RECORD-LIGHT WEIGHT C-SI MODULES BASED ON THE SMALL UNIT COMPOUND APPROACH – MECHANICAL LOAD TESTS AND GENERAL RESULTS

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ABSTRACT: The “small unit compound” (SUC) concept [1] allows the preparation of very light weight c-Si solar laminates utilizing thin glass or plastic materials. A main difference to the common module type is the replacement of the frame at the laminates fringe by a lattice-like structure at the rear or at the rear and front side. Due to the small distances between the mechanical supporting elements which prevent the dishing of the laminate, the stiffness of the laminate itself can be reduced to a minimum. This enables the use of thin glass or alternative materials such as polymer foils. In this paper we present results of mechanical tests with such modules and discuss general results concerning the module lay-out. The paper has a focus on glass/glass and glass/backsheet laminates with glass thicknesses of 0.8, 1.1, 1.6 and 2 mm. A 60 cell glass/backsheet module 0.8 mm front glass with a weight of as low as 6.3 kg (without junction box and cables) has been fabricated. According to our knowledge this is the lowest weight for 60-cell c-Si modules with front glass ever reported. First hail resistance tests show that these modules may surpass the IEC 61215 norm. Only slightly lower weights are possible if alternative materials are used instead of glass for the front side cover.

Keywords: PV module, new concept, compound, new material, construction

1 INTRODUCTION

For some PV applications the weight of c-Si PV modules is an obstacle. Particularly roofs of commercial and industrial buildings are sometimes not suited for conventional rooftop solar installation without costly structural improvement. In addition some special PV systems, e.g. PV elements for foldable parking roofs or greenhouses need lightweight modules to enable cost effective mounting structures [2].

In general, a lower module weight may also result in more lightweight and thus cheaper mounting solutions. This fact is increasingly relevant as the share of cost for mounting the PV modules has increased significantly in the last years due to the falling prices of PV modules. Thin light weight modules without frame may also drastically enhance the packing density and therefore have a great potential to lower the transport cost.

The segment of light weight modules can be subdivided in thin film and crystalline silicon modules. Light weight thin film modules are mainly flexible structures intended for a flat installation on roof tops. However, a horizontal positioning on the ground is unfavorable with regard to energy harvest, soiling and residual water, which can lead to faster degradation of the modules. Most light weight 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 [6]. However, there are also approaches for light weight c-Si PV modules on the basis of glass/backsheet and glass/glass laminates.

Standard, 60 cell, crystalline silicon glass/backsheet modules typically have a weight in the range of 18- 22 kg, depending on the thickness of the glass and the frame. This results in a specific weight of about 12.5 kg/m^2. The mechanical rigidness is due to the glass and a circumferential aluminum frame.

Glass/glass modules are gaining market share, due to a presumed longer lifetime and other benefits such as the potential bifaciality. Glass/glass modules may be mounted without an additional frame depending on the thicknesses of the glasses and the sub construction used. Light weight glass/glass modules have been reported from Fujipream achieving a weight of 8.2 kg using glass thickness as low as 1.1 mm and an ionomer– based encapsulant [3, 4]. The size of the 215 Wp module is not given in the references, therefore a specific weight cannot be calculated. Currently heat strengthened solar glass is commercially available with a thickness in the range of 2 mm. We have included thermal strengthened glass with a thickness of 1.6 mm. Thinner glasses are, to our knowledge, chemically strengthened and by far more expensive. However there are ongoing research activities, which aim at thermally strengthened glass with 1 mm thickness [5].

Modules using alternative materials to glass are commercially available and achieve specific weights of as low as 2.74 kg/m^2 [6]. These semi-flexible modules use a polymeric material as front sheet and glass-fibre reinforced plastics to obtain sufficient mechanical stability.

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 forces which have to be considered in the module design, particularly because of the large open laminate area [7].

The stiffness of a standard c-Si module is basically 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 means to obtain reliable modules with reduced weight. Even though inexpensive, thermally hardened 2 mm solar glass is readily available it cannot replace the typical 3.2 mm glass in a standard glass/backsheet layout. Obviously, the use of glass with thickness below 2 mm or alternative materials such as polymers or GRP is even more problematic.

One option to achieve sufficient mechanical bending strength is to use a rigid supporting structure on the back of the module. A different approach to prevent dishing for light weight c-Si laminates uses a lattice instead of a backing plate [1]. Compared to a standard module the laminate area is now subdivided into smaller units. This results in reduced lever arms between supporting points and suppressed dishing. Due to the subdivision of the modules in smaller mechanical segments the modules are named Small Unit Compounds (SUC) modules. The beams can be positioned on the modules rear side or on the rear and the front side. The latter lay-out may be of particular interest for glass/glass modules or other concepts with symmetrical lay-out, because the cell matrix within the laminate is then along the neutral fibre.

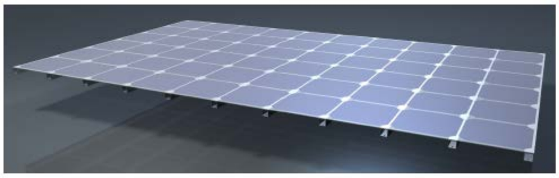


Figure 1: SUC modules with conventional glass/backsheet laminate and lattice structure at the rear.

In this approach, drawing a dividing line between module laminate and sub-construction cannot be done so easy any more. The function of the sub construction is normally to fix the rigid module onto the building or mounting structure. In the new approach, the sub-construction has two functions: enhance the mechanical rigidness of the module and fixing the module to building or mounting structure.

This aspect has to be considered when weights are compared. In this respect it makes more sense to compare weights of complete installed systems (module together with sub-construction) rather to compare the modules / laminates itself. However, when comparing complete systems, one has to consider the different prerequisites. PV modules installed on a flat roof with a tilted angle for example, need additional mechanical elements comparing to a modules installed flat on a tilted roof.
Also for measuring the mechanical stability it makes sense to measure the complete system consisting of the relevant part of the sub-construction together with the module laminate.

Furthermore the approach of assigning functionality of the mechanical rigid module to the sub-construction opens the door to transport extreme lightweight PV laminates and increase the packing density considerably by reducing the module height due to the missing frame. Increasing the packing density will decrease the transportation costs of PV modules.

2 MECHANICAL LOAD TESTS

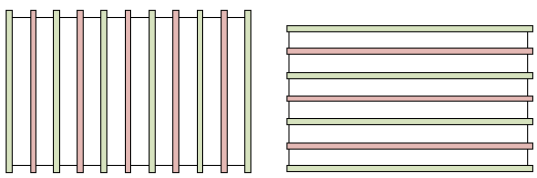
Different SUC designs with lattices and beams (mainly aluminium, but also GRP) were tested, mainly in form of rear side support structures with several laminate types. For each laminate/lattice structure combination the bow was determined as a function of load. Loads up to 285 kg per m^2 (480 kg in total) were applied, which is above the 240 kg/m^2 as required by the IEC 61215. In order to enable a comparison with the state-of-the-art a standard glass/backsheet module (3.2 mm glass/frame) was tested in the same manner; also the weights of the respective structures are compared.

The experiments with different set-ups focused on two groups of designs. The first group of trials was carried out with a comparatively conventional 60 cell glass/backsheet laminate with 2 mm glass thickness. Beams with different arrangements, diameters, weight and material were applied to this laminate type in order to reveal general trends and to measure the resulting bow when exposed to mechanical load.

In the second group of trials different laminate structures with thinner glass and alternative material were respectively tested with two sets of rear side beams (same dimensions but with two different arrangements). Glass/glass and glass/backsheet laminates (60 cells) were prepared with 0.8, 1.1, 1.6 and 2 mm glass thickness; also a glass/backsheet laminate with 3.2 mm glass and a flexible laminate based on GRP were included in the experiments. Again the respective bow was determined for different loads up to 2854 Pa. The 0.8 mm and 1.1 mm glass is a non-standard, chemically hardened solar glass since heat strengthening is not possible for this low solar glass thickness. Latest tests have been performed on glass/backsheet laminates using a 1.6 mm thermally strengthened glass.

The mechanical tests have been performed by using a test rig on which the tested module is loaded with sand sacks with a weight of 12 kg each. The sand sacks were positioned in a defined sequence in order to achieve a homogeneous load.

Different module lay-outs were tested and already presented earlier [1]. It was found that a real lattice structure is not superior to simpler lay-outs with supporting beams parallel or perpendicular to the length axis of the laminate, see figure 2. When installed, the respective ends of the small beams at the rear side are connected to two perpendicular oriented main beams of the mounting. For the lay-out with beams parallel to the length axis (figure 32) an additional central support is beneficial to obtain the best results with regard to weight and mechanical stiffness. The lowest weight of the total system was obtained with the shorter beams as depicted in figure 3a. In order to carry out mechanical load tests the mounting system is replaced by the test rig.



a) b)

Figure 2: Positioning of the supporting beams; either perpendicular (a) or parallel (b) to the length axis of the laminate.

Even though some experiments were carried out with beams made of glass fibre reinforced plastics (GRP) aluminium beams were used as standard. Using GRP instead of aluminium may be beneficial in several regard, particularly if a real lattice structure has to be applied, as intersections could be easier realised than with aluminium beams. Using GRP leads however also to additional issues, such as the connection to the laminate, UV stability and cost. Since very low weights in combination with sufficient mechanical rigidness's were obtained with layouts as shown in figure 3a and 3b using aluminium beams, we focused on these approaches for the moment.

Figure 3: Laminate with applied mechanical load in form of sandbags on the back side of the laminate.

3 EXPERIMENTAL RESULTS

When using very thin glass, hail testing is an obvious issue. First hail tests according to the IEC 61215 norm had been performed. Deviating from the norm, the velocity of the ice bullet was not measured in situ. The setting was adjusted in order to ensure a velocity of the ice bullets with a diameter of 25mm to be higher than 25 m/s. Up to now we found no indication (IV-measurement, EL) for a significant damage even for laminates with 0.8 mm glass (glass/backsheet laminates with 0.8 mm glass still have to be tested).

By comparing the dishing of laminates with different glass thicknesses it was found that the influence of the glass thickness on the mechanical rigidness is negligible for glass thicknesses of 2 mm and below [1]. The mechanical stiffness is only determined by the amount, the cross section and the orientation of the supporting beams.

Figure 5 shows the mechanical stiffness of designs with differing supporting beam lay-outs (amount of beams, cross-section, and material) obtained by mechanical load tests. The general lay-out, which was used in this particular series, corresponds to figure 3a. The stiffness is reflected by the bow of the central laminate area (dishing), which is caused by the applied load. It is not surprising that the stiffness is increased with increasing amount and increasing thickness of walls of the beams. From figure 5 it can be seen, that configurations using 6 or 11 supporting beams result in a less pronounced dishing compared to the reference module (3.2mm glass/backsheet, Al-frame).

It is assumed that the measured dishing is an appropriate means to appraise the potential damage to the cell matrix within the laminate. While the assumption may not be perfectly valid on all regards, e.g. due to local bending effects, it probably gives a very good indication if the IEC 61215 can be passed.

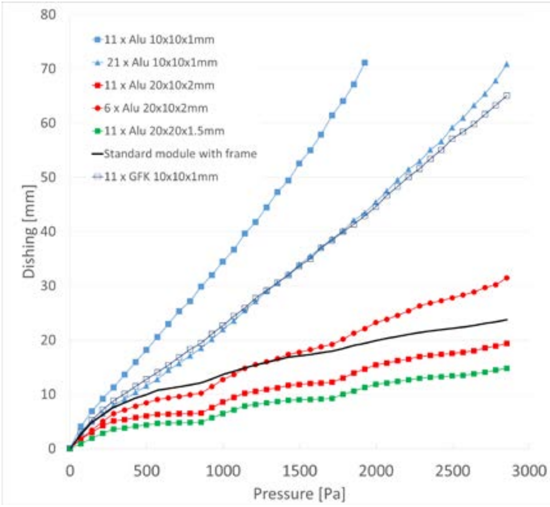


Figure 4: Maximum dishing as a function of the mechanical load for different types of supporting beams. The supporting beams are orientated parallel to the short edge of the laminate (see figure 3a). The supporting beams exhibit different cross sections and wall thicknesses as indicated. All beams are made out of aluminum except one built out of glass fiber reinforced plastic (GRP). The measurements were done on glass/backsheet laminates using a 2 mm thick front glass. A standard glass/backsheet module (framed, 3.2 mm glass) is shown as a reference.

A final approval of the system can only be achieved, if the whole mounting system has been designed and tested. This aspect makes the tests more complicated. Corresponding tests were also carried out; an example is shown in figure 5.

Figure 5: PV laminate and sub-construction under load demonstrating the mechanical stability of the construction.

Testing of the specific example shown in figure 5 showed that the total system, including the sub-construction, is mechanically stable Dishing could be limited to values below the ones observed for standard modules with frame.

4 DISCUSSION, CONCLUSION AND OUTLOOK

The replacement of the module frame by a lattice like structure opens the path towards the use of glass with thickness equal or below 2 mm or the use of very thin and flexible non-glass laminates. It could be shown, that with this approach, the dishing of modules under mechanical load can be limited to similar values of standard modules at considerably lower weight. Also first hail tests indicate that such light weight modules with thin glass could be an alternative to standard modules.

Figure 6 shows a system using a Tritec sub-construction which was adapted by us to mount SUC modules as presented in this paper. The Tritec sub-construction is designed for the installation of framed standard modules on lightweight corrugated metal roofs, e.g. on industrial buildings [8]. In this design the modules are in landscape position, as mainly used for flat roofs and east/west orientation. The tilt angle is adjustable in the low angle range around 15°. The basic layout of the beams corresponds to the one shown in figure 3 b. For this layout it was found to be beneficial to insert an additional central mounting beam, parallel to the two mounting beams at the short sides. The module layout is shown in figure 7 in more detail.

Figure 6: Modified sub-construction based on a Tritec mounting system for corrugated metal roofs. The sub-construction is adapted to the mounting of a SUC-module with rear side aluminum beams. In this example a frameless glass/backsheet with 0.8 mm glass thickness has been applied.

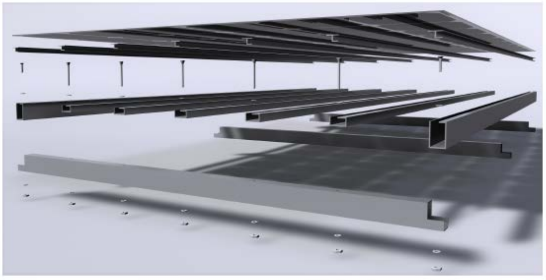


Figure 7: Assembly drawing of the laminate with seven aluminum profiles parallel to the long side of the module and three crosswise oriented bars.

Even though the shown example was not optimized with regard to the system weight a considerable weight reduction to the standard could be obtained. (see table 1) The new approach results in a weight reduction of 5.1 kg (module and sub-construction) using standard aluminum profiles available on the market. According to our calculations a further weight reduction of 3.4 kg would be possible by increasing the aspect ratio of the aluminum bars.

Table 1: The total weight of the designed system of figure 6 compared to a standard system.

System	Module weight + sub con. [kg]	Gross weight [kg]	Gross weight per area [kg/m^2]
Construction see fig. 6	6.3 + 11.1	17.4	10.5
Standard	19.7 + 2.8	22.5	14.1

This would, by keeping the mechanical stiffness, lead to a gross weight of only 14 kg and a weight per area of only 8.8 kg/m^2 for the whole system.

From BenQ a light weight glass/backsheet module is commercially available. The module has a weight of 10.5 kg [9]. Our module laminate itself has a weight of only 6.3 kg (3.9 kg/m^2). To our knowledge, this is the lowest ever reported value for a glass/backsheet 60 cell module. Including the cross bars the weight increased to about 9.5kg (5.9 kg/m^2), depending on the orientation and cross section of the bars. It has to be mentioned however, that the module of BenQ has already a mechanical supporting structure resulting in a mechanical stiffness in all directions without additional sub-construction. In our approach the perpendicular cross bars of the mounting need to be added in order to reach similar mechanical stiffness summing up to similar weights.

Using a supporting beam structure in combination with an ultra-light weight PV module can be an approach for serving a niche market. Even though the extremely thin, chemically hardened solar glasses with 0.8 mm and 1.1 mm did pass the mechanical load and hail tests in our experiments, their price is an obstacle. Thermally strengthened glasses are commercially available (Lisec), making a cost effective light weight glass/backsheet module more likely to be transferred to mass production. The approach would also be suited for ultra-light weight modules using GRP [6].

The SUC laminate design could allow a high packaging density during transportation. In addition the new approach also opens the path for using larger modules, as the mechanical stiffness is no longer depending on the dimension of the frame. Whether the use of large light weight modules could lead to a cost reduction of PV systems by reducing the installation cost needs to be proven. Using large laminates could also be of interest for special applications such as carports.

5 ACKNOWLEDGEMENT

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