Recycling strategies to valorize EVA recovered from PV panels

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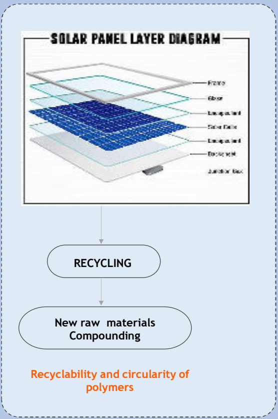
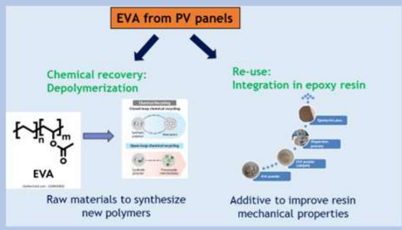
Motivation



Among renewable energy sources, **photovoltaics (PV)** technology has emerged as a promising and low-cost approach. However, due to the increasing installation of PV modules, a significant amount of waste will be generated in the near future. One of the most problematic materials to be recycled from PV panels is the **Ethylene Vinyl Acetate copolymer (EVA)** that is used as encapsulating material, because during its curing process creates crosslinked networks (crosslinking degree can be up to 90%). Traditional recycling of cross-linked polymers via mechanical reprocessing is impractical because their structures preclude flow, even at elevated temperatures. Their insolubility also precludes solution reprocessing. One of the alternatives is the incineration or pyrolysis. However, the main drawback of this strategy is that a treatment step is necessary before releasing into the environment the toxic gases generated during the process.

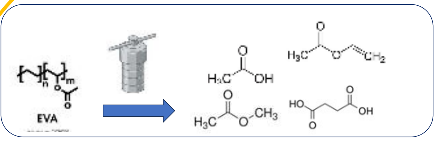
Challenge

The objective of this work was to investigate the recyclability of EVA, both (non-crosslinked + crosslinked) and non-crosslinked, coming from a grinding process from end-of-life PV panels. For this purpose, **chemical recovery** and **re-use** routes were studied. Non-crosslinked EVA was recovered by a chemical route, a hydrothermal process, whereas the EVA (non-crosslinked + crosslinked) was re-used by the incorporation into an epoxy resin for further possible application in composites or structural adhesives.



Chemical recycling

EXPERIMENTAL PROCEDURE



Process conditions

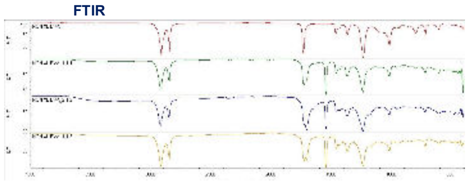
- Time t1<t2
- Temperature T1<T2
- [Acidic aqueous media] [1]<[2]<[3]

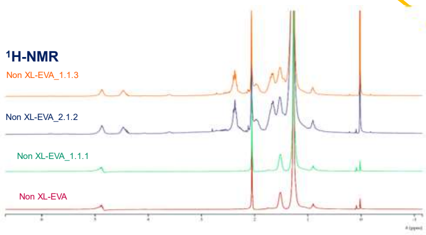
Possible chemical structure

Reference	Time (h)	T (ºC)	[Acidic Aqueous media]
Non XL EVA_1.1.1	t1	T1	[1]
Non XL EVA_2.1.2	t2	T1	[2]
Non XL EVA_1.2.2	t1	T2	[2]
Non XL EVA_1.1.3	t1	T1	[3]

RESULTS

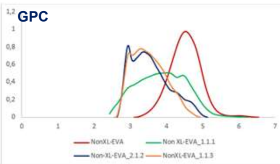
CHEMICAL STRUCTURE





*Non XL EVA_1.2.2: Non soluble on solvent used for ¹HNMR analysis

DEPOLYMERIZATION



Reference	M_n (g mol^{-1})	M_w (g mol^{-1})	Đ
Non XL EVA	20398	57724	2,8
Non XL EVA_1.1.1	2582	22598	8,7
Non XL EVA_2.1.2	2031	8287	4,1
Non XL EVA_1.1.3	2029	5963	2,9

FTIR: peak of carbonyl group from EVA (1737cm^{-1}) disappears and shifts to 1708cm^{-1} ➔ presence of acidic structures.

^{1}H-NMR: 2.1.2 & 1.1.3. Signals of vinyl acetate:

- Vinylic Hydrogens on the double bond: 4.5-6 ppm,
- Acetate Methyl Hydrogens: 2.0-2.5 ppm.

GPC: 10 times lower Mw.

Re-use as additive in epoxy resin

EXPERIMENTAL PROCEDURE

Deagglomeration of EVA recovered from PV panel

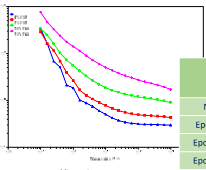
Dispersion of EVA fine powder in epoxy resin

Epoxy matrix: structural epoxy resin system for infusion and injection (Resoltech 1800/ Hardener 1805)

Mixing method: Dispermat high-shear mixer

EVA content (% wt):

- 5
- 10
- 15



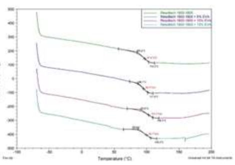
Viscosity curves

Sample	Viscosity (mPa.s) (at 100 s-1)	Viscosity increase %
Neat epoxy	315	-
Epoxy / 5% EVA	496	57
Epoxy / 10% EVA	1197	280
Epoxy / 15% EVA	2735	768

RESULTS

Characterization of Epoxy / EVA composite properties

- Glass Transition Temperature (Tg)



DSC curves

No significant effect on Tg

- Mechanical properties

Tensile test results:

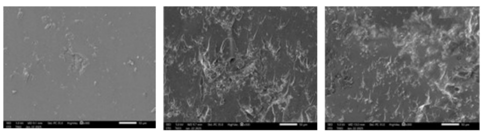
Sample	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)
Neat epoxy	82	3292	6.3
Epoxy / 5% EVA	56	3073	2.1
Epoxy / 10% EVA	46	2851	3.2

Flexural test results:

Sample	Flexural strength (MPa)	Flexural modulus (MPa)
Neat epoxy	145	3375
Epoxy / 5% EVA	91	3262
Epoxy / 10% EVA	76	2770

Incorporation of EVA affects negatively to mechanical properties

- EVA distribution / integration in the matrix



5 wt.% EVA — 10 wt.% EVA — 15 wt.% EVA

At higher %-s → agglomerates of EVA

Conclusions

- Two different routes were found to valorize EVA.
- Non-crosslinked EVA was depolymerized to acidic and monomeric structures following a hydrothermal process.
- Non XL EVA Mw was reduced 10 times
- EVA (non-crosslinked + crosslinked) powder was incorporated into an epoxy resin without modifying its processability and glass transition temperature.
- Microscopy and mechanical test results evidenced poor compatibility between EVA and epoxy resin. Thus, further studies are required to improve compatibility and to ensure a good integration of EVA filler in the matrix.

Acknowledgements

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