End-of-Life Solar Panel Recycling by Using Organic Solvents

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End-of-life solar panel recycling technology is still in its infancy, and the cost-benefit analysis has yet to show profitability from a materials recovery point of view[1]. This work focused on using organic solvent to separate the different parts of solar panels under moderate conditions to draft a cost-effective for processing waste. The Solar Panel consists of various parts such as back-sheet, glasses, polymer, and photovoltaic cells. Previously, Chitra et. al reported that recycling of the solar panel by using toluene[2]. Additionally, Rejon et. al also demonstrated the recovery of silicon photovoltaic cells by swelling the ethyl vinyl acetate polymer of the whole solar panel at different temperatures[3]. This research work is focused on the separation of the different components of the solar panel by implementing a solvent mixture (toluene and xylene) that can efficiently disentangle various components of the solar panel as compared to the reported literature. Previously, the separation of the polymer from the solar panel was the utilization of toluene as a solvent; whereas this research work identifies the use of a solvent mixture (toluene and xylene) enhances the separation efficiency of the polymer from the solar panel.

Unprocessed samples of EOL solar panels with the front glass still on were tested in solvent mixtures. The large glass fragment can be easily separated from the swollen front EVA layer. The EOL solar panel was cut into 2.5 cm × 2.5 cm piece samples for this set of experiments.

- Solvent mixtures to enhance EVA swelling and the separation of solar panel components
- Separation of the photovoltaic cells (silicon fragments) from the swollen polymers by pyrolysis method under N_2 atmosphere.

Unprocessed EoL solar panel in solvent mixtures

The whole solar panel was immersed in 21 ml toluene and waited until the solar panel was swollen and carved in shape (approximately 21 minutes). After that 9 ml of different solvents (acetone acetonitrile, cyclohexane, dioxane, xylene, DMSO, ethyl acetate, and isopropanol) was added to the previous solution. Wait for another 3 and a half hours. After waiting for 3 and half hours put the sample solution for 15 minutes sonication. Then the glass was removed quickly and the polymer (EVA) was separated from the back sheet of the solar panel. The swollen EVA layers in the PV cells' front and back show different properties. The front EVA swelled into a transparent gel, while the back became an opaque white swollen gel. This may be due to a different crosslinking degree, where the back layer of EVA has a higher degree of crosslinking. The swollen gel is very soft and can be crushed between fingers and PV fragments can be released. The FTIR spectroscopy of these two EVA layers shows differences at low wavenumbers, which is evidence of chain torsion vibrations due to increased crosslinking degree (Figure 1A). The front EVA shows higher O-H functionality as a broad band around 3300 cm^{-1} (Figure 1B). Also, other minor peaks appear at 1542, 1578, and 1164 cm^{-1} for the front EVA. The back EVA lacks the previously mentioned peaks but shows a strong broad peak around 636 cm^{-1} and a minor peak at 426 cm^{-1} (Figure 1C). These two peaks may be assigned to large-scale chain torsion due to cross-linking. In general, the FTIR spectroscopy shows a slight difference in the chemical structure of the two EVA layers. After analyzing all the solvent mixture treatments for WSP (whole solar panel), it was observed that xylene and cyclohexane are the best solvents to separate the PV cell and EVA polymer. As cyclohexane has a lower boiling point than xylene, xylene can be a potential solvent for the separation of EVA polymer and PV cells.

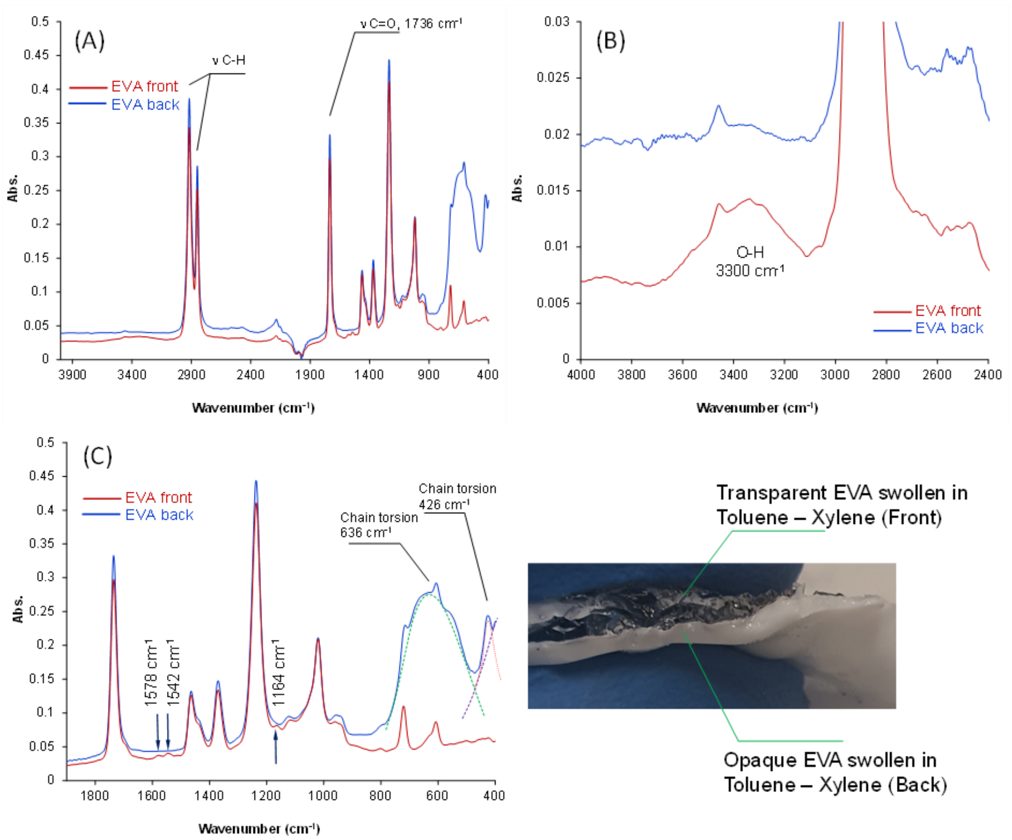

Figure 1. The FTIR spectra of EVA front and back layers (A), and enlarged areas of the spectra at low and high wavenumbers (B, C).

Unprocessed EoL solar panel in toluene-xylene at various ratios

The solar panel was swollen in different ratios of toluene: xylene at 0:10, 1:9, 3:7, 5:5, 7:3, 9:1, and 10:0 ratios. At toluene: xylene 7:3 the back sheet was the easiest to remove, and the EVA polymer was swollen into a very soft transparent gel. The PV cell fragments were easy to remove from the EVA layer by squashing. The gels obtained in pure xylene produced hard transparent gel and it was difficult to remove the back sheet from the assembly. The PV cell fragments were hardest to remove as compared to other ratios of xylene and toluene. Figure 2A is the swelling kinetics of the EVA in the various toluene: xylene ratios tested here, showing swelling reaching equilibrium in about 90 minutes in all samples. Swelling in pure toluene gives high values up to 280% weight increase, while pure xylene gives a swelling value down to 60% weight increase, with a general downward trend to lower swelling degree with increasing xylene ratio (Figure 2B).

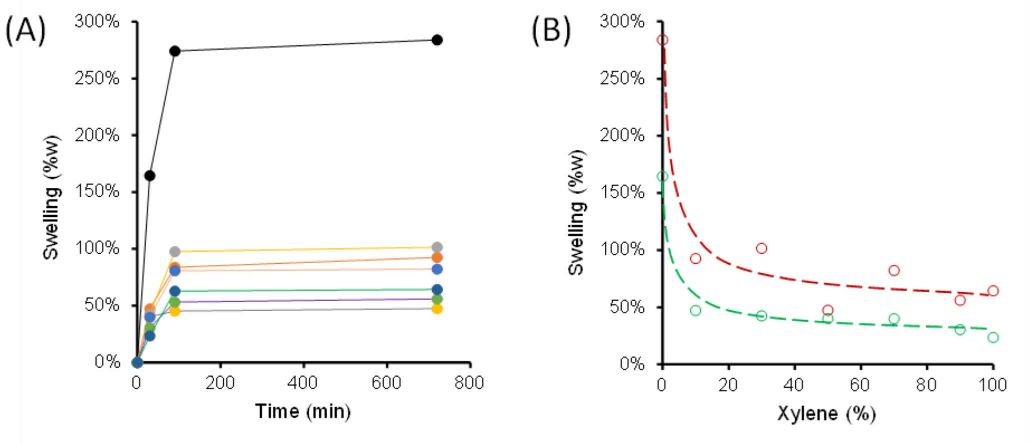

Figure 2. The swelling kinetics of the EVA in unprocessed solar panel assembly (A), and the swelling degree at various toluene: xylene ratios at 30 minutes and 12 hours solvent treatment (B).

Pyrolysis of the polymer and photovoltaic cell composite:

The polymer and photovoltaic (PV) cell swollen composite is dried in the oven overnight. Then the composite was pyrolyzed at 500 ℃ for 2h in N_2 and the photovoltaic cell was obtained, and the polymer was converted into carbon. The silicon is strated drgraded above 700 ℃ temperature which is reported in previous reports[4]. We have obtained pohovoltic cells which are intact after pyrolysis at 500 ℃ temperature (Figure 4). the Scanning electron Microscopic (SEM) energy-dispersive X-ray spectroscopy results (Figure 3) showed the presence of valuable Ag on the PV cell surface. This process successfully able to separates different parts of solar panels for example glass, backsheet, and PV cells.

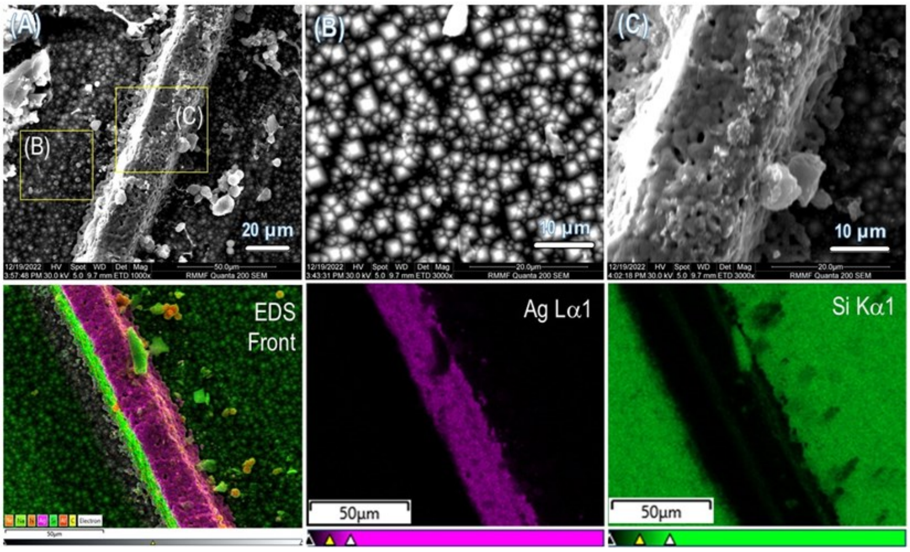

Figure 3: SEM micrographs of PV fragments front side, and EDS maps showing the silver leads on a Si substrate.

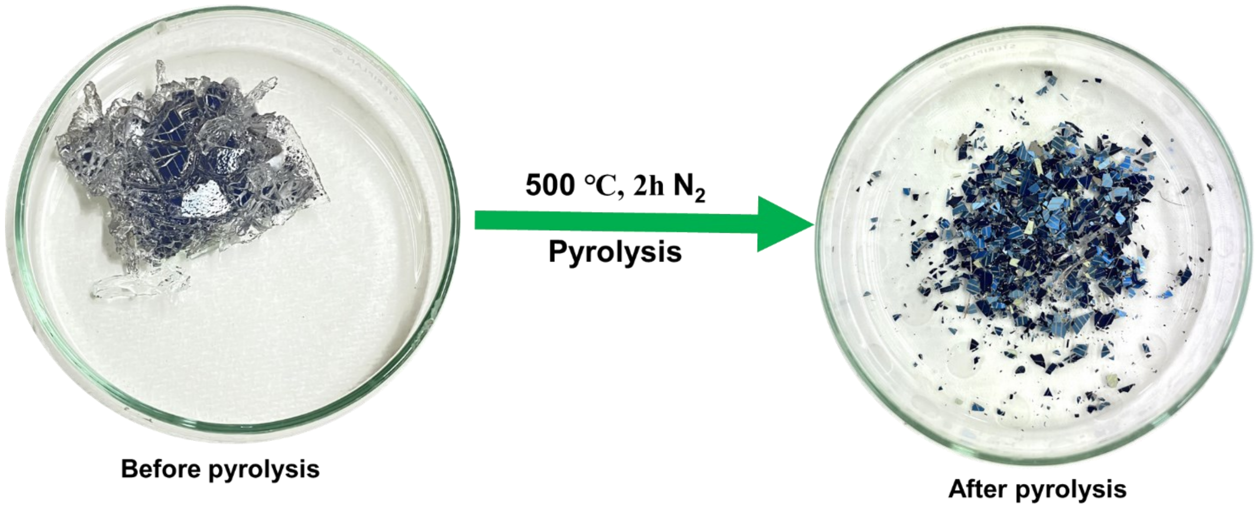

Figure 4: Images of photovoltaic cells and polymer of solar panel before and after pyrolysis treatment.

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