# MECHANICAL CHARACTERISTICS OF BIPV MODULES UNDER DIFFERENT LOAD SCENARIOS AND ENCAPLSUATIONS

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## 1. Introduction

The penetration of the Building integrated Photovoltaic (BIPV) still remains a small scale compared to the fast growing photovoltaic market. Significant obstacles are legal and administrative process as well as technical barriers. For instance, BIPV is currently not categorized in the building regulation lists, the link between PV- and construction sector is not clear enough and a lack of BIPV standards based on building product requirements are critical issues [SUNRISE, 2008].

Currently, the requirements for BIPV modules are based solely on building codes and photovoltaic standards without any consideration of its individual product aspects. Every BIPV products that replace building components of the roof or façade has to comply with both the conventional building codes (e.g. EN12543, EN1449, and DIN18008) and PV standards (e.g. EN61215, EN61646, EN61730) [IP-Performance, 2008].

In order to verify the capability of BIPV modules in terms of building applications, additional aspects such as glass fracture, weather resistance, cell characteristics and building regulation must be taken into account. These can be determined by mechanical behaviors (bending stress and deformation). This mechanical behavior of building products is one of the main issues under 'mechanical resistance and stability' in Construction Products Directive (CPD).

Moreover, there is no explicit standard or test procedure for mechanical behavior of BIPV modules as part of the building shell. In addition, each country has its own set of national regulations and standards, making it difficult for the PV-module manufacturers to identify such a format that best suit to a widely accepted building codes

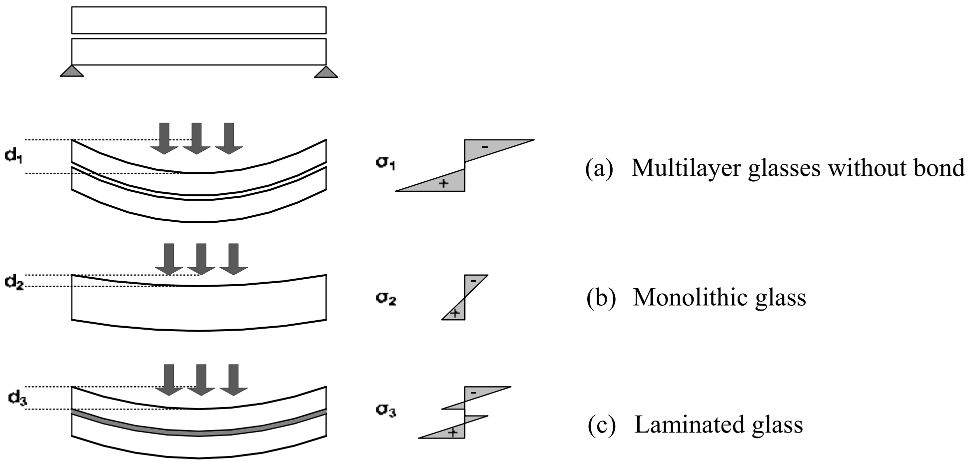
The aim of this paper is to examine the mechanical behaviors of BIPV modules (BIPV-laminated glass). It describes methods for mechanical load scenarios under consideration of different operating temperatures and load duration. The testing modules are classified according to the encapsulation (EVA and PVB) under 4-side mounting system. Besides, acceptability of EVA foil as a building product is also a major issue in this study.

In the BMU research project "MULTIELEMENT, the Fraunhofer Institute for Wind Energy and Energy System Technology (IWES) together with 15 industrial partners study on the development of manufacturing, testing and installation methods of multifunctional photovoltaic devices / modules in buildings [Misara et al. 2009].

## 2. Mechanical behavior of BIPV modules

BIPV modules are typically fabricated in laminating process with 2 glass panes and described as a laminated glass [VDE 0126-21]. Laminated glass consists of at least two panes and one interlayer, whereby the panes are bonded to the interlayer in the manufacturing. The mechanical behaviors of laminated glass depend on not only glass material, but also on the bonding properties of interlayer. Following are the different bonding stage of laminated glass.

- Multilayer glass (without bond) - When two or more panes are laid loosely on top of each other without any interlayer bonded in between the individual panes, then the loads are split in proportion to its bending strength.
- Monolithic glass (Rigidly bonded) -Monolithic glass is a glass panel comprised of a single sheet of float glass. The glass can be tinted, coated, and otherwise processed, but it is used as a single sheet.
- Laminated glass (with bond) - In case of two layers of glass panes bonded with a shear-resistant interlayer, the load can no longer be split in proportion to the strengths but are carried by a composite unit.




$$d_2 < d_3 < d_1 \qquad \sigma_2 < \sigma_3 < \sigma_1 \qquad \text{(eq. 1)}$$

**Figure 1 Deflection behavior and stress distribution of (a) multilayer glasses without bond, (b) monolithic glass and (c) laminated glass.**

The mechanical behaviors of laminated glass can be described in terms of bending stress ($\boldsymbol{\sigma}$) and deflection ($\boldsymbol{d}$). Figure 1 describes the mechanical properties of laminated glasses under different bonding states of interlayers. The lower limit is the so-called *layered limit*, where the glass panes react without shear bond (a). The upper limit is the *monolithic limit* where all glass panes are rigidly connected (b). The mechanical behaviors (bending stress and deflection) of laminated glass are between these upper and lower limits (c), (eq. 1) [Schittich et al, 1999].

With respect to higher operating temperature of BIPV module, the mechanical behaviors will be changed compared to conventional laminated glass. For mechanical behaviors of glass material, there are no significant changes regarding higher operating temperature of BIPV module. However, the bonding properties of interlayer depends mainly on operating temperature of BIPV module compared to conventional laminated glass. Moreover, the load duration is also another parameter effects on bonding properties and mechanical behaviors of BIPV-module, respectively. Therefore, interlayer material is playing a major role in mechanical behaviors of BIPV-laminated glass.

Interlayer characteristics

Polyvinyl Butyral (PVB) is widely used in glass lamination. The main use of PVB is in safety laminated glass due to its special properties like resistance to physical attack and its residual load bearing capacity, thanks for long experiences in glass industries. In the PV industry, alternative interlayer materials are used instead such as ethylene-vinyl acetate (EVA) or polyethylene (PE) with improved temperature stability. Other special applications are realized by using thermoplastic polyurethanes (TPU) as interlayer. These interlayer materials differ in their chemical composition and morphology.

The mechanical behavior of interlayer can be characterized by the viscoelastic material (viscous + elasticity). This viscoelastic response may be modeled as a spring for elasticity (so called Hook-model) and a damper for viscous (so called Newton-model) in series, also called the Maxwell model (Figure 2).

Elasticity depends mainly on operating temperature of interlayers (Figure 3). The elasticity (storage module) of different interlayers decrease with higher operating temperature. At low operating temperature, the storage module of PVB is higher than other interlayers. With respect to glass transition temperature of PVB at 25°C, therefore, the storage module of PVB is now lower than other interlayers at higher operating temperature [Weller et al. 2009]. Viscous describes the time-delayed characteristics of elasticity of interlayers but completely reversible deformation behavior of a material under external mechanical load, so called shear modulus. This behavior is explained by the process of creep, which describes a time-dependent increase of strain at constant stress, and the process of relaxation, which describes the reduction in strain at constant deformation. The process of creep and relaxation depends also on operating temperature and time duration under mechanical load. Figure 4a describes the creep charactertic of PVB-interlayer with different operating temperature, while Figure 4b describes the creep characteristic of EVA-interlayers. It can be evaluated that the decreasing creep rate of PVB-interlayer is faster than EVA-interlayer. At higher operating temperature, the decreasing creep rate of EVA-interlayer is nearly zero [Sobek et al 2000], [Dietrich et al. 2009], [Eitner et at. 2010]. Therefore, it can be evaluated that the mechanical behaviour of interlayer depends mainly on operating temperature and load duration.

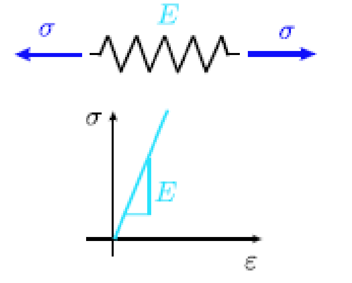
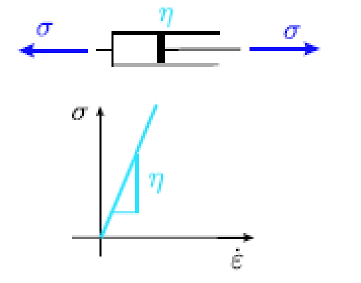
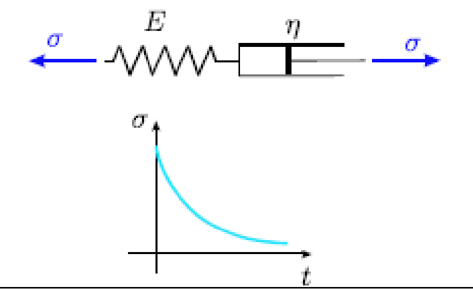
| Hook Model (Elastic) | Newton Model (Viscous) | Maxwell-Model (Viscous + Elastic) |
|---|---|---|
|  |  |  |
| $\sigma = E \times \varepsilon$ | $\sigma = \eta \times \dot{\varepsilon}$ | $\sigma = \sigma_E = \sigma_\eta \ , \ \varepsilon = \varepsilon_E + \varepsilon_\eta$ |

**Figure 2 Rheological behavior of polymers: Hook, Newton and Maxwell Models**

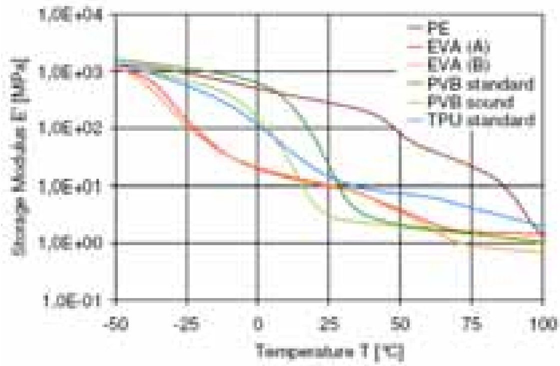



**Figure 3 Thermo-mechanical behavior on the elasticity of interlayers [Weller et al. 2009]**

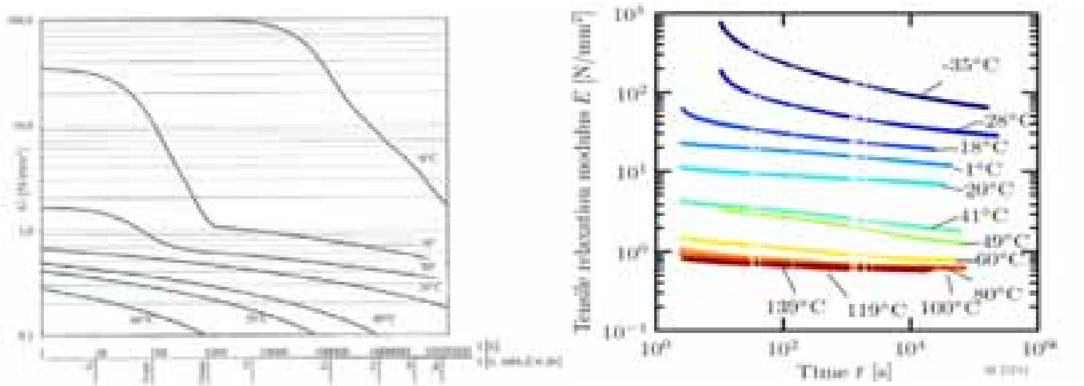



**Figure 4 The creep and relaxation characteristic of interlayers based on different operating temperature. (a. PVB-interlayer [Sobek et al. 2000], b. EVA-interlayer [Eitner et at. 2010])**

## 3. Problem

The mechanical characteristic is the one of the most characteristics to describe the failure modes of BIPV modules in both terms of electrical and mechanical failures; glass fracture, weather resistance, cell characteristics and building regulation [Dietrich et al. 2009].

For building regulation, the laminated glass with PVB-interlayer is accepted as laminated safety glass in a regulated building product list, thanks to their long experience in glass industry. With respect to German building regulation, it is not allowed to calculate the bonding characteristic of interlayer by calculating the static of the laminated glass and laminated safety glass due to poor bonding characteristic of PVB-interlayer at long load duration (high creep rate). In the static calculation of laminated glass, therefore, the bonding characteristics will be considered at long load duration as worse case. Hence, the mechanical behaviors of laminated glass will be solely considered under external mechanical load concerning to EN 1991 for wind and snow load without any consideration of load duration.

Most of laminated glasses perform their functions at room temperature. With respect to higher absorption rate of BIPV modules and representing higher operating temperature, therefore, the mechanical behaviors of laminated glass and its interlayer will be changed. The operating temperature of BIPV modules are varied based on solar irradiation, ambient temperature, etc. This leads to different amount of external mechanical loads (wind and snow load) on the BIPV modules.

Up to now, there are neither common regulations nor relevant building codes on how to calculate the mechanical behaviors of laminated glass together with its bonding properties under consideration of operating temperature and load duration along with corresponding magnitude of external mechanical loads.

In the PV industry, alternative interlayer materials have been used instead; such as EVA, PE, TPU, etc. Even though these interlayers demonstrate better mechanical behaviors (better elasticity at high operating temperature and lower creep rate), these interlayers are not accepted as laminated safety glass in regulated building products due to less experience of their characteristics. These alternative interlayers are quite new for building product industries.

## 4. Objective

The bonding characteristics of interlayer (elasticity and creep) are the primary issues for investigating the mechanical behaviors of BIPV module under consideration of operating temperature and load duration. The bending stress and deflection will be considered as major parameters. The testing modules are classified according to the encapsulation (EVA- and PVB interlayers) under 4-side mounting system.

Firstly, the mechanical behaviors of PV laminated glass with PVB-interlayers have been simulated by FEM-Analysis under different bonding characteristics of interlayers, affected by operating temperature and load duration.

With respect to different operating temperature, load duration and amount of external load at BIPV module in outdoor applications, the matrix of load scenarios have been considered under thermal and mechanical load along with load duration.

Afterwards, the mathematical models for different modules configuration and systems have been developed in order to assess the mechanical properties (bending stress and deformation) of BIPV modules in building construction based on different module dimensions (500 – 2500mm), different load scenarios of external mechanical loads and different operating temperatures.

Besides, acceptability of EVA foil as a building product is also a major issue in this study.

## 5. Simulation modeling

With the help of the FE modeling to determine bending stresses and deformations under mechanical stress, the numerical investigation of the behavior of PV elements was carried out using ANSYS software. The modeling is based on the findings of the structural behavior of laminated glass.

In this FE modeling, the module dimension of 1200 x 1000 mm is used with 4-side mounting system with different module configuration and different loads (Table 1a). In order to evaluate the mechanical characteristic of PV laminated glass, the bonding characteristic (shear modulus) of PVB-interlayer have been considered as a function of operating temperature and load duration (Table 1b). The limits of bending stress and deflection of PV-module will also be taken into account [EN12448].

Figure 5 represents the bending stress and deflection of different module configurations and loads scenarios under consideration of different bonding characteristics of PVB-interlayer elements together with its limitation defined in EN 12488.

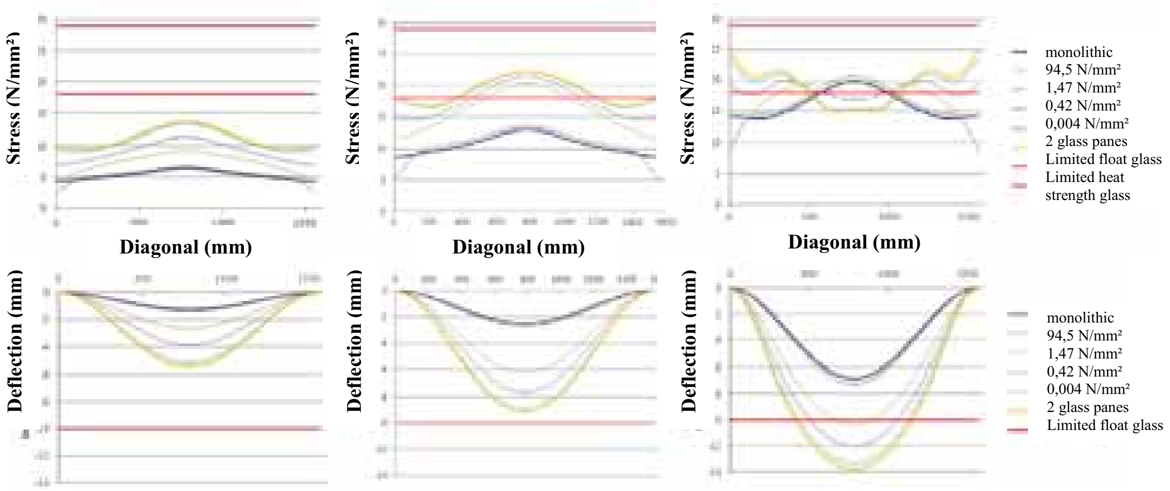
| No. | Dimension (mm) | Configuration (mm) | Load (kN/m²) |
|---|---|---|---|
| a | 1200 x 1000 | 6-1-6 | 3.00 |
| b | 1200 x 1000 | 6-1-6 | 6.00 |
| c | 1200 x 1000 | 3-1-3 | 3.00 |

(a)

| Temperature (°C) | Load duration | Shear modulus |
|---|---|---|
| Rigidly bond | - | ∞ |
| 0 | 1 h | 94.5 |
| 20 | 10 sec | 1.47 |
| 40 | 1 min | 0.42 |
| 70 | 1 min | 0.04 |
| Without bond | - | 0 |

(b)

**Table 1 a) different module dimension with different module configuration and load scenarios
b) Shear modulus as a function of temperature and exposure time**




(a) (b) (c)

**Figure 5 Simulation of bending stress and deflection of the PV modules (1200x1000 mm) for PVB interlayer under different PV module configuration and load scenario**

The maximum bending stress and deflection are at the middle of the modules. With high bonding properties of 94.5 n/mm² (operating temperature at 0°C and load duration of 1h), the laminated glass can be nearly assumed as monolithic glass, while low bonding properties of 0.04 N/mm² (operating temperature at 70 °C and load duration of 1min) can be assumed as 2 single glass panes without any bonding properties of interlayer. The membrane effect can be seen after the bending stress has passed the glass limitation (Figure 5b and 5c) [Diaz, 2010].

FEM analysis is a good software with high accuracy for consideration of entire module area. The Membrane effect can also be seen. However, this membranes effect will happen after the module deflection is higher than their thickness, which is of course, not be allowed in the building regulation. Most of building authorities require only maximum values of stress and displacement, which have to be lower than limitation defined in building codes above. Moreover, it takes lots of time to do the simulation with ANSYS for different module sizes and configuration and etc.

Therefore, many manufacturers are working now with simple static calculation (such as glass statics, üko, etc.). At this point, the membrane-effect is not taken into account because the limit has been exceeded, if the membrane effect happens. However, the operating temperature and load duration have not been considered in these simple static calculations. Hence, the new numerical calculation model has been developed under consideration of operating temperature and load duration.

## 6. Numerical simulation

The numerical simulation aims at predicting the mechanical behaviour of laminated glass. Critical issues are the temperature, load duration, type of multilayer laminated glass, and type of the interlayer.

Load scenarios

Wellershoff has developed the new load scenarios for static calculation on different operating temperature and load duration [Wellershoff, 2006]. The scenarios are based on gust wind speed and ambient temperature from DWD-Data from 1970 – 1998 together with his measurement of interlayer temperature of laminated glass with black screen printing glass. The different wind loads can be applied to its corresponding operating temperature of BIPV module. Along with other mechanical loads of snow and own loads, Table 2 represents the load scenarios for the numerical simulation. The operating temperature can be classified into 5 scenarios from 0°C to 80°C. In each scenario, there are 3 different load durations with its corresponding wind, snow and own loads.

| Load Scenarios | Operating Temperature | Wind Load (of $w_{max}$) | | | | Snow Load (of $s_{max}$) | Own Load |
|---|---|---|---|---|---|---|---|
| | | 4 days | 10 min | 3 sec | | | |
| 1 | 0 °C | 0.250 | 0.500 | 1.000 | + | 1.000 | 1.000 |
| 2 | 0 °C | 0.250 | 0.500 | 1.000 | | 0.000 | 1.000 |
| 3 | 20 °C | 0.250 | 0.500 | 1.000 | | 0.000 | 1.000 |
| 4 | 50 °C | 0.125 | 0.250 | 0.500 | | 0.000 | 1.000 |
| 5 | 80 °C | 0.080 | 0.160 | 0.320 | | 0.000 | 1.000 |

$w_{max}$ = maximum wind load from EN 1991 or DIN 1055
$s_{max}$ = maximum snow load from EN 1991 or DIN 1055

**Table 2 Wind load scenarios for the design of laminated glass**

Calculation methods

For the static calculation, it is not possible to define a complete mechanical characterization on the whole photovoltaic system due to the multiple possibilities of installations. However, the module has to be dimensioned on the ways they intended to be mounted. Table 3 represents the bending stress and deflection equations of monolithic glass and multilayer glass without lamination, where $\boldsymbol{q}$ represents the external mechanical loads from EN 1991 and its own load in N/mm². The parameter $\boldsymbol{l}$ and $\boldsymbol{t_G}$ are the length of the module on short side and glass total glass thickness in mm, respectively. The elasticity of glass is around 70kN/mm². Regarding different mounting systems (4-side, 2-side or 4-point), the parameters of $k_1$ and $k_2$ can be received from (Table 4) [Widjaja, 2009].

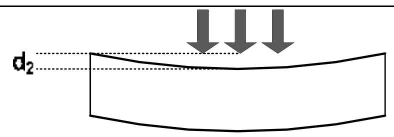
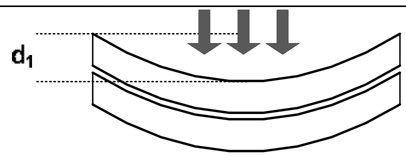
| | Monolithic Glass | Multilayer Glass without lamination |
|---|---|---|
| |   |   |
| **Stress** $(N/mm^2)$ | $\sigma_{mono} = \frac{k_1 \cdot q \cdot l^2}{t_G^{\ 2}}$ | $\sigma_{ohne} / \sigma_{mono} = 2$ |
| **Deflection** $(mm)$ | $f_{zul,mono} = \frac{k_2 \cdot q \cdot l^4}{E \cdot t_G^{\ 3}}$ | $f_{zul,ohne} / f_{zul,mono} = 4$ |

**Table 3 Calculation method of stress and deflection of monolithic and 2 glass panes without lamination**

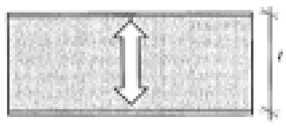
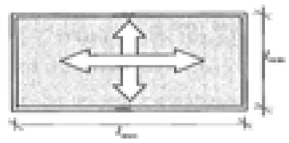
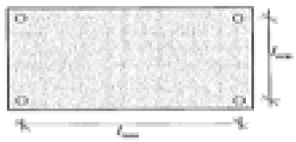
| $L_{min}$ / $L_{max}$ | Mounting System | | | | | |
|---|---|---|---|---|---|---|
| | 2-side | | 4-side | | 4-points | |
| |  | |  | |  | |
| | **K1** | **K2** | **K1** | **K2** | **K1** | **K2** |
| **0.0** | 0.750 | 0.156 | | | | |
| **0.1** | | | | | | |
| **0.2** | | | 0.748 | 0.147 | | |
| **0.3** | | | 0.725 | 0.142 | | |
| **0.4** | | | 0.673 | 0.131 | | |
| **0.5** | | | 0.603 | 0.115 | 0.803 | 0.177 |
| **0.6** | | | 0.526 | 0.099 | 0.832 | 0.187 |
| **0.7** | | | 0.451 | 0.083 | 0.861 | 0.199 |
| **0.8** | | | 0.383 | 0.068 | 0.892 | 0.227 |
| **0.9** | | | 0.323 | 0.056 | 0.925 | 0.275 |
| **1.0** | | | 0.272 | 0.046 | 0.964 | 0.332 |

**Table 4 Parameter K1 and K2 for different mounting systems: 4-side, 2-side and 4-ponits**

For laminated glass, Table 5 represents the static calculation under consideration of bonding characteristics of interlayer (shear modulus – G) in shear parameter ($\beta_1$) together with different glass configuration in stiffness parameter ($\alpha$) [Kutterer, 2009]. This bonding characteristic of interlayer (G) depends on different operating temperature and load duration at different scenarios as defined in Figure 4.

| Bending stress of laminated glass | Deflection of laminated glass |
|---|---|
| $\frac{\sigma_{lam}}{\sigma_{mono}} = \frac{4+4\bar{h}+\left[2\cdot\beta_1\cdot\left(1+\frac{1,35}{\lambda^{1,8}}\right)\cdot\pi^2\right]}{\left[\beta_1\cdot\left(1+\frac{1,35}{\lambda^{1,8}}\right)\cdot\pi^2\right]+1+\frac{1}{\alpha}}$ | $\frac{w_{lam}}{w_{mono}} = \left[\frac{3\cdot\kappa\cdot\left(1+2\bar{h}\right)^2}{\left(1+\kappa\right)^2+4\pi^2\cdot\kappa\cdot\left(1+\frac{1,35}{\lambda^{1,8}}\right)\cdot\beta_1}+\frac{1+\kappa^3}{\left(1+\kappa\right)^3}\right]^{-1}$ |
| Shear parameter: $\beta_1 = \frac{E}{G}\cdot\frac{\kappa\cdot\bar{h}}{\left(1+\kappa\right)^2\cdot\bar{l}^{\,2}}$ | Stiffness parameter: $\alpha = \frac{1+\kappa^3}{3\cdot\kappa\cdot\left(1+\kappa\right)\cdot\left(1+2\bar{h}\right)^2}$ |
| where<br>$\kappa = t_o/t_u$ $\quad t_G = t_o+t_u$<br>$\bar{h} = h/t_G$ $\quad \bar{l} = l/t_G$<br>$\lambda = l_{max}/l_{min}$ | $t_o$ = Thickness of front glass (mm)<br>$t_u$ = Thickness of back glass (mm)<br>**h** = Thickness of interlayer (mm)<br>**l** = Length of short side (mm)<br>**E** = Elasticity of glass (N/mm²)<br>**G** = Shear modulus of interlayer (N/mm²) |

**Table 5 Calculation of bending stress and deflection for laminated glass in correlation with the bending stress and deflection of monolithic glass.**

## 7. Analysis of the results

Roof-Specimen

For this numerical simulation, the module dimension was assumed to be varied from 500 mm – 2500 mm on both length and width sides with module configuration of 3-0.76-3 mm (front glass, interlayer and back glass). The maximum load scenario was taken from industry roof with inclination of 10° from horizontal at 12 m height. The

PV module was mounted with 4 side mounting system. The location of building is at wind zone 3 and snow zone 4 as defined in EN 1991, represents the maximum wind and snow loads of -2.09 kN/m² (pull) and +0.88 kN/m² (push), respectively. The own load of this laminated glass is +1.66 kN/m² (push).

In order to evaluate the mechanical behaviours of BIPV Module, the numerical model are determined under consideration of operating temperature and load duration. For each analysis, using glass dimension as the domain, the bending stress and deflection will be evaluated.

<u>Evaluation</u>

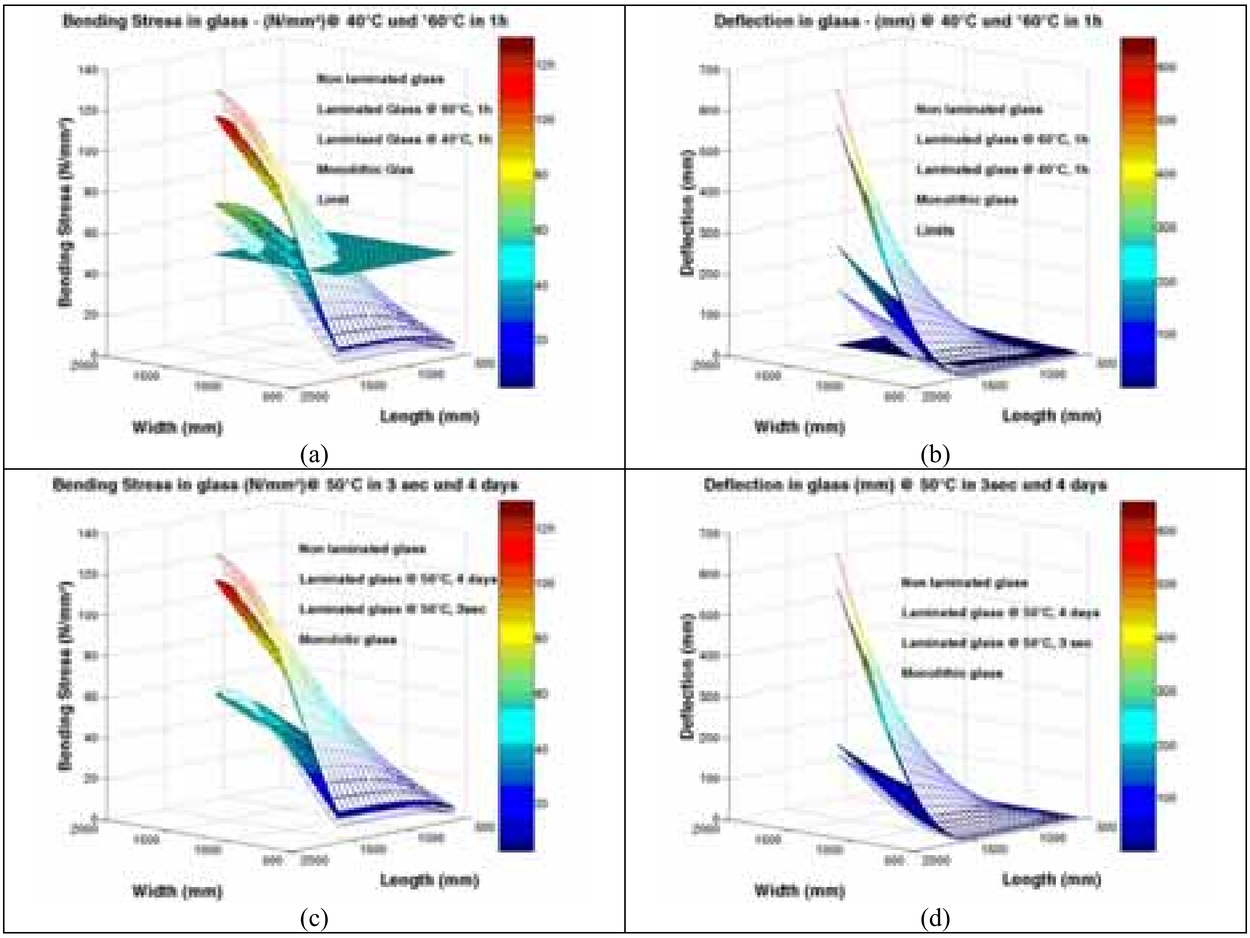
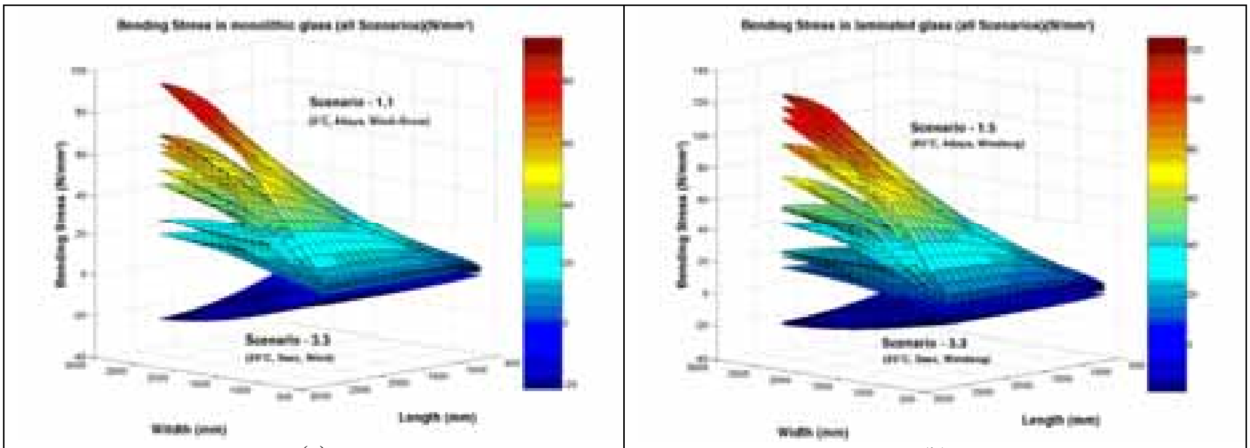



**Figure 6 Bending stress and deflection of laminated glass with PVB interlayer at different operating temperature and load duration; Dependency on operating temperature (a, b), Dependency on load duration (c, d)**

<u>Temperature dependency:</u> In Figure 6a and 6b, the computational bending stresses and deflection are compared with regard to the different operating temperature of the laminated glass. For BIPV module with 60°C operating temperature, the bending stress and deflection are greater compared with 40°C operating temperature due to lower elasticity of interlayer at higher operating temperature. The bending stress and deflection of laminated glass increase dramatically with increasing temperature over glass transition temperature ($T_G$) of interlayer.

<u>Load duration dependency:</u> The load duration dependency gives a clearer picture of the phenomenon of the increasing bending stress and deflection over the exposure time period. Figure 6c and 6d describes the difference in mechanical properties with regard to the different load duration. For BIPV Module with 4 days load duration, the bending stress and deflection are greater compared to with 3 second load duration. It represents the creep characteristics of the interlayer materials. Therefore, the bending stress and deflection increase with longer load duration.

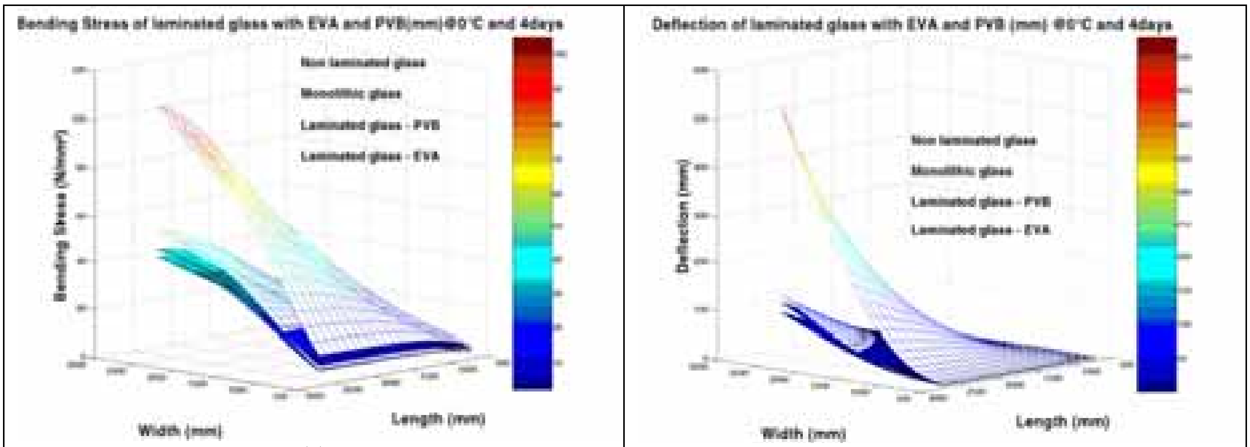
These temperature and load duration dependencies were good agreement between the theoretical creep and storage modulus characteristics and the computational results.




(a) (b)

**Figure 7 Bending stress of monolithic glass (a) and laminated glass (b) under different load scenarios.**

<u>Characteristics under different load scenarios:</u> Of all the data collected, the set of results from different scenarios are compared. Figure 8 presents the series of scenarios of monolithic glass and laminated glass. The maximum bending stress for monolithic glass could be found under scenarios 1.1 (@ 0°C, 4 days, wind and snow loads), whereas the maximum bending stress for laminated could be found under scenario 5.1 (@ 80°C, 4days, wind load). This can be evaluated that the mechanical behaviour tendency of laminated glass could not be assumed as of monolithic glass.




(a) (b)

**Figure 8 Bending stress and deflection of laminated glass with PVB and EVA interlayers at low operating temperature; (a) bending stress, (b) deflection**

<u>Interlayer dependency at low operating temperature:</u> In order to closer evaluate on the operating temperature dependency on the mechanical behaviours of the laminated glass, a simulation of bending stress and deflection at low operating temperature are also determined. At operating temperature of 0°C, the bending stress and deflection decrease for both laminated glass with PVB and EVA and shows better mechanical behaviours than the monolithic glass due to higher shear modulus of interlayers (Figure 8).

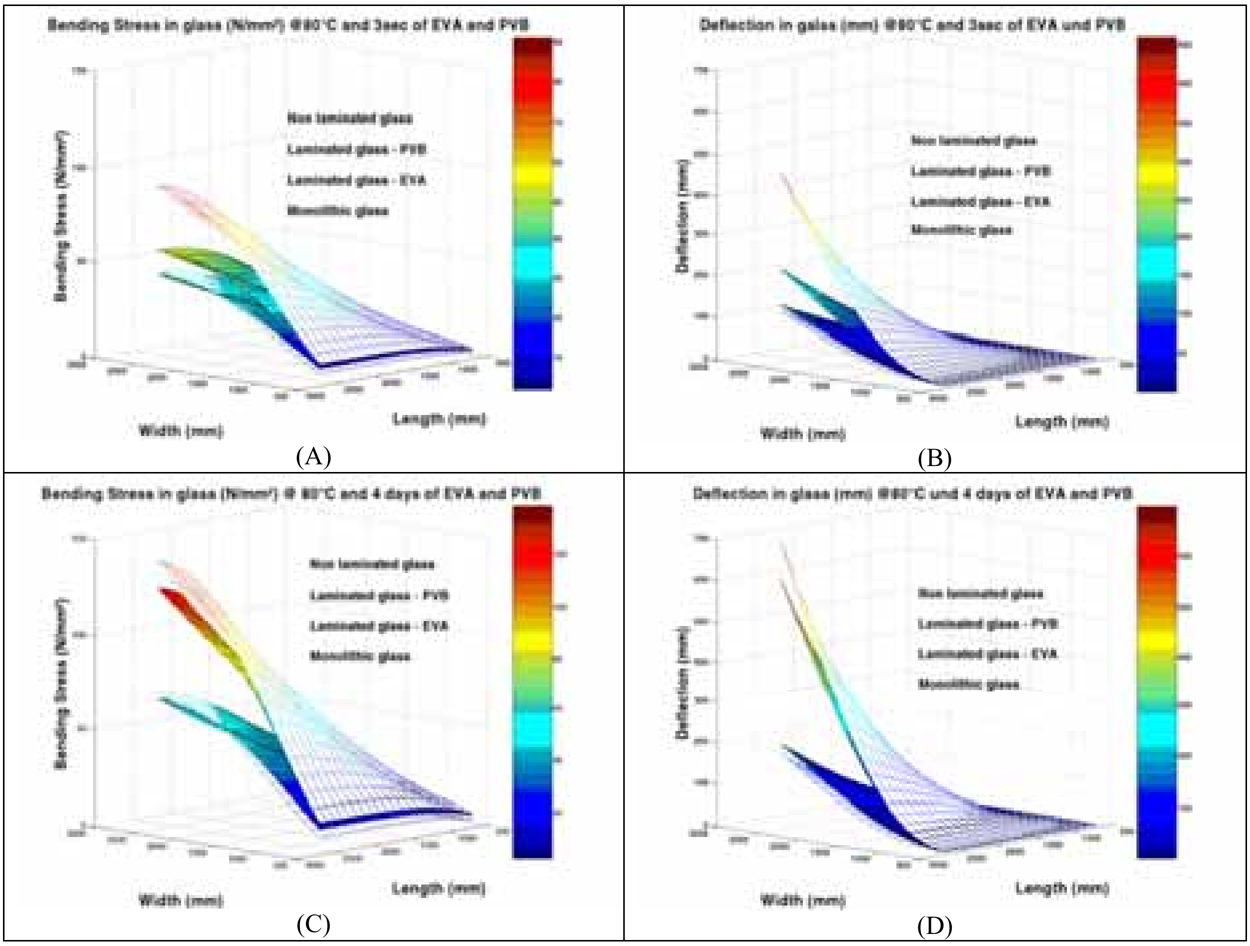



**Figure 9 Mechanical behaviors (bending stress and deflection) of laminated glass with EVA and PVB interlayers at high operating temperature; with short load duration (A, B), with long load duration (C, D)**

<u>Interlayer dependency at high operating temperature:</u> Vice versa of low operating temperature, the computed bending stress and deflection of the laminated glass at high operating temperature show a reduction in mechanical behaviours, representing the effect of the elasticity of the interlayer materials. The laminated glass with EVA shows much better mechanical behaviors than laminated glass with PVB-interlayer due to lower elasticity of PVB interlayer compared to EVA-interlayer at higher temperature (figure 9-A, 9-B).

<u>Interlayer dependency with different load duration at high operating temperature:</u> With respect to long load duration at higher operating temperature, the laminated glass with EVA-interlayer shows much better mechanical behaviors than with PVB-interlayer due to better creep characteristic of EVA-interlayer compared to PVB-interlayer (Figure 9-C, 9-D).

## 8. Conclusion

The mechanical behaviors were defined by bending stress and deflection occurred in glass. It is influenced by the temperature, load and load duration. In this paper, a methodology based on the shear modulus characteristics of the interlayer material has been validated and then applied to the investigation of the effect of various parameters.

The numerical model proves that at lower operating temperature, both laminated glass with EVA or PVB interlayers have better mechanical behaviors than monolithic glass. On the other hand, laminated glass with EVA-interlayer shows better mechanical behaviors than with PVB-interlayer at higher operating temperature due to lower storage module reduction. In particularly at longer load duration, laminated glass with EVA-interlayer shows much better mechanical behaviors than with PVB-interlayer due to lower creep characteristic. Therefore, EVA can be proved to be used as laminated safety glass in building applications.

## 9. Outlook

From the mechanical point of view, experimental data from mechanical test are needed in order to prove the validation of the model. In addition, the generality of the model should be examined by applying it to different conditions such as type of glass formation and different clamping. This would provide generic information and improve the modeling.

Regarding neither common regulations nor relevant building codes on mechanical behaviors of BIPV, therefore, the new calculation methods is needed for the standard or building codes under consideration of operating temperature, load duration.

## 10. Reference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