



# Incorporation of surgical mask residues and aerogel granules into polyurethane foams

Extended abstract

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## Abstract

In this thesis, the inclusion of surgical mask residues in polyurethane foams was tested so they can be reused while reducing polyurethane foams production, maintaining performance demands, and lowering the production price. At the same time other polyurethane foams with no particle inclusion, and with aerogel granules (of silica superinsulator material) incorporation were produced for comparison.

Several masks brands (All Procure, BTMC, CNU, Betinatêxteis and others) were separated into their different parts, and the filtering layers analysed by FTIR. These layers were then milled into particles smaller than 2 mm and introduced in a polyurethane foam with a known formulation. This inclusion changed the foam final properties, thus, they were optimized by adjusting the ratio between equivalent NCO and OH.

After this adjustment, the foams presented dimensional stability, and heat transfer (measured with the planar probe) similar to the known base formulation (with 11,6% mask inclusion, and 5% aerogel inclusion, both mass percentages). The foams with mask inclusion showed high capillarity throughout the test duration and lower mechanical resistance to compression, reason why it should be inserted in sandwich panels. However this inclusion lowers the composite price, in opposition to the aerogel inclusion. Since aerogel inclusion also didn't improve any of the tested properties, its inclusion is not beneficial.

Since this work has strong environmental motives, the inclusion of particles in polyurethane foams produced with a biopolyol was also studied, being the polyol characterized. The best formulations were selected and characterized through TGA, SEM, uniaxial compression, capillarity, and thermal conductivity analysis.

**Keywords:** Polyurethane; Foams; Thermal conductivity; Sandwich Panels; covid masks; aerogel

## Introduction

The raise in surgical masks utilization, allied to the fact that they are not recyclable and non-degradable [1], made them a new world environmental problem. It's not known how much time they take to decompose in the nature, and they release uncountable fibres, harmful to life [2]. The fact that the mass of polyurethane produced worldwide is raising, and predicted to continue this tendency [3], is another problem, which can be minimized with the inclusion of wastes in these foams. This work was made in order to respond to these problems, being the masks characterized, milled into particles smaller than 2 mm, and introduced in polyurethane (PU) foams.

At the same time, PU foams without particles inclusion, and with silica aerogel granules were made, so the properties can be compared. Aerogel is a nanostructured material that results from sol-gel process, having high porosities and low densities. Aerogel granules inclusion has gained interest, since it's a superinsulator material that have shown to improve PU foams thermal insulation [4]. The aerogel used was Kwark GL (produced by Enersens) which, have 0,1 to 3,5 mm diameter, apparent density of 75 kg/m<sup>3</sup>, and thermal conductivities of 0,012 ( $\frac{W}{m \cdot K}$ ) (intrinsically) and in the range 0,018-0,022 ( $\frac{W}{m \cdot K}$ ) (when in a granular bed). Silica has good excellent fire behavior, being non-flammable, not releasing particles or flaming droplets or toxic smoke [5].

The insertion of particles in PU matrix is much used to optimize thermal insulation properties of the composite, because they act as nucleation agents, tending to reduce pore size [6], and consequently the heat flow [4]. This inclusion can also improve mechanical and flame retardation properties, but it changes the reaction kinetics (requiring adjustments in the formulation) [4].

These adjustments were made by calculating the ratio of equivalent NCO (n° of isocyanate molecules with NCO functional groups multiplied by its functionality) divided by equivalent OH (the same, but a sum for every reagent with OH functional groups). For example, the internal layer of the mask receives a surface treatment to become hydrophilic (to absorb the particles emitted by the user) [7], so it is expected that more water needs to be added to the formulation.

Since PU foams are widely used for insulation purposes, the studied properties were: thermal conductivity, thermal degradation, mechanical behaviour under compression, capillarity, being the cellular structure analysed with a SEM. To test the composite application as insulator material, the best formulations were introduced in sandwich panels.

The method used to produce the foams is named one-shot, and it consists in mixing the polyol with all the additives that are going to be used (like catalysers, surfactants, blowing agents, and particles that won't take part in the reaction). Afterwards, the isocyanate is mixed, and the reaction starts in an exothermic and exponential way [8]. The main reactions are the polyurethane formation reaction where an isocyanate reacts with an alcohol forming urethane, and a reaction between isocyanate and water, that forms unstable carbamic acid which dissociates into an amine and gaseous carbon dioxide, that leads to the foaming process [9].

## Materials and Methods

### Reagents

#### Polyols

They are alcohols with hydroxyl (OH) groups, in the foaming process these are the groups that react with NCO of the Isocyanates producing urethane [10]. Usually they are produced with petroleum, but Polyols produced through environmental friendly alternatives, like ricin or food oils have gained interest.

In this work 2 polyols were used. A synthetic one is called polyol 3500, (because it has a molar mass of 3506,1g/mol), with an OH value of 48, and a functionality 3, and a bio-based one, that is called polyol

polyester 1700-2000, which has a 2,5 functionality, an OH value of 23,5; and a molar mass of 5968g calculated through the formula  $Mw = \text{functionality} \frac{56100}{vOH}$  (being vOH the OH value)

## Isocyanates

It's the other fundamental reagent to the PU formation, because it has NCO groups that allow the urethane formation reaction. Usually, Isocyanates with 2 or 3 NCO groups, or aromatic polyisocyanates are used. The aromatic ones are highly reactive with amines and OH due to resonance effect, being the most used ones toluene diisocyanate (TDI) and methylene diphenyl isocyanate (MDI) [10]. In this work it was used the ISO-PMDI 92410. And a functionality of 2.7.

## Catalysers

They are used to adjust the foam final properties, and usually we use one to promote the NCO reaction with the OH groups, making the chains grow faster. In this work the catalysers used to this finality were 1,4-diazabicyclo[2,2,2]octane (or DABCO) and the Niox A1Catalyst (diluted in the reason 1 part of niox A1 to 10 of diethylene glycol). Simultaneously, another catalyzer with the function to promote the CO<sub>2</sub> formation and release (in this work we used the Dibutyltin dilaurate known as DBTL). The proportions between the different types of catalyzers must be considered, since if too much of the first type is used, the chains will grow too fast and lose fluidity much quicker than the CO<sub>2</sub> is released, not allowing the foam to grow. In the opposite scenario, if the CO<sub>2</sub> is all released before the polymer chains have enough length to hold the foam form, it will shrink.

## Surfactants

They are used to ensure an homogeneous particle and pores distribution, and to prevent cells coalescence during the foaming reaction. It also reduces the surface tension of the polymer, help mixing the less mixable reagents, and compensate the anti-foamy process caused by solid particles addition [10]. In this work the surfactants used were silbyk-9001, BYK-9076 and Tegostab B8825.

## Blowing Agents

They are substances that under determined circumstances, release gas in a foaming process, that origin the cellular structure of the foam. The most used in PU foams is water, that through a secondary reaction with Isocyanate generates gaseous CO<sub>2</sub> [8]. The amount of blowing agent must be well considered, since if it makes the diffusion tax from inside the bubble to outside higher than in the other direction, the bubbles will collapse. In this work we used water as blowing agent [11].

## Methods

### Adjustments in NCO/OH ratio

So the  $\frac{eqNCO}{eqOH}$  can be quickly calculated, a list of all the reagents with their equivalent NCO and OH was made, and through the insertion of the quantities of every reagent (except isocyanate), and the  $\frac{eqNCO}{eqOH}$  ratio desired, it gives the amount of isocyanate needed to fulfill the required ratio.

The optimum theoretical ratio is 1,15 to ensure that all the OH reacts.

### Ball Milling

In order to study the mechanical resistance in wearing mediums, the masks were inserted in a ball mill, and milled in different conditions and times. This test gives a succinct idea of how the masks decompose. The used mill was produced by A. J. D'Almeida Lda.

### FTIR

It's the acronym for Fourier-transform Infrared Spectroscopy, and it consists in focusing a light spectrum (in the infrared range), in the sample, and measuring the transmission/absorption of the light in the

different wavelengths. The different wavelengths correspond to different chemical bonds, allowing the bond identification, and the material identification through comparison with the literature. The more the bonds with a certain energy, the more the light is absorbed in the corresponding wavelengths. In this work it's used the PerkinElmer Spectrum 65 FT-IR Spectrometer, that gives the transmittance (in %) in function of the analysed wave numbers (in  $\text{cm}^{-1}$ ), in the range 4000 to 6000  $\text{cm}^{-1}$ . It was made with ATR system which consists in focusing beam at an angle larger than the critical in an ATR crystal (high refraction index) occurring total internal reflexion in the surface that contacts the sample. It requires little to no preparation of the sample, and the more reflexions occur, the more precise are the results, being this technique easily reproducible through users and samples [12].

### Mask milling

The masks are milled so they are easily and homogeneously introduced in the foams, they have to be disrupted into smaller particles. For that purpose, the Retsch SM200 was used. It is a mill with 6 cutting discs spirally organized to cut in sequence. The materials inserted doesn't stay long in the milling chamber, since when the particles achieve a size smaller than the spaces between the sieve (placed below), they fall with gravity to a bucket attached to the machine.

### Thermogravimetric analyses

It is used to determine the mass variation (in %) through a temperature range that can go up to 1600°C, at a heating speed also defined. The sample is putted in metal supports, and constantly weighted during the heating. Since it loses weight during the test, this is a destructive test. The heating chamber atmosphere can be controlled (inert or oxidative), or not, depending on what it's being studied [13]. In this work the used device was Hitachi STA7200 .

### SEM

It's the acronym to Scanning Electron Microscopy, it emits an electron beam that scans the surface of the sample, interacting with it. Some of the incident electrons are reflected, other are absorbed, other are backscattered, and sometimes they release electrons from the sample. Reading this data, it's possible to analyse the materials morphology, within a large range of amplifications that can go from 10 to 10000 times. The sample is in a vacuum chamber so the beam doesn't have interferences. The device utilized in this work is the Phenom ProX G6 by ThermoFisher Scientific.

### Capillarity test

It consists in weighting the samples, put them with a face with known dimensions in contact with water, removing them in defined space times, weighting them and putting them back with the same face down. This allows to calculate the water mass absorbed through the time.

### Thermal conductivity

This test consists in inducing an heat flow in the sample, and measuring the temperature change in it. There are several probes and ways to do this, but in this work we used a planar and a needle probe to do that. The planar one is used to test hard materials, being simply settled on the sample, and the needle one on softer materials, being introduced in them. Both the probes need a thickness of at least 2 cm between itself and the end of the sample for satisfactory precision, and a thickness of 4cm to maximum precision [14]. The used device was IOMET 2114.

### Uniaxial compression

As the name indicates, the sample is compressed in one direction, being the values of force applied and distance moved registered in defined time spaces. To better analyse the distance that the sample was compressed, an extensometer must be used. It consists in a zig zag folded wire, with a known nominal tension. The ends of the wire are fixed to the sample, so their dislocation is equal. The change in the extensometer length is measured through the difference in electrical conductivity during the test. The force applied must be divided by the orthogonal cross section area, and the dislocation by the initial length of the sample, so the tension and extension are obtained (respectively). Several types of tests

can be made with this equipment. The device used was HTE Hounsfield H25KN/558, the data acquisition program was NI SignalExpress 2015, being this data treated on Microsoft Office Word.

## OH titration

To calculate the OH value three titrations are needed, the first to calculate the acid value of the sample, and then 2 more to calculate the OH value (one of them is for comparison). To calculate the acid value 1 to 2 g of sample are weighted and dissolved in 40 to 50 mL of tetrahydrofuran THF, being titrated with a potassium hydroxide (KOH) solution, 0,1N in ethanol, using phenolphthalein as indicator.

The acid value (AV) obtained was 12,6, and can be calculated through the formula:

$$AV = \frac{C * MW(solution) * \Delta V}{m(sample)}$$

Where C is the concentration of the titrant solution (0,1); MW(solution) is the molecular weight of the solution (56,1);  $\Delta V$  is the titrated volume and m(sample) is the sample mass.

For the OH value we have to titrate 0,5N KOH in ethanol, using 1% thymolphthalein (in THF) as indicator. To prepare the solutions to be titrated, we must put 40 to 50 mL of THF in 2 separate cups (dissolving 1 to 2 g of sample in only one of them), adding 10 mL of 1% 4-n,n-Dimethylaminopyridin in THF, and 10 mL of 12,5% acetic anhydride in THF, mixing all for 10 min. After that introduce 2 mL of water and mix for more 30 min.

The OH value (vOH) obtained is 23,5, calculated through the formula:

$$vOH = \frac{C * PM(solution) * (\Delta V(white) - \Delta V(sample))}{m(sample)} + AV$$

Where C is the concentration of the titrant solution (0,5); MW(solution) is the molecular weight of the solution (56,1);  $\Delta V(white)$  is the titrated volume without sample;  $\Delta V(sample)$  is the titrated volume with sample; m(sample) is the sample mass and AV is the acid value of the sample.

## Results

### Adjustments in NCO/OH ratio

All the produced formulations (except the base and the biopolyol 1 to 6) were made by this method, based on the "base" formulation, and are presented in Table 1 (show the quantities used in grams to make a 20g foam, but this can be read as mass parts).

The formulations called "aerogel" have inclusion of aerogel particles, the mask with mask particles, (both with polyol 3500) and the "biopolyol" produced with the polyol polyester, and with mask particles (compost C).

It was noticed that the particles inclusion changed the ratio of the reaction, reason why the best formulation with mask inclusion (mask 7) had a calculated NCO/OH ratio of 0,56; and the best with aerogel "aerogel 5" a ratio of 0,38. Mask 7 formulation grew 1,7 times more than the base one, allowing 60% reagents safe to produce the same volume.

The formulations "biopolyol" 1 to 6 were not made by this method, they were based on another base formulation and adjusted empirically. None of them presented good characteristics, reason why their formulations are not presented here. The biopolyol 7 and 8 were made by adjusting the  $\frac{eqNCO}{eqOH}$  ratio to the base value (1,15) and to the mask7 ratio (0,56) but still didn't present usable characteristics, so none of the formulations with a biopolyol was tested.

Table 1 - Produced formulations by adjusting eq NCO/OH ratio

	Polyol 3500	glycerol	H2O	Tegostab B8825	Silbyk-9001	NiAx A1 catalyst 10%	DBTL	BYK-9076	Composto C	Isocyanate
base	6,22g	0,69g	0,41g	0,93g	0,07g	0,07g	0,07g	0,04g	0,00g	11,54g
Aerogel 1	6,22g	1,04g	0,41g	0,93g	0,07g	0,07g	0,07g	0,04g	1,05g	11,54g
Aerogel 2	6,22g	1,04g	0,90g	0,93g	0,07g	0,07g	0,07g	0,04g	1,05g	11,54g
Aerogel 3	6,22g	1,04g	1,70g	0,93g	0,07g	0,07g	0,07g	0,04g	1,05g	11,54g
Aerogel 4	6,22g	0,69g	1,90g	0,93g	0,07g	0,07g	0,07g	0,04g	1,05g	11,54g
Aerogel 5	6,22g	0,69g	1,80g	0,93g	0,07g	0,07g	0,07g	0,04g	1,05g	11,54g
Aerogel 6	6,22g	0,69g	1,80g	0,93g	0,10g	0,07g	0,07g	0,04g	1,05g	11,54g
Aerogel 7	6,22g	0,69g	1,80g	0,93g	0,07g	0,07g	0,07g	0,04g	1,05g	15,07g
Aerogel 8	6,22g	0,50g	1,80g	0,93g	0,07g	0,07g	0,07g	0,04g	1,05g	11,54g
Aerogel 9	7,00g	0,69g	1,50g	0,93g	0,07g	0,07g	0,07g	0,04g	1,05g	11,54g
Aerogel 10	7,50g	0,69g	1,60g	0,93g	0,07g	0,07g	0,07g	0,04g	1,05g	11,54g
Mask 1	6,22g	0,69g	0,41g	0,93g	0,07g	0,07g	0,07g	0,04g	1,05g	11,54g
Mask 2	6,22g	0,69g	0,41g	0,93g	0,07g	0,07g	0,07g	0,04g	1,58g	11,54g
Mask 3	6,22g	0,69g	0,41g	0,93g	0,07g	0,07g	0,07g	0,04g	2,10g	11,54g
Mask 4	4,00g	0,89g	0,53g	0,30g	0,04g	0,04g	0,04g	0,04g	1,58g	14,10g
Mask 5	6,22g	0,69g	0,41g	0,93g	0,07g	0,14g	0,14g	0,04g	1,58g	11,54g
Mask 6	4,04g	0,67g	1,35g	0,60g	0,04g	0,08g	0,08g	0,04g	1,58g	13,20g
Mask 7	4,04g	0,67g	1,35g	0,60g	0,04g	0,04g	0,04g	0,04g	1,58g	13,20g
Biopolyol 7 (1,15)	2,43g	0,41g	0,81g	0,36g	0,03g	0,03g	0,03g	0,04g	1,58g	16,09g
Biopolyol 8 (0,56)	4,03g	0,67g	1,34g	0,60g	0,04g	0,04g	0,04g	0,04g	1,58g	12,97g

## Ball Milling

All the millings were made with balls during 1h, being one only with balls, other with balls and sand and the other with balls, sand and water. In the first case the masks stayed practically equal, in the second some wear was noticed, but in the 3<sup>rd</sup> case is where the wear is most noticeable. This 3<sup>rd</sup> test was repeated with a duration of half an hour, and 2 hours. The water and sand of the longest test was sifted, and weighted, showing that only 0,26g of fibres were released, corresponding to a mass percentage of around 0,39% of the 20 masks tested.

## FTIR

It was used to analyse the masks filtering part of several brands (All Procure; BTMC; CNU; and Betinatextêis), that was noticed to be separated in 3 different layers. These layers seem different, but they had similar results that show that they are all mostly made of polypropylene.

## Mask Milling

When the whole masks were introduced, the mill jammed, and it was noticed that after the ear rubber bands, and the metal nose support were removed, this problem only occurred if the milling chamber was too full. For industrial application, the quantity of masks per mill must be studied, to minimize the energy and time spent.



## Thermogravimetric analyses

The metal supports were made of aluminium, the atmosphere inert due to a 200 mL/min supply of nitrogen, being the sample heated until 30 °C, maintained at that temperature for 5 min, then heated until 600 °C at a speed rate of 10 °C/min, and maintained at that temperature for another 5 min. The first test had to be repeated because it showed a mass gain, which is nonsense. All the formulations showed a raising degradation speed at around 250 °C, and the highest degradation speed around 385 °C, but this degradation speed starts stabilizing around 420 °C without inclusions, 470 °C with aerogel inclusion, and 500 °C with mask inclusion, resulting in mass loss of 81,6%; 80,3% e 89,5% respectively. Since the polypropylene shows its fastest degradation in the range of 450 °C to 500 °C, and that the mask 7 formulation showed the biggest mass loss, and at latest temperatures, we can conclude that before the degradation speed stabilizes, the polypropylene is being degraded.

## SEM

Clear differences in porosity are shown in Figure 2, being the pores of the foam with mask particles inclusion much smaller than without any particles, as expected [9]. In the less ampliation image, it is shown a mask particle so its easier to understand how it connects to the foam matrix. It is possible to understand that the particle fibres are wrapped by the PU, generating mechanical interlocking (an adhesion mechanism). This is very important because to the particle-matrix connection, since PP has weak surface adhesion properties in its natural state [15].

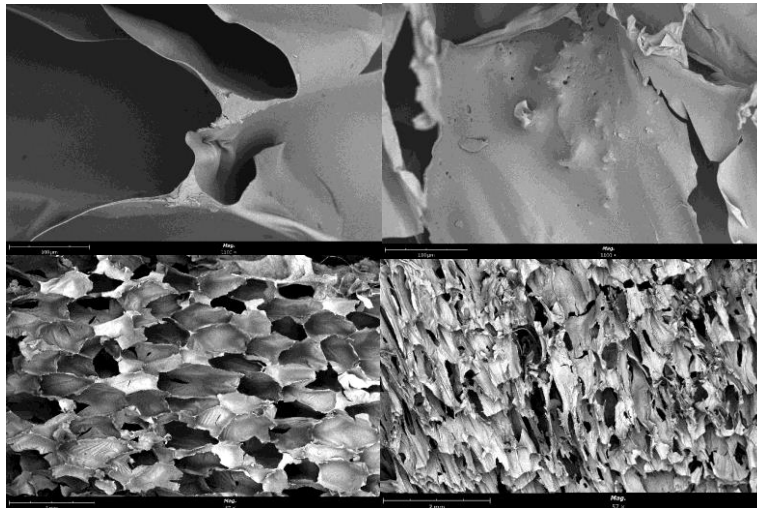


Figure 1 - SEM analysis of base (left) and mask 7 (right) formulations with ampliations of 57x (up) and 1100x (down)

## Capillarity test

In the beginning, the foams absorb water fast, starting to stabilize at the end of 90 min, but they all kept absorbing water until the end of the test, being the foam with mask particles the one that absorbs faster at the end of the test. The base formulation shows a lower absorption coefficient than the aerogel (except in the first 10 min). This can be related to the fact that the particles absorb some water, and to the foam porosity, which can affect the capillarity effect. The fact that the formulation with mask inclusion is the less dense, also makes possible that the foam absorbs more water, since it has more space in its interior. The results are shown in Figure 3.

Table 2 – Absorbed water mass divided by contact area (cm<sup>2</sup>)

Tempo (min)	base	máscara	Aerogel
0	0g	0g	0g
10	0.0456969g	0.050168691g	0.037179487g
90	0.0607201g	0.063677463g	0.072538462g
1350	0.0750523g	0.105020243g	0.093294872g
11520	0.1159582g	0.412125506g	0.164955128g

## Thermal conductivity

The device was used in “constant power mode” and the ranges analysed were 0,04 to 0.3  $\frac{W}{m \cdot K}$  (for the planar probe) and 0,015 to 0.05  $\frac{W}{m \cdot K}$  (for the needle probe). The needle probe was not used in the sandwich panels (table 3) analyses since it's not suitable for hard materials. Since the probe only analyses 2 to 4 cm of thickness, the results of the sandwich panels analyses are highly influenced by the material of the panel's face sheet, not being conclusive of the foams properties.

The planar probe contacts with more area of foam than the needle probe (showing a more representative average of the whole foam), and since the samples were cut, making that this probe is not influenced by the foam differences at its surface, the planar probe analysis results are more representative of the foam than the needle probe results. The thermal conductivity showed to be very similar through the tested formulations, which is the most important characteristic for a thermal insulator.

Table 3 - Thermal conductivity analysis of the foams with ISOMET2114

Formulation	Probe	Test	$\lambda (\frac{W}{m \cdot K})$	$Cp (\frac{kJ}{m^3 \cdot K})$	$a (\frac{mm^2}{s})$	Tmean (°C)	$\Delta T$ (k)
Base	Planar	Test 1	0,04	84,4	0,4736	29,794	8,7951
		Test 2	0,0397	87,7	0,4529	31,04	10,048
		Average	0,0398	86,1	0,4632	30,417	9,4214
	Needle	Test 1	0,0671	83,4	0,8049	27,621	10,306
		Test 2	0,061	82,4	0,7399	28,116	9,9433
		Average	0,064	82,9	0,7724	27,869	10,125
Mask 7	Planar	Test 1	0,039	68,6	0,5689	31,204	8,9146
		Test 2	0,0392	67,7	0,5784	31,832	9,9723
		Average	0,0391	68,2	0,5737	31,518	9,4434
	Needle	Test 1	0,0856	52,6	1,6269	28,803	9,9308
		Test 2	0,1186	51,5	2,3023	29,159	9,9491
		Average	0,1021	52,1	1,9646	28,981	9,94
Aerogel 5	Planar	Test 1	0,0393	60,2	0,6524	29,507	8,7761
		Test 2	0,0394	63,9	0,6165	30,224	9,9988
		Average	0,0393	62	0,6344	29,865	9,3874
	Needle	Test 1	0,0777	59,9	1,2967	27,731	10,047
		Test 2	0,0862	56,7	1,519	28,043	10,179
		Average	0,0819	58,3	1,4079	27,887	10,113

## Uniaxial compression

This test consisted in making 4 compression cycles to each sample, compressing them until -0,5 extension at a speed rate of 10 mm/min. For each cycle, 400 s were counted from the beginning of the compression, until the decompression (being the dimensions maintained since the sample achieves - 0,5 extension until the 400 s passed). The compression was made with 100% of a 2000 N load cell. The tension values at the end of the each cycles (in MPa) are presented in the table 4



Table 4 – Tensions (in MPa) at the end of each cycle with 100% load cell

Type	Base			Mask 7			Aerogel 5		
sample	1	2	3	1	2	3	1	2	3
1º cycle	-26,316	-6,52057	-22,3576	-2,1507	-13,5244	-12,8835	-36,7367	-13,2235	-10,9056
2º cycle	-14,4406	-26,316	-54,0254	-15,4263	-13,5244	-9,35185	-17,6982	-34,9725	-23,2608
3º cycle	-26,316	-6,52364	-26,316	-2,1507	-2,40242	-9,35185	-17,6982	-16,8483	-6,7872
4º cycle	-22,3576	-22,3576	-18,3991	-5,4696	-9,81708	-16,4151	-36,7367	-27,7229	-6,7872

These values shown much noise, even reaching some positive tensions during the test, which is nonsense, so other samples were tested with 10% of the same load cell (2000 N), and the results shown in the table 5

Table 5 - Tensions (in MPa) at the end of each cycle with 10% load cell

Tipo	base	Mask 7		Aerogel 5	
sample	4	4	5	4	5
1º cycle	-27,5232	-6,86106	-8,95062	-9,54992	-12,4585
2º cycle	-25,1177	-7,59691	-7,70775	-10,5864	-10,7774
3º cycle	-24,3158	-6,86106	-7,70775	-8,51369	-10,7774
4º cycle	-23,9149	-7,96484	-6,88109	-8,8591	-9,93699

Since an elastic deformation would always show the same tension (only related to the materials bonding energy), and plastic deformation would lead to a decrease in compressive strength during the test (since some bonds changed position), the sample 4 of mask 7 and aerogel 5 formulations aren't conclusive about the deformation regime that the samples were subjected, and the values might have happened due to foam lack of heterogeneity. The other results of the test with this load (10%) show a clear tendency to reduce the load, meaning that plastic deformation occurred during the cycles. It is also noticeable that the mask 7 needs the minimum force to stay with the defined dimensions during the defined time, after the aerogel 5, and the base formulation shows more than the double of the tension than the aerogel 5 foam. This can be a problem, but the introduction of the foam in reinforced sandwich panels can solve it.

## Conclusion

It is noticeable that the three filtering layers of the surgical masks are made of polypropylene, and their different characteristics must come from different molecular lengths and the way they are connected to each other. The masks showed resistance to mechanical wear, however they slowly decompose into smaller fibres that are harmful to the environment. These layers, after separated from the other parts of the mask, are easily milled into particles smaller than 2 mm, and homogeneously introduced in the foams.

The introduction of particles in the formulation makes that the  $\frac{eqNCO}{eqOH}$  theoretical had to be changed from its original value (1,15) to 0,56 (with mask inclusion) and 0,38 with aerogel inclusion. In both cases the foam lost mechanical resistance to compression, and absorb more water, reason why they must be introduced in sandwich panels, solving both these problems. Since the mask lowers the composite price, its introduction is beneficial, in opposition to aerogel introduction which raises the price.

TGA analyses showed that until 150 °C all of the foams showed to be highly stable, being able to be used for thermal insulation at ambient temperatures.

Sem analyses shows mechanical interlocking between mask particles and PU matrix, which is good for composite cohesion.

The use of the formulation "Mask 7" allows to save around 60% of reagents to produce the same volume, while preserving the thermal conductivity when tested with planar probe (better describer of the sample). This allied to the fact that the capillarity and mechanical strength problems can be solved by the foam introduction in sandwich panels, and that the Mask 7 formulation is the cheapest per volume unit, the mask inclusion showed to be a useful way to reduce the price of the panel, maintaining the insulation properties.

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