Encapsulant Selection and Accelerated Lamination for TOPCon PV Modules: From Material Screening to Full-Size Validation

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Introduction

- TOPCon replaced PERC as dominant cell technology [1]
- TOPCon cells and modules: significant degradation under damp-heat (DH) and UV-induced conditions (UVID) [2,3]
- **Goal**: Develop a locally produced Bill-of-Materials (≥ 75 % Turkish content) and evaluate long-term reliability of TOPCon modules under DH, TC, and combined DH + UV stress tests [4]

Experimental Approach

BOM

- Non-UV-blocking EPE from local Turkish manufacturer applied on both module sides (at study's outset, no turkish UV-blocking options available)
- Glass (2 mm thick, 2285 mm × 1134 mm), TOPCon cells (M10, 10BB) and frame sourced exclusively from Turkish manufacturers

Lamination Processes

- Comparing reference process (Batch 1) with two accelerated processes with higher lamination temperatures (Batch 2 and Batch3)
- Initial quality control: Soxhlet extraction to quantify the gel content of each batch.

Table 1: Lamination Processes

Batch	Evacuation Temp	Evacuation Time	Curing Temp	Curing Time
Batch 1	135 °C	300 s	145 °C	430 s
Batch 2	145 °C	300 s	155 °C	300 s
Batch 3	145 °C	240 s	155 °C	300 s

Reliability

- 1000 h Damp Heat Test (DH) acc. to IEC61215 MQT13
- 200 cycles Thermal Cycling Test (TC) acc. IEC61215 MQT11
- Sequence B acc. to IEC61730-2:2023 (DH200+UV60+HF10)

Production

- 15 full-size TOPCon butterfly modules (5 per batch); 2 modules per batch tested under DH, 2 under TC, one served as reference
- Parallelly, 10 modules produced with the reference process (comparable to Batch 1) on industrial manufacturing line

Results

Modules manufactured with different lamination process

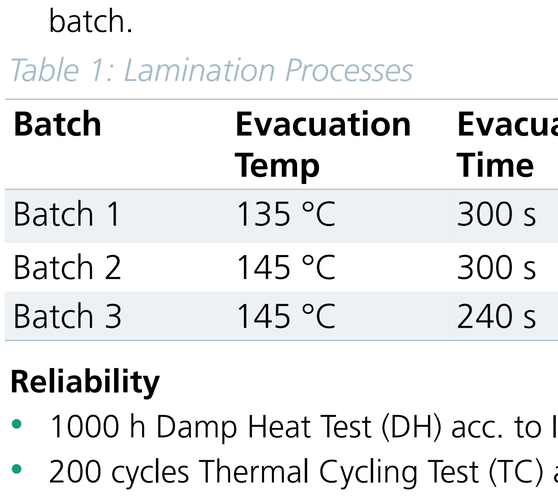


Figure 1: Gel Content Values of the three processes

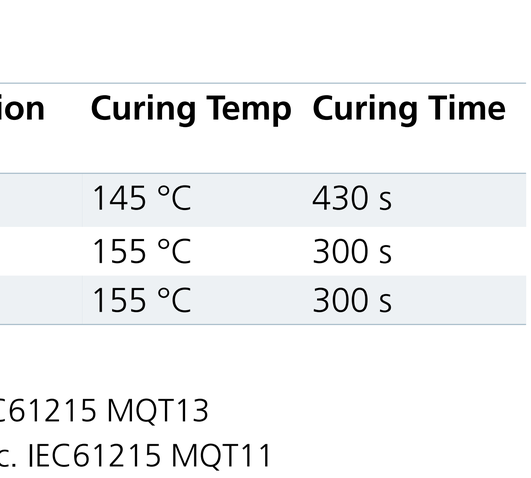


Figure 2: Initial Power Outputs

- Batch 2 exhibited the highest gel-content despite a shorter process duration; Batch 1 showed the lowest.
- All batches achieved comparable output (± 3 %).

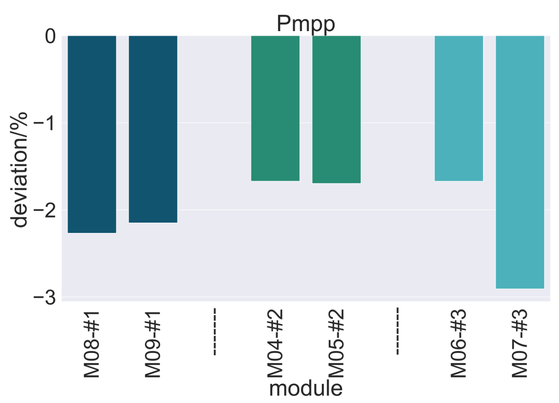


Figure 3: Power loss after DH1000 for lab modules

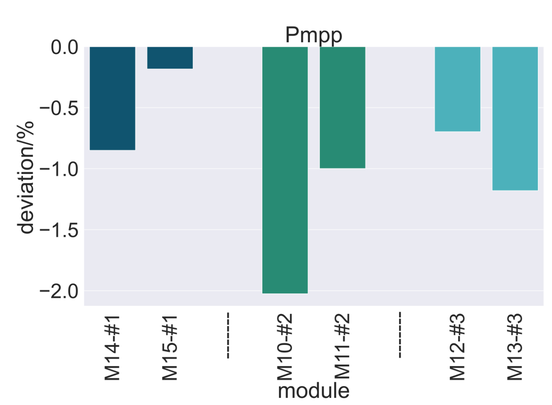


Figure 4: Power loss after TC200

- Batch 2 recorded the lowest power loss (DH1000)
- Results for all processes after TC200, one module of Batch 2 with more deviation due to contacting issues

Line module results compared to other commercial modules

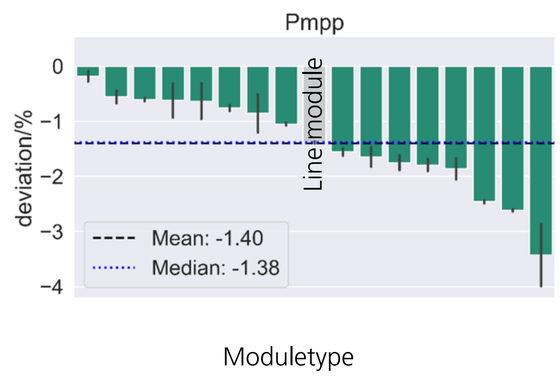


Figure 5: Power loss after DH1000 for the line modules (Batch 1)

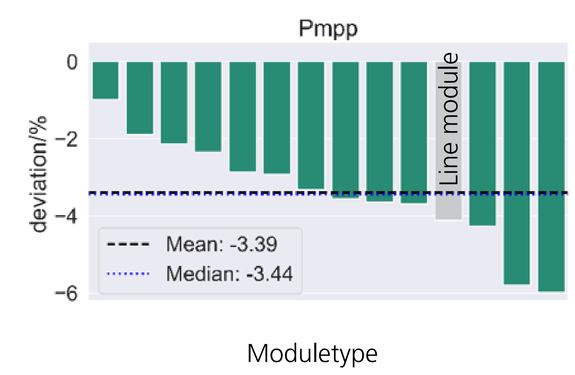


Figure 6: Power loss after DH200 + UV60 + HF for the line modules (Batch1)

- Corrosion of interconnectors in both tests
- UVID degradation confirmed, attributable to non-UV-blocking encapsulant.

Summary

Locally produced Bill-of-Materials (≥ 75 % Turkish content) for TOPCon modules: fabricated and evaluated under damp-heat (DH), thermocycling (TC), and combined DH + UV stress tests

Three lamination processes compared: reference process (Batch 1) and two accelerated processes (Batch 2 & 3) employing higher cure temperatures

- Batch 2 (10 min) achieves DH1000 & TC200 performance comparable to reference (Batch1), **reducing process time by ~ 20 %.**
- DH200 + UV60: UV sensitivity of the cells → a UV-blocking encapsulant or down-shifter required for long-term stability
- DH1000 results for line-manufactured modules: acceptable relative to commercial modules; DH2000 recommended for future runs

[1] M. Fischer, M. Woodhouse, P. Baliozian, International Technology Roadmap for Photovoltaics (ITRPV), 2024.
[[2] F.T. Thome, P. Meßmer, S. Mack, E. Schnabel, F. Schindler, W. Kwapil, M. C. Schubert, UV-Induced degradation of industrial PERC, TOPCon, and HJT solar cells: the next big reliability challenge? Sol. RRL (2024)
[3] P. Gebhardt, U. Kr¨aling, E. Fokuhl, I. Haedrich, D. Philipp, Reliability of Commercial Topcon PV Modules-An Extensive Comparative Study
[4] SPECIFICATIONS FOR ALLOCATION OF SOLAR-BASED RENEWABLE ENERGY ZONES AND CONNECTION CAPACITIES (YEKA (REZ) SPP-2024 SPECIFICATIONS)