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Experimental Tests on Solvent Solutions for the Recycling of Coated Polypropylene in Food Packaging

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Featured Application: The potential applications of the method studied in this work concern the recycling of lacquered or metallized polypropylene film, which is an industrial waste.

Abstract: The aim of this research is to analyze and develop technical methods that allow the recycling of food packaging coated in polypropylene films using solvents for the removal of the lacquer and/or aluminum layer without modifying their mechanical properties. Thus, this would allow the regranulation and re-extraction of the treated material for the creation of new polypropylene films. Water solutions of KOH 1M and methanol 99.9% were tested as solvents using the selective dissolution method. In order to rule out a significant effect of the mechanical stirring action on the removal of the surface layer, a deionized water solution was used as a control sample. By means of UV-VIS-NIR (ultraviolet, visible, near-infrared), LWIR (long-wave infrared), and ATR-IR spectrophotometers, spectrophotometric analyses were carried out on the samples before and after treatment. In order to investigate the efficiency of the solvents in removing the coating of polypropylene films, samples taken from the industry Jindal Films Europe Brindisi s.r.l., named BF (basic film, pp film not lacquered or metallized), AC (aluminum-coated pp film), and ACRC (acrylic-lacquer-coated pp film), were compared with samples treated with solvent solutions. The comparison was made by comparing the spectra obtained from the analyses carried out with the two different spectrophotometers. The absorbance values at the level of characteristic polypropylene spectrum peaks, detected with an ATR-IR, were also compared using the Pearson correlation coefficient. The results suggest that the optimal solvent for removing the aluminum and acrylic lacquer from pp films is the solution of KOH 1M. Future analyses will aim to investigate the maintenance of the mechanical characteristics of polypropylene treated with a selective dissolution using KOH. It is also planned to test the methodology of this study on an industrial scale.

Keywords: metallized polypropylene film; lacquered polypropylene film; selective dissolution; KOH solvent solution; methanol solvent solution; plastic films; food packaging; plastics recycle

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1. Introduction

The environmental pollution caused by plastics is one of the most important and worrying issues of the last decade. Plastic materials are also largely used in agricultural and food production chains.

Many scientific works deal with this issue from different points of view, including the production of alternative materials and increasing the efficiency of recycling. However, both economically and functionally, plastic represents the most valid alternative in many sectors today, primarily in the food packaging sector.

Plastic materials have long been considered the best choice for the packaging of numerous foods due to several advantages that they offer: they do not react with foods, they offer the best shelf-life performance because contamination would be difficult, they are the cheapest option, they increase the aesthetic value of the products, and foods packaged with plastic are easier to handle, transport, and store [1].

The packaging sector in the food market plays a very important role. The main functions of packaging are the protection and preservation of food from deterioration and external contamination, such as heat, light, oxygen, enzymes, odors, microorganisms, insects, dust, etc. This prolongs the life of food and maintains the high quality of the packaged food. In addition, some secondary packaging functions that aim to make food more appealing and attractive to consumers are becoming increasingly important [2].

In contrast to these advantages regarding the efficiency of plastic as a packaging material, there are several negative aspects, mainly due to difficulties in the recycling of these materials and the various forms of environmental pollution they cause. Over the past 50 years, the production of various types and shapes of plastic has grown worldwide. Plastic has caused the generation of considerable amounts of waste.

Different types of plastics are widely used in all fields, mainly in food packaging industries [3,4]. According to Plastics Europe [5], global plastic production in 2021 reached 390.7 Mt, 44% of which belonged to packaging use. The amount of plastic production in Europe in 2021 was 57.2 Mt, including fossil-based plastics (50.1 Mt), post-consumer recycled plastics (5.8 Mt), and bio-based plastics (1.3 Mt) [5]. In 2021, polypropylene was the first polymer type for the European converter demand, with 10.0 Mt, and the European packaging industry was the first converter demand (39.6%) of global plastic production. The number of polypropylene films for food packaging produced in Europe in one year is about 5 million tons/year. A statistical survey conducted by Eurostat reports that 38% of the plastic waste produced from food packaging was recycled, and the remaining part was sent to landfill or dispersed in the environment [6].

Almost half of the plastic produced is used only once. As a result of high consumption and low recycling rates, plastic waste has led to increasingly serious pollution problems [7]. This includes the emission of powerful greenhouse gases (GHGs) such as methane during landfills [8], the emission of toxic chemicals (e.g., bisphenol A and polystyrene) [9], and the poisoning of marine species [10]. One way to address this problem is to develop various reuse and recycling techniques for these materials, such as recycling the material [11] and recovering raw materials [12] for energy production [13]. Improving the quality of recycled plastic products and extending their applications are also effective ways to promote recycling rates [14].

The European Parliament is paying great attention to this issue. An important tool for addressing the growing plastic waste crisis and promoting sustainable waste management practices is European legislation on plastic recycling, which aims to address the plastic waste crisis by promoting sustainable waste management practices, reducing the use of disposable plastics, promoting recycling, promoting the use of recycled plastics, and improving the management of plastic waste.

In addition to the Single Use Plastics Directive, the EU adopted the Regulation (EU) 2019/1692 on product life-cycle information to promote the recycling and sustainability of plastic products. This regulation requires the manufacturers of plastic articles to provide information on the recycled content of their products in order to promote greater transparency and the use of recycled plastics.

For this purpose, extended producer responsibility (EPR) systems have been established for the management of packaging waste, including plastics [15]. These systems require manufacturers of plastic products to recycle as much of the waste as possible from production processes. The processing waste produced during the industrial process can be regrouped and re-exported in proportion to virgin material. To do this, the recycled material must maintain good chemical and mechanical characteristics [16]. However, it should be considered that, in most cases, plastic films intended for food preservation are covered with a layer of lacquer and/or aluminum, which creates a barrier to water, oxygen, and light and also prevents the exchange of chemicals between plastic and food. The coupling of polymeric films to these substances makes it difficult, if not impossible, to recycle the coated plastics at the end of their life cycle [17,18].

The aim of this research is to analyze and develop technical methods to allow the recycling of coated food packaging polypropylene films using solvents for the removal of the lacquer and/or aluminum layer and thus allow the regranulation and re-extrusion of the treated material for the creation of new polypropylene films.

2. Material and Methods

2.1. Sampling

In order to investigate the recycling procedures of plastics for food packaging, three different types of plastic polypropylene film samples were supplied by Jindal Films Europe Brindisi s.r.l.: two of these samples had a surface coating treatment, but one did not. Polypropylene (pp) is one of the most common thermoplastic polymers; it is obtained by the polymerization of monomeric units of propylene. Polypropylene has good mechanical characteristics, resistance to chemical agents, is an excellent thermal and electrical insulator, and does not absorb water [19]. Due to these properties, it is one of the most common materials in the production of films for food packaging. Although the barrier properties, especially against oxygen, are poor, polypropylene covers about 18% of the world food packaging market. To be suitable for the purpose of food packaging, polypropylene films are coated with aluminum or multiple types of lacquers, such as acrylic lacquer. Both coating types greatly reduce pp's permeability to gases and allow the foods' organoleptic properties to last longer [20].

Samples of polypropylene film before and after metallization by aluminum and lacquering processes were picked directly from the industrial coils. The three samples were denominated as follows: "basic film" (Figure 1A), consisting solely of polypropylene, and "metallized film" (Figure 1B) and "lacquered films" formed of polypropylene coupled, respectively, to aluminum and lacquer.

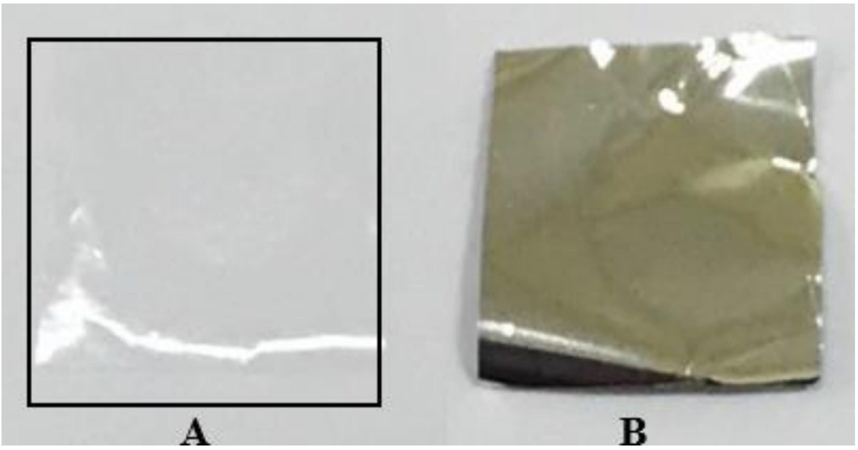

Figure 1. (**A**) Picture of polypropylene film specimen intended for metallization (BF); (**B**) picture of metallized polypropylene film specimen (AC).

The thickness of the polypropylene film samples was measured with a mechanical micrometer (Manutan, 0–25 mm).

The samples were assigned univocal codes as follows: BF (basic film, 18 µm thick) for polypropylene film without an aluminum or lacquer covering layer, AC (aluminum-coated, 19 µm thick) for metallic film with aluminum, and ACRC (acrylic-coated, 30 µm thick) for lacquered film with acrylic lacquer.

The images related to the lacquered film specimens are not shown in the figure because they are all transparent and there are no appreciable differences with the naked eye.

2.2. Selective Dissolution

The selective dissolution technique is based on the concept that different substances are dissolved in multiple solvents or with the same solvent but at different temperatures. This technique has been studied for the recycling of materials composed of different types of plastics [21].

Coated film samples were cropped into 5 cm squares, creating specific specimens. Two solvents, one composed of 99.9% methanol and one of KOH 1M solution, were tested for the selective dissolution reaction, which should remove the coated surface layer of the pp film samples. The KOH 1M solvent and 99.9% methanol were selected as solvents because they are used to remove non-polymeric layers from the film by manual scrubbing. This procedure is commonly performed by the Quality Control Centre of the Jindal Films Europe Brindisi s.r.l. Both solvents are relatively inexpensive and easy to produce [22]. The FDA (U.S. Food and Drug Administration) considers the two solvents risk-free when operated under good manufacturing practice [23]. Moreover, neither potassium hydroxide (National Toxicology Program, the International Agency for Research on Cancer, or the Occupational Safety and Health Administration) [24] nor methanol [25] are classified as carcinogen substances.

In order to test for the possible effects of the magnetic stirring mechanical action, a deionized water solution was used as the control.

Each specimen was immersed in 50 mL of the three different solvent solutions and subjected to magnetic stirring at room temperature for 15 min. After the reaction time, specimens were washed with deionized water and dried on a stove at 45 °C overnight. Each type of film was treated in triplicate for each of the three solutions, obtaining a total of 18 film specimens treated with selective dissolution. The specimens were labeled with a name indicating the treated film (AC or ACRC) and the solvent used (_SH_2O = treated with deionized water as solvent; _SKOH = treated with potassium hydroxide 1M as solvent; _SMET = treated with methanol 99.9% as solvent).

2.3. UV-VIS-NIR and LWIR Spectrophotometer Tests

Radiometric tests in the solar spectrum wavelengths were conducted using a UV-VIS-NIR (ultraviolet, visible, near-infrared) spectrophotometer (Lambda 950, Perkin Elmer Instruments, Norwalk, CT, USA). Measurements were made at wavelengths between 200 and 2500 nm with a nominal resolution of 10 nm.

An integrated sphere (diameter 60 mm) was used as a receiver of the Lambda 950 spectrophotometer using a double beam comparative method to measure the spectral total transmissivity [26].

Using the spectral distribution of solar radiation at the ground level as a weighting function, the transmission coefficient was calculated as a weighted average value of the spectral transmissivity.

To obtain spectral transmissivity in the long-wave infrared range (2500–25,000 nm), an LWIR (long-wave infrared) spectrophotometer (1760 X, Perkin Elmer Instruments, Norwalk, CT, USA) was used in step of 4 cm^{-1}.

The spectra of the different polypropylene specimens were measured in the solar wavelength range and in the long-wave infrared radiation range.

2.4. ATR-IR Spectrophotometer Tests

Analysis with a plasma attenuated total reflection (ATR) spectrophotometer provides qualitative information of the samples' surface layers for a thickness of roughly 1 μm. Base film specimens, metallized/lacquered films, and films treated by selective dissolution were analyzed using the ATR_IR spectrophotometer (Bruker, VERTEX 70, Karlsruhe, Germany) to measure their absorbance. Spectra were recorded via a diamond crystal prism equipped with cells sized between 4000 cm^{-1} and 400 cm^{-1} (2500–25,000 nm) with a nominal resolution of 2 cm^{-1}. Distilled water was consumed as a reference for the background spectrum before collecting the specimens' spectra.

ATR spectrophotometric tests were carried out on the 18 specimens subjected to selective dissolution and, in triplicate, on the 3 types of unprocessed films (BF, AC, ACRC) for a total of 27 specimens.

Then, the arithmetic average of the triplicates results was calculated. Since the calculated standard deviation is negligible (approximately equal to 0.001), assessments were made on the average value of the triplets.

3. Results and Discussion

The results of all the experimental tests carried out by means of the three instruments, UV-VIS—NIR spectrophotometer, LWIR spectrophotometer, and ATR spectrophotometer, were consistent.

3.1. UV-VIS-NIR and LWIR Spectrophotometer

Both specimen sets were analyzed using the UV-VIS-NIR and the LWIR spectrophotometers to measure transmittance and reflectance values in the wavelength ranges of the solar and LWIR (from 200 to 25,000 nm). Table 1 shows the values of transmittance and reflectance obtained for the basic film (BF), films with a non-polymer layer (AC and ACRC), and films treated with selective dissolution.

Table 1. Transmittance and reflectance values obtained by UV-VIS-NIR and LWIR spectrophotometers.

Specimens	Radiometric Coefficients			
	Wavelength Range		Transmissivity	Reflectance
		nm	%	%
BF	Solar	200–2500	91.0	7.7
	VIS	380–760	91.0	7.7
	Solar IR	760–2500	91.0	7.7
	UV	280–380	89.7	8.7
	LWIR	2500–25,000	85.5	7.9
AC	Solar	200–2500	0.3	91.0
	VIS	380–760	0.3	88.3
	Solar IR	760–2500	0.3	93.0
	UV	280–380	0.6	91.9
	LWIR	2500–25,000	0.1	86.1
AC_SKOH	Solar	200–2500	90.9	7.8
	VIS	380–760	90.9	7.8
	Solar IR	760–2500	91.0	7.7
	UV	280–380	89.8	8.9
	LWIR	2500–25,000	85.4	7.8
AC_SMET	Solar	200–2500	0.5	94.0
	VIS	380–760	0.4	92.6
	Solar IR	760–2500	0.5	95.4
	UV	280–380	0.7	97.0
	LWIR	2500–25,000	0.2	85.6

Table 1. *Cont.*

Specimens	Radiometric Coefficients			
ACR	Solar	200–2500	91.3	7.4
	VIS	380–760	91.4	7.4
	Solar IR	760–2500	91.4	7.3
	UV	280–380	89.4	8.3
	LWIR	2500–25,000	74.1	9.6
ACR_SKOH	Solar	200–2500	89.3	8.4
	VIS	380–760	89.1	8.5
	Solar IR	760–2500	89.5	8.2
	UV	280–380	88.1	9.6
	LWIR	2500–25,000	76.6	6.9
ACR_SMET	Solar	200–2500	89.3	8.4
	VIS	380–760	88.4	9.3
	Solar IR	760–2500	90.5	7.3
	UV	280–380	85.6	12.0
	LWIR	2500–25,000	79.6	7.1

Since the results with ATR showed no significant difference among triplicate repeats, UV-VIS-NIR and LWIR spectrophotometric tests were conducted on one specimen per solution for a total of ten specimens.

The LWIR spectrophotometer analyses the radiometric characteristics of the entire thickness of the samples that varies between 18 and 30 μm. The thickness of the non-polymer surface layer, measured by the company's Quality Control Center, is not superior to 10 nm. For this reason, the presence or lack of a lacquered surface layer does not affect the transmissivity and reflectance values in a manner detectable by the instrument. Instead, since aluminum has values of transmittance and reflectance opposite to the transparent film in pp, its presence/lack can be effectively detected with the LWIR spectrophotometer.

It is possible to observe that the transmittance and reflectance values obtained for the basic film specimen (BF) and for the AC_SKOH differ by less than 0.5% in the wavelength range of 200 nm to 25,000 nm.

In fact, looking at the graphs in Figures 2 and 3, it is clear that the spectra of the two specimens are comparable. For the specimen AC_SKOH, as for the basic film in polypropylene, there are transmittance values greater than 80% and reflectance values lower than 10%.

In contrast, the untreated metallized specimen (AC) and the specimen treated with 99.9% methanol (AC_SMET) both have transmittance values less than 1% and reflectance values greater than 85% in the wavelength range of 200 nm to 25,000 nm (Table 1, Figures 4 and 5). This proves that the aluminum surface layer used to metallize the polypropylene film has been removed by the solvent KOH 1M and did not undergo significant alterations if treated with methanol.

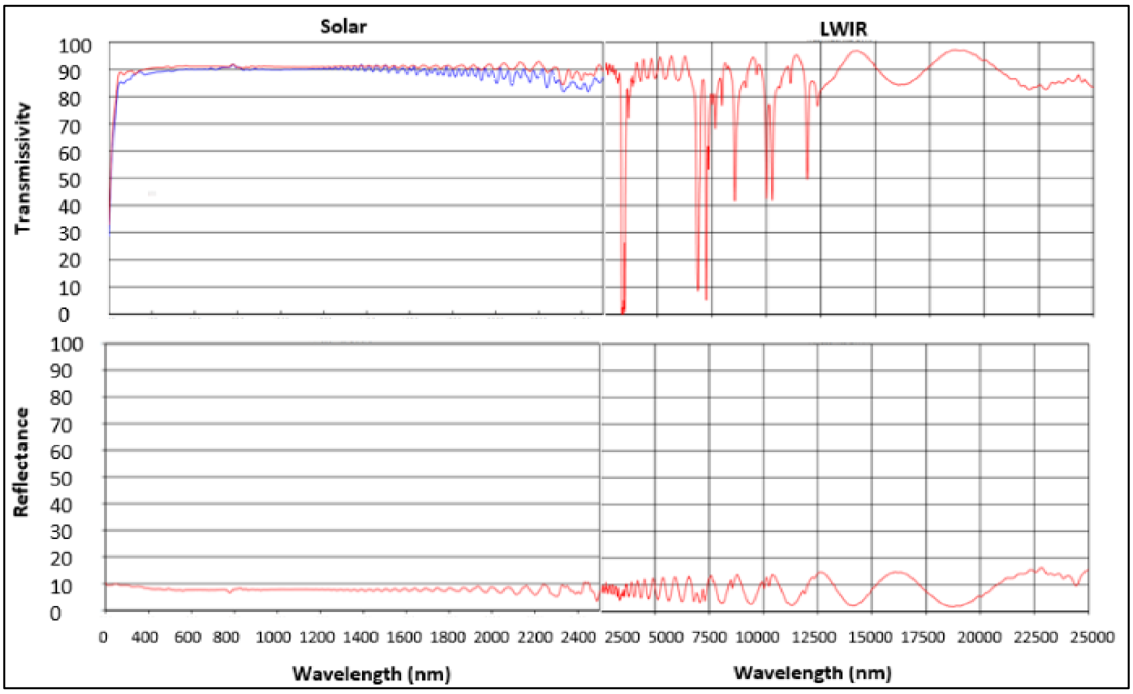

Figure 2. Total transmissivity, direct transmissivity (blue), and reflectance spectra in the solar and the long-wave infrared of the BF specimen.

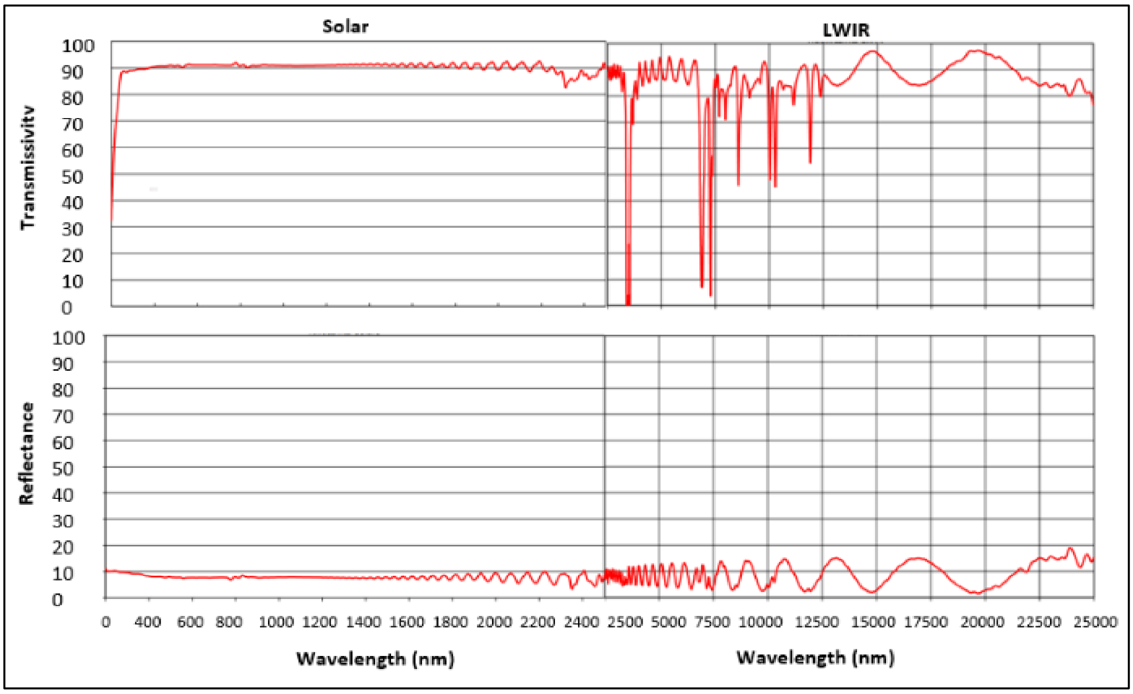

Figure 3. Transmissivity and reflectance spectra in the solar and the long-wave infrared of the AC_SKOH specimen.

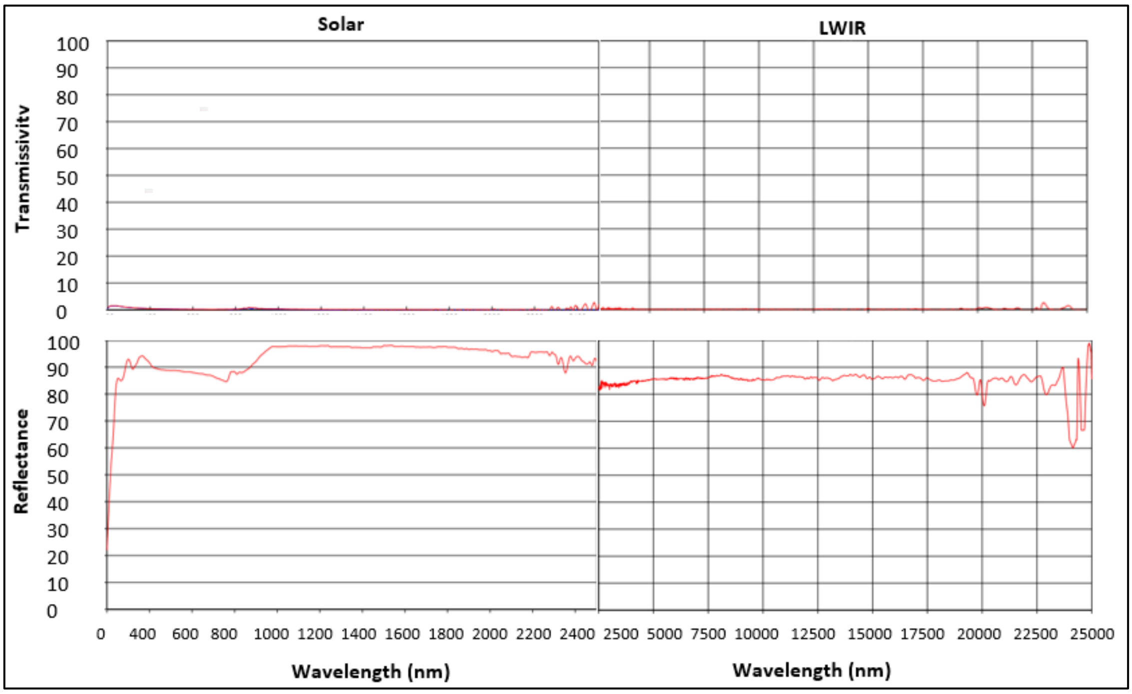

Figure 4. Transmissivity and reflectance spectra in the solar and the long-wave infrared of the AC specimen.

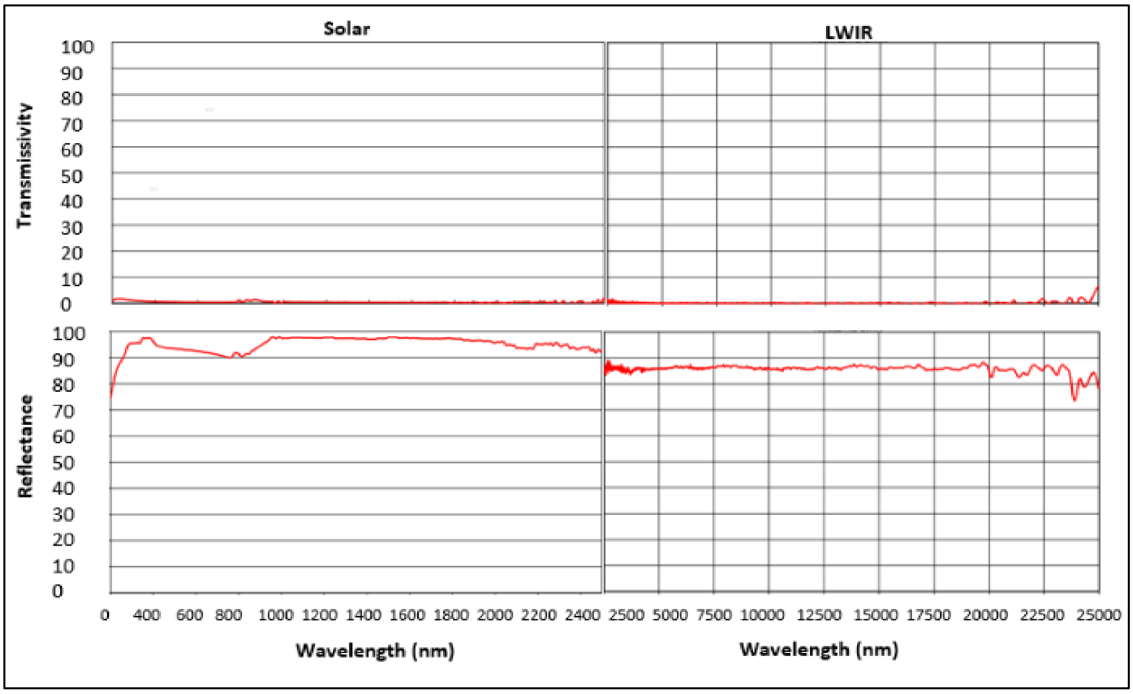

Figure 5. Transmissivity and reflectance spectra in the solar and the long-wave infrared of the AC_SMET specimen.

3.2. ATR-IR Spectrophotometer

In order to gain a higher precision level on the alteration of the thin surface layer, especially for the lacquered sample, another analysis was carried out on the specimens using the ATR spectrophotometer for the measurements of the absorbance of the coated surface, for which the thickness is roughly 1 µm.

Depending on the composition of the specimens' surface layers, absorbance graphs with typical peaks were chosen.

The polypropylene films are characterized by several absorbance peaks (Figure 6) attributable to vibrational modes of different functional groups [27]. Table 2 shows the wave numbers and vibrational modes of chemical bonds corresponding to the absorbance peaks of polypropylene.

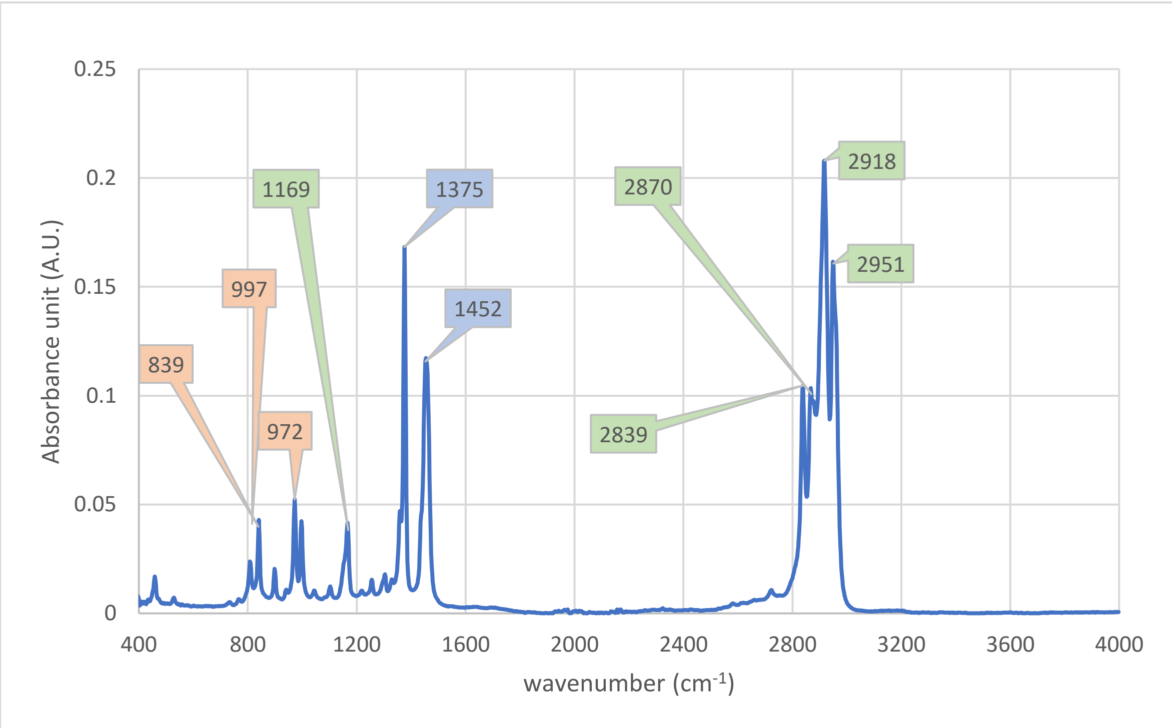

Figure 6. ATR absorbance spectrum of the BF specimen. Labels in the figure indicate the wavenumber of polypropylene characteristic peaks.

Table 2. Identification of functional groups' vibrational movements corresponding to the absorbance peaks in the BF specimen.

Wavenumber (cm^{-1})	Bond Vibrational Mode
839	$CH(CH_2)$ Rocking
972	$CH(CH_3)$ Rocking
997	$CH(CH_3)$ Rocking
1169	C-C Stretching
1375	CH_3 bending
1452	CH_2 bending
2839	CH_2 Symmetrical stretching
2870	CH_2, CH Symmetrical stretching
2918	CH_3 Asymmetrical stretching
2951	CH_3 Asymmetrical stretching

Thanks to this characterization of the polypropylene composition, it is possible to compare the resulting curves to assess the results of the effectiveness of the solvents used for the surface treatments.

Therefore, the approach used refers to a comparison of the spectrophotometric analysis of metallized films' specimens before the addition of the non-polymeric layer (BF), after the addition (AC and ACRC), and after a selective dissolution treatment (AC_SH_2O, AC_SKOH, AC_SMET, ACRC_SH_2O, ACRC_SKOH, and ACRC_SMET). Deionized water was used as the control treatment.

The spectrum obtained from the ATR analysis of the film specimens treated with KOH's 1M solution (AC_SKOH) shows that the surface layer has the same chemical characteristics as the polypropylene base film (BF). In fact, similar absorbance values were found in correspondence to the characteristic peaks of polypropylene previously observed (Table 3, Figures 6–8). Likewise, similar absorbance values were found for the untreated metallized film specimen (AC) and the film specimen treated by selective dissolution in deionized water (AC_H_2O) (Table 3, Figures 7 and 8). Water treatment was used as the control, and the results obtained suggest that the action of mechanical stirring alone is not sufficient to alter the aluminum layer.

Table 3. Absorbance values at highlighted peaks of the metallized specimens set.

Wavenumber (cm^{-1})	Absorbance (A.U.)				
	BF	AC_SKOH	AC_SH_2O	AC_SMET	AC
839	0.03975727	0.032625098	0.029203976	0.115803689	0.029874312
972	0.052302863	0.04449223	0.032744721	0.122323856	0.033428654
997	0.042378213	0.035799116	0.027895574	0.111345075	0.028465927
1169	0.038221929	0.036313497	0.026688617	0.096902728	0.028004123
1375	0.168231934	0.163158551	0.022197524	0.082647502	0.023092547
1452	0.115665048	0.108762488	0.022378158	0.082543373	0.023343995
2839	0.104665585	0.097680114	0.020665959	0.058129326	0.021667363
2870	0.100733645	0.09663114	0.020827761	0.058454797	0.021915155
2918	0.20801717	0.201709479	0.018122342	0.0611206	0.019465473
2951	0.160669282	0.146111205	0.020937137	0.060904201	0.022170335

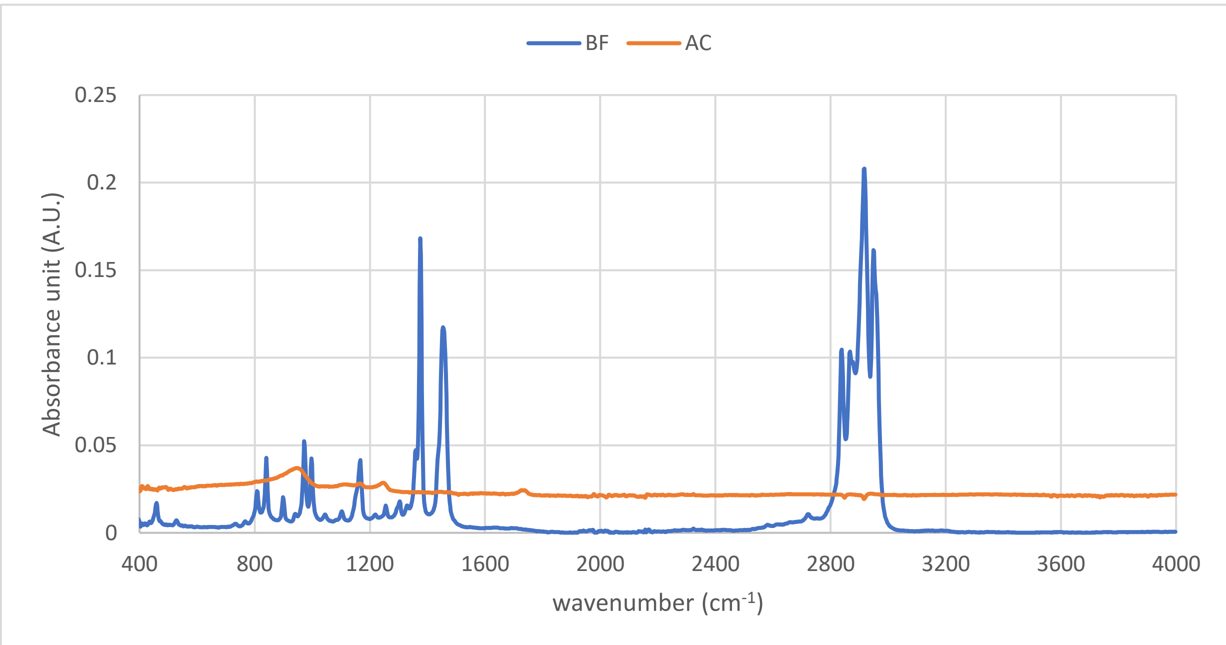

Figure 7. Absorbance curves of the AC and BF specimens.

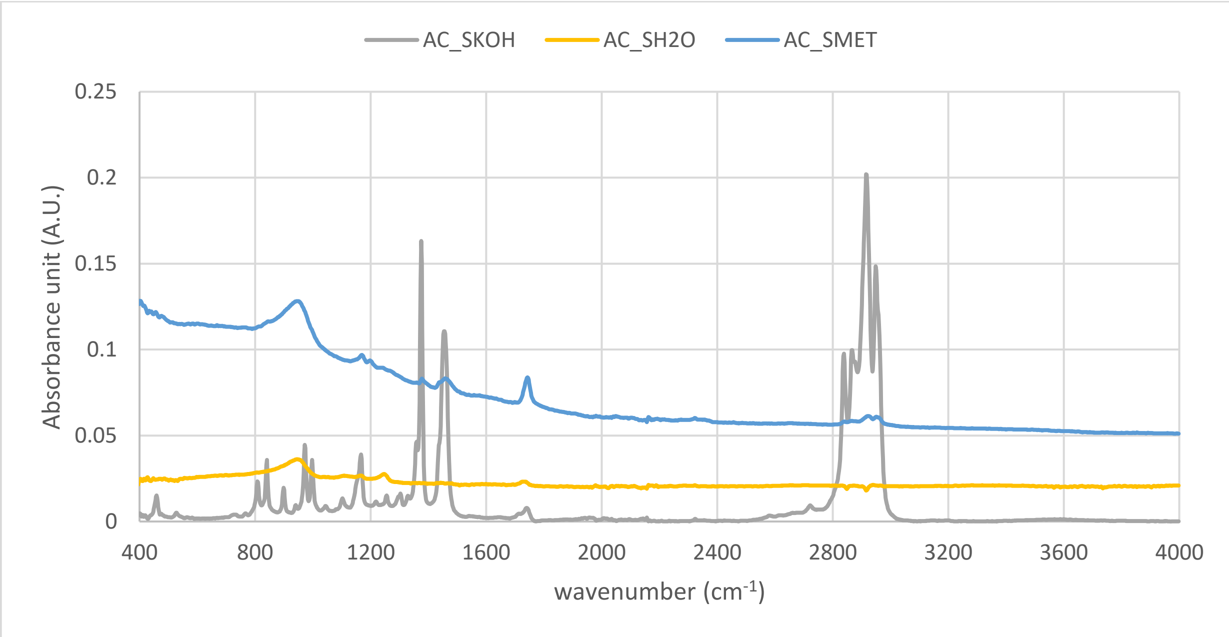

Figure 8. Absorbance curves of the metallized specimens after selective dissolution with deionized water (AC_SH$_2$O), methanol 99.9% (AC_SMET), and KOH solution 1M (AC_SKOH).

The film specimens treated with ≥99.9% methanol (AC_SMET) have a spectrum profile similar to that of the metallized film but with different absorbance values (Table 3, Figures 7 and 8). Indeed, as can be observed from Figure 9B, the surface layer remains covered with aluminum which, according to the visual analysis, is only slightly abraded.

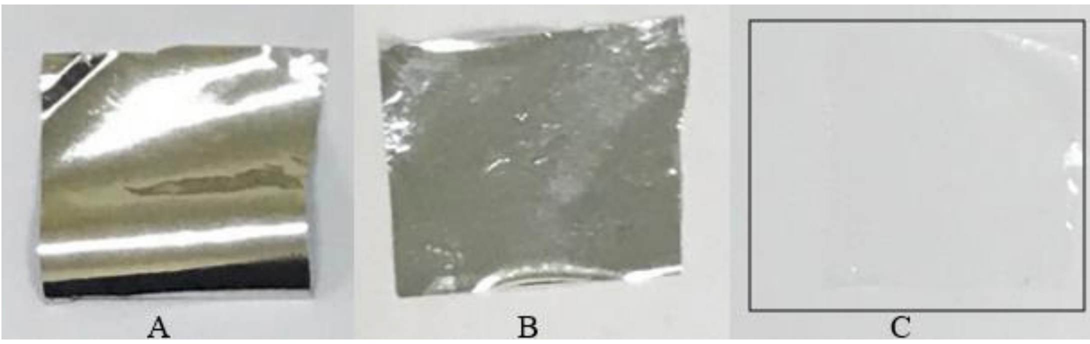

Figure 9. Metallized film treated with: (**A**) deionized water; (**B**) methanol 99.9%; (**C**) KOH solution (1M).

From the visual observation of the treated films and the analysis of the spectra obtained through ATR-FTIR, KOH's solution seems to be the one that brings the metallized film back to a more similar state to that of the base film.

Applying the Pearson correlation index [28] to the measured absorbance values for the various spectra, the coefficients shown in Table 4 were obtained. A strong correlation (0.998441874) can be noted between the absorbance values of the specimens BF and AC_SKOH and between the absorbance values of the specimen AC and those of specimens AC_SH$_2$O and AC_SMET (0.996048 and 0.874766, respectively). The strong correlation indicates the presence of similar chemical bonds and functional groups on the surface layer of the specimens compared.

Table 4. Pearson correlation indices calculated on ATR absorbance values of the metallized specimens set.

	BF	AC_SKOH	AC	AC_SMET	AC_SH$_2$O
BF	1				
AC_SKOH	0.998441874	1			
AC	0.030746021	0.016305	1		
AC_SMET	0.043863292	0.028291	0.874766	1	
AC_SH$_2$O	0.017371948	0.002584	0.996048	0.875892	1

On the contrary, there is no linear correlation between the absorbance values of metallized, treated with deionized water, and treated with methanol specimens neither with the polypropylene basic film nor with the film treated with KOH.

Similar results were obtained for the acrylic lacquer film specimen set. The specimen treated with KOH solution as a solvent obtained absorbance values very similar to the basic film values, while the measured values for lacquered film (ACRC) are comparable to the absorbance values of ACRC_SH$_2$O (Table 5, Figures 10 and 11).

Table 5. Absorbance values at highlighted peaks of acrylic lacquered specimens set.

Wavenumber (cm^{-1})	Absorbance (A.U.)				
	BF	ACRC_SKOH	ACRC_SH$_2$O	ACRC_SMET	ACRC
839	0.03975727	0.038165	0.064406	0.042879	0.07238
972	0.052302863	0.051496	0.086299	0.055206	0.097269
997	0.042378213	0.04272	0.07301	0.046404	0.081726
1169	0.038221929	0.042362	0.29203	0.171095	0.315067
1375	0.168231934	0.202698	0.115039	0.084044	0.116143
1452	0.115665048	0.133933	0.121527	0.073815	0.128608
2839	0.104665585	0.134424	0.045497	0.030598	0.047881
2870	0.100733645	0.132759	0.045631	0.029859	0.048006
2918	0.20801717	0.266848	0.095278	0.05579	0.098756
2951	0.160669282	0.200288	0.080766	0.047157	0.086993

The lacquered film specimen treated with ≥99.9% methanol (ACRC_SMET) has a spectrum profile similar to that of the lacquered film untreated (ACRC) but with different absorbance values (Table 5, Figures 10 and 11).

This indicates that the acrylic lacquer has not been removed but has been slightly worn away.

As seen for the metallized film, as well as for the film specimen covered by acrylic lacquer, the solution of KOH 1M is very efficient in the selective removal of the non-polymeric layer.

Additionally, for the specimen with acrylic lacquer, the coefficients (Table 6) indicate a strong correlation (0.990549016) between the trend of the absorbance values of the specimens BF and KOH and between the values of the lacquered specimen (ACRC) with the specimens ACRC_SH$_2$O and ACRC_MET (0.999548648 and 0.986809541, respectively).

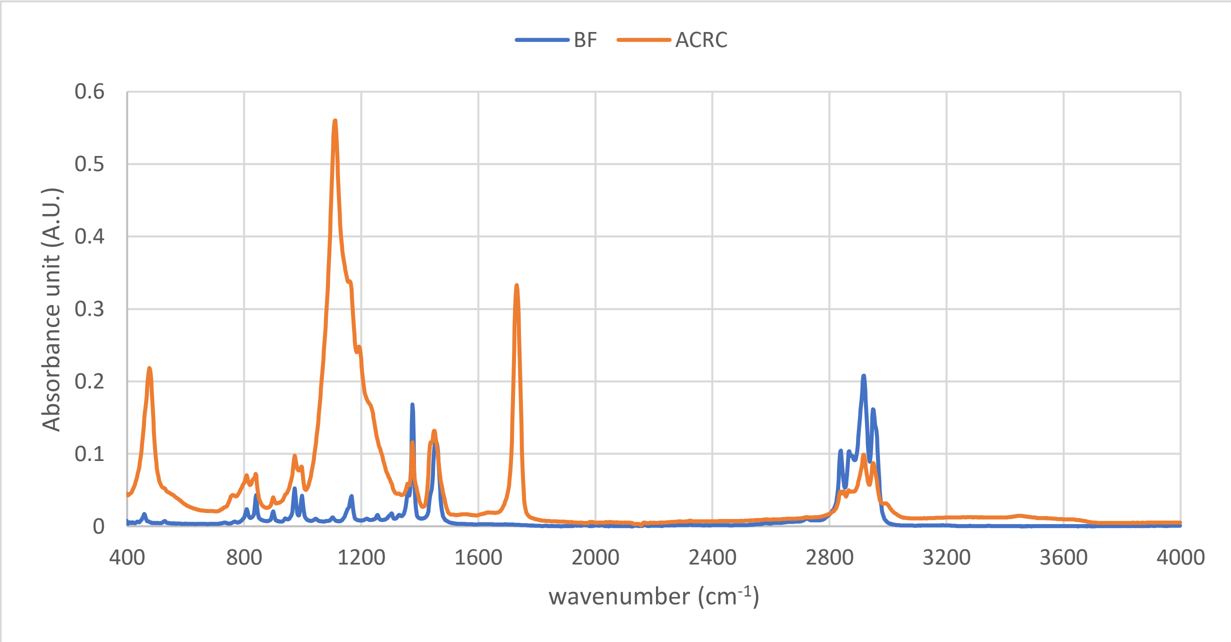

Figure 10. Absorbance curves of the ACRC and BF specimens.

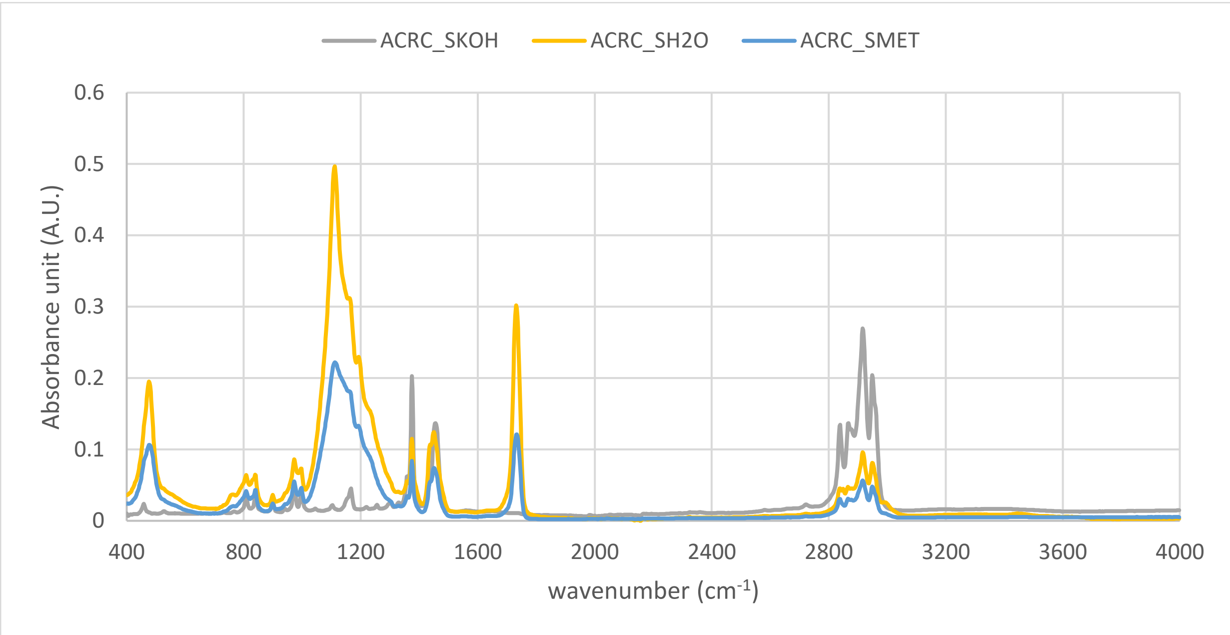

Figure 11. Absorbance curves of the film lacquered with acrylic lacquer after selective dissolution with deionized water (ACRC_SH$_2$O), methanol 99.9% (ACRC_SMET), and KOH solution 1M (ACRC_SKOH).

When comparing the basic film with the methanol-treated specimen (ACRC_SMET), the Pearson coefficient is 0.235644866. This shows that the chemical composition of the two test specimens is different.

Table 6. Pearson correlation indices calculated on ATR absorbance values of acrylic lacquered specimens set.

	BF	ACRC_SKOH	ACRC	ACRC_SMET	ACRC_SH$_2$O
BF	1				
ACRC_SKOH	0.990549016	1			
ACRC	0.186280446	0.13942014	1		
ACRC_SMET	0.235644866	0.184579559	0.986809541	1	
ACRC_SH$_2$O	0.201683132	0.154356521	0.999548648	0.989508364	1

4. Conclusions

Plastic materials pollution is one of the most serious environmental issues faced worldwide, and the correct management of agricultural post-consumption plastics, including food packaging, can contribute to mitigate its impact with a circular economy approach.

For this purpose, this research deals with technical methods based on solvents which may be implemented in plastic films' post-production process so as to remove the coated layer from polypropylene films for food packaging and obtain industrial post-consumption lacquered and metallized recyclable pp films.

The rationale behind this study was to examine the efficiency of two different solvents intended for the selective removal of the non-polymeric layer from polypropylene films for food packaging in order to recover the polymeric portion from industrial processing waste, preserving its mechanical characteristics, to be mixed with virgin material in the production of other polypropylene films. By applying the Pearson correlation index to the absorbance values measured by the ATR analysis, the tests showed that 99.9% methanol was ineffective at removing, in the absence of manual scrubbing, both aluminum and lacquers, while KOH's 1M solution was found to be the best solvent for removing the aluminum layer from the metallized film and acrylic lacquer from the lacquered film.

In fact, both the metallized film and the one covered with acrylic lacquer, once subjected to selective dissolution in KOH 1M solution, lost their non-polymeric surface layer and returned to being composed solely of polypropylene. This is a necessary condition to allow the regranulation of industrial waste and its subsequent use in the extrusion of a recycled pp film. Future activities could include both investigations on the possible influence of the selective dissolution process on the mechanical properties of the recycled product and to test the transferring on pilot stacking of the experimental methods for the recycling of the polypropylene film. The method of selective dissolution, associated with the regranulation and re-extrusion of the polymer, represents a useful tool for plastic film manufacturers who aim to increase the percentage of recycled material used throughout the production process in order to comply with European legislation on the recycling of plastics.

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