Use of Mixtures of Shredded Face Masks and Fine Soils in Layers of Flexible Pavements

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ABSTRACT— ***In recent years, since the onset of the COVID-19 pandemic, there has been a disproportionate increase in the use of face masks by the general population, which generates that a residue that was previously almost exclusively pathogenic, starts to present a predominant component in terms of the residential area. The latter leads to the generation of an environmental threat if solutions are not adopted regarding their recycling. One of these solutions may be to dispose of this residue in pavement structures, given the potential structural contribution that the textile that constitutes them may present.***

Given this, the LEMaC Centro de Investigaciones Viales UTN FRLP-CIC PBA (Argentina) analyzes the existing antecedents, concluding that the field of application in fine soils has not yet been explored. To cover this, a pre-feasibility study for the use of these shredded wastes mixed with fine soils in subbase layers and improved subgrade is being developed.

The study allows obtaining good preliminary results from the mechanical point of view, mainly with the California Bearing Ratio test, which are complemented with an analysis regarding the environmental implications, the available shredding forms, and the materialization on site. All these aspects are covered in this article.

As conclusions, it can be pointed out that the optimal content can be between 1.5% and 2.0% of face masks in weight above 100% of dry soil weight, which would translate into more than 1,000,000 face masks per lane for every 100 m of a treated layer.

Keywords—road engineering; road soils; subgrade; subbases; waste; single-use face mask; light blue face mask; environmental threat; COVID-19

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1. INTRODUCTION

The entire manuscript, including mathematical equations, tables, and figures must be prepared in electronic form and submitted as Word for Windows files. Use only fonts that come with Windows software. For the text use Times New Roman size 10. For all special characters (e.g., Greek characters) use the font **Symbol**. Line spacing is single; spacing after paragraphs is 6 pt; first line is indented **.2** inches; text alignment is justified. Use carriage returns only to end headings and paragraphs, not to break lines of text. Verify the correct spelling for the final version with the Spelling and Grammar function of Word.

In the Introduction section, present clearly and briefly the problem investigated, with relevant references. The main results should be enunciated.

The COVID-19 pandemic has generated a notable increase in the use of disposable face masks worldwide [1]. In Argentina these face masks are known colloquially as "light blue face masks", qualifying as "Type 1 - Basic" when they are materialized with a double layer of synthetic fabric or as "Type 2 - Class I" when they have three layers; both are "procedural face masks" [2] and are the most used [1].

In Oceania, at the other end of the planet, since the beginning of the pandemic on the beaches of several small uninhabited islands of the Soko archipelago (between Hong Kong and Lantau) thousands of used masks have been found (Figure 1), probably from Hong Kong and its area of influence, when before it these residues had not been observed [3].

***Figure 1**. Increase of face masks on beaches in Oceania at the beginning of the pandemic. Source: [3]*

At around that time, the MercadoLibre company, a South American leader in online sales, reported that the demand for face masks through its platform had increased by 608% [4].

The most current data, after 2 years of the pandemic, according to the National Geographic magazine, indicates that 129,000 million disposable face masks are used worldwide per month, that is, three million per minute [1]; while is estimated that just 8 billion were used in all of 2019 [5].

However, the increase in single-use plastic garbage (gowns, gloves, masks, etc.) is an issue little addressed in the framework of the COVID-19 pandemic, which is reflected in the low percentage that it has among the publications that are generated around it [6].

While they've helped protect humans from COVID-19, the masks today are mostly made from plastic fibers that can take hundreds of years to disintegrate [5]. Researchers from the Consejo Nacional de Investigaciones Científicas y Técnicas of Argentina (CONICET) at the Instituto Argentino de Oceanografía (IADO CONICET-UNS) analyzed the situation of solid waste management systems in Latin America, before and during the pandemic, and established that the pre-existing deficiencies in these systems were accentuated by the lack of preparation for the handling of a greater volume of medical waste and by the fact that the collection of household waste was restricted; which would be one of the factors in which to work to avoid. The work, published in the journal Science of the Total Environment, predicts that most of these elements made with polymeric materials will end up forming pools of microplastics in the oceans. The waste arrives there transported by winds, rivers, tides, storm drains, and by direct discharges. The analysis of the specialists of the IADO points out that "… the lack of knowledge about the type of domestic waste generated and its deficient classification by people at home…" has contributed to the increase in pollution and adds: "… on many coasts of South America, it is increasingly common to find face masks... which are potential sources of microplastics…" [7]. The fibers of the face masks break up into microplastics that are impossible to collect far more quickly than plastic bags, making them a bigger threat than plastic bags, according to a University of Southern Denmark study [5].

There is no doubt then that the world, and specifically Argentina, are facing a new challenge in this regard. "Plastic pollution was already one of the greatest threats to our planet before the coronavirus outbreak..." United Nations official Pamela Coke-Hamilton said in a report from the Organization's Conference on Trade and Development. "The sudden boom in the daily use of certain products to keep people safe and stop the disease is making things much worse..." [5].

Different initiatives have been generated concerning to the theme, some of which seek to give this waste, after some treatment, a commercial value. Such is the case, for example, of companies with various inputs from these used face masks.

Single-use face masks waste is an established problem in Argentine society. When the LEMaC social networks announced in September 2021 that possible solutions were being analyzed, multiple messages were received from representatives of institutions and individuals who were already concerned about the issue and were collecting them, without knowing for sure what they were going to do with them.

When it was later announced that preliminary positive conclusions had been reached in the study, the authors were contacted by numerous media to generate notes and interviews, which were widely received by the community. Finally, when the availability of the LEMaC was announced to face test sections for development, various companies and departments contacted them, treaties that are advanced for the realization of such work at the time of this publication.

Because road engineering is not left out of initiatives that seek a solution to the problem [8]. Such is the case of the studies carried out at the RMIT University of Australia regarding the incorporation of the crushing of these face masks, identified as SFM (Shredded Face Mask), in granulometrically stabilized layers, with crushed concrete as aggregate, in optimal percentages of between 1% and 3% and through tests, among others, of resistance to unconfined compression [9].

However, there has been no record of studies that imply the use of these residues for the improvement or stabilization of fine soils. That is why, from the LEMaC, this study is carried out, included in the R&D Project approved in the Incentive Program of the Ministry of Education of Argentine called "Inclusion of new technologies and alternative materials in flexible multilayer pavements; design, economic aspects, and structural analysis" (Code TVTCBLP0008084TC). This project, directed by the LEMaC, has members of the Universidad Tecnológica Nacional Fac. Reg. La Plata and Avellaneda, and the Universidad Nacional de Córdoba (Argentina), the Universidad de la República (Uruguay), the Universidad de Piura (Peru) and the Universidad Politécnica de Cataluña (Spain).

2. MATERIALS AND METHODS

The materials that make up the mixtures under study are the "blue light face masks" and different road soils, which allow covering a range of existing possibilities in the road scene.

2.1 The blue light face masks

These face masks are constituted, in addition to their elastics and an element for the adjustment in the nose (which are considered of negligible influence for this pre-feasibility study), by layers of a synthetic fabric known as "SMS non-woven fabric" (Spunbond-Meltblown-Spunbond). This material is composed of polypropylene filaments welded by the "spunland thermobonded" method, which make up the two layers that cover the "meltblown". It is used in its different versions in disposable medical applications (for example gowns, caps, shoe covers, sheets, etc.). To reduce the variability of the environmental determining factors, this study is limited to the face masks already mentioned, but the conclusions that emerge from here can probably be transferred to any other series of related waste, which does not even come from the field health, as is the case of the bags currently used for purchases in markets and stores, among others.

On average, it can be pointed out that these face masks in their version with three layers have a weight of 3.5 g of which 2.7 g are made of fabric, which is used in the present study.

In the experience carried out in Australia, a segmentation of this fabric is used in fragments of 20 mm x 5 mm [9]. The analysis carried out by the authors makes it possible to survey various methodologies at a production scale to achieve particles of sizes like the one mentioned. Among them, there are those corresponding to equipment with shredding shafts. These machines exist at an industrial level in various ranges of importance, associated with the level of production sought. If it is thinking of a possible application at the municipal level, for example, in such a way as not to imply a cost for transporting the material and to provide an environmental solution at the local level, then smaller crushing equipment would be recommended, which could be used both for the experiences of design in the laboratory as in the crushing of the product to be used in the road. Equipment of this type has been surveyed with costs of $ 2,500.

Another line of equipment that could be used is rotary mills. This equipment has a rotor with blades (flat or in V) that perform the cut in conjunction with fixed blades, complemented with a system of sieves and recirculation of the material to generate a pre-established particle size. Equipment of this type has been surveyed, with a useful working width of 300 millimeters, a cut size of between 5 and 50 millimeters, and a production capacity that can reach 150 kg/hour, with values from $ 10,000.

The other shredding system that could be implemented would be that of guillotines. This equipment has a blade that automatically cuts the textile material that is incorporated using a conveyer belt. For example, in La Plata, the area in which the LEMaC is located, one of this equipment could be accessed, with an approximate value of $ 100,000. With this equipment, a test crushing was carried out (Figure 2a and 2b), with which a sample with prismatic crushing material with a maximum dimension of 20 mm was obtained (Figure 3), at a crushing rate of 400 kg/h.

Figure 2: a) Guillotine used in the test crushing. b) Trial crushing of the face masks.

Figure 3: The product resulting from the test grind

Based on the existing antecedents at the laboratory level and the crushing achieved at the industrial level, it was decided to carry out the experiments with the hand-cutting of the face masks into segments of approximately 20 mm x 5 mm (with the largest dimension in the longitudinal direction of the face masks), as a sample is observed in Figure 4. In this way, an environment variable of the model under study is adjusted, concerning the degree of variability of dimensions that logically introduces the crushing at the production scale.

Figure 4: Sample of hand-cut face masks for the laboratory experiences

An additional issue is the health safety of concentrating and handling these masks. In this sense, it is worth noting what has been stated by various sources, in that after 72 hours of use, the face masks that could potentially have been used by a COVID-19 patient should no longer present active traces of said virus [10]. To limit the investigation, it is decided that the face masks involved in the laboratory test are:

- From private use.

- They have not been used in people who present bleeding or who have diseases that generate perennial pathogens.

- Are sterilized before to grinding.

2.2 The road soils

The pre-feasibility analysis is carried out for the nearby area of influence of the LEMaC, which can be considered covers at least the province of Buenos Aires [11]. As already mentioned, the initial idea is to check whether the use of natural soil mixtures plus face masks grinding has a contribution from the road point of view and, if positive, the percentage order of this residue that could be being used in an optimal situation. This application would then be carried out at the level of generating an improvement or stabilization of the subgrade or, in the best of cases, of a first sub-base of a hypothetical structural package of flexible multilayer pavements [12]. It can be pointed out that, in the study area and for the applications, fine soils of the broadest spectrum are usually used. From this, it is decided to implement the analysis on three categories of typical soils, in such a way as to arrive at initial conclusions of the application that have an adequate minimum scope of use. It is decided to implement these categories through a qualification system of low, medium, and high road aptitudes, based on the HRB Classification [13]. Thus, it was decided to use soils with high plasticity (with a Plasticity Index greater than 10), medium plasticity (with a Plasticity Index close to 5), and frictional soil (with a Plasticity Index of 0), respectively.

2.3 The mixture

The mixture of both materials, plus the compaction water, is a task that is carried out in trays manually in the laboratory, achieving a product like the one shown in Figure 5.

This task must have its counterpart in the application on-site, which requires some precautions. One of them relates to how easy it can be for crushed face masks to be blown away by the wind. Therefore, at least two options are on the horizon. One of them is that the mixing is carried out in the plant, transporting the mixture of ground and crushed face masks in its Optimum Moisture Content (or close to it), in such a way that it can then be distributed using a paver (finisher), or other equipment that allows such action, and immediately compacted. For this task, for example, a mixer for bases can be used, in which the crushed face masks are incorporated from one of the closed silos and the soil from an open one. This equipment carries out mixing with paddle shafts, which would be adequate for the type of product being approached.

Figure 5. The mixture of soil and shredded face masks at their Optimum Moisture Content

The other option is to generate the mixing on-site with equipment that has a closed mixing chamber, as is the case with recyclers; but in this case, they should be adapted so that the incorporation of the crushed face masks is carried out inside the chamber, together with the moistening, so that the degree of humidity of the mixture at the exit of the same is such that they do not blow away face masks fragments. This option, at least initially, seems too complex for the type of works to which it is aimed; however, it would also be worth delving deeper into its analysis.

To establish the approximate structural responses to be expected, it is decided to use a methodology by the fact that it is a pre-feasibility analysis, for an application in rural roads with a very low level of traffic or in suburban roads with similar characteristics, at least in a beginning. That is, it is decided to use a basic analysis methodology, which may become more complex in future studies, as the degree of the particularity of the application so warrants (for example, with determinations of resilient modulus in the laboratory and deflections on-site).

The optimum content of crushed face masks, expressed in % by weight above 100% of dry soil weight, is established for the Maximum Dry Density and Optimum Moisture Content established by the corresponding Proctor Test according to the Standard [13] by the California Bearing Ratio (CBR) without embedding and on specimens molded at predetermined density [13]. Figure 6 shows the placement of a mixture in the mold (left), the static molding of the specimen (center), and its subsequent testing (right), as an example. Figure 8 shows how a compacted CBR specimen would appear superficially, with a percentage of face masks close to the optimum.

Figure 6: CBR test process with predetermined density molding

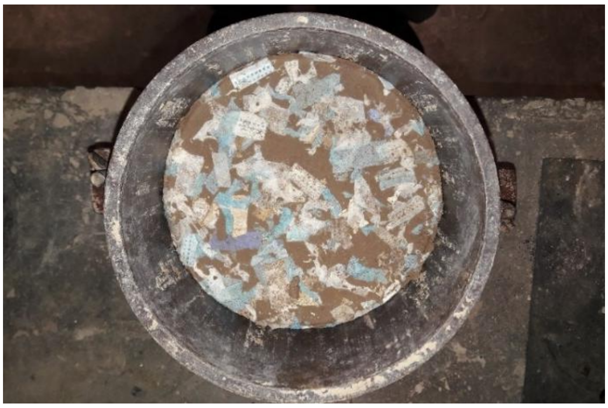

Figure 7: CBR test specimen surface with face masks content close to optimal

The Proctor Test Type to be used in each soil is established in Argentina by linking the test standard and the DNV 1998 Edition of General Technical Specifications Sheet [14]. It is decided to keep it by incorporating the different contents of crushed face masks.

3. RESULTS

The main results obtained in the experiences with the three representative soil typologies selected are presented below.To representatively analyze these types of soil, samples from different regions of the province of Buenos Aires are used. The frictional soil sample comes from the west of Buenos Aires in the Rivadavia area, the medium plasticity sample comes from the Buenos Aires suburbs in the Pilar area, and the high plasticity sample from the center of the province in the Olavarría area. Said soils are determined to have the characteristics indicated in Table 1. In the said table, the percentage of pass sieve number X is expressed as “PTN°X” and with “np” it does not have.

Table 1: Characterization of the soils used in the experiences

			Face Masks Percentage			
Soil	**Type**	**Parm.**	**0.0%**	**1.5%**	**3.0%**	**Mean**
A-2-4	V	MDD (g/cm3)	1,807	1,812	1,798	1,806
		OMC (%)	11,0	10,9	10,7	10,9
A-4	II	MDD (g/cm3)	1,606	1,610	1,569	1,595
		OMC (%)	22,4	19,0	20,3	20,6
A-6	I	MDD (g/cm3)	1,656	1,649	1,658	1,654
		OMC (%)	17,0	17,2	16,5	16,9

Due to the classification obtained, it then proceeds to analyze samples with different face masks contents, using the Proctor Test according to the corresponding Type for the HRB Classification of each natural soil, obtaining the results shown in Table 2. As can be seen, at least in the analyzed range, there are no noticeable trends in the modification of the Maximum Dry Density (MDD) or the Optimum Moisture Content (OMC). For this reason, structural response analyzes are carried out from the mean values of the records for each soil, as a valid decision for a pre-feasibility analysis with results such as those obtained.

Table 2: Proctor Test results according to the corresponding Type

	Frictional soil	Medium plast. soil	High plast. Soil
	A-2-4	**A-4**	**A-6**
Liquid limit (%)	np	35	32
Plastic limit (%)	np	29	21
Plastic index	0	6	11
PTN°10 (%)	99,7	86,3	99,4
PTN°40 (%)	89,7	78,0	88,4
PTN°200 (%)	23,5	63,5	72,7
HRB Class.	A-2-4(0)	A-4(3)	A-6(7)

The results of non-embedded CBR achieved in specimens molded at a predetermined density are those observed in Table 3, graphed in Figure 8.

Table 3: Results of non-embedded CBR with the analyzed soils

	Non-embedded CBR		
Face Masks Percentage	**A-2-4**	**A-4**	**A-6**
0,0	20,2	19,9	9,8
0,5	24,0	20,2	9,9
1,0	24,9	20,8	10,0
1,5	34,2	29,5	10,5
2,0	48,3	25,4	15,7
2,5	34,4	20,1	13,0
3,0	34,4	17,7	11,1

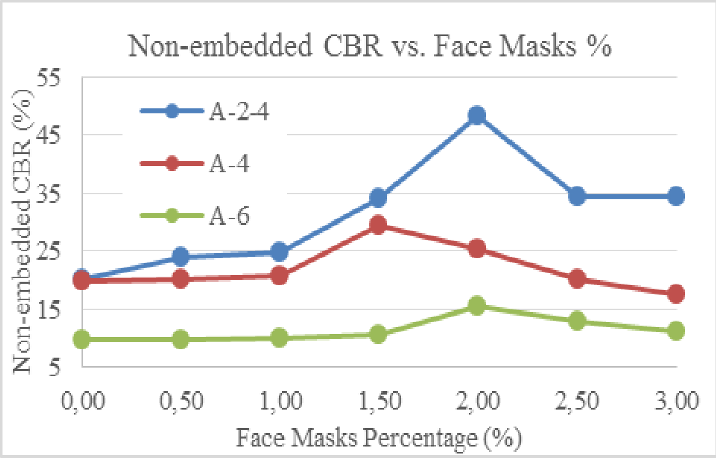

Figure 8: Graphs of non-embedded CBR versus % of face masks in the analyzed soils

Finally, the relation of increase of structural contribution in terms of non-embedded CBR is analyzed in the soils, for the 100% obtained for the natural soil, in each of the optimal contents of established face masks (Table 4).

Table 4: Increase in CBR not embedded in optimal face masks content vs. in natural soil

		Non-embedded CBR (%)		
Soil	**Opt. % of face masks**	**Natural soil**	**Soil + face masks**	**Increase %**
A-2-4	2,0	20,2	48,3	139
A-4	1,5	19,9	29,5	48
A-6	2,0	9,8	15,7	60

4. DISCUSSION

The tests carried out show preliminary results that should be confirmed in studies in deeper specific applications; establishing, for example, if the trends are maintained under saturation conditions (in embedded CBR), what happens to the volumetric behavior under these conditions (Swelling) and if it is necessary to modify the Proctor test typology used by increasing the face masks content (based on a modification in the workability of the mixture and the corresponding change in the compaction methodology on-site).

However, these preliminary results, with all the exceptions that a pre-feasibility implies, allow it to observe in a general way that:

- There would be a structural contribution from the inclusion of crushed face masks, at least up to a certain limit percentage.

- This optimal structural contribution seems to be around 1.5% and 2.0% of face masks.

- There is no clear trend about to how much the increase in structural contribution would be expected generically.

Additionally, it is worth noting in this section what would be some implications derived from the optimal content tentatively established. For example, if the results achieved with the frictional soil are analyzed, it could think about the use of the optimal mixture in the formation of a subbase. Since it would be a mixture with a Dry Density close to 1.800 g/cm3 (1,800 kg/m3), usually applicable in a subbase layer thickness of 20 cm, it would have a face masks weight of approximately 7.2 kg/m2. This, applied to a typical block that can be adopted in a suburban area of 100 m in length by 6 m in width, would translate into 1,600,000 face masks per block based on its useful weight, which is considered more than an interesting number for the intended application. It is also worth noting that if these numbers are excessive for the collection possibilities in any application, this would not mean the impossibility of employment; it is not necessary to use exactly the optimal content (with lower content, an increase in contribution would also be evidenced) nor is it necessary to use the mixture only in the constitution of complete block bases (it could be used in deep localized potholes or civil applications outside the road area).

5. CONCLUSIONS

The preliminary study undertaken allows it to conclude that:

- There is worldwide an environmental threat generated from the exponential growth in the use of single-use face masks because of the COVID-19 pandemic, of which Argentina would not be a stranger.

- This environmental threat is related to specific household waste, but it can be amplified if the results obtained are extrapolated to other similar waste.

- Depending on the area in which the application is carried out and the volumes involved, there is various equipment that would allow the planned face masks grinding to be carried out.

- There would also be ways for the materialization of the layers on site, either by preparing the mix on plant or on-site.

- The optimum face masks inclusion percentage setting (expressed in face masks weight above 100% of the weight of dry natural soil) would be between 1.5% and 2.0%.

- This content should be established, however, for each soil, deepening the analysis regarding implications in its saturation and compaction methodology on-site; in addition to how much would the implied increase in structural contribution be located.

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