Design of Fixation and Rack Solutions for Frameless Thin-film Modules Based on Numerical Calculations

DR.-ING. CEDRIK ZAPFE. ENGINEER'S OFFICE FOR CONSTRUCTION, CIVIL ENGINEERING AND SOLAR TECHNOLOGY – DR ZAPFE GMBH, SCHLETTER GMBH

In view of permanently decreasing compensations for electricity from photovoltaic plants fed into the grid the requirement for economically efficient operation forces innovative optimizations of the system in order to reduce the system costs, until the fundamental target of grid-parity is reached. Besides the increase in the specific module performance, which forms the focus of the increase of cost – efficiency, also the system components have to make an appropriate contribution to the reduction of costs. In this context a forceful material utilization to the limits of the used materials allows a certain saving potential. Further opportunities could be provided by the optimization of mounting and construction maintenance.

Photovoltaic plants generating electricity through solar energy are exposed to the environmental conditions of their respective locations. Wind, snow and temperature impacts create loads, which the modules and their bearing components have to bear reliably throughout the life cycle of the plant. Building regulations in Europe stipulate that, photovoltaic plants are to be regarded as parts of a building or buildings themselves. The designs of these plants are governed by principles of structural engineering and hence static calculations need to be done as per accepted rules of technology and architecture. Due to the political guideline of permanently decreasing compensations for electricity fed into the grid, the economic operation of photovoltaic plants determines rationalizations in the area of module technology, which go along with higher utilization factors of all system components. In this context, thorough static analyses in combination with experimental verifications are indispensable, in order to avoid damage during the operating life of the system.

Fig. 1 contains a sample of fixation methods. There are fundamental requirements on a solar module from both a constructional and a construction operational point of view. Thereby, the characteristic of cost-efficiency is in the focus. Besides the consideration of the material use and the production expenditure the factors construction maintenance and handling during assembly also play a considerable role. The minimization of the construction maintenance costs leads to the need for frameless modules, for example, so that no drain water can accumulate at the frame, which would lower the yield and require cleaning works in certain cycles. Therefore the use of framed modules becomes more and more limited to architectural applications. In the sector of open area plants with high piece numbers, a considerable cost-reduction can be realized by using frameless modules.

Fig. 1. General fixation concepts (backrail / clamps / spot fastener).

An essential question is the optimum size of the solar modules. On first thought, the basic idea of ever-bigger modules seems to be target-aimed, because that way the number of repetitive mounting steps, the number of connections, and the cabling effort could be reduced. On the other hand, this requires the use of machines for mounting, because, among other aspects, under the aspect of module weight the handling gets more and more difficult for the installers. But mechanization often requires the presence of optimum conditions, for example still air in case of roof mountings or solid, un-weakened subsoil in case of open area mountings. In order to be able to grant planning reliability for the progress of the project, independently of weather conditions, the demand for lighter modules which can be handled by persons, is evidently present. In turn, from that derive a consistent minimization of the glass thicknesses of glass-glass-modules and the adherence to reasonable module measurements. In the most convenient case, one single person should be able to move and mount the module, because then no coordination will be required.

Mechanical Conditions for Glass-Glass Laminates

In case of laminate safety glass often a PVB – encapsulant or an EVA – encapsulant is used between the glass plates to produce the laminate. An essential characteristic of the laminate materials is a distinctively temperature-dependent load deformation behaviour. In Fig. 2I this correlation is shown by means of a stress-strain diagram. This chart makes evident that this material reacts in a very inflexible manner at low temperatures T < 0°. Therefore, in case of open area applications under the condition of a possible snow load, there is only a laminate effect with considerably lower flexibility between the glass plates, as it would be the case in midsummer conditions. At temperatures of over 60°C the flexibility of the examined material is so high that the condition of an independent carrying capacity of the glass plates would have to be regarded as the ultimate limit value.

Besides the temperature dependence the load duration is important in a similar way, because the modulus of shear decreases under permanent load. Under snow load, this leads to an increase of the stresses. With increasing flexibility of the laminate joint (low shear modulus of the laminate encapsulant), the deformations and also the tensions at the edges increase considerably. It is an essential ascertainment in this context that the laminate is only loaded by its own weight and wind impacts during the warm season, whereat the wind has to be regarded as a temporary phenomenon.

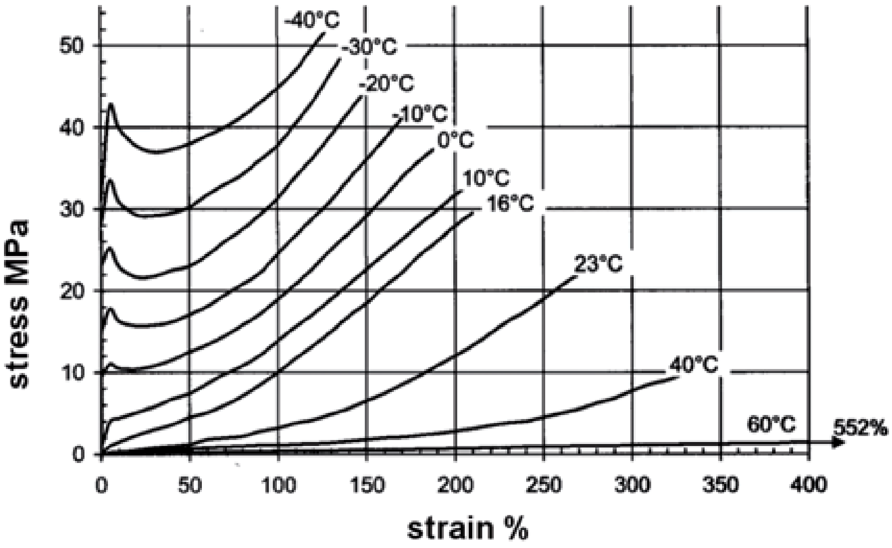

Fig. 2 Temperature dependent strain-stress-diagram of TROSIFOL MB.

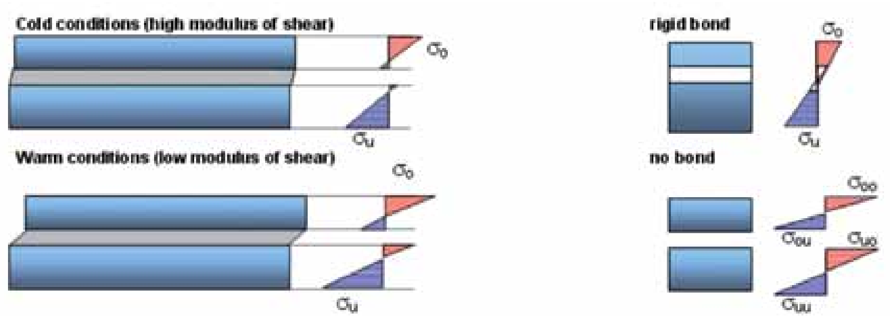

Fig 3. Stress distributions in different thermal conditions and long term loading.

Calculation Methods

The static calculation of glass - glass modules with an elastic composite-layer film is a complex task. In this case the finite elements method offers a suitable instrument to analyze and visualize the non-linear correlations. Thereby, all components are divided into small elements and put in a numeric equilibrium.

Fixation Concepts

At present, a clamping with four module clamps or alternatively inlay-systems have to be regarded as the state of technology in the fastening of unframed glass-glass modules. In the former case, tension concentrations arise in the direct clamping area. For the measuring, the maximum tensions in the clamping area at the sensitive module edge are decisive, whereas the tolerable tensions in the field area are only partially exploited.

Fig. 4 clarifies this correlation for current module sizes. Whereas in case of the module size 1200x600x6,8 with 2·3,2 mm glass and 0,76 mm PVB encapsulant

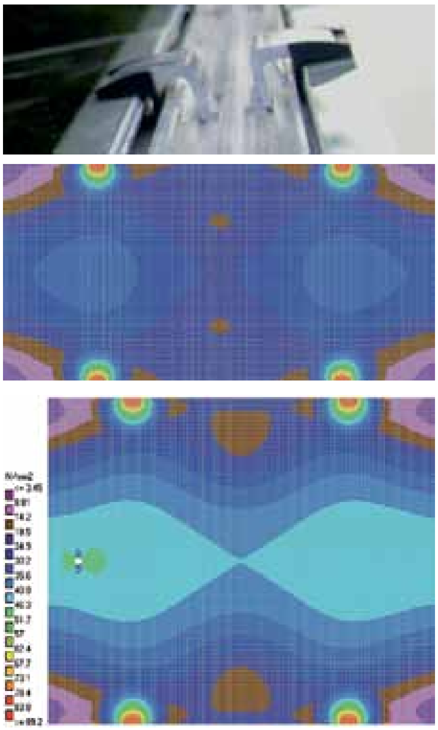
Fig. 4 Stress distribution at clamped modules (1200x600x6,8 and 1300x1100x7,0).

the tolerable tensions of float glass (without safety factor) are adhered to, they are significantly exceeded in case of the module size 1300x1100 with 2·3,2 mm glass and 0,76 mm PVB encapsulant. In the field area the tensions are on a level of about 40 % compared to the clamping area.

Therefore, it seems consequent to relocate the module fastening away from the critical area at the edges of the module towards the inner area of the module surface. Appropriate solution approaches lie in a punctiform or linear mounting, with the fastening elements being glued to the lower side of the modules. Thus, the utilized adhesive has to be considered as the critical point, which has to durably transfer the stresses caused by external loads (self weight/wind/snow) as well as temperature-related restraints for the whole operational life span of the module. In that case two-component silicone adhesives are a good choice, as there is

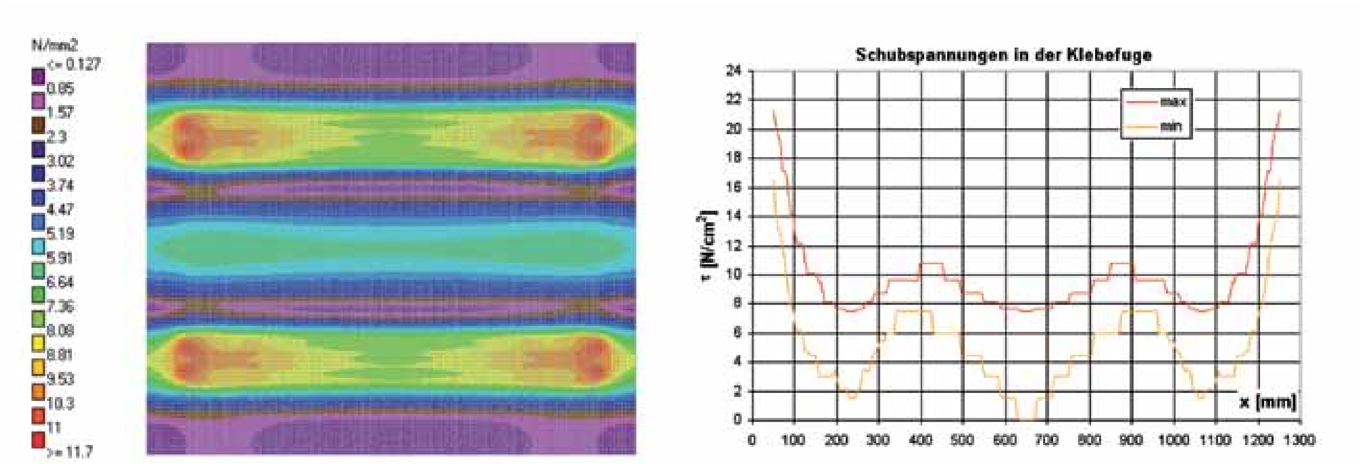

Fig 5 Stresses with backrails (1400x1100x7,0).

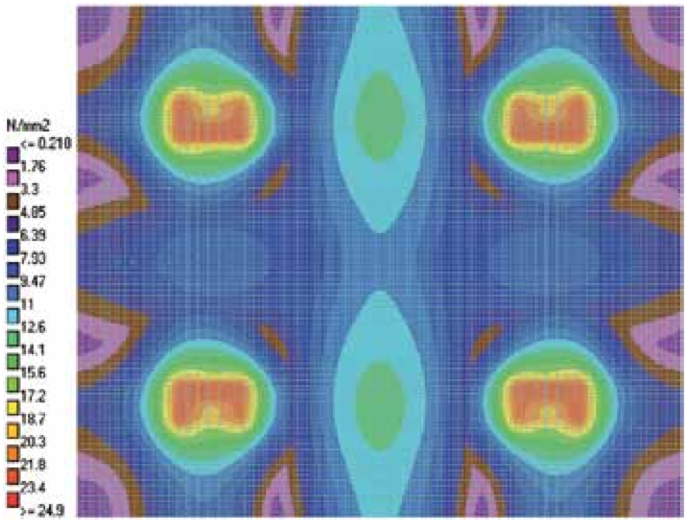

Fig 6 Stresses with Optibond (1300x1100x7,0).

long-term experience from the field of car production for these products. VHB Tapes showed a critical behaviour in internal applicability tests, whereas defined limit values concerning the tolerable shear stresses are available for short-term loads, the evaluation of permanent shear stress is more difficult. Typically, additional mechanical connections are required in this case. Fig. 5 shows tensions in the glass plate of a module equipped with two backrails and the measurements 1300x1100 as well as the shear stresses in the adhesive joint under DIN IEC load (5400 Pa). Even if the glass tensions in case of using backrails can be lowered significantly, permanent shear stresses from composite action arise. The shear stress level is 8-10 times higher than from downhill-slope forces.

Shear stresses in the adhesive joint due to the laminate bearing effect between glass-glass-laminate and thermal restraints can be avoided by choosing spot fasteners in the optimum fastening spots instead of the linear mountings.

Fig 6 shows the maximum tensions in a 1300x1100 mm and 3,2 mm glass-glass-laminate with the Optibond® system by the Schletter solar mounting GmbH (limited company) with a specific glueing area of 120 cm^2 per fastening spot. Due to the system, the reduction of the tensions in the glass does not reach the level of the large-surface linear mounting of backrails. Anyway, the glass tensions are within the range of tolerable glass tensions. Due to a low material usage and a significantly smaller glueing area the application of glued-on punctiform – fasteners seems reasonable from an economic point of view, especially as no limitations concerning safety are to be expected.

Conclusions

Systematic numeric analyses allow the development of technically and economically optimized fastening strategies for frameless glass – glass laminates. In the course of the examinations of the present report it could be shown that a change from a clamp fastening at the edges of the modules to glued punctiform fastenings allows a significant enlargement of the modules without an increase of the glass thicknesses. Based on this basic consideration, it is to be expected that in the future a module size will establish itself, which takes the general requirements of cost-efficiency and module handling into account.