CHALLENGES OF INTEGRATING PHOTOVOLTAIC CELLS ONTO THE WINGS OF AN UNMANNED SOLAR-POWERED AIRCRAFT

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Abstract

Fixed-wing Unmanned Aerial Vehicles (UAVs) have transformed the aerospace industry, finding applications in monitoring, environmental surveys, and site mapping due to their versatility and ability to operate without human intervention. However, limited energy capacity poses a challenge. Addressing this, the AGH University of Krakow's students have developed solar-powered UAVs. This research focuses on advancing solar-powered UAV technology by developing innovative methods for integrating photovoltaic cells into composite wings. The study highlights a multi-step lamination process and the use of specialized materials, aiming to enhance the durability and performance of solar UAVs in various applications.

Keywords: solar-powered UAV, Unmanned Aerial Vehicles, solar cells lamination, renewable energy sources, electromobility

1. Introduction

Fixed-wing Unmanned Aerial Vehicles (UAVs) are a reliable and irreplaceable technology that has revolutionised the aerospace industry. Thanks to their multi-purpose capability and their ability to operate in dangerous or hard-to-reach areas, they have found their way into a wide array of industries enabling a monitoring, environmental surveys or site mapping, among other applications. The main advantage of UAVs over passenger aircraft is that there is no need for human intervention to directly operate such a machine; moreover, their smaller size reduces the cost of both the construction and the infrastructure required.

Despite the many advantages of such a system, a major limitation is still the range of the drones, which can only take a mass-limited amount of energy. In response to this problem and the need for alternative energy sources, work is underway on solar-powered fixed-wings. Inspired by the Swiss Atlantik Solar project initiated at the ETH Zurich [1, 2], students from the AGH University of Krakow undertook the task of designing and building a solar UAV as part of the Student's Scientific Association AGH Solar Plane. Over the past 5 years, several designs have already been developed that were capable of performing multi-hour flights. This has been possible thanks to the development of own technology for integrating photovoltaic cells into the surface of composite wings. This task is not trivial and involves a number of problems such as the fragility of the cells and the need to maintain the plane of the curved wing profile. The aim of this research is to present the technology for laminating cells to the surface of solar planes developed over the years by AGH Solar Plane students, with particular emphasis on the materials and methods used. In addition, the paper will describe the methods used to evaluate the quality of the samples obtained and their performance.

Figure 1 – Solar-powered UAV Foton at international competition in Turkey - TEKNOFEST.

Figure 2 – Solar-powered UAV Foton during flight.

2. Materials and methods

2.1 Used photovoltaic cells

The requirements that are placed on manufacturers of photovoltaic cells in terms of their usefulness in solar aircraft are primarily flexibility. Although, according to many sources, perovskite cells would work best in this regard, they are not yet widely available on the market [3]. There are also thin films of cells, but they have very low efficiencies. Therefore, in the construction of solar drones, it is common to use cells with more than twice the efficiency of the SunPower Maxeon III gen brand, the characteristics of which are given in the Figure 3.

Electrical Characteristics of a typical Maxeon Gen III Cell
At Standard Test Conditions (STC)
STC: 1000W/m², AM 1.5G and cell temp 25°C

	Cell Bin	Pmpp (Wp)	Eff. (%)	Vmpp (V)	Impp (A)	Voc (V)	Isc (A)
Ultra Peak Performance	Me1	3.72	24.3	0.632	5.89	0.730	6.18
Ultra Premium Performance	Le1	3.63	23.7	0.621	5.84	0.721	6.15
Ultra High Performance	Ke1	3.54	23.1	0.612	5.79	0.713	6.11

Electrical parameters are nominal values.
Temp.Coefficients in SunPower Panels: Voltage: -1.74mV/°C, Current: 2.9mA/°C, Power: -0.29%/°C

Figure 3 – Electrical Characteristics of a typical Maxeon Gen III Cell At Standard Test Conditions (STC). *https://sunpower.com, access: 26.12.2023*

When selecting photovoltaic cells for solar aircraft wings, due to the limited surface area, the power per unit cell area is also an important factor. For the product used, it was calculated that with an area of 153 cm2, this coefficient is between 231 and 243 Wp/m2. This is a very satisfactory value, especially considering another advantage of the cell's weight of 6.5 g. In addition to the high flexibility of the cells in question, they also have the advantage of having back-contact connectors that provide a permanent connection via back contacts without the need for additional wires. This allows the manufacturer to dedicate the entire top surface of the cells to a radiation-absorbing layer.

2.2 Sample generation methodology

The first stage of the work is to prepare the photovoltaic cell modules by soldering the individual cells together using the manufacturer's dedicated connectors made of thin sheet metal as shown in Figure 4. This process requires a high degree of accuracy in order not to damage the electrical paths of the cell and lead to their destruction.

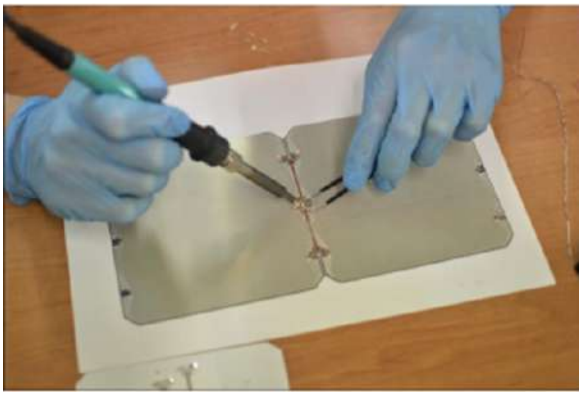

Figure 4 – Soldering

The cells are then subjected to thermal lamination using paper lamination film. A blanket to ensure proper air extraction, baking paper as a separation between the blanket and the cells, 24 g/m2 fiberglass, photovoltaic cells, and lamination film are placed sequentially on a clean table. The whole thing is covered with a vacuum film and, after sealing it, air is extracted from inside until it reaches about 0.2 atmospheres. This ensures that the thermal film adheres evenly to the cell surface. Then, using an electric heat gun, the top surface is heated to about 120 Celsius and the cells and glass fiber integrate permanently into the film.

Figure 5 – Thermal lamination

The next step is to laminate the cells and fiberglass with epoxy resin. When making the test specimens, L285 aerospace resin and HG287 hardener were used, which is used in the aerospace industry due to its high static and dynamic strength. At this stage, the cells are laminated only to a single layer of glass pre-bonded to the cells and film in the previous step. After the application of a resin and hardener mixture equal in weight to that of the glass fiber, the whole thing is put into a vacuum bag along with a styrodur negative of the wing profile on which the cells are to be applied. This allows for a pre-bending to the curvature of the airfoil.

Once the composite has cured under vacuum, it is time for the next iteration of laminating with resin. Depending on the design goals, any material in the glass and carbon fiber range with different weights can be used here. At this stage there is also a division of the technology into two different processing methods.

The first method involves laminating successive layers of fiberglass or carbon fiber to an already existing fiberglass composite with photovoltaic cells. The underside of the wing is separately laminated and then the two layers are carefully laid over the wing core and left under vacuum for a minimum of 24 hours. The wing core is an airfoil cut out of a block of extruded polystyrene using a thermal plotter with a resistance wire, which is heated under the influence of a current to temperatures that allow it to melt the expected shape. While the second method involves separately pre-laminating the wing and then laminating the previously prepared fiberglass cell module.

Materials used to make wing samples for this article:

- for measuring current-voltage characteristics under wing deflection: Interglass fiber 81 g/m2
- for evaluation of galvanic insulation: carbon fiber TeXtreme

The wings shown in the photos from the electroluminescence study were made using different methods and from different materials, because they are only intended to show the damage that can occur on photovoltaic cells.

2.3 Methodology for comparison of two methods of laminating under deflection

One of the objectives of the study was to compare the two methods described above for laminating photovoltaic cells to the surface of a composite wing under load-bearing surface conditions. For this purpose, two wings of 110 cm in length were installed on a test stand equipped with 18 halogen bulbs with a total power of 2.7 kW. The irradiance at the height of the cell placement averaged 1430 W/m2. It was measured using a Benning SUN 2 solar and temperature meter by Conrad. during the measurement, the surface temperature of the cells was also measured, which oscillated in the range of 40-52 Celsius. During the measurements, each wing was loaded by suspending under it successively 2, 4, 6, 8 and 10 kg of load concentrated on its center.

Figure 6 – One of the wings during the test

2.4 Electrical insulation assessment methodology

Several different techniques were used to compare different methods of galvanic isolation of photovoltaic cells from the surface of the carbon fiber wing, which conducts electricity, with the aim of preventing the occurrence of a short circuit. Electrical meter was used to measure parameters such as short-circuit current and open circuit voltage, which made it possible to assess whether the cells in question are not short-circuited with the surface of the wing. The tests were carried out under natural illumination, and the irradiance indicated by the pyranometer was approx. 850 W/m2.

2.5 Electroluminescence testing

Electroluminescence is an inverse phenomenon to the photovoltaic effect, which makes it possible to visualize in which areas of the cells are working properly and in which there are some defects. It involves powering the tested photovoltaic modules with a direct current source, which causes electrons to connect with holes and excite photons. The radiation thus produced was observed in images by using a specialized camera that records radiation in a darkroom in the appropriate wavelength band between 950 and 1350 nm (https://magazynfotowoltaika.pl , access: 26.12.2023). The research was performed in cooperation with the Photovoltaic Laboratory of the Institute of Metallurgy and Materials Science of the Polish Academy of Sciences in Kozy.

3. Results

3.1 Comparison of two methods of laminating under deflection

Measurement of the deflection of the two tested wings (the distance in the vertical axis between the center point of the wing without load and the same point with load) shown in Figure 7 demonstrate that the first method has a higher bending strength. Not only was the measured deflection lower for each load, but it also collapsed only after a while under a load of 10 kg, while the wing made by the second method broke already at 8 kg, not allowing the current-voltage characteristics to be made for this value.

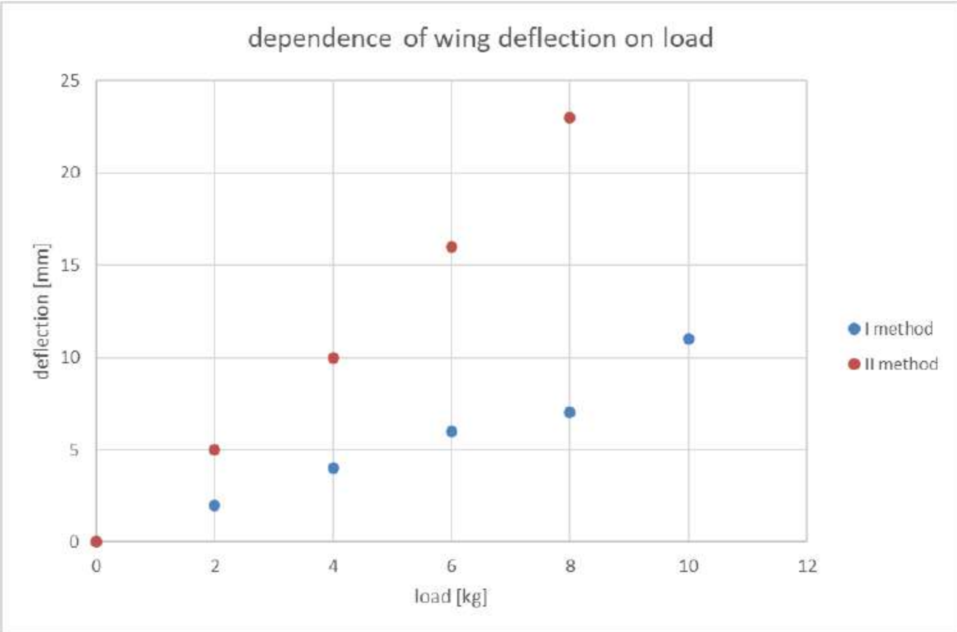

Figure 7 – Comparison of deflection dependence on wing load for two lamination methods

Figure 8 shows the characteristics determined for four cells laminated with the first method, and Figure 9 with the second method. For both methods, a decrease in efficiency with load and wing deflection can be seen.

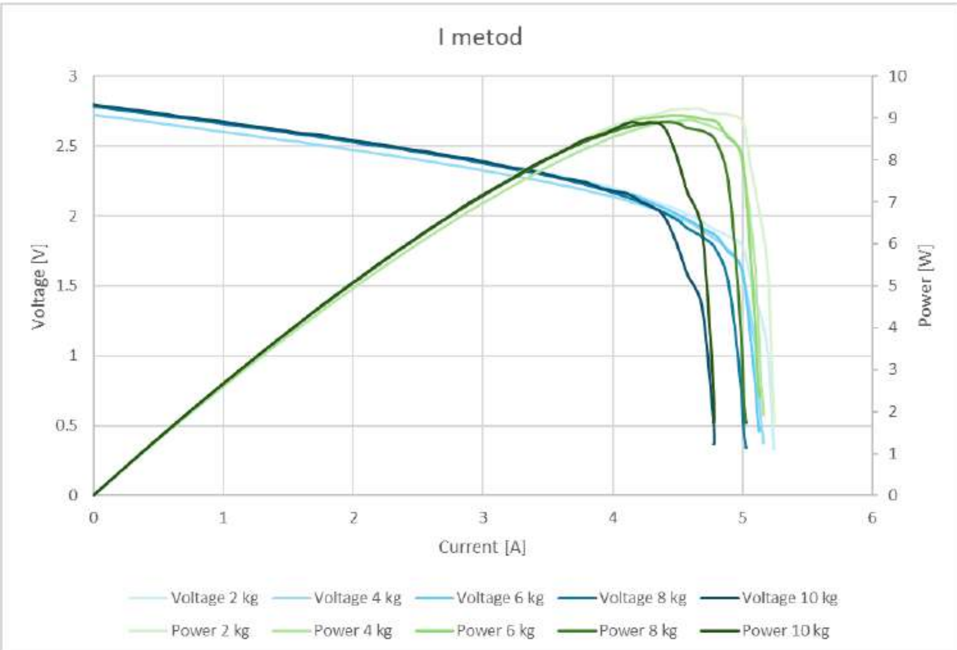

Figure 8 – Operating characteristics of cells on wings laminated by the first method

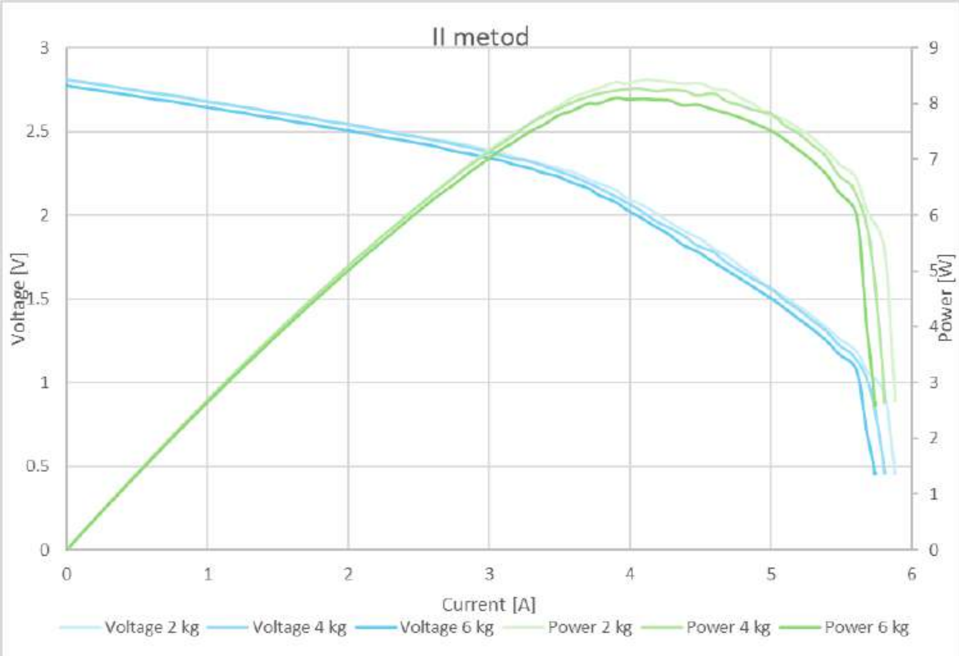

Figure 9 – Operating characteristics of cells on wings laminated by the second method

For both the smallest (Figure 10) and largest (Figure 11) load implemented for both wings, higher performance was shown for cell modules laminated with the first method.

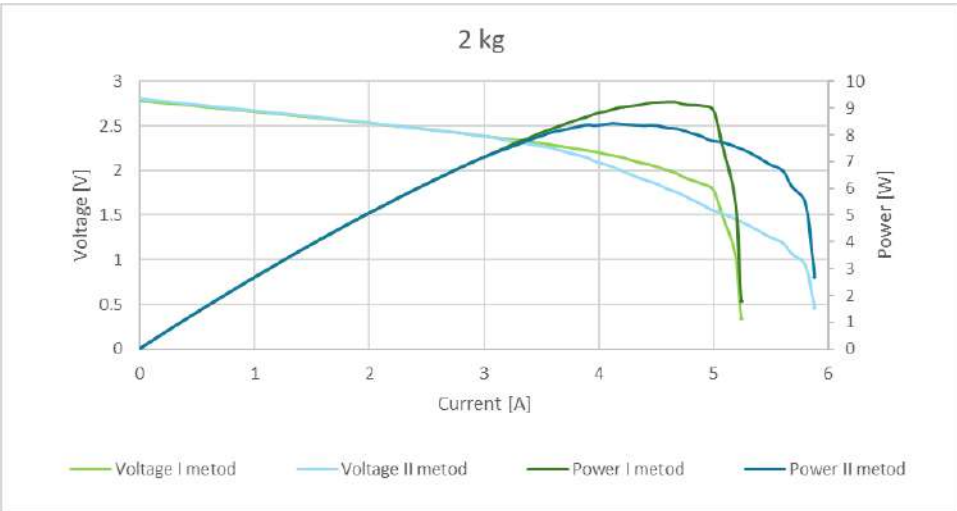

Figure 10 – Operating characteristics for 2 kg load

For a 2 kg load, the maximum power obtained at MPP (Maximum Power Point) was 9.5% more for Method I than Method II, and with a 6 kg load the difference was 12.5%.

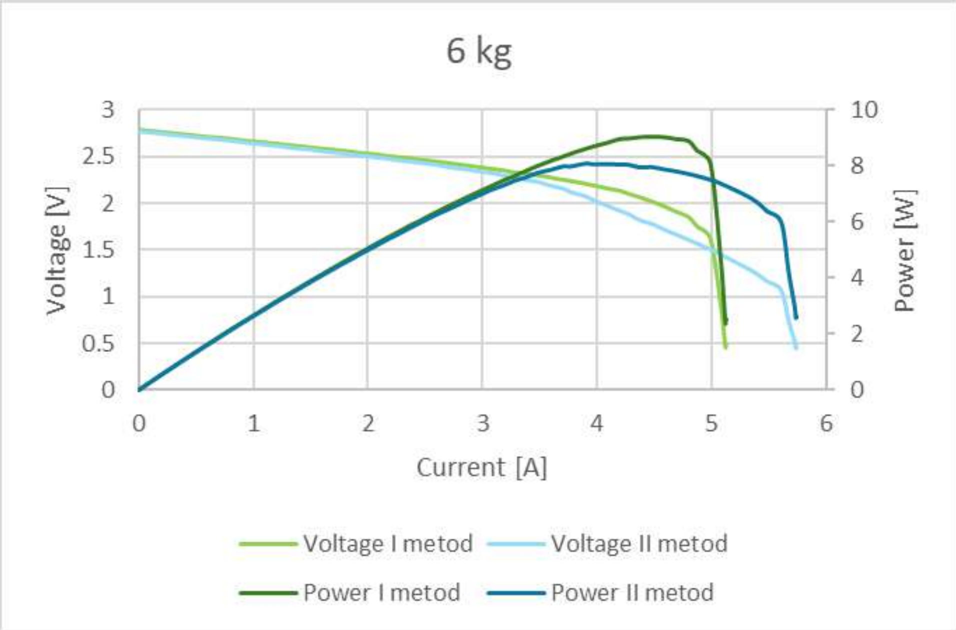

Figure 11 – Operating characteristics for 6 kg load

3.2 Electroluminescence testing

The first challenge of integrating photovoltaic cells is their vulnerability to micro-cracks. They can be caused both by small dirt getting under the cells (left Figure 12) and by structural elements inside the wing, which result in linear pressure on the photovoltaic cell module during the lifting force. For example, on the right side of Figure 12, a linear crack can be seen where there is a connector between the two parts of the wing.

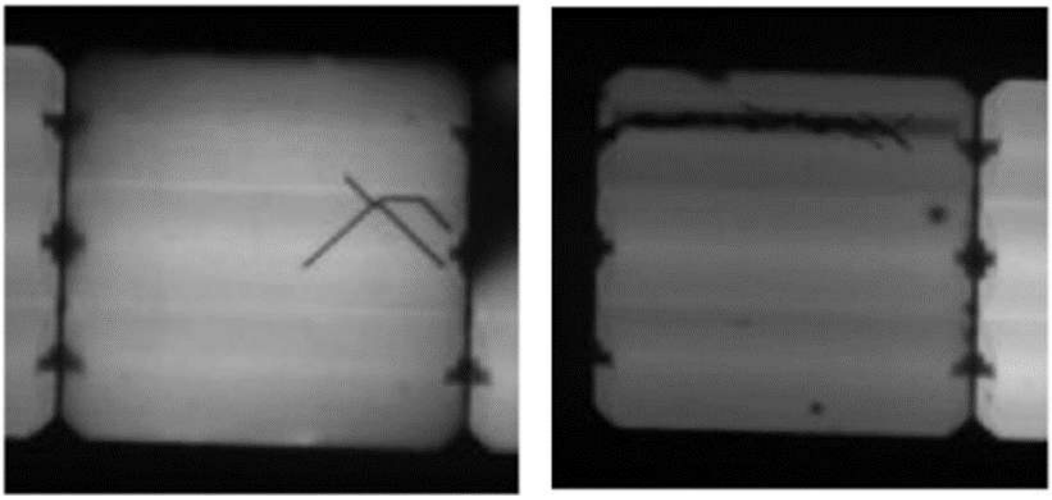

Figure 12 – Cracks on photovoltaic cells

Malfunctioning of individual cells can also be caused by human error such as incorrectly soldering connectors between cells, which results in parts of the cell going out of service as seen at Figure 13.

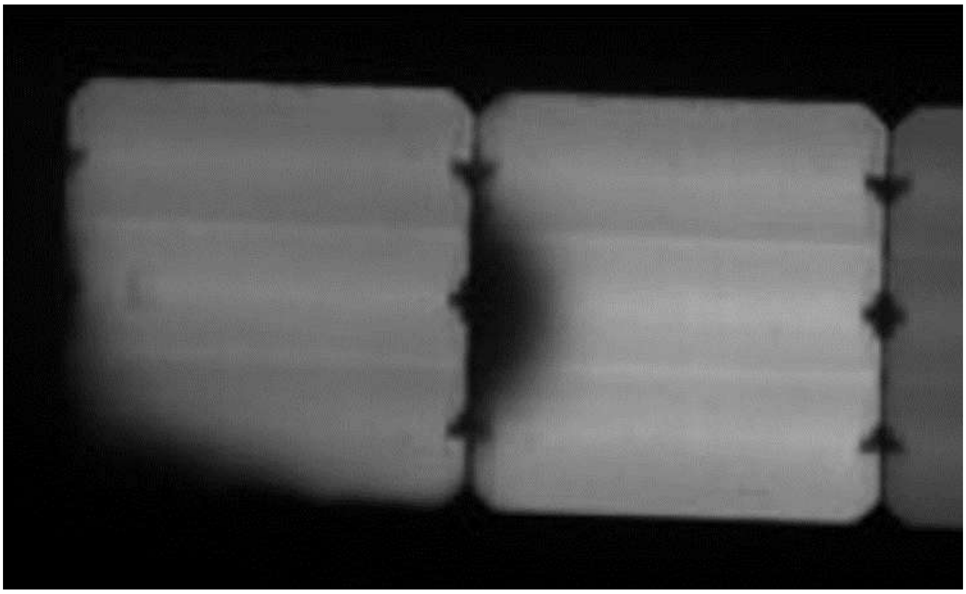

Figure 13 – Malfunction due to incorrect soldering

Unfortunately, when estimating the output of photovoltaic cells at the design stage, one must also take into account manufacturing defects that reduce the efficiency of the entire string. The Figure 14 shows a defect in the silicon layer created during the production of the cell itself.

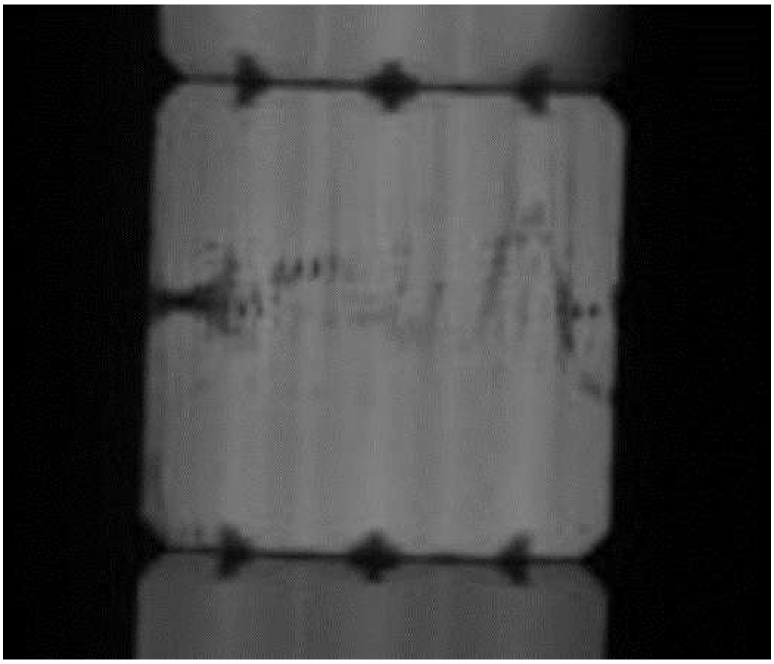

Figure 14 – Manufacturing defect

4. Conclusions

The first method which involves laminating successive layers of fiberglass or carbon fiber to an already existing fiberglass composite with photovoltaic cells has proven to provide significantly higher stiffness as well as strength of the wing, which is also manifested in better performance of photovoltaic modules. However, in spite of these results, further tests are planned to confirm this thesis also with equal loading of the wing surfaces and with a consistent temperature on the test station. A very positive result in terms of future work is also the finding that the aforementioned method provides adequate and durable galvanic isolation of the cells from the surface made of carbon fiber. Nevertheless, one should always keep in mind the risks of damage to the cells, which are indicated in the photos taken by electroluminescence regardless of the method used.

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6. Copyright Statement

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