Coatings or tapes?

Imaging methods to show the successful repair of backsheets cracks

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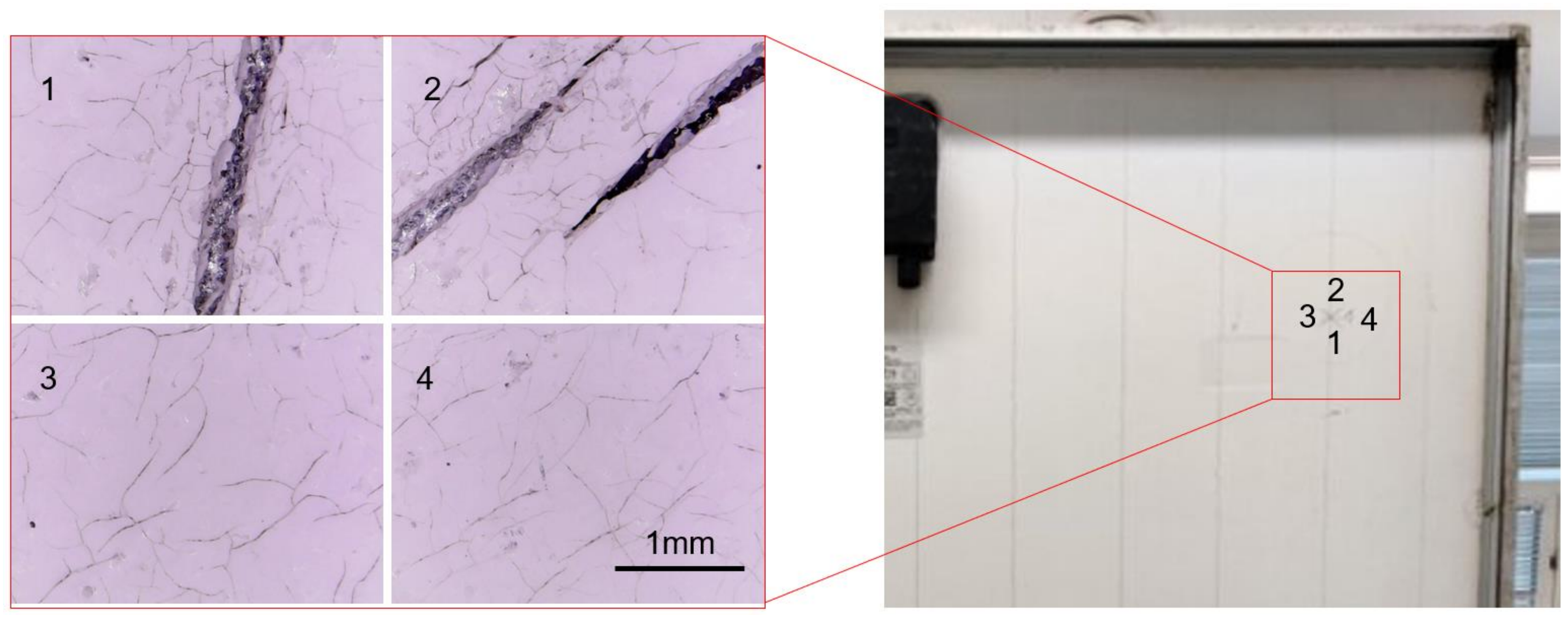
Motivation & Status Quo

The PV industry faces the critical challenge of extending the lifespan of PV modules. While new PV technologies with enhanced reliability are one avenue, another effective approach is to **prolong** the operational life of existing modules through **reuse, repair, or refurbishment**. Repair solutions for damaged backsheets (BS) help to ensure that PV modules can meet their expected lifespan of 20+ years without (i) significant energy loss, (ii) safety issues due to insulation breakdown in wet conditions (R_{iso}) or (iii) progressive material degradation.

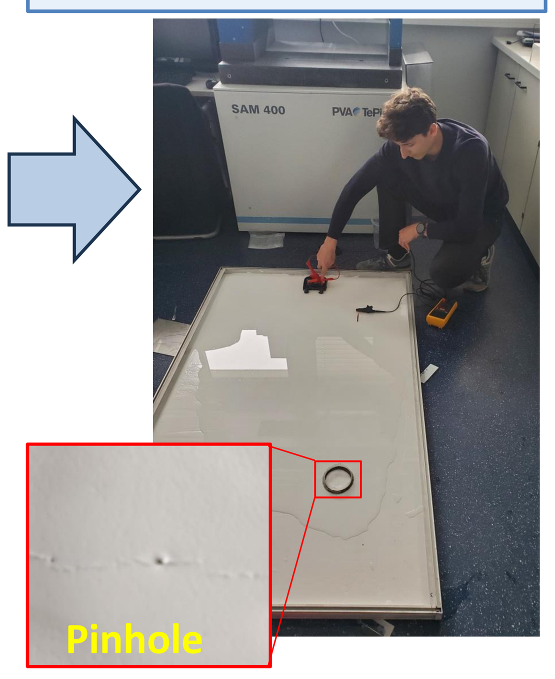
The **ReNewPV** research project focuses on creating effective repair solutions for cracked or defective BS, primarily by **restoring R_{iso}** of these modules. Reliable repairs not only extend the service life of PV modules, offering **cost benefits** to solar farm operators and owners, but they also maintain **stable electricity yields** and restore operational safety by **applying coatings** to damaged BS films. By extending the service life, **PV waste is reduced, resources are saved, logistics costs** and **CO_2 emissions are reduced** by the possibility of on-site repairs.

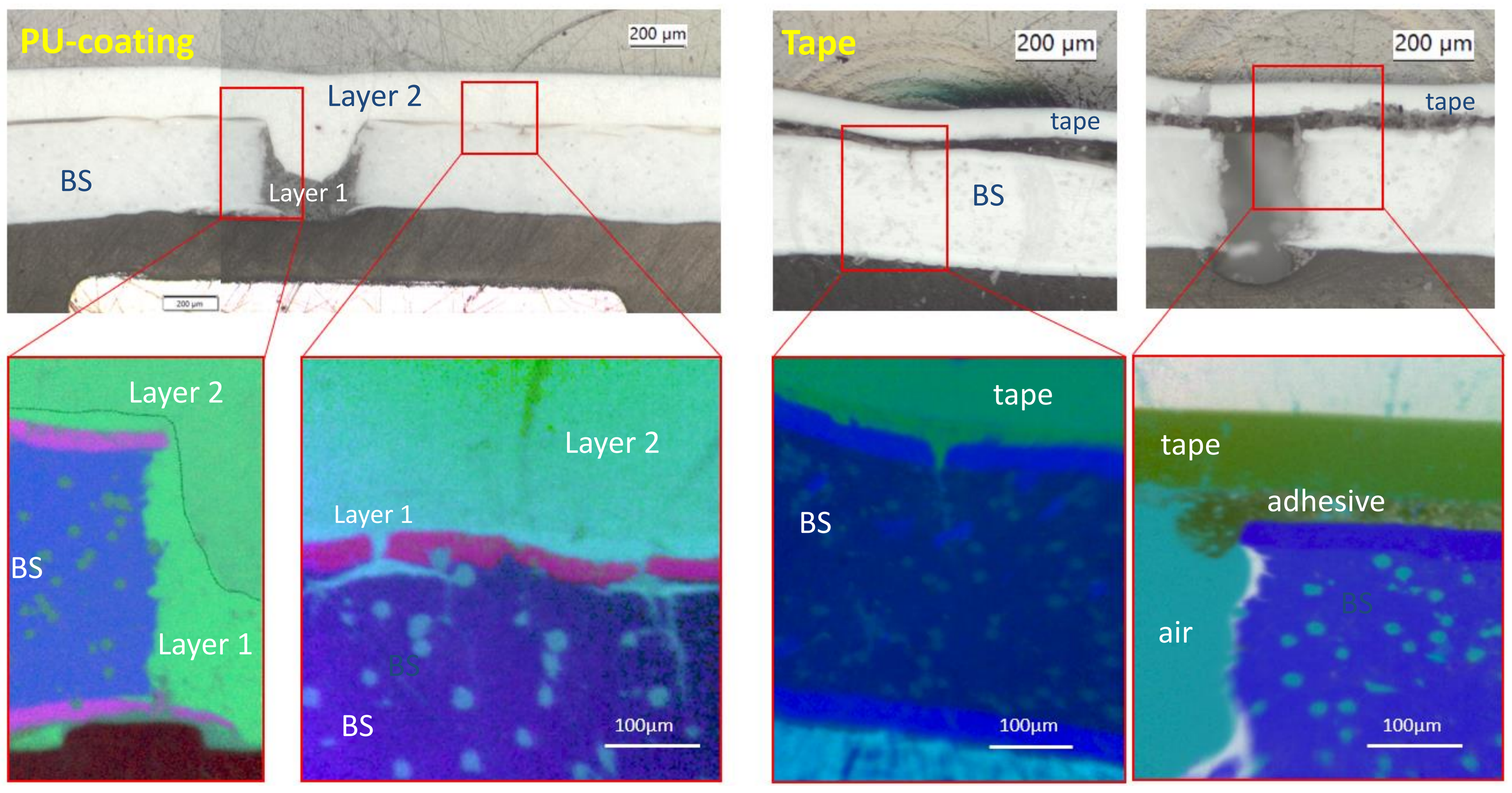


Light microscopic images (left) and foto (right) of cracked polyamide BS;
1, 2 deep longitudinal cracks LC (whole BS torn); 3, 4 micro cracks MC (outer BS-layer affected)

Repair Method & Evaluation of Crack Filling

After coating / taping of the cracked BS, a wet leakage test was performed to verify successful restoration of the insulation resistance (R_{iso}).





The **developed repair method** focuses on restoring the functionality of cracked backsheets through the application of coatings or adhesive tapes or foils.

Key is the ability of the repair material (1) to **fill the cracks** and (2) to **build a protective barrier layer** on the surface. The table summarizes the characteristics and evaluation of crack filling of **3 repair options:**

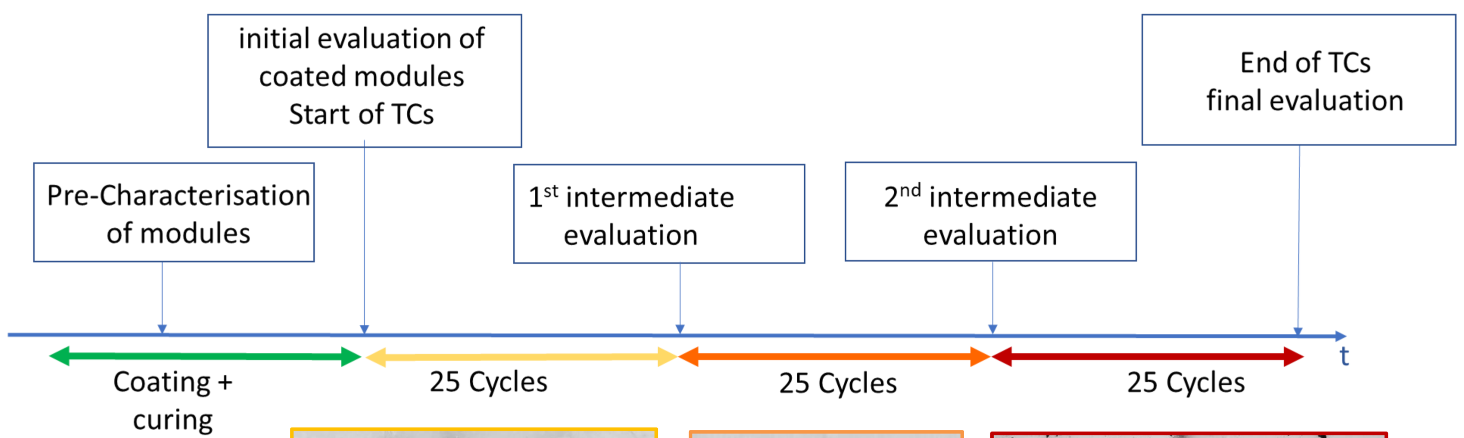
Material	Compo-nents	Contains solvent	Coating layers	Crack filling (ATR)	
				MC	LC
Silicon-coating	1	no	1	yes	yes
PU-coating	2	yes	2	yes	yes
PVC-tape	1	no	1	yes	no

Reliability Testing

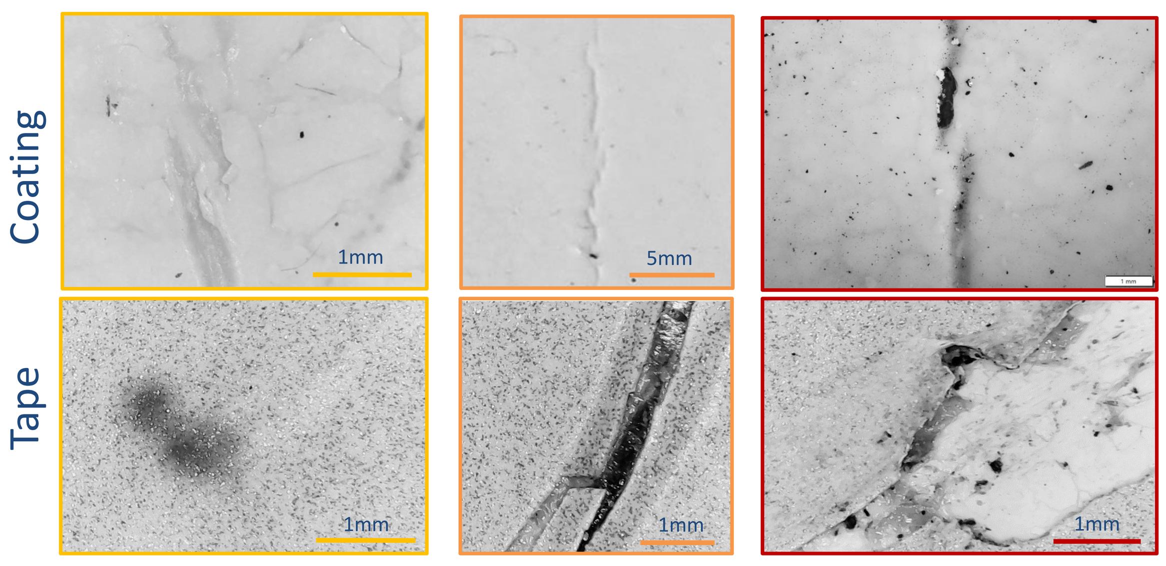
Accelerated aging tests IEC 61215-2 MQT 11 temperature cycling (-40 -> +85°C) were conducted to evaluate the long-term stability of the repaired modules. Two intermediate evaluations were conducted during the process to assess the effect of the stress-impact of the TCs on (i) the material stability, (ii) R_{iso} and (iii) adhesion quality and (iv) electrical performance (P_{MPP}).

Results

IEC 61215-2 MQT 11 temperature cycling -40 → +85°C



Silicone coating: minor cracks in the top layer; only after 75 cycles (c). R_{iso} restored
PU-coating: embrittlement of coating; formation of cracks in coating; breakdown of R_{iso}
Tape/Foil: minor damage (tear of the foil, delamination) after 50c; more severe damage after 75c; breakdown of R_{iso}



Results of the final evaluation after the accelerated aging tests

Repair/ Material	performance loss (ΔP_{MPP})	Physical stability of repair layer	Adhesion to BS (test tape TESA 4651)	R_{iso} restoration	Chemical stability of repair layer
Silicon-coating	-12.7 %	yes	good	yes	yes
PU-coating	-10.3%	stiffening after aging -> brittle	good	no	yes
PVC-tape	-18.7%	shrinking	good, detachment at the rims	no	yes

Characterization

The effectiveness of each repair option was assessed through several characterization methods:

Non-destructive methods:

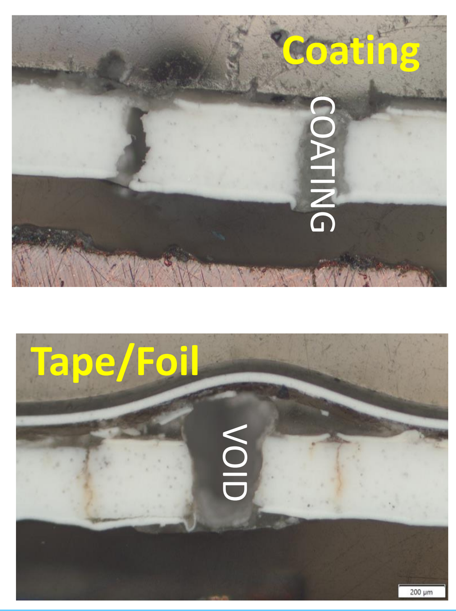
- **Ultrasonic microscopy (USM):** visualization of various interfaces within the PV module stack with the aim to identify which layers within the BS are already cracked -> lateral
- **Electrical performance measurement (P_{MPP}):** evaluation the overall performance pre- and post-repair of the PV-module and after accelerated aging
- **Electroluminescence imaging (EL)**: detection of defects/cracks of the solar cells; allows for a pre- and post-repair comparison and the aging effect
- **Isolation Resistance measurement (R_{iso}):** verification of the insulation properties of the module under wet conditions (IEC 61215-2, MQT 15, wet leakage current test;

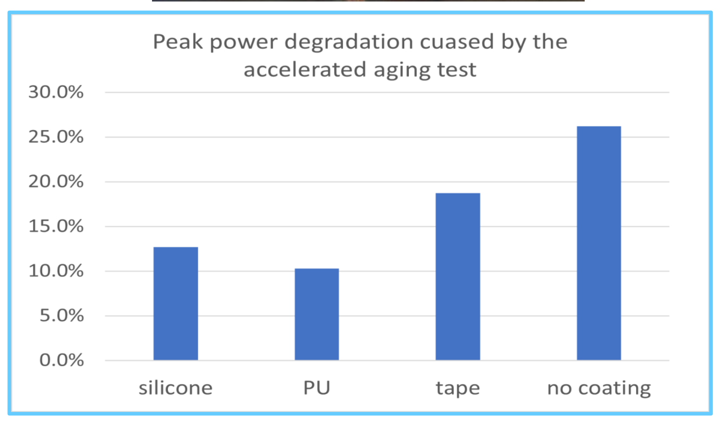
Destructive methods on module cross sections:

- **Light microscopy (LM)**: examination of the physical structure and integrity of repaired sections, revealing the effectiveness of crack filling and material restoration
- **ATR-FTIR imaging:** visualization and spectroscopic identification of materials, facilitating the evaluation of crack filling quality; analysis of chemical stability of the coatings and adhesives

Results of the characterisation

- → **After repair, the R_{iso} of all repaired modules was restored.**
- → **Crack filling** was best characterized on cross sections with light microscopy and ATR-imaging; **USM** is a useful method to analyse the depth of LCs; the lateral resolution of this method, however, is not sufficient to visualize MC or crack filling of the coatings
- → **Repair tape solutions** effectively fill the MCs (with adhesive) and prevent further crack growth; however, they are ineffective in repairing deep BS cracks as they do not fill the crack voids and therefore do not restore full BS functionality.
- → **Coatings (PU and silicone)** can fill MCs and deep LCs (thus replacing the backsheet material) and restore the insulating and protective properties of the backsheets





Conclusions & Outlook

After repair, the R_{iso} of all repaired modules was restored. After accelerated aging tests the **silicon coating performed the best**, as the silicone coated modules were the only passing the R_{iso} test. Furthermore, silicone is a **cost effective** and **environmentally friendly** material as it does not contain any solvent or fluor. As a 1-component system, it is easy and **quick to apply even in the field.** The coating process requires only one single layer and **hardens quickly**. The **PU coating** is effective in crack filling and restoring R_{iso}, but suffered from embrittlement upon temperature cycling. It is currently in the process of being optimized, we can confirm a reduction in brittleness in the second generation. First long-term reliability data with silicone and PU-coating are already available for a test-installation with repaired backsheets (operative since 08.2021). Based on the results of the PVC tape, the use of an additional protective BS foil glued on top of the cracked BS will be tested next.

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FFG Forschung wirkt.