [3]

Ethylene Vinyl Acetate (EVA) is widely used as encapsulation material of solar cells in PV modules. Therefore, PV modules with EVA were chosen for testing. Previous studies [3, 4] show a strong influence of temperature to the mechanical properties of EVA. At temperatures below 0 °C, Young's modulus increases strongly (figure 1). With increasing stiffness, EVA loses its function as a damping layer. Mechanical stress is more directly transferred to the cells. In this study, the

influence of this effect on cell breakage is examined.

2 EXPERIMENTAL

Three different load profiles were set at three different temperatures. Before and after every test, the modules were characterized with respect to performance, electrical safety and cell cracks.

2.1 Test setup

The mechanical load tests were applied by means of special test equipment. The test setup is implemented in a climate chamber (see figure 2) and is capable to test PV modules and solar thermal collectors at temperatures between -40 °C and +60 °C. The equipment is a development of Fraunhofer ISE in cooperation with PSE AG, Freiburg. The project 'MechTest' was funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) (FKZ: 0325968A).



Figure 2: Project MechTest

Due to the possibility of temperature adjustments the test conditions can better reproduce real conditions. The load is applied by means of stamps. The setup also allows testing of modules and mounting racks at different tilt angles.

2.2 Testing procedure

Three different load profiles were defined. Each of them was conducted at three different temperatures (see figure 3). In total, nine monocrystalline modules and nine polycrystalline modules were tested with one module in each load scenario and temperature. All tests were performed by using the same test setup (see figure 4).

Load scenario 1 was a cyclic load test which is with 1000 Pascal at a frequency of 0.1 Hz based on a draft for dynamic mechanical load testing (planned IEC 62782). At this load, overall 1750 cycles were completed per module. **Load scenario 2** was a quasi-static load test according to IEC 61215 – 10.16 with a maximum load of 5400 Pa as qualification for heavy ice and snow loads. **Load scenario 3** was a cyclic load with 2400 Pa in overall 1000 cycles. The load was deduced on a wind load of 130 km/h with a safety factor of 3, according to IEC 61215 – 10.16.

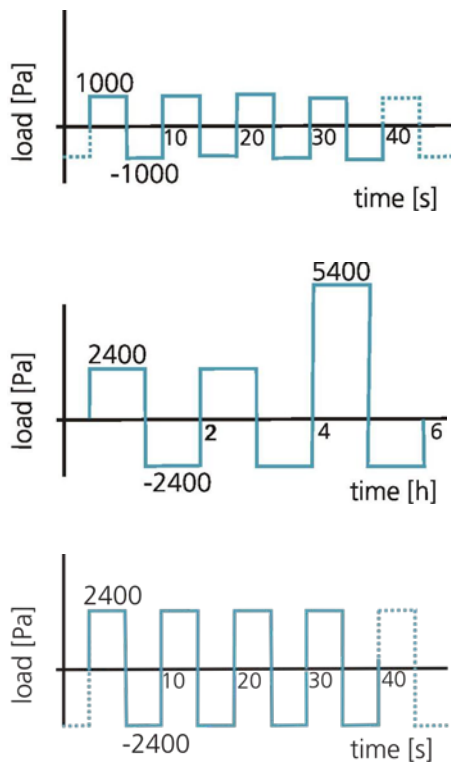


Figure 3: Load profiles – top: 1000 Pa cyclic; mid: IEC 61215 - 10.16 snow load test; bottom: 2400 Pa cyclic.

As described in 2.1, in the used test setup the load application on the module surface was carried out by several stamps that passed on the load from pneumatic cylinders (fig. 4). Subsequently to the described test cycles, one additional test was conducted. In this test, the load was applied by means of sandbags in order to investigate the influence of the stamps themselves. The 'sand-bag' method is assumed to be a more homogeneous load application (figure 5).

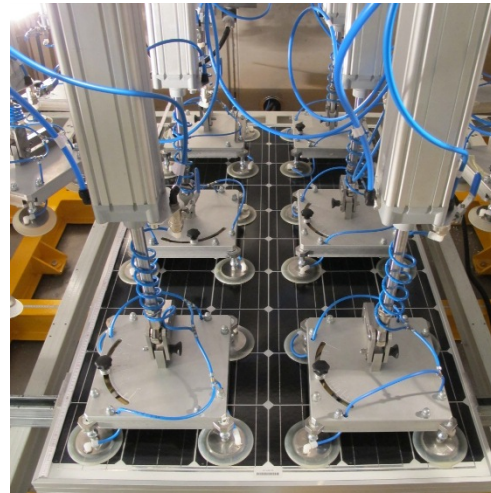


Figure 4: Test setup with pneumatic cylinders



Figure 5: Test setup with sandbags at -40 °C

3 RESULTS

Comparing the influence of the three applied load profiles, the results indicate that the cyclic scenarios (fig. 3, top and bottom) result in less power loss and cell defects compared to the quasi static load scenario (fig. 3, mid). Figure 6 and 7 show the loss of power and the increase of cell defects for all three load scenarios at a temperature of -40 °C.

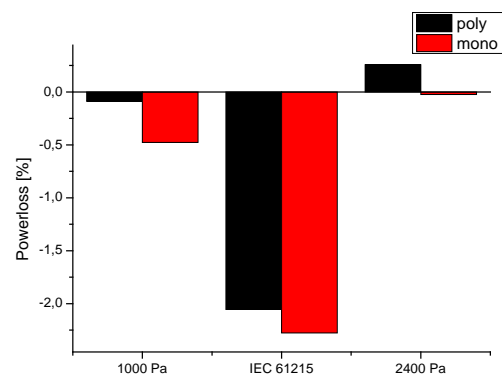


Figure 6: Power loss

In comparison to the other load profiles, the highest impact was found on the module performance and number of new cell breakages after the application of the mechanical profile according to IEC 61215 – 10.16.

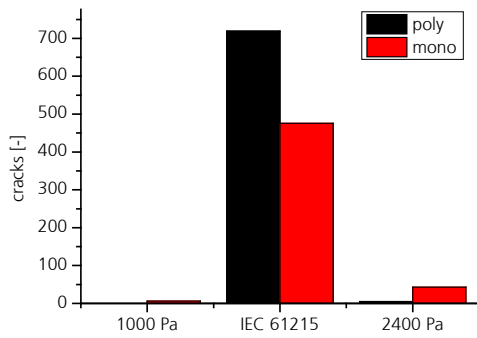


Figure 7: Counted cell cracks

The influence of the test temperature is clearly visible comparing the results of the conducted tests according to load profile two. Although this show only a slight power loss at $-40\text{ }^{\circ}\text{C}$ ($\sim 3\%$), the number of cracks rises by several orders going to low temperatures (see figure 7 and figure 8).

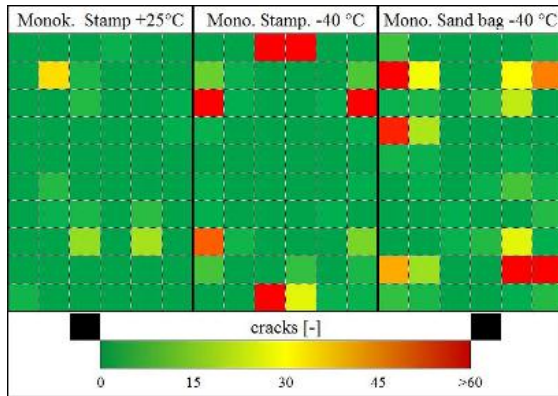


Figure 8: Distribution of cell cracks with different test scenarios

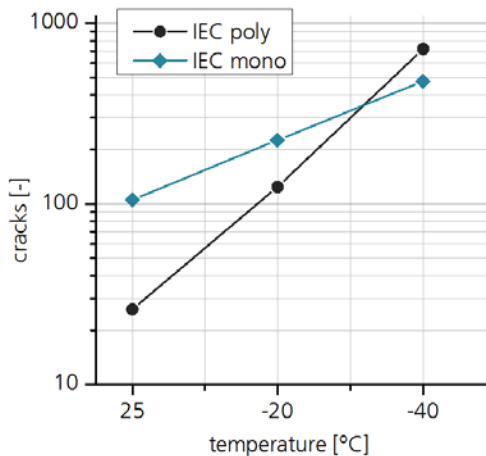


Figure 9: Number of cell cracks depending on test temperature

Additionally, the deflection of the PV modules has been measured. Decreasing test temperature shows a decreasing deflection of the PV modules under

mechanical load (see table I).

The increasing stiffness of EVA itself should have no measurable influence on this effect but lead to stronger force transmission into the cells. Out of this, the cells are slightly participating in total stiffness of the PV modules at lower temperatures, reducing the deflection.

Table I: Module deflection (in mm) under load, mid of module, polycrystalline PV module

	+25 °C	-20 °C	-40 °C
5400 Pa push	31.1	29.8	28.7
2400 Pa pull	-22.7	-21.5	-18.9

The test with 5400 Pa at $-40\text{ }^{\circ}\text{C}$ using pneumatic cylinders shows a remarkable local distribution of cell cracks on the electroluminescence (EL) image. Some cells with multiple cracks are showing an overlap with the position of the stamps. Testing with 5400 Pa using the sandbags method also shows many cell cracks but the local distribution is different (see figure 10). The pattern of cell cracks is forming a path to the module corners.

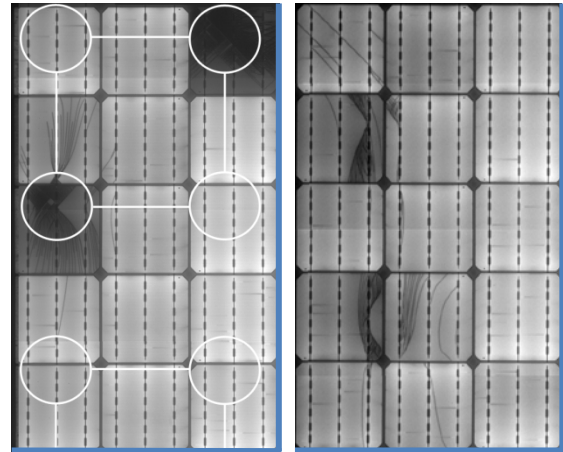


Figure 10: Crack pattern from different load types; left: stamps, right: sandbags (top-left-quarter; EL)

4 CONCLUSION

- The influence of the temperature on cell breakages and power loss could be detected applying a load profile according to IEC 61215.
- There is less deflection at low temperature under mechanical load. This might be a result of higher module stiffness, resulting from higher stiffness of the EVA and force absorption by the cells.
- Mechanical load test at $-40\text{ }^{\circ}\text{C}$ resulted in many cell cracks and a significant loss of power. However, none of the tests led to a power loss of more than 5 % which is the fail criterion acc. to IEC 61215.
- Cyclic testing with a load of 1000 Pa and 2400 Pa showed no significant power loss. The number of cell cracks is very low compared to testing according to IEC 61215 – 10.16 with 5400 Pa.
- Considering the influence of low temperature, there is no systematic difference between the tested mono and poly crystalline cell type.
- It has to be kept in mind that the results referred to in this paper are gained from tests with high quality

modules and cannot be transferred to other module types.

- Testing at -40 °C with sandbags instead of pneumatic cylinders shows also significant cell damages. The local distribution of cell cracks is different.

5 REFERENCES

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