# DESIGN OF FIBRE REINFORCED PV CONCEPTS FOR BUILDING INTEGRATED APPLICATIONS

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ABSTRACT: Fibre reinforced polymers present an interesting encapsulation medium for PV-modules. Glass fibres can provide increased strength and stiffness to thin polymer layers overcoming the brittleness and limited deformability of glass-panes. Glass fibre reinforced polymers allows for transparency over a broad range of the solar spectrum while the material properties and integral production processes create possibilities for novel product concepts with embedded PV technology. To explore such possibilities, innovative design methods were used to design novel PV product concepts for applications in the build environment.
In our paper three conceptual designs are presented; (1) a thin film module with an adjoining interconnection system functioning as structural element for geodetic roofing structures, (2) a PV lamella with single-axis tracking utilizing a linear concentration effect caused by the geometry of the product and the materials applied, and (3) a prepreg PV-material which allows for easy shaping during the production of PV modules with complex geometries. Each concept employs a specific PV technology and demonstrates a possible application aimed at a specific market. In this way we show the potential of integration of PV technology in fibre reinforced composites. The paper will be illustrated by concept renderings.
Keywords: Building Integrated PV, PV Module, Design, Manufacturing

## 1 INTRODUCTION

Glass fibre composites consist of load bearing bundles of continuous glass fibres in a polymer matrix. Production methods are numerous, but mostly consist of impregnating layers of fibres with a resin. Initially glass fibre composites were developed for microwave transparent structures (radomes) during World War 2, however applications for optically transparent composite structures are still underdeveloped. Most experience with glas fibre reinforced polymers has been gathered in aerospace applications since the 1940-ies. Glass fibres can provide increased strength and stiffness to thin polymer layers without the brittleness and limited deformability of glass-panes. The material is transparent over a broad range of the solar spectrum. Moreover GFRP allow for integral production processes. Given these properties it would be interesting to apply these materials in combination with PV technology [1]. Therefore, in our project we considered new PV product concepts that could be enabled by combining the properties of PV technology and GFRP. Though at first sight it seems logical to perceive glass fibre reinforced polymers as an alternative for glass sheets in PV modules, we decided to develop new product concepts. Namely, lessons learned of implementation of composites in the aerospace industry show that it is more advantageous to find new possibilities provided by a technology rather than translating a new technology or material to existing concepts [2]. In Section 2 we will discuss the properties of fibre reinforced polymers. Subsequently in Section 3 we will focus on samples of GFRP in combination with PV cells, see Figure 1, as well as test performed on these samples. Next in Section 4 the conceptual design of three products will be illustrated. The concepts will be positioned in the market of building integrated PV, because BIPV's potential is enormous provided that suitable PV products will be available. In Section 5 the concepts will be discussed and conclusions will be drawn.  Also we will shortly mention future work necessary to further explore and elaborate on products that combine PV technology and GFRP .

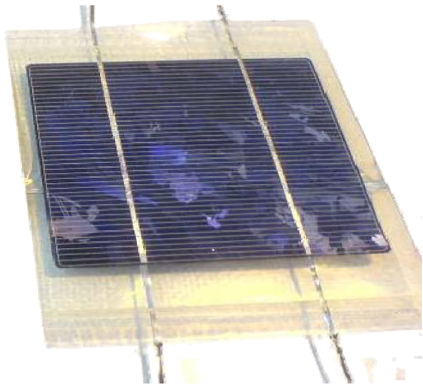

**Figure 1:** Sample of a PV-cell embedded in a glass fibre laminate

## 2 FIBRE REINFORCED POLYMERS

In this section we will describe the properties of fibre reinforced polymers and their production processes.

### 3.1 Plastics

Plastics are extensively used for their low density, robustness and low costs for mass production. Plastic materials can be subdivided into thermosets, thermoplastics and rubbers. Thermoplastics are typically used in consumer products. They can be heated, formed and cooled within minutes, enabling short production cycle times. Complex product geometries can be accomplished by injection moulding processes. Thermosets can be formed using similar processes, where the reactants create a polymer network which is no longer (de)formable afterwards. Often the cycle time is longer than for their thermoplastic counterparts. Fibre reinforced polymers are thermoset plastics reinforced by fibres of glass, see Figure 2, carbon or other –possibly organic- materials.

**Figure 2:** A bundle of glass fibres

3.2 Properties of fibre reinforced polymers

Because of the combination with PV technology we focus in the following on transparent polymers in GFRP, such as epoxies, polycarbonates, polymethacrylates, polyurethanes, fluoropolymers and polyetherimides, see Table I. The service temperature of these polymers complies with the operational circumstances of PV systems which are in between -25 and 80 °C. The strength and stiffness of the transparent polymers though are very low compared to regular glass which has a Youngs modulus of about 50 to 90 GPa and a strength of 50 MPa. Hence in GFRP fibres determine the Youngs modulus and strength of the composite material. Depending on whether glass or carbon fibres are applied, with an ultimate strength of rep. 3400 MPa or 5600 MPa, the number of fibres and their direction, Youngs modulus of a fibre reinforced polymer can vary from 45 to 150 GPa. Glass fibres usually have diameter of 10 μm and usually are elongatedly structured in a regularly woven fabric that has a thickness in the order of 0.2 to 0.3 mm. In some fabrics though short curled fibres are randomly distributed. The length and thickness of the filaments, the type of weave and number of layers of fabric applied in a GFRP influences the overall mechanical properties of a part. As such GFRP are designer materials which properties can be customized to the final application.

**Table I:** Properties of transparent polymer groups

| Polymer types | Service temp (°C) | Tensile strength (kPa) | Youngs modulus (Gpa) | Cost (Euro/ kg) |
|---|---|---|---|---|
| Epoxies | -42 - 138 | 45 - 90 | 2.3 – 2.5 | 1.6 |
| Polycarbonates | -42 - 115 | 62 - 72 | 2.3 – 2.4 | 2.7 |
| Polymethacrylates | -42 - 56 | 34 - 62 | 1.6 – 3.4 | 1.8 |
| Polyurethanes | -42 - 78 | 31 – 62 | 1.3 – 2.0 | 2.7 |
| Fluoropolymers | -200 - 158 | 42 – 47 | 0.7 – 0.8 | 30.0 |
| Polyetherimides | -42 - 180 | 90 - 101 | 2.9 – 3.0 | 12.0 |

Costs of GFRP are determined by the costs of the polymer, in between 1.6 and 30 Euro/kg see Table I, the costs of the weave which can range from 2 Euro/m$^2$ for low-end fabrics to 15 Euro/m$^2$ for hi-tech textiles, and the costs of the production process.

3.3 Production processes

Thermoset materials such as polymers can be processed using sheet forming processes and resin transfer injection. Besides this, spraying can be an option as well.

Resin transfer moulding (RTM) is a popular method to impregnate dry fibre reinforcement structures, see Figure 6. This process consists of filling a rigid and closed mould cavity by injecting a resin through one, or several, points, depending on the size of the component. Usually, polyesters, epoxy, phenolic and acrylic resins are used. RTM allows the moulding of components with complex shape and large surface area with a good surface finish on both sides. The process is suited for medium to large series production.

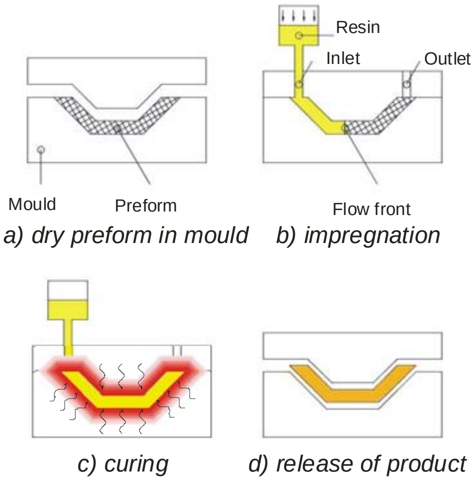


**Figure 3:** Resin transfer moulding

## 3 COMBINING GFRP AND PV CELLS

Several reasons exist to combine GFRP and PV cells:
GFRP are transparent for which reason it's possible to add layers of GFRP on top of PV cells. Thin layers of GFRP can provide excellent mechanical support to PV cells. Moreover, the strength and stiffness of the GPRP can be customized for application. GFRP are less heavy and brittle than glass sheet. The production process of GFRP enhances the freedom of form compared to existing production process for glass-based PV modules.
So far it seems that if GFRP are applied to PV cells no other encapsulating materials are required. Production of GFRP with TRM-like processes requires a limited number of production steps.
For these reasons samples consisting of GFRP and PV cells were made to preliminary test the feasibility of the idea and to provisionally evaluate the combination of materials.

3.1 Sample production

Samples were made using vacuum injection with epoxy resin, glass fibre weaves and –optional- PV cells (Figure 4). In this process resin is inserted in a laminate by a vacuum. The resin is drawn through the laminate, creating a flow front as shown in Figure 5. Because of the possibility of the creation of air bubbles in a sample, degassing of the resin prior to injection is important.

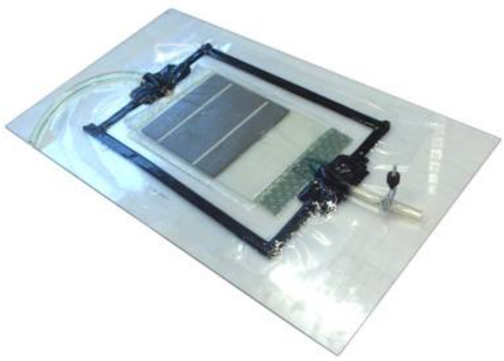

**Figure 4:** Setup of sample production, this sample comprises a PV cell. The inlet is connected to vessel containing an epoxy resin, the outlet with a vacuum pump.

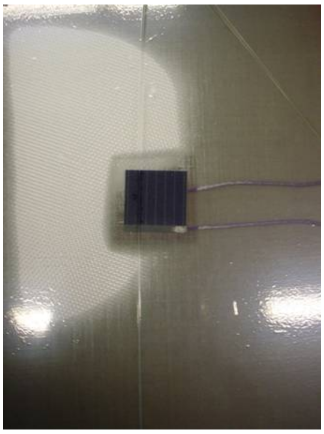

**Figure 5:** Flow front of resin during sample production

3.2 Transmittance and efficiency of samples

To test the optical transmittance in a GFRP, samples were made with varying layers of fabric. The samples' spectrally distributed transmittance was measured at ECN, see Figure 6. It was found that the effect of the layers of fibres on the transmittance was minimal and similar for layers of elongated and chopped fibres.

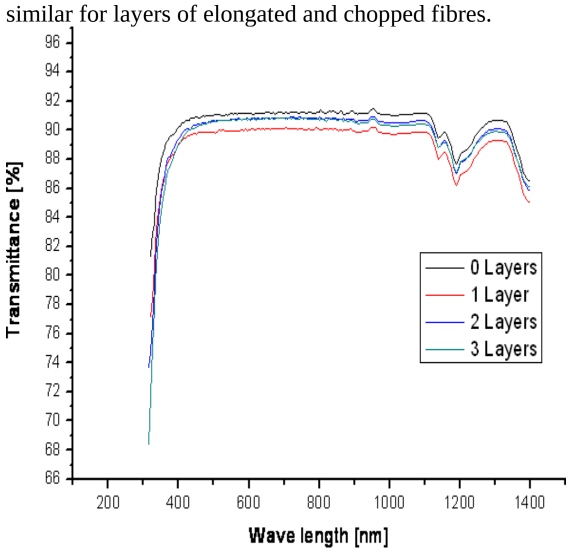


**Figure 6:** Transmittance versus wavelength for 4 samples of GFRP containing zero up to four layers of regular glass fibre weaves.

Measured transmittance is roughly equal to special high-transmittance glass and Ethylene-Vinyl-Acetate. This result is promising considering that the combination of a polymer and fabric wasnot tuned for refractive index or developed for optimal transmittance.
Subsequently the efficiency of crystalline PV-cells before and after lamination in GFRP was measured. Despite the cells being damaged due to transportation between UT and ECN, efficiency was hardly affected by cracks or lamination.

3.3 Degradation of GFRP

Despite experience with GFPR under high irradiance conditions such as in PV applications is limited, it is known that degradation of a polymeric matrix is affected by the following five mechanisms: 1) thermal degradation, 2) photo-degradation, 3) oxidation, 4) hydrothermal aging, and 5) chemical degradation. Besides this, the bonding between fibres and matrix can weaken due to moisture absorbed by the matrix.
In our project we were not able to setup an experiment to investigate the speed of degradation, however we believe that it would be wise to pay attention to these issues during future research activities.

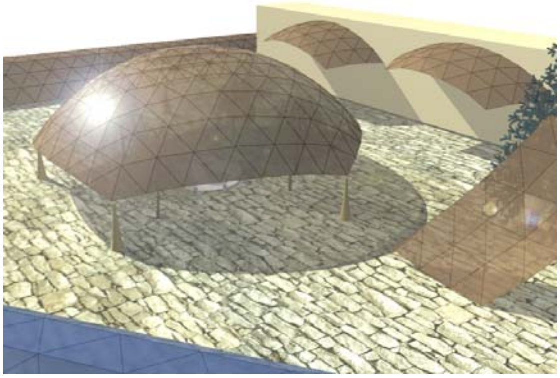

**Figure 7:** Concept 1: artist rendering of geodesic structures

## 4 PRODUCT CONCEPTS

In this section we will present three product concepts based on the combination of GFRP and PV technology developed in the framework of this project [3].

4.1 Concept 1: Thin film PV module

In this concept thin film PV-modules serve as structural elements in a modular roofing system for a variety of geodetic shapes (see figure 7). The concept is intended for new construction projects. The equilateral triangular modules are made from preconsolidated thermoplastic composite and they are covered by a thin film PV layer of CdTe that can be deposited at low temperatures. The edges of the module are wrapped around aluminium profiles to create a stiff panel. An interconnection system using rods with elastic coatings is used to assemble a structure. When the rods are tightened the structure becomes essentially a stabilized structure.

The length of a module is 1.2 meter, resulting in a light-weight module of just 3 kg which has a nominal power output of approximately 50Wp. See Figure 8 for an impression. Parallel connection of electrically active parts of the module ensures minimal energy losses due to different areas of these parts because of the triangular shape of the modules. Also this king of connection reduces the negative effects of partial shading or damage on the electricity production of the PV module.

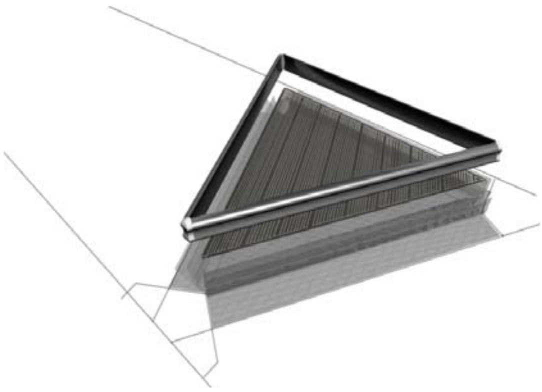

**Figure 8:** Concept 1: a triangular thin film PV module.

4.2 Concept 2: PV lamellas

This concept combines conventional x-Si PV technology with a sun-blind system which can be used in the build environment, see Figure 9. The product is combined with a single axis tracking mechanism allowing for a linear concentrator design . The shape is tailored to focus the light on the cells while a reflective strip also projects light on the cell through internal reflection. This results in a concentration factor of 1.2. A water filling is used as refractive medium and cooling of the module by spreading absorbed irradiance heat of the cells over a larger surface.

Using pultrusion braiding a continuous lamella can be produced to be cut to size to produce a range of lamella widths for varying windows. The output is estimated at 5.3 Wp per meter lamella.

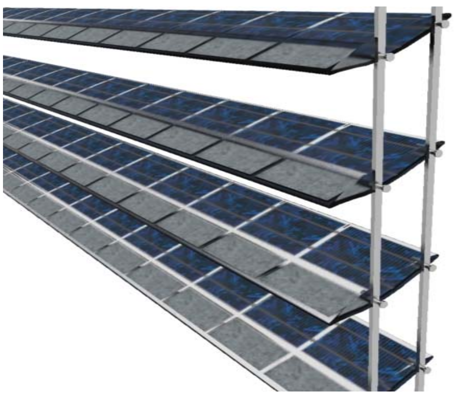

**Figure 9:** Concept 2, Artist's rendering of a lamella mounted in a blind system,

4.3 Concept 3: PV fabric

Due to the frequent application of glass sheet and brittleness of PV-cells itself, current PV-modules are limited in deformability particularly when double curvature is required. Therefore our third concept has been designed for future applications in complex geometries. It is a prepreg material employing spherical cells in a stitched glass fabric, see Figure 10. Using the fabric to position and hold the individual millimeter sized cells and a metallic stitching wire as electrical interconnect, the resulting prepreg can be processed on a roll to roll basis, cut to size and withstand large deformations in the further production process which mainly consist of heating to the glass transition temperature of the matrix and deforming in a mould.

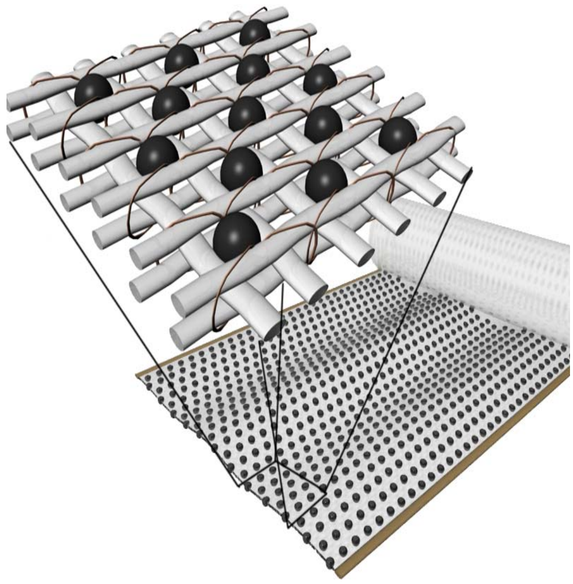

**Figure 10:** Concept 3: Spherical PV cells in a stitched fabric with the metal stitching wire as an electrical interconnection.

## 5 DISCUSSION AND CONCLUSIONS

The combination of PV technology and GFRP seems promising given the transparency of GFRP, their light weight, high mechanical strength, opportunities for customization of mechanical properties, freedom of form, and favorable modifications in production process

The combination of PV and GFRP is relatively new therefore experience with use and applications must be built up regarding mechanical behavior in relation to the type of glass fibres, the weave, the number of layers applied and specific polymers used in transparent GFRP.

Besides this for future research we recommend to pay attention to ageing of GFRP, because until now degradation mechanisms have not yet been well understood. Moreover the transmittance of light in GFRP should be further explored, because it's highly dependent on the difference in refractive index of the fibres and the polymer and their volume share.

In our paper we have shown three concepts for GFRP embedded PV applications in the build environment. We believe however that the field of applications could be broader. Namely consumer products, boats and vehicles could be interesting near-future product groups for combined use of PV cells and GFRP.

## 6 ACKNOWLEDGEMENTS

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