Compressive shear test to accurately measure adhesion of PV encapsulants

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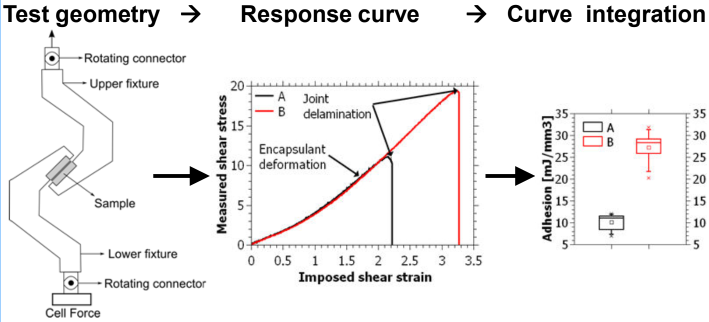
Motivations and goals

- **Good adhesion of PV encapsulants to glass or other module materials is needed to guarantee long lifetime**
- **Deep understanding of the adhesion test is needed to ensure reliable data collection**

Compressive Shear Test

Test geometry → Response curve → Curve integration



V. Chapuis and al., Prog. Photovolt: Res. Appl. (2012), DOI: 10.1002/pip.2270

Advantages

- Simple induced stress state
- Delamination mode controlled
- High reproducibility
- Stored elastic energy used as an indicator of adhesion

Drawbacks

- Limited to encapsulant bonded to rigid substrates in a subtrate/encapsulant/substrate configuration
- May lead to cohesive failure if the encapsulant is too soft

Understanding adhesion

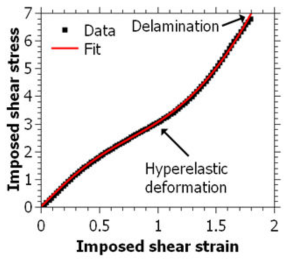
Mechanics of joint response

EVA has a hyperelastic behavior

$$S_{ss} = \frac{dW}{d\gamma} = \frac{\gamma}{\gamma^2+3}\sum_{r=1}^{2} 3^{1-\alpha_r}\mu_r(\gamma^2+3)^{\alpha_r} \quad [1]$$

Stored elastic energy in the encapsulant represents the delamination energy

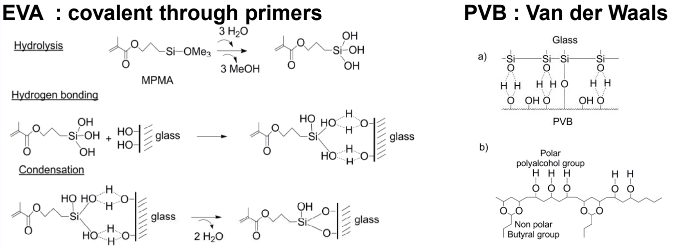
$$E^{el} = \int \tau(\gamma)d\gamma$$



[1] : O. Lopez-Pamies, C.R. Mécaniques 338, pp.3-11, 2010

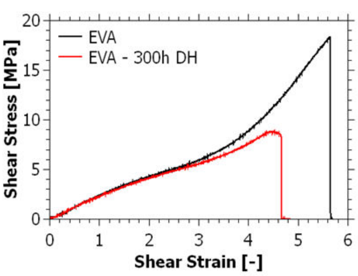
Chemistry of adhesion

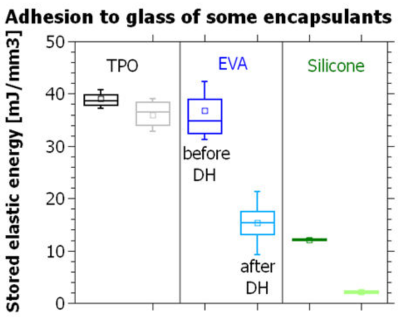
EVA : covalent through primers **PVB : Van der Waals**



Different examples of encapsulant/glass adhesion mechanisms

Comparison of different encapsulants and aging effect

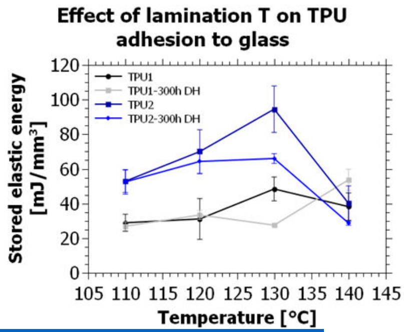




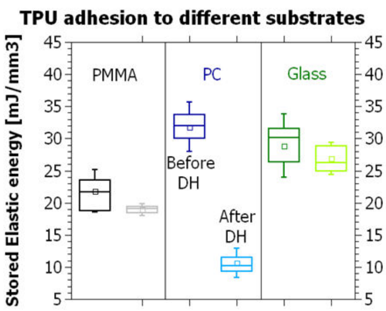
Observations:

- Adhesion of different encapsulants to glass after Damp Heat (300h) on evidences different behaviours:
  - TPO and EVA same initial adhesion due to similar chemical structure and adhesion promoters but lower moisture diffusion barrier of EVA leading to more important drop after DH aging
  - Silicone has much lower adhesion in initial conditions and tend to be extremely low after DH aging
  - TPU shows an extremely high adhesion to glass even at lamination temperatures as low as 110°C
  - TPU adhesion to other rigid and transparent substrates such as PMMA is stable after aging

Comparison of different lamination temperatures



Comparison of different substrates



Conclusions

- ***Compressive shear test allows reproducible and reliable adhesion measurement for PV encapsulants bonded to rigid substrates***
- ***Testing different encapsulants allows a clear ranking in adhesion before and after aging (i.e. on glass TPO>EVA>Silicone)***
- ***Process tuning to optimize adhesion is straightforward (i.e. glass/TPU adhesion optimization)***