Plasma polymer film as an interlayer to improve polymer-metal composites disassembly and recycling efficiency

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Context

Metal coatings on polymers are widely used in industries such as electronics, automotive, and packaging for their conductivity, barrier properties, and aesthetics. While strong adhesion between metal and polymer is typically beneficial, it poses a significant challenge for recycling. The separation of these layers is highly challenging (e.g., mechanical cleaning, burning, dissolving) and costly, often resulting in the disposal of such waste causing considerable environmental impact.

In this context, this study explores the use of plasma polymer films (PPF) as intermediate layers between metals and polymers to improve the recyclability. The PPF would ensure a strong adhesion with the metallic layer (i.e., Al) while weakening the interface with the polymer when exposed to a stimulus (e.g., heating). The PPFs are synthesized from a gas mixture of C_2H_4 and CO_2, known to generate PPF with a high content of carboxylic acid and alcohol functional groups[1] ensuring a strong interaction with aluminum coatings[2].

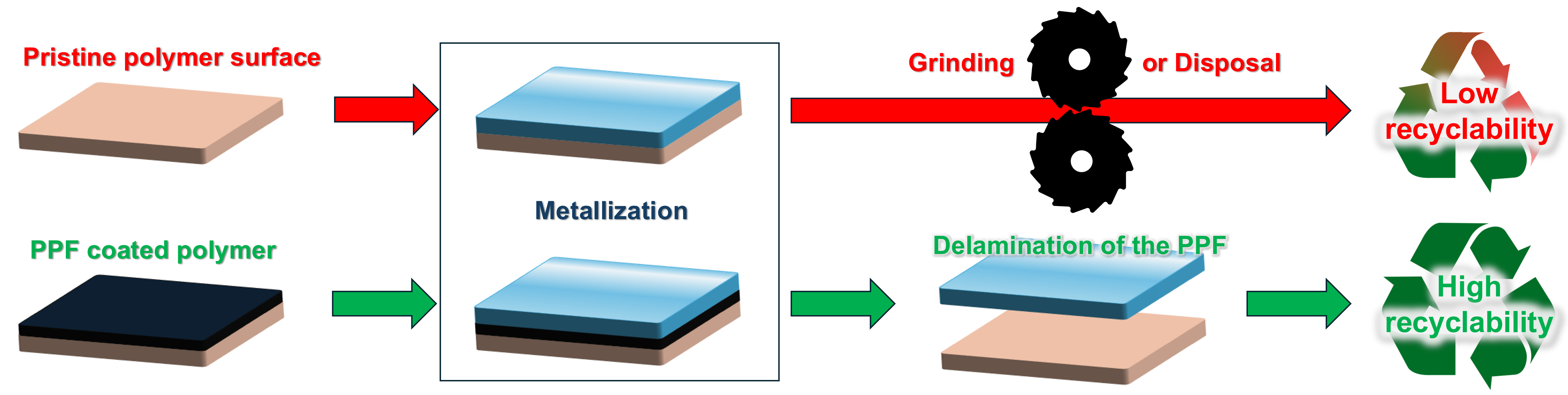

Figure 1 : Research strategy

Packaging

Automotive

Functionalization of the PPF

- Adding CO_2 in the precursor gas mix generates oxygen containing functional groups
- COOH and OH groups ensure a high adhesion of Al coatings[2] on the PPF

[CO_2] ↗ Oxygen content ↗

Power ↗ Oxygen content ↗

- Decrease of oxygen content at 150 W 80% CO_2

→ Etching of oxygen containing species takes over the deposition

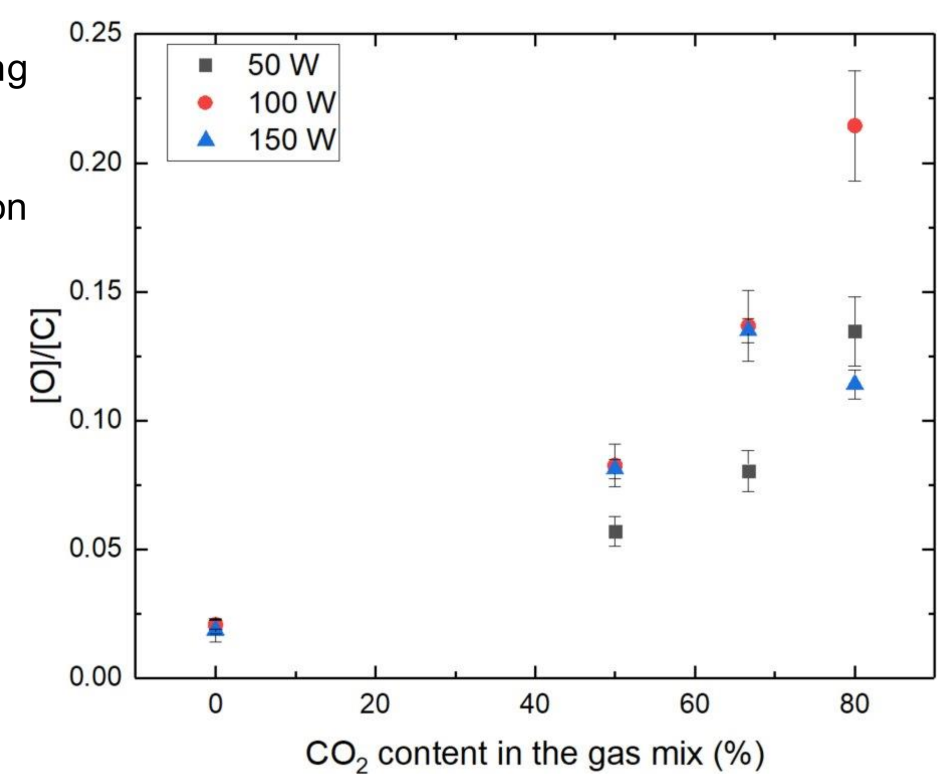

Figure 2 : Chemical content of PPF in function of [CO_2] and P_{RF} obtained by XPS

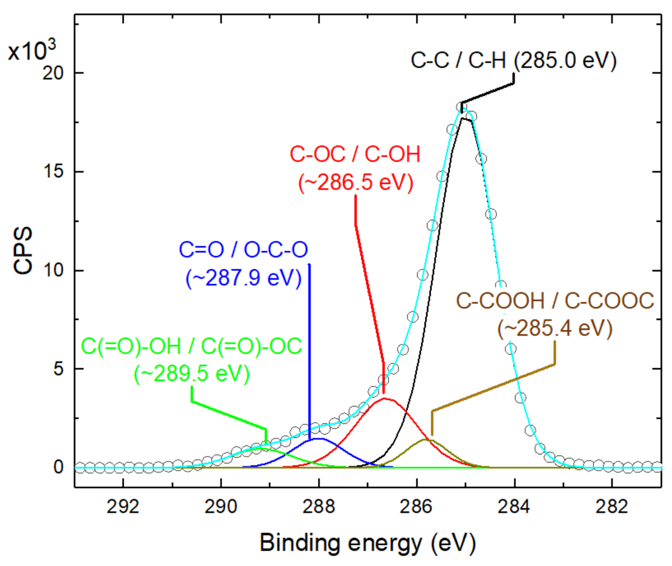

Figure 3 : Fitting of the C1s peak in XPS spectra

[CO_2] ↗ [-OR] [-COOR] ↗

- Best production of –COOR at P_{RF} = 100 W [CO_2] = 80%

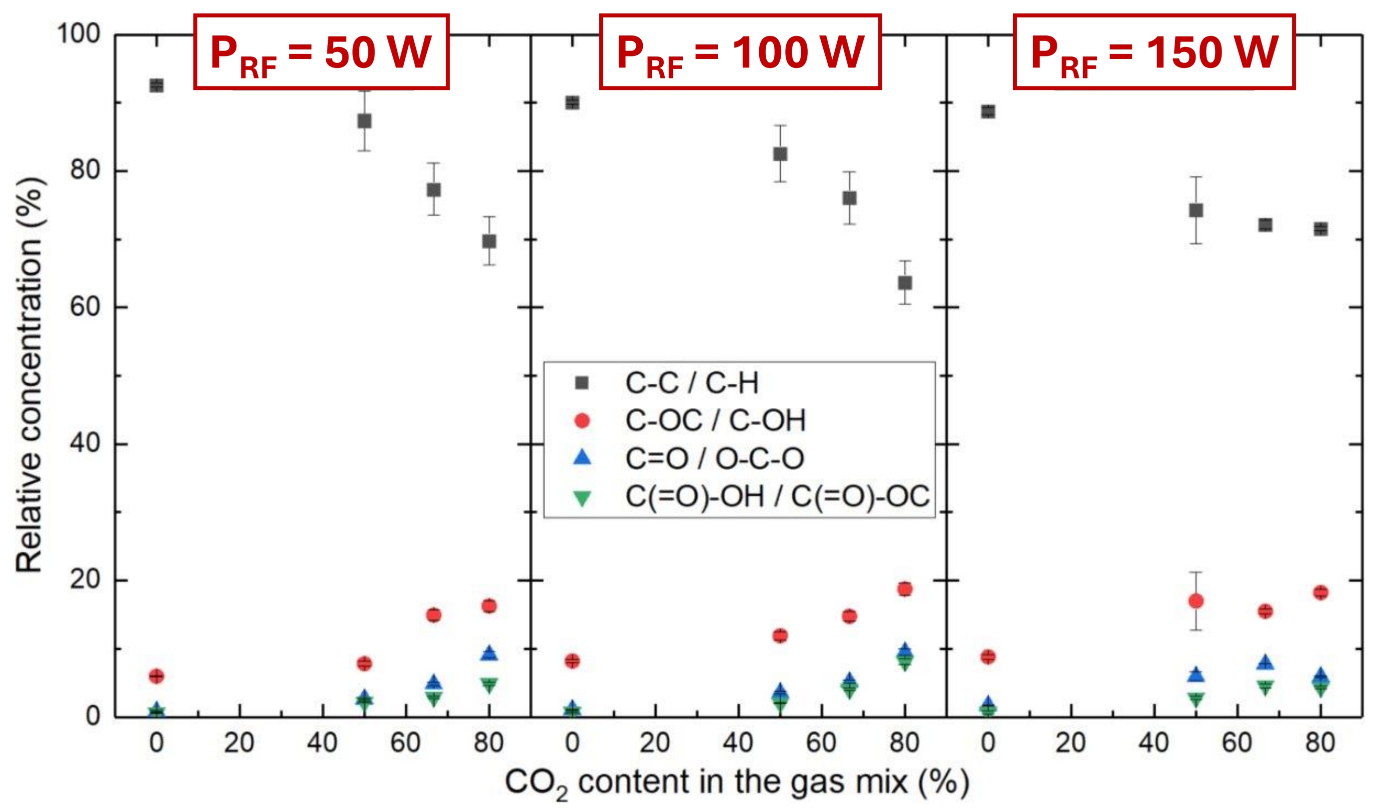

Figure 4 : Relative concentration of functions present in PPF in function of [CO_2] and P_{RF}

Delamination using water

The delamination process which was assessed for the PPF is the immersion of the material in water. The thickness of the PPF is compared before and after immersion to analyze the resistance of the films to the stimulus. The objective is to obtain the highest loss of thickness after the immersion in water.

[CO_2] ↗ Thickness loss ↗

Power ↗ Thickness loss ↗

→ Follows the same trend as oxygen content

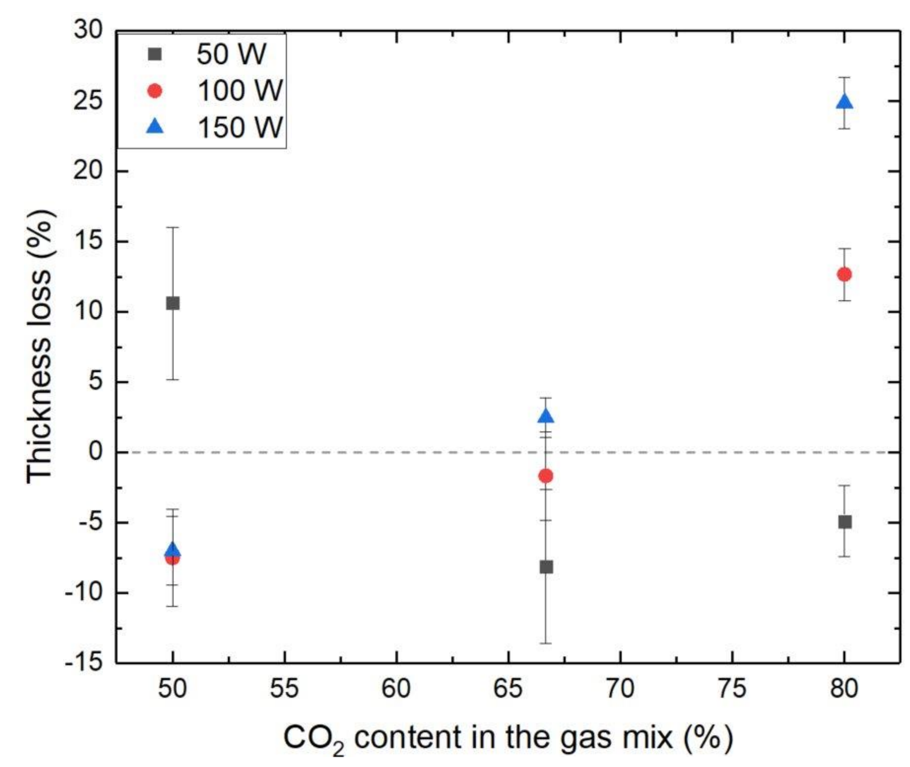

Figure 5 : Thickness loss of PPF after 24h of immersion in function of [CO_2] and P_{RF}

One of the critical parameters for the water resistance of PPF is the cross-linking density[3], which could be assessed by ToF-SIMS analysis[4].

- The total intensity of the secondary ions is inversely proportional to the **cross-linking density**[4].

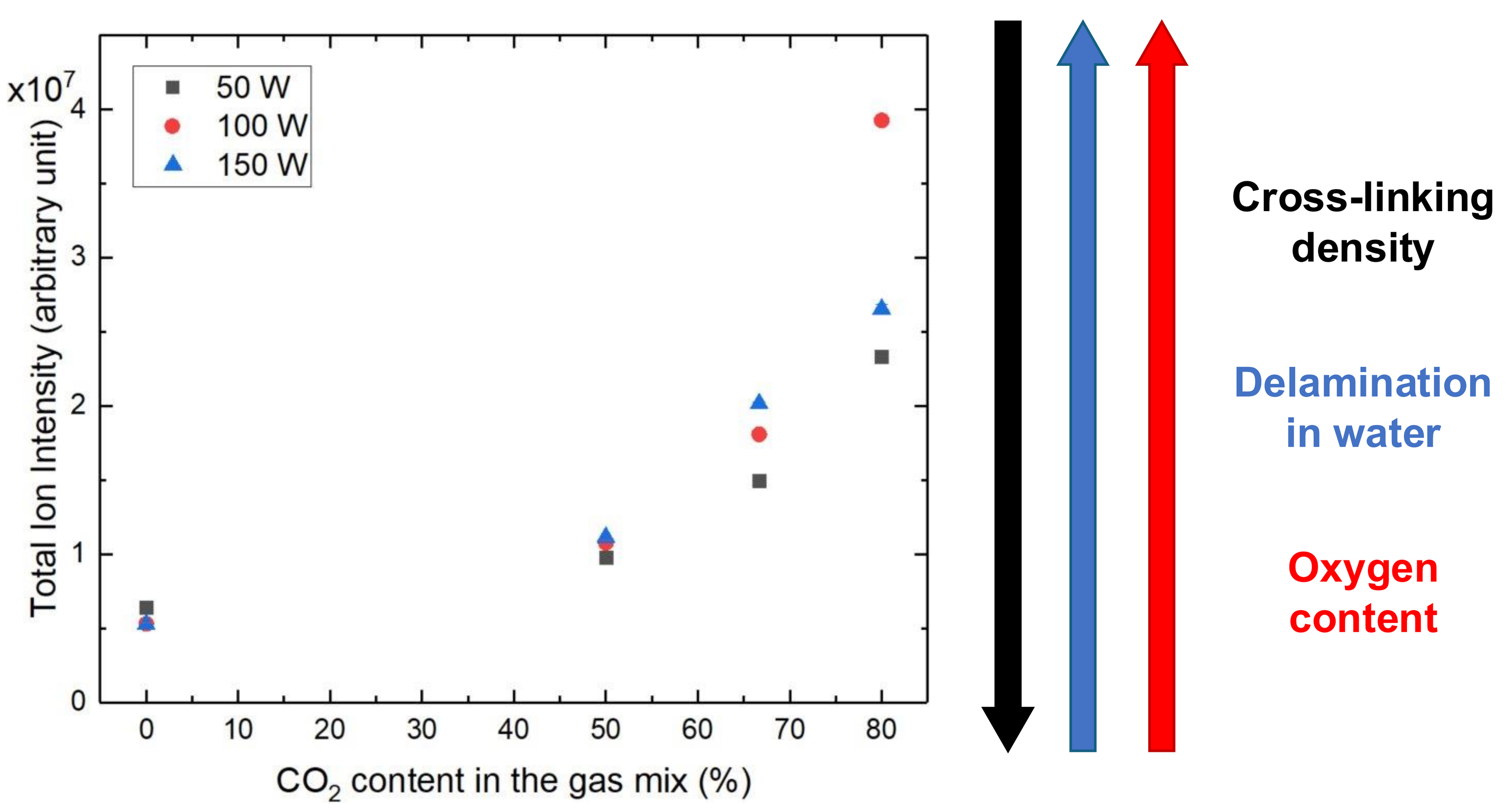

Figure 6 : Total ion intensity in the ToF-SIMS spectra of the PPF in function of [CO_2] and P_{RF}

- **Oxygen reduces the cross-linking density** due to its low valence

→ The functionalization and the delamination in water follow the same trend

Conclusions

- Tunable content of –OH and –COOH functional groups for enhanced metal grafting

→ Suitable for metal (i.e., Al) grafting

- High resistance to immersion in water

→ Requires tuning of the properties to increase the delamination process

Perspectives

- Increasing the deposition pressure to reduce de resistance to immersion in water
- Mass spectrometry of the plasma to identify the species involved in the growth mechanism
- Evaluation of glass transition temperature of the PPF
- Assessing other delamination stimuli than immersion in water

Method advantages

Plasma Polymer Films with high content of carboxylic acid and alcohol functions have been synthetized through **PECVD** using C_2H_4 and CO_2 as precursor gases.

- Cheap
- Solvent-free, one-step process
- Easy industrial upscaling
- Tunable properties

References

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