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Original
Proposal of mechanical recycling and feasible applications for disposable surgical masks / Cravero, Fulvia; Bernagozzi, Giulia; Battegazzore, Daniele; Frache, Alberto. - STAMPA. - (2022). (Intervento presentato al convegno XXIV Convegno Nazionale AIM tenutosi a Trento nel 4-7 Settembre 2022).

Proposal of mechanical recycling and feasible applications for disposable surgical masks

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Introduction

In a singular period, such as during a pandemic, the use of personal protective masks has become mandatory for all citizens in many countries worldwide. Actually, it is extremely difficult to quantify the disposable masks used because there are no data on sales or quantities disposed. A forecast made by Politecnico di Torino in March 2020 estimated the use of 1 billion face masks each month in Italy [1]. Considering that every mask weights at least 3 g, it turns out 3000 tons of waste to be generated every month, amounting to 2.6% of the national plastic collection [2].

Moreover, when the use as personal protective equipment (PPE) ends, according to the legislation of many countries, Italy among others, they become “municipal waste” and are conferred with the unsorted household waste [3]. Taken into account that in most cases, these PPE are made of polymeric material and disposable [4, 5], the environmental impact is therefore not negligible [6, 7].

The most sustainable scenario in this field is to mechanical recycle the waste to obtain a regenerated material that can be possibly recycled over and over again [8]. In this perspective, the study focuses on the validation of a recycling protocol and subsequent possible material expolitations. The first phase of the study was performed on non-used masks. Furtherly, after-use and after-sanitization masks were exploited.

For both non-used and after-use phases, the mask materials was firstly identified and morphologically, chemically, and thermally characterized with Scanning Electron Microscopy (SEM), Energy Dispersive X-ray Spectrometry (EDX), Attenuated Total Reflection (ATR), Differential Scanning Calorimetry (DSC), and Thermogravimetric Analysis (TGA) [5].

Subsequently, a separation step was performed to ungroup the filtering part, the earloops and the nose clip. Then, four different recycling protocols were adopted, leading to a recycling index ranging between 78% and 91% [5].

Furtherly, the materials were processed and characterized on a rheological, mechanical and thermomechanical point of view. Also, a comparison with commercially available alternatives was done. Specifically, the processing included compression molding, wire and film extrusion, FDM 3D printing and injection molding.

Result and discussion

The SEM image in Figure **1** a) shows the external layer of a new mask. As can be seen, the fabric is made of non-woven fibers with uniform circular section of approximately 40 μm. These fibers are stuck together thanks to square melting junctions. In addition, with the backscattered electron analysis was appreciated the presence of a dot-like filler. The results of the EDX analysis on it (22.0 ± 0.7 wt.% of Ca, 29.0 ± 0.8 wt.% of O and 47.7 ± 0.7 wt.% of C elements) likely identified it as $CaCO_3$.

On the other hand, the filter layer was made of less uniform fibers in terms of diameter and no filler was present. Moreover, the morphological analysis on the earloop (Figure **1** b)) highlighted the presence of two kind of fibers, named Type I (bulky fabric and lower diameter) and Type II (isolated straight bundles of about ten fibers) [5].

Referring to the three layers, the DSC (Figure 1 c)) analyses show a singular melting peak between 166 and 168 °C. These temperatures are in accordance with the ATR results, showing the materials of the three layers to be PP [5].

Furtherly, rheological analyses (Figure **1** d)) involved the material obtained from the three fabrics alone, the one from the earloops alone, and the joint of the two.

The material from the fabrics alone (FM_EX190) exibits a Newtonian plateau at around 150 Pa.s and a slight shear thinning behavior at low frequencies, due to the presence of the well dispersed calcium carbonate filler. On the other hand, a clear shear thinning behavior can be appreciate for the earloops (EL_EX230). In this case, it has to be attributable to the presence of a second non-melted phase [5]. This trend is also maintained when the mask material and the earloop materials are blendend (FM_EL_EX190 and FM_EL_EX230 in Figure **1**).

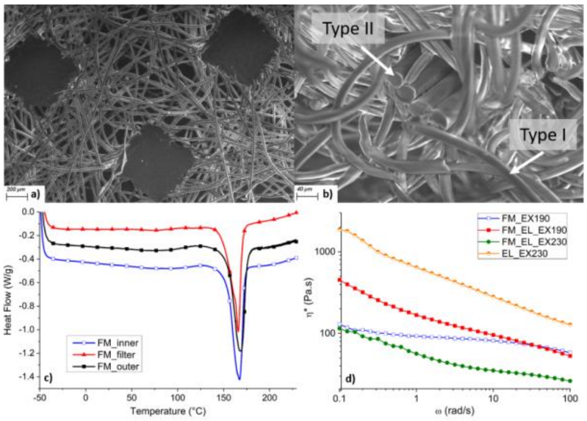

Figure 1 –a) SEM image of the first layer of the mask; b) SEM image of the ear loop highlighting two types of fibers; c) DSC of the three layers of the masks; d) Rheology at 190 °C and 230 °C of the face masks jointly or severally the earloops.

After the characterization step, the masks underwent a manual separation step. In the case of the after-use masks, this was preceded by a sanitization step. In both cases, the filtering layer were compression molded and granulated to obtain a pellet-like shape. On the other hand, the earloops were manually cut in length of less then 10 mm [5, 9].

All the materials have then been processed following different approaches. As first transformation step, the pellets were extruded. The validation of this process was important on several levels. Firstly, the mask material proved to be extrudable both in wire and film shape. Secondly, it was possible to granulate the material in a more uniform way for further transformation processes. Thirdly, during the extrusion, it was possible to additivate the mask material. In particular, earloops were blended to investigate the joint recycle. Moreover, with the purpose of exploitation in FDM 3D printing, two formulations containing talc and polypropylene were studied and extruded.

The pellets obtained with extrusion have been further transformed. Compression molding and injection molding were both assessed as viables processing approaches. Moreover, the mask-based wires for FDM 3D printing were then produced, characterized and compared to a commercial available product.
In addition, the above transformation processes were exploited for the production of samples for different characterizations steps. In particular, injection molding and FDM 3D printing for the mechanical properties, compression molding for rheology, DMTA and mechanical properties.

Specifically considering the mechanical properties, the comparison among the non-used, the after-use and the 3D printed masks is shown in Figure 2.
Both the modulus (974±21 MPa vs 1000±12 MPa) and the maximum strength (28,3±0,5 MPa vs 26,2±0,8 MPa) seem not to be affected by the life in use of the masks. On the other hand, the elongation at break is reduced in the after-use material (13,2±2,2% vs 7,7±1,3%). Moreover, the presence of talc results in a more fragile material, having higher modulus (1378±159 MPa and 1247±91 MPa) and lower strain (2,4±0,4% and 3,5±0,8%).

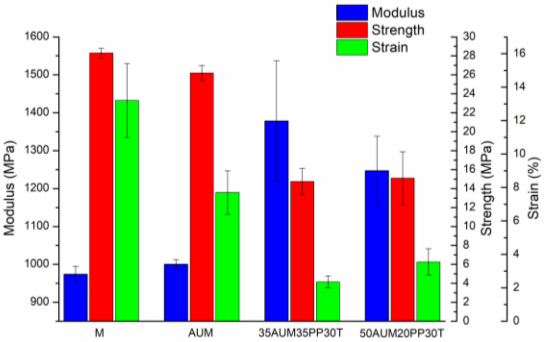

Figure 2 – Comparison of the Young Modulus, maximum strength and strain of the non-used masks (M), after-use masks (AUM) and the formulations for FDM 3D printing (35AUM35PP30T and 50AUM20PP30T).

Conclusions

Due to the current law dispositions in terms of disposal, the after-use disposable filtering masks are environmentally impacting. In the present study, the materials were characterized and different approaches of recycling were attempted, leading to a recycling index ranging between 78% and 91%. Moreover, the material was validated as secondary raw material with several transformation tecniques and further characterized.

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