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Single Use Personal Protective Equipment Reinforced Asphalt

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Abstract

Due to the COVID-19 pandemic, global personal protective equipment (PPE) volume production and demand increased by 300-400% between 2019 and 2021. In this scenario, the present study aims to propose and validate an innovative circular economy scenario for end of life (EoL) PPEs, reusing them to produce reinforced bituminous mixtures. Despite that several studies confirmed the possibility of reusing plastic in the asphalt mixtures, none of them investigated the potential of PPEs, highlighting the innovativeness in the scientific panorama. Five different alternatives of EoL PPE mixtures (different products, materials, dosages, etc.) were tested at laboratory scale to verify the technical feasibility of the proposed scenario. The most promising solution resulted to be the mix of gloves and face masks composed by polypropylene, polyethylene, nitrile and lattice at a dosage of 0,5% weight/weight that allowed to produce bituminous mixtures with acceptable performances in terms of relevant mechanical parameters while recycling waste PPEs. This leads to environmental benefits, since more than 3kg of EoL PPEs per square meter of road pavement can be reused instead of disposed (about 1,5 million tons/year considering the bituminous mixtures produced at European level), as well as economic benefits for public administrations and the collectivity, due to the reduced landfilling of solid wastes.

Keywords: Personal protective equipment; Circular economy; Reuse; Reinforced asphalt

1. Introduction

A study published in the Environmental Science and Technology journal estimated a monthly use of 129 billion masks and 65 billion gloves since the beginning of pandemic [1]. Most of this personal protective equipment (PPE) contain plastic and its derivatives. Such waste flow represents a threat to both the terrestrial and marine environment, and suggests the need to identify circular economy scenarios for the recovery and recycling of waste generated from single-use plastics [2].
In Italy, ISPRA (Institute for Environmental Protection and Research) conducted a study to value the average requirement for masks, deriving a demand of 37.5 million masks per day [3]. Considering an average weight of 11g, this corresponds to 410 tons of waste mask per day, with an average value of about 100 thousand tons per year. Polypropylene (PP) is the main type of plastic used in disposable surgical masks. It is a thermoplastic polymer that takes more than 25 years to decompose in landfills [4].

The increased production and consumption of face masks worldwide created an additional environmental challenge under the already existing issue of managing plastic wastes resulting from other widespread single-use products (e.g. packaging). Single-use masks reaching the environment are potentially an emerging source of microplastics, due to their degradation and breakdown into pieces under 5mm [5]. This kind of devices are very difficult to recycle with traditional plastic recycling technologies, due to their structure (i.e. combination of several layers of non-woven fabrics). This leads to the generation of relevant flows of plastic wastes for which no consolidated routes of recycle or reuse exists, thus they can be only landfilled or incinerated with problems in terms of

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resource depletion and greenhouse gases emissions [6][7]. Moreover, currently there are no uniform regulations for the management of wastes deriving from end of life (EoL) PPEs at the national and international levels. Therefore, it appears very important to develop solutions that would promote their decrease.

In this context, the present study proposes and explores an innovative way to reuse wastes generated during the COVID-19 pandemic, in base/sub-base road pavement applications. In scientific literature, several studies investigated the application of plastics in asphalt mixtures [8][9][10]. For instance, in a recent study [11], chopped basalt fibers (CBFs), flocculent basalt fibers (FBFs), lignin fibers (LFs), and polyester fibers (PFs) were mixed into Styrene-Butadiene-Styrene (SBS) modified asphalt at four contents. The results demonstrated that the rheological behavior differed significantly with the type of fiber incorporated, but generally the deformation recovery ability and anti-fatigue ability of SBS modified asphalts were improved by adding fibers. Another study [12] assessed the effects of asphalt concrete specimens with PP fibers. The improvement of the properties of asphalt concrete shows the positive effect of PP fibers. A research by Dehghan and Modarres [13] evaluated the fatigue properties of asphalt reinforced with recycled polyethylene terephthalate (PET) fibers. The fatigue life of fiber reinforced mixtures was higher than the reference one. Closely related to the idea of the present study there is the recent experimentation conducted by the University of Melbourne to introduce shredded face mask (SFM) into a recycled concrete aggregate (RCA) for base/sub-base pavement applications [14]. The introduction of chopped face mask not only increased the strength and stiffness, but also improved the pliability and flexibility of RCA/SFM blends.

Summarizing, the scientific literature shows that the incorporation of different fibers potentially improves the properties of asphalt mixtures. However, the proposed scenario appears to be original because the use of fibers derived from PPEs as reinforcement in asphalt mixtures has never been investigated in previous research or development experiences. Moreover, it seems feasible because it is based on popular ideas such as the use of reinforcements in construction materials in order to recycle end of life products/materials and/or even increase their performance.

More specifically, the main objective of the present study is to investigate and validate an innovative product based on the reuse of waste plastic material derived from the disposal process of PPEs that are currently mostly disposed in landfills or incinerated. Such fibers, opportunely treated and processed, may find application in the production of products to be used in the road infrastructure sector, with the focus on proposing a circular economy scenario. The ambitious goal aims to enhance waste textile material, coming from EoL PPEs, to make asphalt mixtures characterized by equal (or even better) technical characteristics than standard unreinforced mixtures.

This research will be able to turn the imminent environmental threat, due to the use of face masks and other plastic based PPEs, into a precious resource for the road pavements, in a win-win scenario for both the world of plastic waste management that will be able to allocate a waste flow in a second-life application, and the road infrastructure sector. Polymer fibers extracted from PPE-derived wastes can be used as asphalt reinforcement, with positive effects especially in terms of asphalt sustainability.

After this introduction, the paper is organized as follows. Section 2 illustrates the input materials and their characteristics, as well as the standard methods used in the experimentation phase. Section 3 presents the results obtained with the experimentation at laboratory scale, together with a critical discussion on potential benefits of the proposed scenario. Finally, Section 4 summarizes the outcomes of the study and provides different ideas for future developments.

2. Materials and Methods

2.1. PPEs materials and dismantling scenarios

The most common face masks are made of synthetic thermoplastic polymers such as PP, polyurethane (PU), polyacrylonitrile (PAN), polystyrene (PS), polycarbonate (PC), polyethylene (PE), PET, or other polyesters. Among them the most common material is PP, a thermoplastic polyolefin polymer widely produced and used for a large variety of industrial applications. The second relevant material is PET, while the other ones are only used in rare cases or otherwise represent minor flows in terms of quantities [15]. Melt-blown fabrics (i.e. non-woven fabrics produced through a particular production process based on the extrusion of a polymer melt through small nozzles surrounded by high speed blowing gas, as compressed air) are often used as mask filters, due to their ability to prevent the flow of small particles, bacteria and viruses. Spun bond fabrics (i.e. non-woven fabrics produced through the mechanical, chemical or thermal bonding of a web made of small fibers), instead, are commonly used for internal/external layers of face masks, due to their favorable properties in terms of skin contact and water repellency [16].

Gloves for professional, medical and domestic use are generally made of latex or nitrile, with about a 1:1 ratio [15].

Waste regulations and legislations at the European level are governed by Directive 2008/98/EC [17], modified in 2018 by Directive 2018/851, which provides guidelines for the collection of PPEs in homes of individuals affected by coronavirus, specifying that PPEs should be disposed in special closed bags and placed in the mixed waste container. Instead, for masks and gowns from health care facilities there is an obligation to dispose them as dangerous waste. In Italy, the way in which the PPEs have to be managed depends on their origin, as indicated by the ISS COVID-19 report of 03/2020 [18]. If they come from homes with COVID-positive individuals, PPEs must be disposed in incineration plants, in other cases, they are processed like mixed solid wastes.

This complex context suggests that it appears necessary to plan separation, storage, and collection of waste PPEs to reduce the amount of disposed plastics and to successively adopt alternative technologies and routes in order to promote their recovery in circular scenarios [6][19].

2.2. The proposed reuse scenario

The present study aims to propose and validate an innovative circular-economy-based scenario for EoL PPEs, reusing them to produce reinforced bituminous mixtures. The proposed reuse scenario starts from waste PPEs, following a series of steps to obtain reinforced asphalts as illustrated in Fig. 1 and listed hereafter:

1. *PPE collection*: Masks and gloves have to be collected separately from the other wastes. As discussed successively, this first phase is currently out of scope of the present study but it can be considered a topic for a further development.
2. *PPE sanitization*: According to a rapid review conducted, it has been found that the most promising sanitization methods are those that use hydrogen peroxide vapor, ultraviolet (UV) radiation, moist heat, dry heat and ozone gas [20][21]. In this study an UV-C radiation system equipped with lamps that emits waves at about 250nm, has been used for the sanitization of waste PPEs. A previous study demonstrated that through this procedure a log abatement of 3 in the viral dose contained in PPEs can be obtained, without compromising the material properties, even after different sanitization cycles [22].
3. *Shredding of PPEs*: A laboratory mill has been used, to produce a mixture of shredded PPEs with a uniform particle size of about 0.5cm. Gloves and masks have been shredded separately to obtain two distinct products. Then the chopped products were mixed opportunely.
4. *Preparation and testing of bituminous mixtures in the laboratory*: Virgin aggregates and bitumen have been heated between 150°C and 180°C, while the reclaimed asphalt (RA) have bene added at room temperature (about 25-30°C). The mixer added in order: virgin aggregates, RA, waste PPEs, bitumen and filler. After each addition, a mixing time of about 60 s elapsed. Test have been performed according to current standard
5. *Application*: Once the tests at laboratory scale verified the technical feasibility of the proposed reuse scenario, the innovative PPE-reinforced bituminous mixtures can be produced in an industrial production plant, and successively used to build a road pavement as any other standard asphalt. This final phase is currently out of scope of the present study and can be considered a future development.

Fig. 1. Circular economy process steps: from waste PPEs to reinforced bituminous mixtures

2.3. Testing methods

The laboratory tests performed on each sample described in the successive section are based on widely used standard, to guarantee reliability of the obtained results, as well as to allow comparison with standard products used in the field of road pavements. The following testing methods have been used:

- Compacting of specimens to 100 mm diameter with a gyratory press, according to *EN 12697 – 31*.
- Determination of void characteristics of bituminous specimens, according to *EN 12697 – 6*.
- Determination of processability parameters *V(0)* and *k*, according to *EN 12697 – 10*.
- Visual analysis of residual solid material to investigate the effect of high processing temperatures on PPEs used in the mixture, according to *EN 12697 – 1*.
- Indirect tensile strength test at 25°C, according to *EN 12697 – 23*. From such test, the following results can be obtained:
  - Indirect tensile strength (*ITS*), which measures the resistance of cylindrical specimens to diametral tension fracture.
  - Indirect tensile coefficient (*CTI*), calculated as the ratio of *ITS* to the vertical strain of the specimen at the time of failure. It is closely related to the stiffness of the material.
  - Cracking tolerance index (*CT-Index*) which represents the material ductility.

3. Results and Discussion

3.1. Sample preparation

During the experimental phase, different types of waste PPEs were considered to compare different solutions in terms of mix compactability and strength characteristics. More specifically, two types of waste PPEs were used, including either masks only or both masks and gloves.

A preliminary study was carried out with the aim to investigate the main characteristics of PPE materials. The literature indicates that the PP is characterized by a melting point close to the hot mix asphalt (HMA) production temperature (about 150 °C) [23]. Therefore, two methods have been applied for the preparation of the mixtures containing the masks: (i) the first one at the ordinary temperature (i.e. 150°C), and (ii) the other one using a special additive to reduce the viscosity of the bitumen so the production temperatures could be lowered by about 30°C (warm mix asphalt – WMA). In the second case the PP did not dissolve during asphalt mixing, except in very small amounts.

The PPE dosage was set at 0.5% by weight on the mix. A second dosage at 1% by weight was studied for the asphalt mix containing both gloves and masks.

Five different asphalt samples were prepared:

1. *HMA-Rif*: reference asphalt mix processed at ordinary temperature, without PPEs waste.
2. *HMA-Masks*: bituminous mixture processed at ordinary temperature, containing 0.5% by weight of masks.

3. *HMA-Masks+Gloves*: asphalt mix manufactured at ordinary temperature, containing 0.5% by weight of masks and gloves.
4. *WMA-Masks*: WMA with a dosage of waste masks equal to 0.5% by weight.
5. *HMA-Masks+Gloves (1%)*: bituminous mixture produced at ordinary temperature, with 1% by weight of masks and gloves.

The considered materials, the proportions among them (e.g. different types of masks made of PP or PET, different types of gloves made of latex or nitrile) and among masks and gloves quantities were defined according to the figures of the current waste PPE scenario retrieved from literature and presented in Sections 1 and 2 [1][3][4][15][16]. In particular, the following proportions were adopted to prepare the samples:

- in case of HMA-Masks and WMA-Masks mixtures:
  - 75% of PP masks.
  - 25% of PET masks.
- in case of HMA-Masks+Gloves (0.5% and 1%) mixtures:
  - 45% of PP masks.
  - 15% of PET masks.
  - 20% of latex gloves.
  - 20% of nitrile gloves.

3.2. Experimental tests results

Fig. 2 shows the experimental results obtained for each of the five sample in terms of void content, *V(0)* and *k* workability parameters, as well as parameters measured through the indirect tensile strength test.

The *HMA-Rif* reference mixture showed volumetric and mechanical properties comparable with the values typically prescribed by the technical specification standards in Italy (voids between 3% and 6%, *ITS* between 0.7MPa and 1.4MPa, *CTI* greater than 60MPa).

The introduction of the masks (*HMA-Masks*) caused a decrease of compactability (lower *k*), with a resulting increase of void content from about 4.5% to 6.5%. In addition, after extraction of the binder, it showed a quite high amount of non-dissolved masks in the form of fibrous filaments. However, a small part of the plastic material of the masks melted and dispersed in the bitumen, resulting in stiffening and hardening of the bitumen that offset the effects of increased porosity. In fact, the *HMA-Masks* mixture showed higher (+10%) *CTI* and lower (-15%) *CT-Index*, than the *HMA-Rif* mixture.

In the mixture with masks and gloves *(HMA-Masks+Gloves*), the nitrile component, with a melting point around 120°C, melted during production and incorporated into the bitumen, increasing its volume. The introduction of nitrile in bitumen also increased bitumen hardness, which led to an increase in *ITS* (+25%) and *CTI* (+50%), as well as a related decrease in *CT-Index* (-50%).

The *WMA-Masks* mixture showed a void content of about 8.5%, higher than both the reference mixture and the similar mixture with only masks produced at ordinary temperature (*HMA-Masks*). The processability parameters *V(0)* and *k* were higher and lower, respectively. It is evident that the lowering of temperature, did not improve the mixture workability.

The *HMA-Masks+Gloves (1%)* mixture was clearly the most difficult to work in both mixing and compaction phases. This caused a reduction of mechanical properties in terms of strength and indirect tensile coefficient.

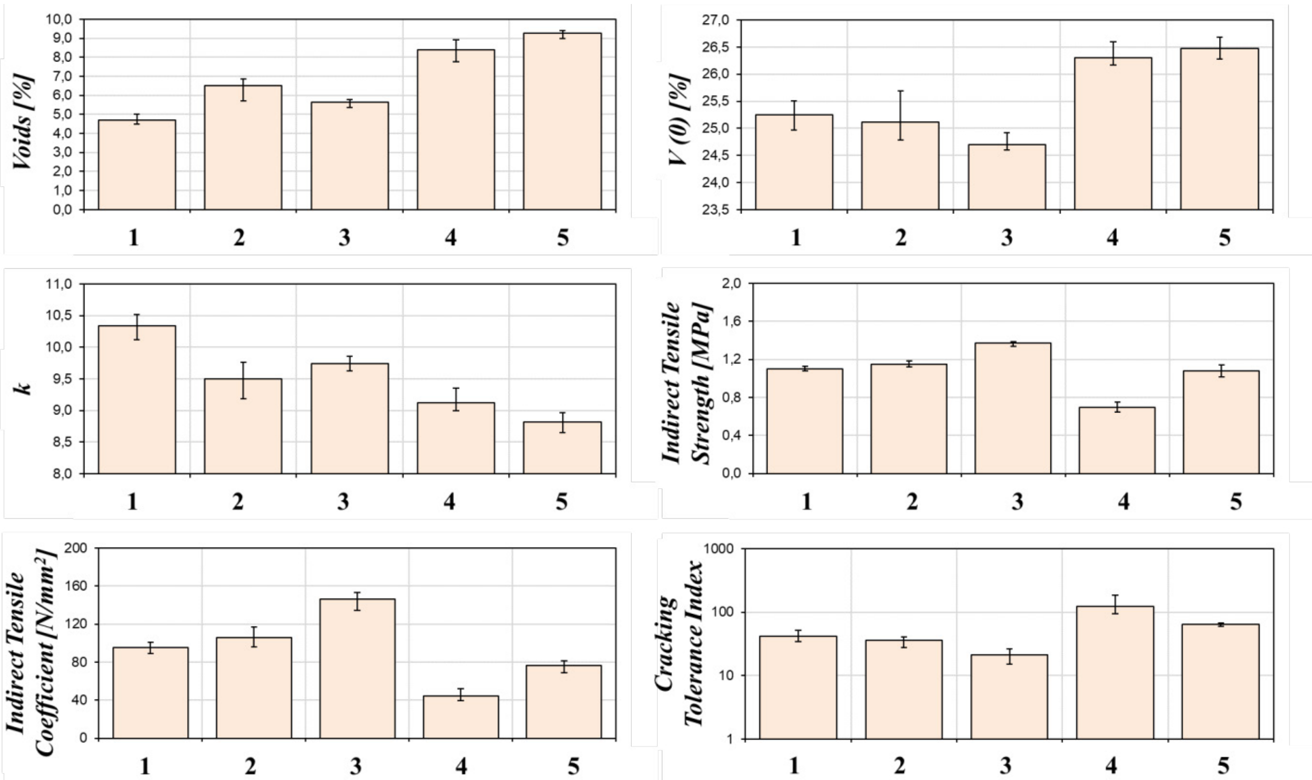

Fig. 2. Experimental results on the five samples

The *HMA-Masks+Gloves* specimen performed the best. Therefore, additional tests were carried out on it. Tests of resistance to cyclic loads (i.e. fatigue) in the indirect tensile configuration at a temperature of 20°C were performed according to *EN 12697-24 - Annex E*. In addition, the indirect tensile modulus of stiffness (*ITSM*) at the temperature of 20°C was carried out according to *EN 12697-26 - Annex C*. The mixture with PPEs showed comparable cyclic stress strength than the reference compound. Also the *ITSM* parameter was similar between both blends, with values around 5000MPa.

Summarizing the results obtained from the experimental tests, it is possible to confirm the possibility of recycling waste PPEs in HMA without reducing the workability and mechanical performance of the mix. In particular, "generic" PPEs, including masks and gloves of different types, can also be used up to a percentage of 0.5% by weight in the asphalt mix. This allows to demonstrate the technical feasibility of the proposed circular economy scenario.

3.3. Discussion on potential benefits of the proposed reuse scenario

Once demonstrated that the proposed reuse scenario for EoL PPEs is feasible from the technical point of view, some discussions about the impacts can be reported.

From the environmental point of view, it is worth highlighting that the proposed reinforced mix allows to reuse more than 3kg of EoL PPEs per square meter of road pavement (in case of the *HMA-Masks+Gloves* mix, the best solution from the technical point of view), considering their use in all the three layers: base, binder and wearing course. This means that the environmental impacts of such quantity of EoL PPEs generated for their dismantling/incineration can be completely avoided. Considering that for a single surgical mask with a weight of about 5g, a recent literature study estimated an impact of 9.29E-03kgCO2eq in terms of global warming potential indicator [24], each square meter of EoL PPE-reinforced road pavement potentially allows to save 27.87E-03kgCO2eq. Analyzing the Italian scenario of bituminous mixtures, the annual production is estimated at 37 million tons for the year 2021 (300 million tons at European level) [25], which leads to a potential reuse of 185000 tons/year of EoL PPEs (about 1,5 million tons/year at European level) , avoiding the landfilling of 148000 tons and the incineration of 37000 tons. Comparing the previous figures with the annual quantities of urban solid wastes generated at Italian (30 million ton/year) and European (250 million ton/year) levels [3], it is possible to estimate that the proposed circular economy scenario could contribute to a reduction of the 0.6% of the total solid wastes.

Concerning, instead, the economic viewpoint, no significant differences in terms of costs of the proposed reinforced bituminous mixtures against a standard one are expected. The production process at industrial scale still remains the same, with only a preliminary pre-treatment phase that is needed to sanitize the EoL PPEs. However, as briefly described in section 2.2, such treatment can be realized through consolidated technologies (e.g. UV radiation, hydroalcoholic solutions) that do not involve the use of huge amounts of resources and/or energy, thus the expected additional costs are almost negligible in comparison to the other cost items. For instance, for the laying of a square meter of wearing course layer (5-8cm of thickness), a quantity of about 150kg of bituminous mix is needed, with a cost of 8-12€, considering a unitary cost of 55-80€/ton [26]. These estimated values remain unvaried for both the standard HMA and the proposed EoL PPEs-reinforced one.

Another potential economic benefit regarding the landfilling of solid wastes, a scenario that in Italy has a cost of more than 200€/ton [27], has to be also considered. As previously explained the proposed circular economy scenario could lead to the avoided landfilling of 148000 tons of EoL PPE, that means an economic saving of about 30 million €, costs generally incurred by public administrations and, as a consequence, by the collectivity. Other potentially saved costs are those one related to the avoided negative externalities due to the avoided emissions, that according to the European guidelines on cost-benefit analysis can be estimated in 37€/tonCO2eq for the year 2022 [28].

Qualitatively speaking, environmental and economic benefits can be foreseen on a medium-long term horizon, particularly for stakeholders directly involved in the circular economy scenario implementation:

- Solid waste management companies that can translate a waste to dismantle (i.e. cost) into a potential resource to exploit (i.e. benefit).
- Producers of bituminous mixtures that can launch into the road pavement market new products with reduced environmental impacts at the same cost of standard products in a green procurement scenario.
- Road management companies (both private subjects and public administrations) that can renew and/or maintain road pavements with sustainable solutions toward the reduction of the environmental impacts of the construction and demolition sector, currently one of the most problematic.

Finally, it is worth highlighting that the scale up of the proposed scenario at an industrial level will certainly require the implementation of a separate collection strategy/system for EoL PPEs in order to have available the needed quantities of materials for feeding the successive reuse in the road pavement sector. However, this does not only depend by technical aspects but improvements of legislations, waste management procedures, as well as consumers' behaviors seem essential.

4. Conclusions

The paper presents an innovative circular economy scenario for EoL PPEs, a relevant waste flow especially during the last years dominated by the COVID-19 pandemic. The reuse scenario that involves the production of reinforced bituminous mixtures has been defined based on a detailed context analysis, and its technical feasibility has been demonstrated at a laboratory scale by evaluating several alternatives. Finally, the best solution resulted to be the HMA containing 0.5% by weight of EoL masks and gloves. Other than acceptable technical performance, such solution potentially allows to reduce the environmental impacts and the costs of the waste management and road pavement construction sectors.

Future work must be focused at first on the experimentation of further alternatives by considering, for instance, different granulometries of the input material, with the aim to obtain improved technical performance, as demonstrated in other similar studies [29]. Then, experimentation at pre-industrial scale is certainly needed to confirm the repeatability of the results obtained at laboratory scale and assure industrial feasibility of the proposed scenario. In addition, full environmental and economic assessment studies should be conducted to quantify in detail the potential benefits for all the involved stakeholders. Finally, some alternative and potentially nobler EoL PPEs recycling/reuse scenarios (e.g. use as reinforcement in other plastic products) could be tested to verify their feasibility.

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