Glass-free lightweight solar modules for integrated photovoltaics: the use of *Velcro as* an alternative mounting system

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ABSTRACT: For some PV applications, the weight of c-Si PV modules is a crucial aspect that needs to be addressed. Commercial and industrial buildings sometimes cannot be designed for conventional rooftop solar installations, especially without costly structural improvement. Also particular PV systems, such as, PV elements for foldable parking roofs or greenhouses need lightweight modules to enable cost effective mounting structures. Often, when old buildings undergo renovation, excessive loads are often not well tolerated by roofs or other architectural structures (e.g. facades). The adoption of conventional PV in these contexts could represent a crucial limit. The use of Lightweight modules appear very attractive, especially for the building-integration of photovoltaics (BIPV), Building Applied Photovoltaic systems (BAPV) as for Vehicles integrated PV (VIPV), due to their reduced weight and strong improvements in durability. One of the great advantages of using a lightweight module structure stands in the possibility to develop a cheap and practical mounting system solution. This is currently becoming a relevant topic, as the share of costs for mounting structures has significantly increased in the last years. Considering the option of "frameless lightweight modules" may also have a dramatic effect in lowering the transport costs.
With this work, an alternative installation for lightweight (~6 kg/m^2) photovoltaic module is proposed. Modules with a composite sandwich backsheet and a polymeric frontsheet structure were manufactured with a new mounting system based on the use of *Velcro (Hook-and-Loop)*. We demonstrate how this alternative mounting system allows a fast and easier mounting that comply with the static mechanical load test present in the IEC 61215.

Keywords: lightweight PV modules, mechanical load, *Velcro (Hook-and-Loop)* , mounting system

1 INTRODUCTION

In several countries, BIPV and BAPV solutions could prospectively contribute to the growth of total installed PV capacity as they enable electricity production with minimal impact on free land [1]. However, the relatively high weight ($\geq$ 15 kg/m^2) of existing glass/glass BIPV modules, the usually high operating temperature and the complex mounting may constitute a barrier to the diffusion of PV in the built environment [2], [3], [4]. This work wants to demonstrate the possibility to simplify the transport and installation of modules intended for BIPV, BAPV and for integrated PV systems in general [5], thanks to the reduced weight of the module and to the introduction of an easy, cheap and fast mounting system based on the use of *Velcro*.

The basic concept of standard c-Si PV modules has not changed significantly in the last couple of years and has proven its long-term reliability. However, the concept also has some inherent structural drawbacks. Due to the laminates dimension and weight, there are considerable aspects, which have to be considered in the module design, particularly because of the large open laminate area [6], [7]. The stiffness of a standard c-Si module is depending on the frame and the front glass; both components are also the heaviest parts of the module structure. Reducing the dimensions and weight of either frame or glass directly results in a lower mechanical stability. Standard glass/backsheet modules with circumferential frame also have a large unsupported central laminate area, for glass/glass modules there are similar issues leading to a considerable dishing of the central laminate area if a mechanical load is applied, which may result in a damage of the module. Using significantly thinner glass as a replacement in the conventional structure is therefore not a suitable mean to obtain reliable modules with reduced weight. Another disadvantage of BIPV modules is the complex and time-consuming PV installation process, related to the accurate positioning of the modules on the mounting sub-structure.
The scientific innovation lies in the use of a thick composite sandwich element (based on glass fibers reinforced polymer and a honeycomb core) as BIPV and BAPV element. Most lightweight concepts for c-Si however use alternative materials to glass, e.g. ETFE as transparent medium at the front side, supported by a rigid material such as glass fibre reinforced plastic at the laminates rear.
Figure 1 shows the different layers of the proposed lightweight module and the arrows shows where the *Velcro (Hook-and-Loop)* is placed (at the backside of the skin). The lightweight module is composed of a composite sandwich structure (made of two skins of glass fiber and one core – aluminum honeycomb– joined together with an adhesive), solar cells embedded in a polymer layer and protected by a thin frontsheet (ETFE). With this material selection, we reduce the module weight up to 70%. We demonstrate that by using *Velcro,* we can further simplify the full installation process of BIPV modules.

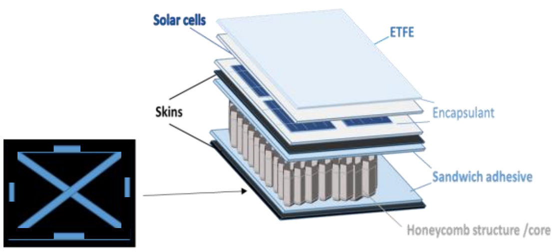

Figure 1: Schematic of a lightweight PV module structure and the location of the investigated material for lightweight PV modules installation: Velcro (Hook-and-Loop).

2 EXPERIMENTAL WORK

2.1 Adhesion test

The adhesion test was performed to study the force needed to open a part/separate the two Velcro bands.
5 cm × 2.5 cm coupons were cut from a Velcro strip, then glued on two compressive plates, installed in a tensile tester, as shown in Figure 2. The test was performed using an Instron Zwick Roell Z020 mechanical testing instrument. A load cell of 20 kN and a speed test of 5 mm/min were used for this measurement. The same sample was loaded until rupture, 15 times, to evaluate the loss in adherence between the two Velcro bands.

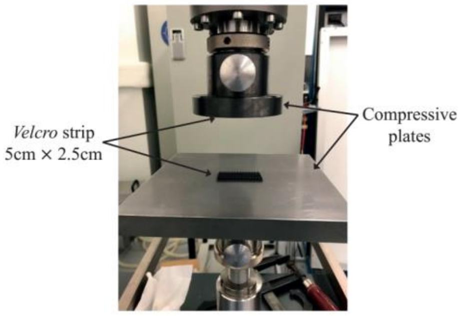

Figure 2: Tensile adhesion test setup used to quantify the adherence between two Velcro bands. The picture shows the two compressive plates in which the Velcro strips (5cm×2.5cm) are glued on.

2.2 Static mechanical load test (ML)

The static mechanical load test applied a load of±2400 Pa to the surface of a LW PV-module to determine module's ability to withstand wind, snow, static or ice loads according to the IEC61215:2016 [9]. The test is performed on 16-cell modules (810 mm × 810 mm) and fixed Velcro wasused to glue the backside of the module in a square/cross configuration to an aluminum plate (see the inset in Figure 3). A total Velcro area of 0.05 m^2 is used.
Electrical performances (*IV* curve) and EL images are acquired before and after the test.

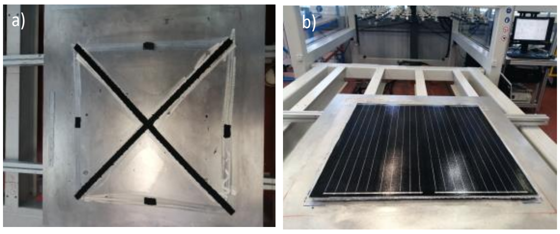

***Figure 3**: Velcro used to bond the backside of the module a). Static mechanical loading performed on sixteen-cell modules: LW PV module placed on the Aluminum plate by using the Velcro, with no loading b).*

3 RESULTS AND DISCUSSION

3.1. Innovative mounting system – Velcro

We propose an innovative mounting system that allows a simple and fast lightweight PV modules installation: *Velcro (Hook-and-Loop)*. This binding material was already used in the built environment [8]. Hook-and-Loop/Velcro is a cheap material (<US$ 0,10), commercially available in different qualities and shapes (dots, stripes). This system may provide considerable advantages: it will reduce the labor and installation time, it is a simple and clean mounting system, it is even easy to remove (in case of needed PV maintenance), and it can resist high loads (average tensile disengagement of 207 KPa).
Figure 4 the *Velcro* adherence strength between two *Velcro* strips. In a tensile configuration, the small pins are pulled until a plateau load is reached (~1.7 N/cm^2). This plateau corresponds to the alignment of all pins. Once the plateau has reached, the load increases until the two *Velcro* bands are completely de-bonded (19.8 N/m^2). The repeatability of the test (performed 15 times) was proved, since the plateau was constantly reached, with respect to the maximum load applied, which was reduced, by approximately 40%, each measurement (between the test 1 and test 15). Thus, to assess the *Velcro*'s ability to function as mounting system, the minimum required adherence strength to support the 2400 Pa was chosen as the plateau value.

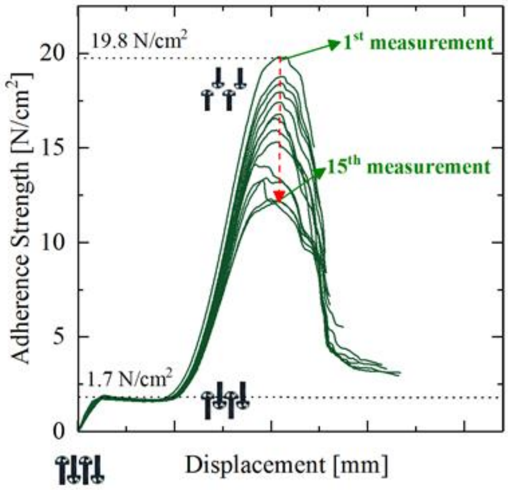

Figure 4: Adherence strength of Velcro in a uniform tensile load test.

To validate these last results a static mechanical load test was performed. In this test, *Velcro* is used to bond the back side of the module, in a semi-square/cross configuration, to an aluminum plate (Figure 3a)). A total area of 0.05m^2 *Velcro* was used. Figure 5 shows the load cycles applied to the module fixed with *Velcro*. Note that this configuration survived the mechanical load test without de-bonding effect. The noisy signal, visible during the suction phase (+2400 Pa), is due to the difficulty to keep a constant vacuum, because of the textured surface of the module frontsheet. Preliminary results indicate that covering only 7.3% of the back surface area with *Velcro* is enough to pass a standard static mechanical load test (± 2400 Pa).

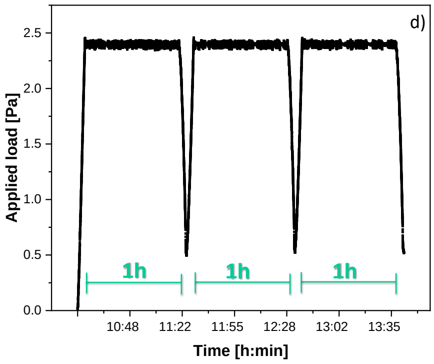

Figure 5: Schematic graph of the applied load versus time:3cycles of 1hour each with 10s of pause in between (d).

The PV module was placed on an aluminum plate and the cycles have been performed only in “suction mode” (and not in “pressure”) since we wanted to simulate the integration of the LW PV module on a rigid surface, as for BIPV or VIPV applications.

3.2 16-cell LW PV module

As part of the results obtained from our parallel study (presented for EUPVSEC-2020- *Optimisation of the frontsheet encaspulant for increased resistance of lightweight glaSS-FREE solar PV modules),* we propose a BIPV module design, which is contemporarily lightweight, rigid and resistant to the relevant climatic and mechanical stresses (e.g. exposure to DH, UV, hail impacts, etc).
The lightweight module (as sketched in *Figure 1*) is so composed of:

- <u>Backsheet,</u> a composite sandwich structure, made of *two skins of glass fiber* and *one core – aluminum honeycomb–* joined together with an *elastomeric adhesive*),
- <u>*Frontsheet*</u> stack, made of *solar cells* embedded in polymer layers (a combination of *thermoplastic* and *elastomeric polyolefines*) and externally protected by a *thin layer of ETFE.*

For this work 16-cells LW PV modules have been subjected to the static ML test (

Figure 6), performed as described in 2.2, to assess the robustness and the reliability of the alternative mounting system easy to integrate into many mobility applications (BIPV, vehicles, boats).

Figure 6: Static mechanical loading performed on sixteen-cell modules: (b) LW PV module placed on the Aluminum plate by using the Velcro, with loading.

This configuration survived the mechanical load test without debonding. None of the modules showed any visual damages after the hail test (no cracks visible by naked eye). The IV measurements and electrical performance, before and after the ML test, were performed and represented in Figure 7. These results clearly indicate that the power loss was <5%, as one of the criteria required to pass the test ($P_{before} - P_{after} < 5\%$), following the IEC 61215.

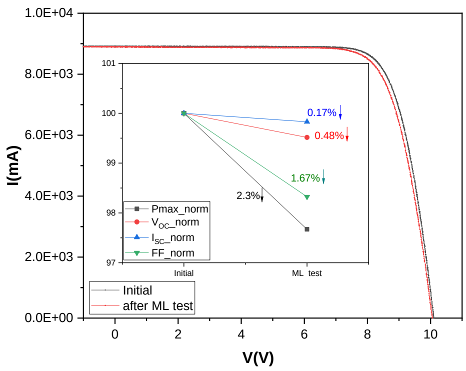

Figure 7: IV curves and electrical performances before and after ML test.

The EL images acquired after the ML test show a few damages, initiated by defects already present in the solar cells (Figure 8-After ML test). These defects possibly occurred after the lamination process; they are in fact visible in the EL analysis performed prior to the test (Figure 8- Before ML test).

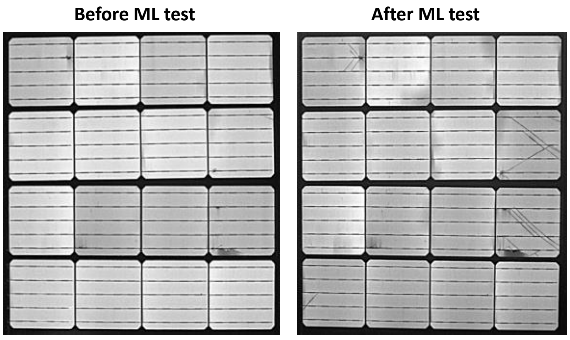

Figure 8: EL images of the 16-cell module manufactured using the optimal combination of FS and BS before (b) and after (c) the ML test (solar cells defects present on the EL images were visible even before the ML test).

After the test, no dramatic power loss or solar cell cracks was detected.
In our lightweight modules, the full rigidity is provided by the combined effect of the composite backsheet sandwich structure and the optimised frontsheet design.

4 Conclusions

With this work we show the potential to use glass-free lightweight PV modules with a weight of 6 kg/m^2 as building component for BIPV, BAPV and in general for integrated PV applications. We demonstrate that *Velcro* fixation system is a good alternative, providing a secure and durable mounting of ligthweight modules. The use of *Velcro* bands could contribute to the reduction of time and complexity of the mounting as transport costs of BIPV, BAPV and Vehicles integrated PV (VIPV).

In conclusion, this work shows that thanks to the innovative design proposed and careful selection of an alternative material for installing lightweight solar modules, it will be possible to introduce a valid cheap, fast, innovative option to the traditional glass-glass PV configurations. A range of PV lightweight modules (from 2-cells mini modules to 16-cells modules) has been mounted and outdoor exposed (on the roof of our research building) by using the Velcro approach. A close monitoring check will occur over the following months. Testing the reliability of this alternative installation system, being it exposed to external environmental conditions, for a range of time of 12 months, at least, would provide a reasonable indication of the real performance of the material investigated, Velcro. Further work will aim to scale up the lightweight module structure and test the Velcro mounting system when larger structures will be installed.

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