



# Study of Recycling Potential of FFP2 Face Masks and Characterization of the Plastic Mix-Material Obtained. A Way of Reducing Waste in Times of Covid-19

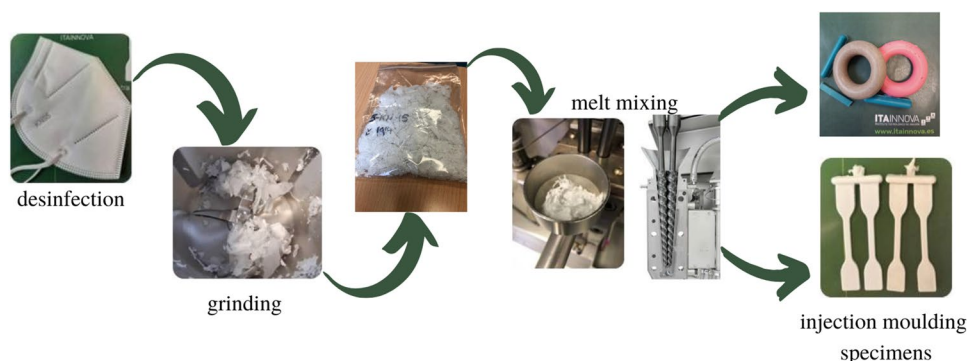
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## Abstract

The purpose of this study is to investigate how to recycle FFP2 face masks used during Covid-19 pandemic without using previous sorting process and to characterize the properties of the material obtained. The way of splitting and processing the mixture of materials was studied as well as the final properties such as chemical, thermal and mechanical characteristics. The resulting recycled material is a blend of polymers with such mechanical and thermal properties that could be used as an alternative to recycled PP (polypropylene). Avoidance of previous sorting process gives the face mask recycling a new and simplified way of preventing this material to be disposed in environment and an opportunity of second life for the polymers they are made of. With this work we lay the basis to reduce the plastic pollution related with the recommended use of face masks during Covid-19 pandemic.

## Graphic Abstract



**Keywords** Recycling · Polypropylene · Face mask · Covid-19 · Waste recovery

## Statement of Novelty

Face masks are treated as the raw material they are made of, that is polymer. Without sorting process and applying steps of mechanical recycling, a recycled material based of a mixing of three polymers is obtained. Four steps are

needed: thermo chemical disinfection treatment, elimination of metal and ear strap, grinding, extrusion and injection. The mechanical properties of this material make it useful to obtain different products where recycled PP is being currently used, such as flower pots, storage bins or shipping pallets where technical specifications are not critical. With this methodology it would be possible to reduce the waste and contamination that those days of Covid-19 are generating.

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## Introduction

The pandemic situation of SARS-Covid-19 and the evidences that the spread of the virus is mainly related to the droplets and aerosols [1–3], in close proximity often speaking, coughing or sneezing, has led to the extensive use of face masks with the aim of stopping the massive infections. Several studies have already shown that the use of face masks could not only reduce the severity of the infection but also could help to cut down the options of transmission [4–6], of course this must not exclude the application of social distance.

Several models of face masks have been commercialized. The most widespread are the surgical ones which main purpose is to protect the community from infections that may be transmitted by the mask wearer, and the FFP2 [7, 8], where FFP2 stands for “Filtered Face Piece”; specially intended for protecting the wearer from inhalation of toxic particles or pathogens. These FFP2 face masks are able of filtering at least 94% of the air particles. Face masks effectiveness is related to the filter that stops respiratory droplets from getting through or around the device, and also related with the level of sealing, once it is adjusted to the face. Generally, FFP2 face mask has a structure of five layers of nonwoven material, where PP (polypropylene) and PE (polyethylene) are the basic materials for the filters layers and PA (polyamide) is used for the ear strap, while the nose wire is made of steel. Usually middle layers are embedded with an electrostatic charge that enhances the mechanical filtering efficiency [9]. There are variations in the product, depending on the manufacturer and also related to their final properties of filtration [10].

At this moment, where unfortunately the virus is spread worldwide and the use of face masks is extended as an easy way of protection and of slowing down the illness propagation, another environmental problem appears that has to be addressed. Face masks are considered as disposable. Making estimations and knowing that a mask weight is approximately 4gr, in one year and taken into consideration that one quarter of the Spanish population could use one FFP2 mask per day; approximately 1.000 ton of plastic waste will be accumulated. Being aware of that situation will not be permanent, and thinking about the likelihood of using face mask will last one or two years, the number of plastic waste that will be generated in every country is more than significant. Furthermore, in hospitals and probably in other community centers, the use of this kind of protection will last.

Several options have been proposed in order to avoid plastic contamination due to face masks use during pandemic time: (1) use of alternative materials, (2) purification and reusability of face masks and (3) use of biodegradable materials.

As part of first option different household materials (commercial air filter fabric, cleaning cloth, coffee filter...) were proposed as alternatives materials for face masks fabrication [11, 12]. In second case of purification and reusability, several investigations were conducting looking for alternatives of using several times the face masks after being disinfected. Juang [9] presents different methods of disinfection proposed by the inventor of KN95 material (equivalent to FFP2), that mainly consists in heating for 60 min at 70° C. Other authors indicate more sophisticated methods for decontamination like an hydrogen peroxide vapor [13] or ultraviolet radiation, as explained by Mackenzie [14] among different options. The use of biodegradable materials is the third way of avoiding this facemask contamination [15]; in Spain, Spanish National Research Council has developed biodegradable antiviral filters based on nanofibers [16] that could be washed and reused for several times, that are commercialized nowadays by Bionicia Open Market; Geochanvre [17] a French company commercializes a full biodegradable mask based on natural fibers of hemp.

Certainly, disposable Protective Personal Equipment (PPE) has the disadvantage of generating a great impact on the environment, causing agglomeration of used masks in public space [18]. The impact of this PPE could be similar to other plastics, dumped in the environment: direct and indirect ingestion by the wildlife, causing respiratory and gastrointestinal obstructions or death by starvation, and the fundamental problem of strangulation. Fadere et al. [19] exposes the potential source of microplastics that face masks constitute. What it is clear is that Covid-19 has generated a number of different plastic residues that must be treated. Specific policies have to be developed in order to diminish this new way of contamination. H.B.Sharma et al. [20] exposed, that during this period; investigation related to the appropriate identification, collection, separation, disinfection and other tasks related with solid waste generated, has to be carried out in parallel with the virus treatment research. Battezzore et al. [21] have recently presented different approaches for recycling surgical face mask; which are made of PP and does not present mixture of materials in the composition of the three layers of the faces masks; in this case they studied the option of including the ear loops made of fabric and elastomer. With this work we want to contribute to solve the problem of mixing different materials present at FFP2 as well as other option for waste reduction.

Thermoplastic recycling can be summarized in three different paths, mechanical, thermal and chemical [22]. The most extended one is the mechanical. However, nowadays chemical recycling for obtaining the initial monomers is taking more relevance [23], and it is considered as a good alternative to the mechanical process.

It is well known that the reuse of material in a production chain can be relatively easy because there is almost

no opportunity for contamination. On the other hand, when talking about waste, whatever the origin is urban or post-consumer it appears a new difficulty due to the mixtures of polymers than can be found [24, 25].

The industrial process of recycling polymers includes a very important step of shortening and classification. One of the main points to have a successful polymer recycling process is the absence of mixtures of different polymers that can behave more like contaminants and impurities rather than reinforcement.

At this moment it is of great importance to investigate and develop alternatives to this new problem of plastic accumulation. First alternatives like valorization through thermal process [26] have been proposed. In this study we propose a new way of recycling the material of the face masks without any sorting or separation process. The FFP2 face masks are mainly made of PP and PE. Because the mixture of PP and PE is one of the most common that can be found in thermoplastic waste recovery, some studies have been carried out in order to improve the blending process and the final properties. One example is described by Fang et al. [27] with nanoparticles and compatibilizers or the study made by Clemons [28] where the blend is used to obtain wood plastic composites. Touati et al. [29], propose the use of diss fibers to obtain a reinforced recycled plastic of PP and PE.

The results shown in this paper aim to be a further step to find a second use of this new residue that generates a big impact in our environment. With this approach the investigation will continue by improving the properties of this new blend material but also with the way of the future steps for possible industrial use.

An additional option for waste and contamination reduction can be proposed if we think not about the product but in the thermoplastic based material of what they are made of. As thermoplastic polymers, they have the property of been melted and reused, and that is the aim of this study. In this work we propose a convenient and simple way of taking advantage of the polymer material that face masks are made of.

## Materials and Methods

For the study of recyclability FFP2 face masks non used and used specimens were studied (Fig. 1). For the analysis of polymer composition of face masks, three different brands were studied, one for non used (Guangzhou Yibo Medical Technology), and other two different for used masks (Wuhu Koupin Protective Equipment Co from China. and Face Mask imported by Audix Bitee S.L.). In the packaging of non used face masks, indications of “*protective mask UNE 149 and non-woven fabric*” appear without material specifications.

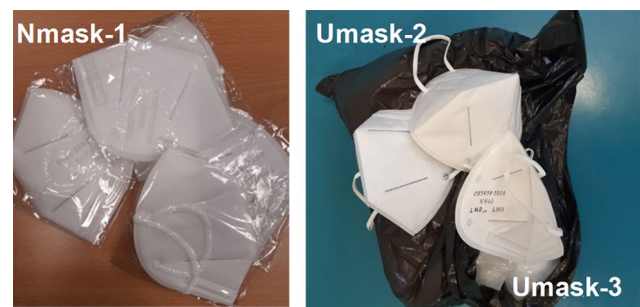


Fig. 1 Face masks used for analysis of polymer composition

For the compounding study of non used face masks, ten specimens of the same brand were selected; in this way initial material to be processed will be known. For the compounding study of the used face masks, ten specimens were collected from ITAINNOVA (Aragon Institute of Technology) employees. The used masks were collected from a specific waste bin, where the employees placed the mask after the labor day; in this way the process could be comparable to a hypothetical massive collection, where it will be not possible to separate according to brands, shape or color. In order to have a reference for the materials properties, recycled PP (rPP) kindly donated by Beologic in form of pellets and derived from different feedstock, was processed and analyzed. According to the supplier information, this rPP is suitable to produce garbage bins or flower pots among other applications. It has a density of  $0.95 \text{ g/cm}^3$  and a melt flow index of  $10 \text{ g/10 min}$  ( $230 \text{ }^\circ\text{C}$ ,  $2.16 \text{ kg}$ ) and no filler.

Used face masks recovered from employees of ITAINNOVA, were disinfected by using a mixed chemical-thermal treatment. The face masks were moistened for both sides with a ethanol 70% in volume of using a spray bottle and let them dry for one hour at  $80 \text{ }^\circ\text{C}$  in a recirculated air oven. Once the face masks were at room temperature, the ear strap and the nose steel wires were removed with manual methods. Face masks were grinded with the help of a crusher.

Blending mix process was carried out by means of a micro twin extruder (DSM Xplorer model 2005) and materials specimens were obtained with a micro injector; from X-plorer using a conical mould for tensile test samples. The injection molding was fed directly with the polymer melt from the extruder. Fig. 2 shows the above described steps.

Bone shape samples (ISO 527, sample 1B) were injected for the mechanical characterization. Five specimens for each sample were tested. Ten non used face masks were needed in order to obtain specimens for mechanical characterization, all of them from the same brand. Ten used face masks were taken from specific waste bin; in which different types and brands were mixed. Trying to emulate industrial collection no brand separation was done. Tensile

**Fig. 2** Mechanical recycling process**Table 1** Identification of face masks and materials used in the study

Reference	Face mask
Nmask-1	Non used face mask brand 1
Umask-2	Used face mask brand 2
Umask-3	Used face mask brand 3
Reference	Material
pNmask	Processed Non used face masks
pUmask	Processed Used face mask
rPP	Recycled PP

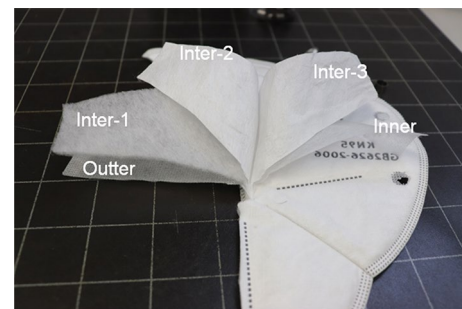
**Table 2** DSC analysis conditions

Step	Conditions
#1	Isothermal 10 °C 5 min
#2	Heating scan From 10 °C to 280 °C at 10 °C/min
#3	Cooling scan From 280 °C to 10 °C at 10 °C/min
#4	Isothermal 10 °C 5 min
#6	Heating scan From 10 °C to 280 °C at 10 °C/min

tests were carried out at 23 °C and 50%RH using Universal Testing Machine from Zwick Roell, according to international standards ISO 527.

Table 1 summarized the materials used in this study.

Spectrum Two from Perkin Elmer was utilized for ATR-FTIR (Attenuated Total Reflectance-Fourier Transform Infrared) analysis of the layers of three different FFP2 brands face masks (see Table 1 for identification). The same equipment was used for the chemical analysis of the melt mixing material after extrusion process. For thermal analysis a differential scanning calorimeter (DSC) DSC-6 from Perkin Elmer was used following ISO 1137-2, (see Table 2 for test conditions). The density of the material after compounding was measured with a pycnometer following ISO 183 standard indications, at 23 °C and using isopropanol as immersion medium; three replicates were measured for each sample. Thermal, chemical analysis of the melt mixing material after extrusion process, and density analysis were carried out with

**Fig. 3** Example of mask composition

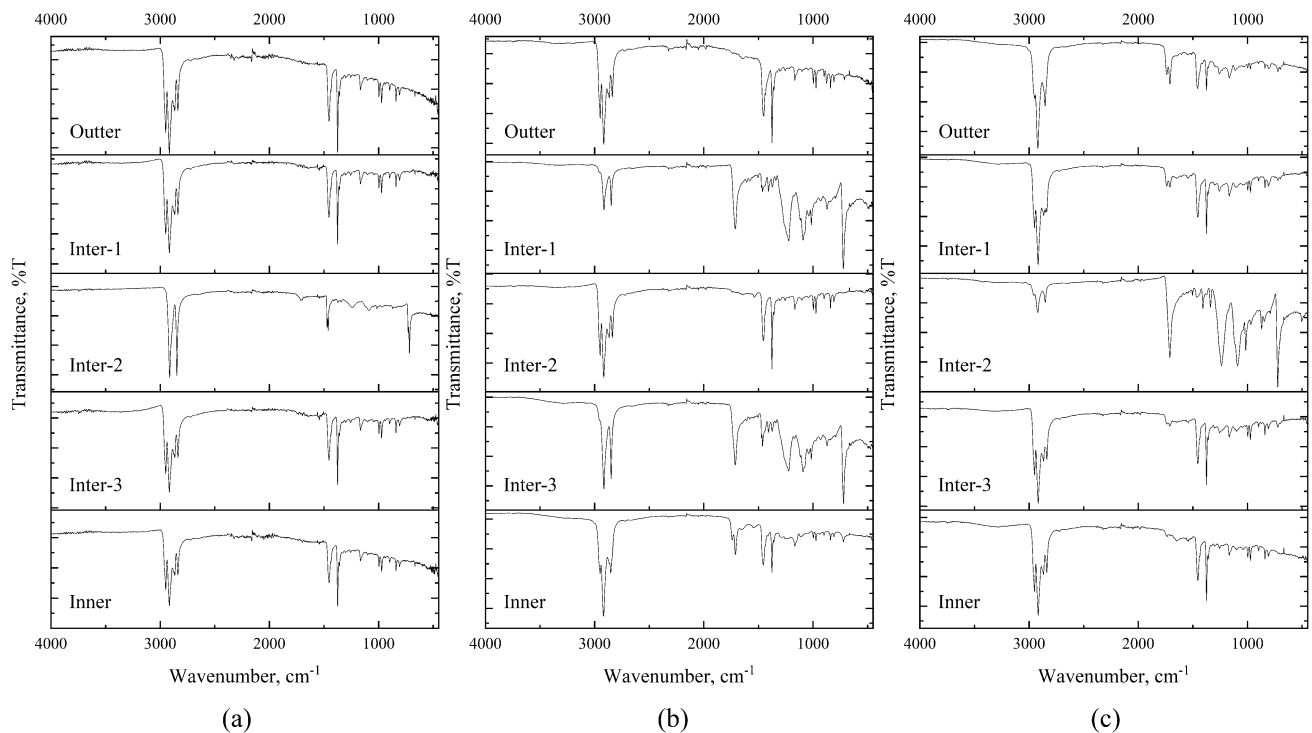
a portion of material obtained from the samples of mechanical characterization.

## Results and Discussion

### Analysis of Polymer Composition of Face Masks

In order to know what kind of materials are in the layers that composed the face masks, three masks brands (Nmask-1, Umask-2 and Umask-3, Fig. 1) were analyzed by ATR-FTIR. The FTIR spectra of the different mask layers (see Fig. 3 as an example of layer composition) were obtained separately (Fig. 4) and analysis of the peaks was conducted in order to identify the main polymer that composed each layer. These results are summarized in Table 3.

The assignments of the most representative peaks found in the spectra are summarized in Table 4. The FTIR spectrum of PP is dominated with several CH<sub>2</sub>/CH<sub>3</sub> stretching vibration bands at around 2900/cm and the pair of CH<sub>2</sub> bending/scissoring vibration bands at around 1400/cm. In the FTIR spectrum of PE were found the same vibration bands, although it differ with PP in the number and relative intensity of these bands (e.g. while PP spectrum contains at least four vibration bands associated with the CH<sub>2</sub>/CH<sub>3</sub> stretching, PE spectrum only contains two vibration bands associated with this mode of vibration). In addition, the FTIR spectrum



**Fig. 4** ATR-FTIR spectra of face mask layers of **a** Nmask-1, **b** Umask-2 and **c** Umask-3

**Table 3** FTIR analysis and identification of main polymer from FFP2 face masks layers

	Outer	Inter-1	Inter-2	Inter-3	Inner
Nmask-1	PP	PP	PE/PET	PP	PP
Umask-2	PP	PET	PP	PE/PET	PP
Umask-3	PP	PP	PET	PP	PP

of PE also contains the  $\text{CH}_2$  rocking vibration bands at 729/719/cm. On the other hand, the FTIR spectrum of PET is mainly dominated by the bands associated with the vibration of the ester group ( $-\text{C}=\text{O}(\text{O})$ ) located at 1713, 1238 and 1091/cm. Considering these characteristics vibration bands of PP, PE and PET polymers, it was observed that the majority of the analyzed face mask layers were composed of a

**Table 4** Assignments of the most representative peaks found in the spectra

Polymer	Wavenumber ( $\text{cm}^{-1}$ )	Description	Refs.
PP	2950 and 2865	Assymm. and symm. $-\text{CH}_3$ stretching	[30]
	2920 and 2840	Assymm. and symm. $-\text{CH}_2$ stretching	
	1453 and 1375	Assymm. and symm. $-\text{CH}_3$ bending (in plane)	
	1165	$-\text{CH}_3$ wagging	
	998 and 971	$-\text{CH}_3$ rocking	
PE	2914 and 2847	Asymm. and symm. $-\text{CH}_2$ stretching	[31]
	1471	Assymm. $-\text{CH}_2$ bending	
	1463	$-\text{CH}_2$ scissoring	
	729 and 719	$-\text{CH}_2$ rocking	
PET	2921 and 2851	Assymm. and symm. $-\text{CH}_2$ stretching	[32]
	1713	$\text{C}=\text{O}$ stretching	
	1238	$\text{C}(=\text{O})-\text{O}$ stretching	
	1091	$\text{C}-\text{O}$ stretching	
	1015	Vibrations of aromatic ring	
722	Ring $-\text{CH}$ out of plane bending		

unique polymer, but in some cases (Inter-2 layer of Nmask-1 and Inter-3 layer of Umask-2) the FTIR spectrum indicated a blend of two PET and PE. Additional peaks were detected which were associated with additives whose identity is not the subject of the study.

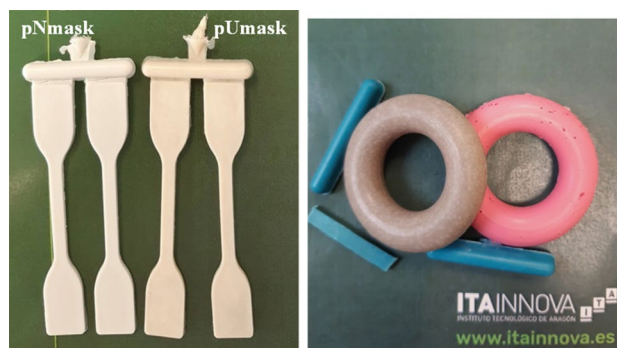
### Compounding of Face Masks

As it has been described above ten non used face masks and ten used face masks were grinded and subsequently processed in a micro twin extruder, and then mould injected in order to obtain bone shape samples. See Table 5 for final process conditions of the material. The recycled polypropylene as reference is also included. Differences in process conditions are related with the mixtures of materials. As an example, the presence of PET increases the melt temperature needed for mould injection in comparison with the one needed for rPP.

The melting process conditions were selected taking into account the differences between individual fusion temperatures of the materials of the face mask. These values are in agreement with the ones used by Zang [34] studying the properties of recycled PET and PP at several conditions using the 240 °C among the temperature profile of the extruder and also the ones used by Mishra [35] who prepared blends of PET and PP. In our case we must consider that not only PP and PET are in the blend but also PE, therefore we chose 240 °C as a compromise for the melt mixing, avoiding to reach higher temperatures for avoiding PE and PP degradation.

**Table 5** Polymer extrusion and injection conditions for bone shape samples

	Face mask material		Recycled PP(rPP)	
	Pressure (bar)	Time (s)	Pressure (bar)	Time (s)
Extrusion temperature	240 °C			
Total mixing time	3 min			
Atmosphere	Nitrogen			
	Mould injection conditions			
Barrel temperature	220 °C		150 °C	
Mould temperature	165 °C		50 °C	
	Pressure (bar)	Time (s)	Pressure (bar)	Time (s)
Step 1	8	0.5	15	0.3
Step 2	9	1	16	1
Step 3	9	2	16	2.5

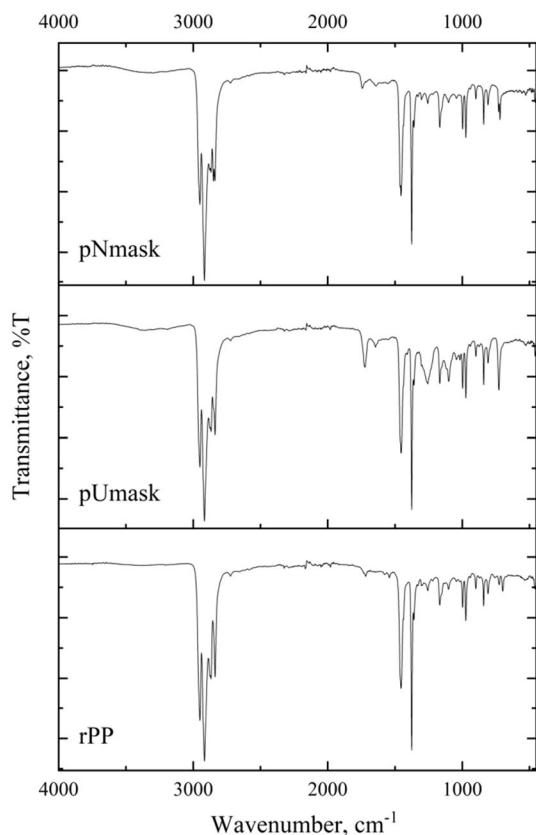


**Fig. 5** Samples and products obtained with recycled material

Figure 5 shows samples obtained with the material from FFP2 face mask for mechanical characterization. Slightly color differences can be observed in samples pUmask obtained from the used face masks, that are darker, related probably with the mixtures of materials and possible contaminations due to the use of the face masks or degradation of polymers after the thermal process. In order to finally validate the recycling process, specific products ring shaped were obtained; these products are not for characterization but a final product for ornamental purposes.

### FTIR Analysis of Melt Blending Material

With the aim of validating the melt mixing recycling process, the FTIR analysis of blending material (a portion of samples prepared for mechanical testing) was carried out; the spectra are shown in Fig. 6. It has to be pointed out that pUmask material has been obtained from a mixture of different brands of face masks collected from a waste bin; that means that to compare this results with the ones of the non used mask (pNmask) will result in knowing the differences between materials as a global; not to know the possible degradation or changes suffered by the material masks for being used. Differences between samples in the FTIR spectra appeared mainly at the vibration bands located at around 1713, 1238 and 1091 $\text{cm}^{-1}$ , bands associated with the vibration of the ester group ( $\text{-C=O(O)}$ ) which were of more intensity in the pUmask sample in comparison with the other samples. As it was assigned in Table 4, these vibration bands are characteristic of PET polymers, whose presence was observed in the intermediate layers of the face masks. The presence of a very weak band at 1730 $\text{cm}^{-1}$  in the FTIR spectrum of rPP could be due to the existence of certain extent of degradation in this polymer associated to the formation of carbonyl groups [36, 37]



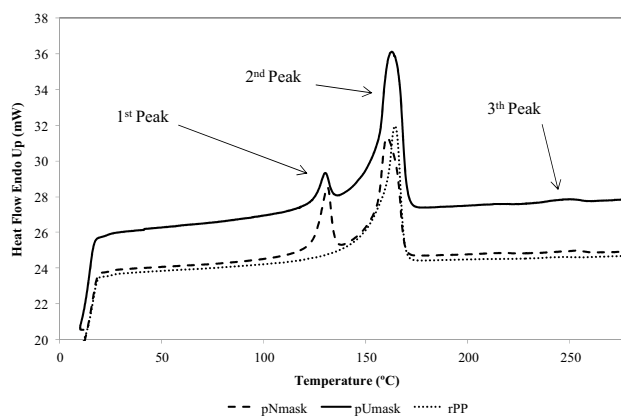
**Fig. 6** ATR-FTIR spectra of face mask material, samples prepared for mechanical testing

**Table 6** Enthalpy and peak temperature results at second heating DSC analysis

Enthalpy (kJ/g) of 2° heating			
	$\Delta H$ 1st peak ( )	$\Delta H$ 2nd peak	$\Delta H$ 3rd peak
pNmask	32.2	81.9	1.4
pUmask	11.6	87.0	1.8
rPP	–	95.4	–
Peak temperature (°C) of 2° heating			
	$T_{peak}$ 1st peak	$T_{peak}$ 2nd peak	$T_{peak}$ 3rd peak
pNmask	131.1	160.4	252.8
pUmask	130.0	162.7	247.6
rPP	–	164.4	–

**Thermal Analysis**

Thermal analysis by DSC was carried out to verify the composition as well as thermal properties of the new blend. Table 6 presents the results obtained in thermal analysis in terms of enthalpy and peak temperature respectively at the second heating step, in Fig. 7 the thermograms curves are shown.



**Fig. 7** DSC analysis of blended material

**Table 7** Polymer presents according to DSC analysis

	Polymer present at the blend		
	PE	PP	PET
pNmask	✓	✓	✓
pUmask	✓	✓	✓
rPP	✗	✓	✗

**Table 8** Mechanical properties of blending material with confidence interval at 95%

	pNmask	pUmask	rPP
Maximum Stress (MPa)	23.6 ± 0.2	25 ± 1	32 ± 3
Deformation at maximum stress (%)	7.2 ± 0.4	10 ± 2	9 ± 0.4
Modulus (GPa)	1.4 ± 0.7	1.4 ± 0.3	1.3 ± 0.6

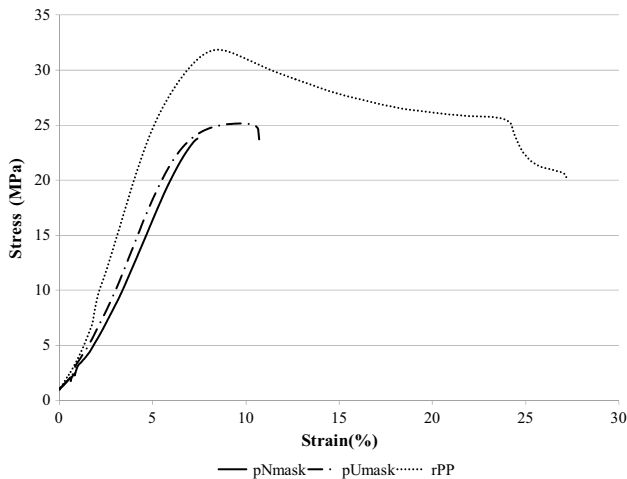
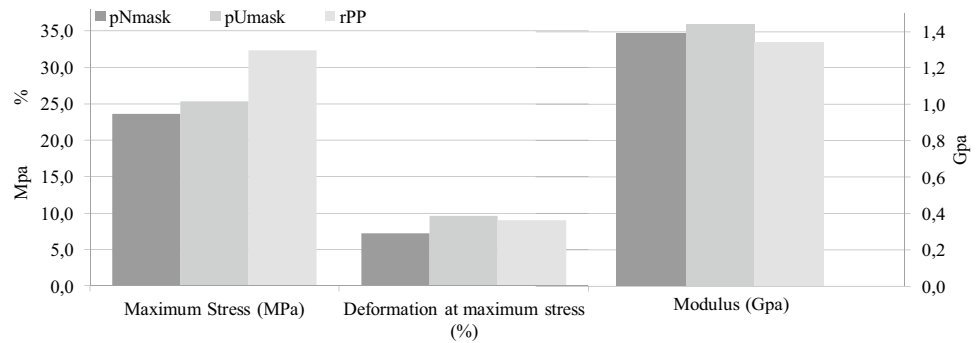
The melting points observed at the thermograms and their correlation with the fusion temperatures of pure polymers (PE ~ 130 °C, PP ~ 160 °C and PET ~ 250 °C), corroborate that the new material from face masks is a blend where, PP is the main polymer and PE as well as PET are present in a less extent (Table 7).

**Density**

Density was measured as a basic property of the recycled material; pNmask material presents a density of 0.92 g/cm<sup>3</sup> while 0.99 g/cm<sup>3</sup> was the value for pUmask material, compared with the rPP of 0.96 g/cm<sup>3</sup>. Those values are consistent with the properties of blending materials.

**Mechanical Properties**

Table 8 and Fig. 8 present the mechanical properties of the recycled materials.

**Fig. 8** Mechanical properties**Fig. 9** Stress–strain curves

Comparable results in modulus have been obtained for the three materials. (pNmask, pUmask, rPP). rPP shows plastic deformation that reaches up to 25%, which has not been visible in the samples of recycled mask material (Fig. 9) due to the mixture of the three polymers (PP, PE and PET).

The materials obtained from recycled face masks (pNmask and pUmask) show lower maximum stress and deformation compared to reference recycled PP. These properties are in accordance of reported results polymeric mixtures such as those from recycled PP of Strapasso et al. [38], in terms of stress and strain with a blend of PP and LDPE (Low Density Polyethylene) injected at 200 °C or the ones of E.G.Hanna of recycled polypropylene/polyethylene mixtures [39] taking into account that the presence of recycled PET could embrittle [40] the final mix and influence directly in the stress of the material. Comparing the results with the ones obtained by Batteggazzore and coauthors [21], who studied the surgical face masks material, it can be noted that the overall mechanical properties of the recycled material from FFP2 masks are higher than the ones from the material from surgical masks. This can be explained taking into account the influence of the three materials present at FFP2 masks,

and the amount of PET in the blending material could be the reason of the higher maximum stress and modulus.

The blending material of the three polymers that compose the face masks is assumed to be a different material from rPP. A point to be deeply studied in future is the possible existence of phases at micro structural level, something that can influence in the mechanical properties of the material as Zhang shows in his report [34]. In that sense, it also must be considered that in the mechanical recycling the process of mixing materials could be improved with different compatibilizers [41] such as the case of thermoplastic elastomers [42], or maleic anhydride grafted polyethylene [27]. These studies of compatibilization are being explored by the authors in current studies.

## Conclusions

In this study we have demonstrated that it is possible to recycle FFP2 face masks using the same protocols that are used in mechanical recycling of thermoplastic, in order to obtain a final blend of materials that can be processed in conventional equipment such as extruder and injection molding equipment. The material is a blend of PP, PE and PET and its thermal behavior presents three different melting points, in that way the conditions of processing at laboratory scale have been selected. Mechanical properties of the blend make it valid to obtain different products, such as flower pots, storage bins, shipping pallets or toys where technical specifications are not critical and can be an alternative to recycled PP.

This recycling process offers an interesting option for the utilization of the high amount of this solid waste that is being produced during Covid-19 pandemic and will contribute to reduce the plastic contamination. The fact of avoiding shortening and separation of different polymers can also contribute to the recycling process in an economic way. Authors plan to continue with this research to complete the characterization and increase the properties of the blending material where compatibilization and additives will be evaluated in order to increase final properties.



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**Author Contributions** CC: Supervision, Conceptualization, Methodology, Writing- Reviewing and Editing. GI: Writing- Reviewing and Editing. PG: Formal analysis, Reviewing. CS: Investigation, Data review, Formal analysis. SR: Investigation, Data review, Formal analysis.

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