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Impact of Vehicular Traffic on Single Use Surgical Face Masks as a Source of Environmental Micro-fiber Pollution

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ABSTRACT

During the COVID-19 pandemic large numbers of single-use, surgical style face masks were lost or discarded in public spaces, primarily in on public streets and car parking settings. Many of these masks were blown onto the road surfaces where they were subjected to degradation through the tire impact of passing vehicle traffic. As series of field observations as well as experimental simulations show that the three-ply polypropylene mask fabric is subjected to shear forces when compressed between the tire and the road surface. The mechanical action breaks the bonds between the fibers (both spunbonded and meltblown) leading to a continual shedding of microfibers. Wind disperses these into the environment along road sides, while surface water action moves them into stormwater drains and from there into the waterways. As the decay is rapid, municipal agencies only have a short window of time to remove stray face masks from the urban environment if micro-fiber pollution is to be reduced.

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INTRODUCTION

Once SARS-Cov-2, the virus responsible for the of COVID-19 pandemic, had seeded into Australia in early 2020, all State governments engaged in a range of public health measures, (Storen & Corrigan, 2020) including ringfencing of areas of outbreaks(Spennemann, 2021e) and border closures(Spennemann, 2021d). To contain the spread of the disease, all states mandated the wearing of 'fitted face coverings' (i.e. masks) in outdoor and many indoor settings (MHMR, 2021). Users had the choice of wearing surgical type, non-sterile single use ('disposable') facemasks, commercial KN95/P2 type dust masks or masks made from fabrics (NSW Health, 2020; Sayers, 2022; Spennemann, 2021a).

Observational studies in Albury, a regional community in Southern New South Wales (Australia)(Spennemann, 2021c) as well as in the metropolitan centers of Melbourne (Spennemann, 2021g) and Sydney(Spennemann, 2022f) showed that single use facemasks were most preferred type of mask worn. It is not surprising then that a longitudinal study of discarded and/or lost masks found on the ground in Albury between March 2020 and March 2022 showed that these masks were the common kind, and their relative frequency reflects public health mandates (Spennemann, 2021b, 2021f).

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Single-use surgical-type masks are made from multiple layers of non-woven, spunbond and melt-blown fabrics, usually made with a polypropylene polymer, which are held together with hot-welded or ultrasonically welded seams (Figure 1). Spunbond fabrics, used for the exterior surfaces of the mask, are manufactured by extruding the melted polymer to form long thin filaments of 5 – 20 µm diameter, which are deposited in an irregular fashion onto a moving belt where they form a fibrous web of variable density (Figure 2a–d). Depending on the composition of the polymer and the residual heat, the filaments may form weak bonds between over-lapping fibers. The fibrous web passes between two heated rollers which thermally bond it together (Figure 2a). (Forouzandeh, O'Dowd, & Pillai, 2021; Kellie, 2016; Liao et al., 2021). To increase the fabric strength, the roller carry raised heated studs that generate thermal weld points (Figure 2b–d).

The filter fabric in the core of the mask is made from melt-blown non-woven fabrics. These are produced by subjecting the extruded fibers to high velocity hot air which stretches the molten polymer into very fine filaments of 1 -5 µm diameter. These discontinuous, shorter filaments are randomly deposited to form a dense fibrous web of variable density, which is thermally bonded by heated rollers without raised studs (Figure 2e–f) (Forouzandeh et al., 2021).

Given the billions of single-use face masks produced, used and discarded during the COVID-19 pandemic (Aragaw & Mekonnen, 2021; Patel et al., 2017; Prata, Silva, Walker, Duarte, & Rocha-Santos, 2020), it is not surprising that a large quantity has escaped the standard waste management stream (Benson, Bassey, & Palanisami, 2021; Benson, Fred-Ahmadu, Bassey, & Atayero, 2021; Topal & Arslan Topal, 2021) and has entered the natural environment in various settings (Chowdhury, Chowdhury, & Sait, 2021; Mejjad et al., 2021; Okuku et al., 2021; Ormaza-González & Castro-Rodas, 2020; Spennemann, 2021f, 2022a) where the masks undergo various processes of environmental decay. Decaying single use facemasks will shed large amounts of microfibers as their bonds break, either due to UV-induced photo-oxidation,(Du, Xie, & Wang, 2021; Rathinamoorthy & Balasaraswathi, 2022; Spennemann, 2022d) due to mechanical impact (Liang et al., 2022; Pizarro-Ortega et al., 2022; Saliu et al., 2021; Spennemann, 2022a; Wu, Li, Lu, Tang, & Cai, 2022) or immersion in turbulent waters (Saliu et al., 2021; Shen et al., 2021).

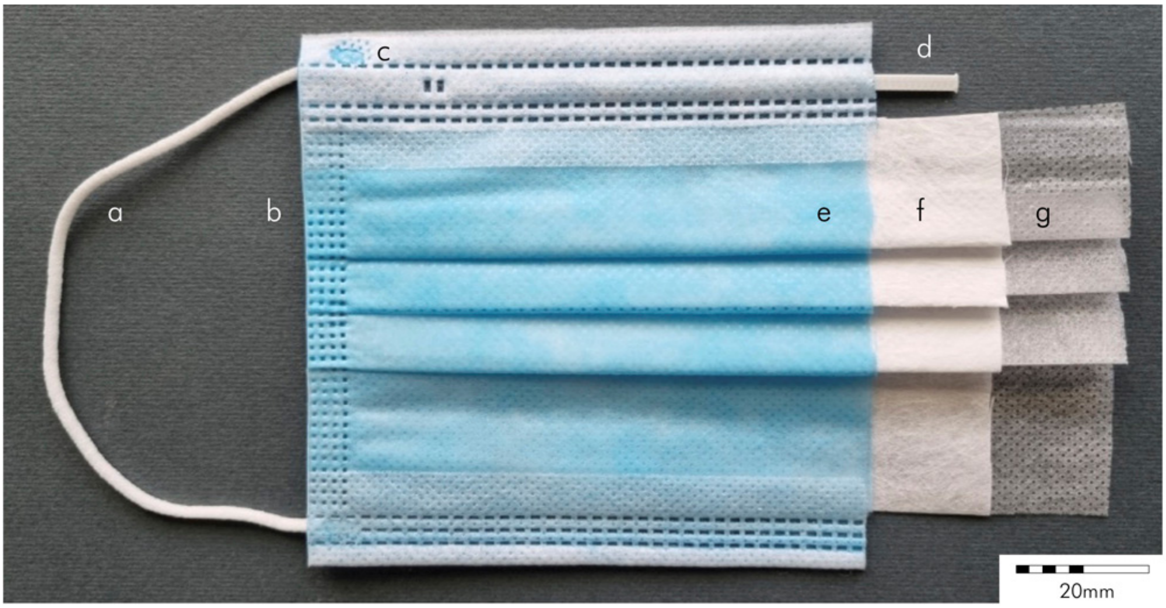

Fig. 1. Components of a surgical-type single-use face mask. a) elastic ear loop; b) heat-wielded seam; c) weld-point for ear loop; d) nose wire; e) outer layer of spunbonded polypropylene fabric; f) central core of melt-blown polypropylene fabric; g) inner layer of spunbonded polypropylene fabric.

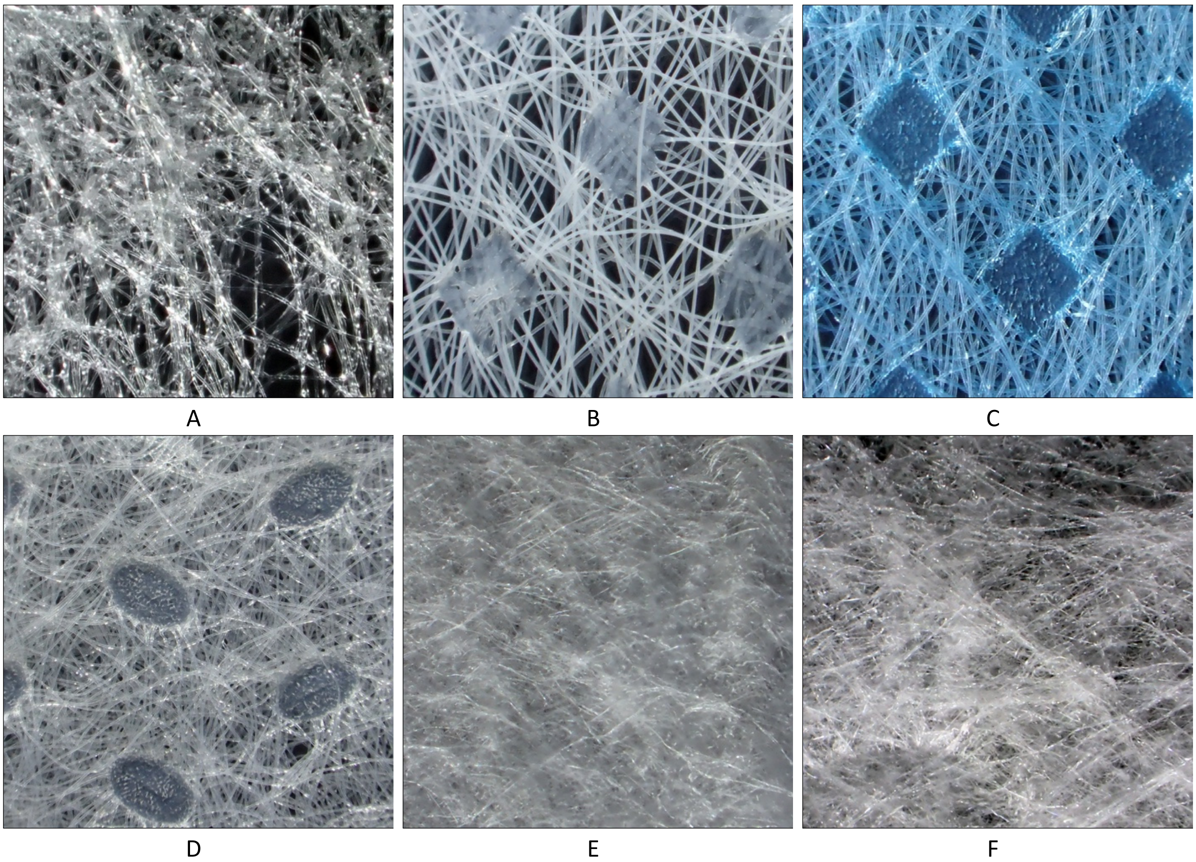

Fig. 2. Examples of the non-woven fabric used in surgical-type single-use face masks A) thermally bonded spunbond polypropylene fabric; B–D) thermally spot welded spunbond polypropylene fabric; E–F) thermally bonded melt-blown polypropylene fabric. Each square measures 3x3 mm.

While observations of the presence of masks in natural environmental settings has received the greatest amount of public and academic attention (see above), a longitudinal observational study has shown that 66.3% of all lost or discarded masks were found in dedicated car parks, at curbside parking spots and on the street (Spennemann, 2021f). It can be posited that these were lost or discarded while entering or exiting parked vehicles, whereas masks encountered on the road surface itself were blown there by wind or by the draught of passing vehicles. While the majority of these masks from the curbs and sidewalks will eventually be swept up by a street sweeper, many of them are missed or are stuck to the road surface, where they become subject to mechanical degradation with a concomitant release of microfibers. Additionally, degradation also occurs in the time interval between deposition and eventual removal,with the degree of the degradation dependong on the quantity and intensity of impacts.

METHODS AND MATERIALS

The aim of this paper is to examine the process of microfiber generation of single-use face masks exposed to vehicular traffic by bringing together and summarizing for a wider audience a range of field observations as well as experimental studies conducted by the author. As such then, this paper does not follow the standard IMRAD pattern, but will first summarize a set of field observations to be followed by a summary of the key findings of an experiment. The final section will pull together these observations into a cohesive narrative of the degradation and decay processes of face masks and the resulting production of polypropylene micro-fibers as environmental pollutants.

RESULTS AND DISCUSSION

Field Observations

A longitudinal project to document the frequency and nature of lost and discarded face masks in Albury, executed between March 2020 and March 2022, demonstrated that the majority of masks were encountered at dedicated car parks, curbside parking spots and on the street (Spennemann, 2021f). During the study, several of these masks were observed that had been

a) 19 February 2022

b) 24 March 2022

c) 5 April 2022

d) detail 24 March 2022

e) mask spread out during extraction attempt 5 April 2022

f) detail of mask 5 April 2022

Fig. 3. A single use surgical-type face mask decaying on a road surface at Borella Road, Albury, NSW. (Spennemann, 2022c)

subjected to physical impact by vehicles. As some of these were not removed by street sweeper, they provided an opportunity to revisit them repeatedly in order to observe their decay over time under natural, non-simulated conditions.

These field observations were carried out as part of a project into the decay processes of single masks in the open environment during the late (southern) summer and early autumn 2022, when daytime temperatures could still reach 35.2°C (Bureau of Meterology, 2022). The field observations fall into two kinds, masks encountered resting on the normal road surface and masks that had stuck in bitumen repair patches. Two examples may serve to illustrate these instances.

Example of masks resting on the road surface

A mask was noted and documented located near the curb of a side road in suburban Albury, located an area of unmarked parallel parking spots opposite a neighborhood grocery story. At the time it was first observed, the mask would have already been subject to several vehicle passes. It had been twisted, appeared structurally impaired and was covered with vegetative debris. The nose wire had become extracted and bent, but still formed part of the assemblage (Figure 3a). When rephotographed five weeks later, the twisting and structural impairment had increased, but the assemblage remained essentially complete (Figure 3b). Detailed photography of the mask in situ showed that the spunbonded fabric had shredded and that many fibers had loosened from the thermal bond points (Figure 3d). Ten days later little had changed (Figure 3c) (Spennemann, 2022c).

An attempt to retrieve the mask 45 days after the first observation as an entity and to examine it in detail in a laboratory setting failed. The mask had become partially embedded in the bitumen binder of the hot mix asphalt in the interstices between the aggregate of the road surface. The mask sheared and shredded during the extraction attempt (Figure 3e), showing that the bonds between fibers of both the recto blue (Figure 3f) and verso white spunbond fabric had already broken down. When the mask fabric sheared, a large quantity of fine sandy dirt and clay particles was released (Figure 3e, f) which had been trapped by the fibers (Spennemann, 2022c).

Example of masks partially embedded in a bitumen patch

A mask was encountered partially embedded in a large bitumen repair patch in the middle of a grocery storr carpark. The mask, when encountered, had already begun to disintegrate. It was stuck in the bitumen with the inward facing side pointing upwards. Both the lateral margins had disintegrated, and the ear loops detached at one of the weld points on each side (Spennemann, 2022b). More detailed observations could be carried out five days later. At that time, the white spunbonded layer (worn towards the face) had lost its integrity, exposing the inner melt blown layer, which had been shredded in sections (Figure 4, Figure 5a–b). In newly manufactured masks, spunbonded polypropylene fibers are further strengthened as a fabric by a pattern of thermal weld points of 0.4 to 0.5 mm size (see Figure 2b–d). In the case of the embedded mask, extensive sections of the white spunbonded layer had been shredded into loose fibers, with very limited evidence of former weld points (Figure 5c–d). Many loosened fibers had also been dragged into and aligned the direction of the vehicle movement (Figure 4) (Spennemann, 2022b). The small weld points of the spunbonded fabric were too weak to prevent this disintegration. By the time of the third observation nineteen days later, the white spunbonded layer, as well as the melt blown layer had almost entirely disappeared, and the black spunbonded layer of the recto surface had also begun to decay. On occasion of the following observations (in intervals of 16, 20 and 24 days), the black spunbonded layer was increasingly reduced to the thicker elements such as the welded seams, as well as the ear loops and the nose wire (Spennemann, 2022b).

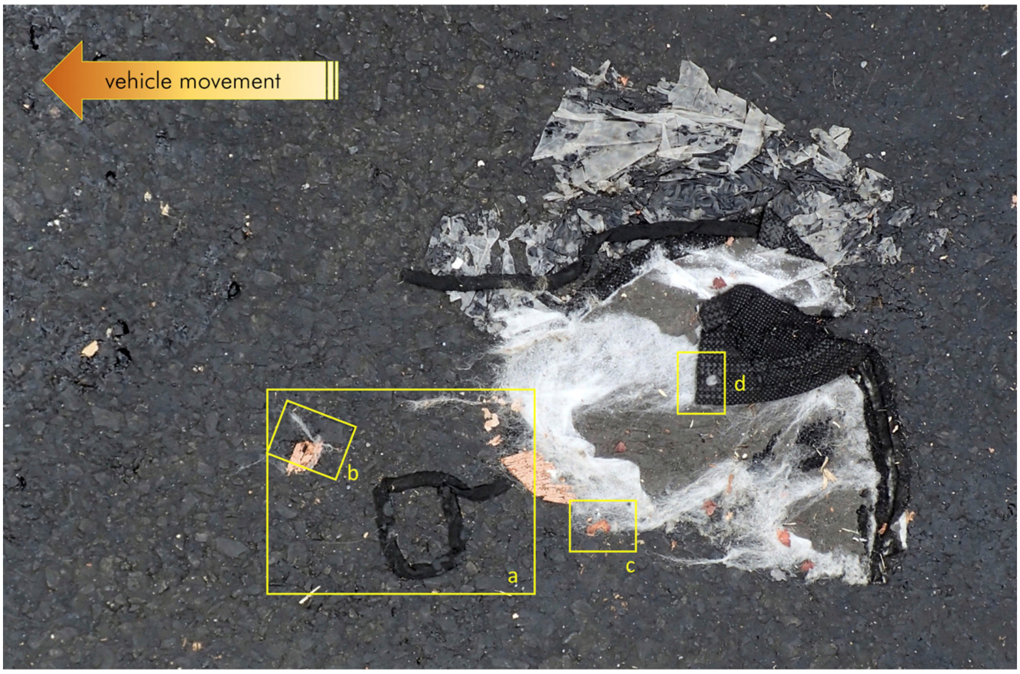

Fig. 4. A single use surgical-type face mask embedded in a bitumen repair patch. The yellow rectangles show the position of the detailed images **Figure 5**a–d.

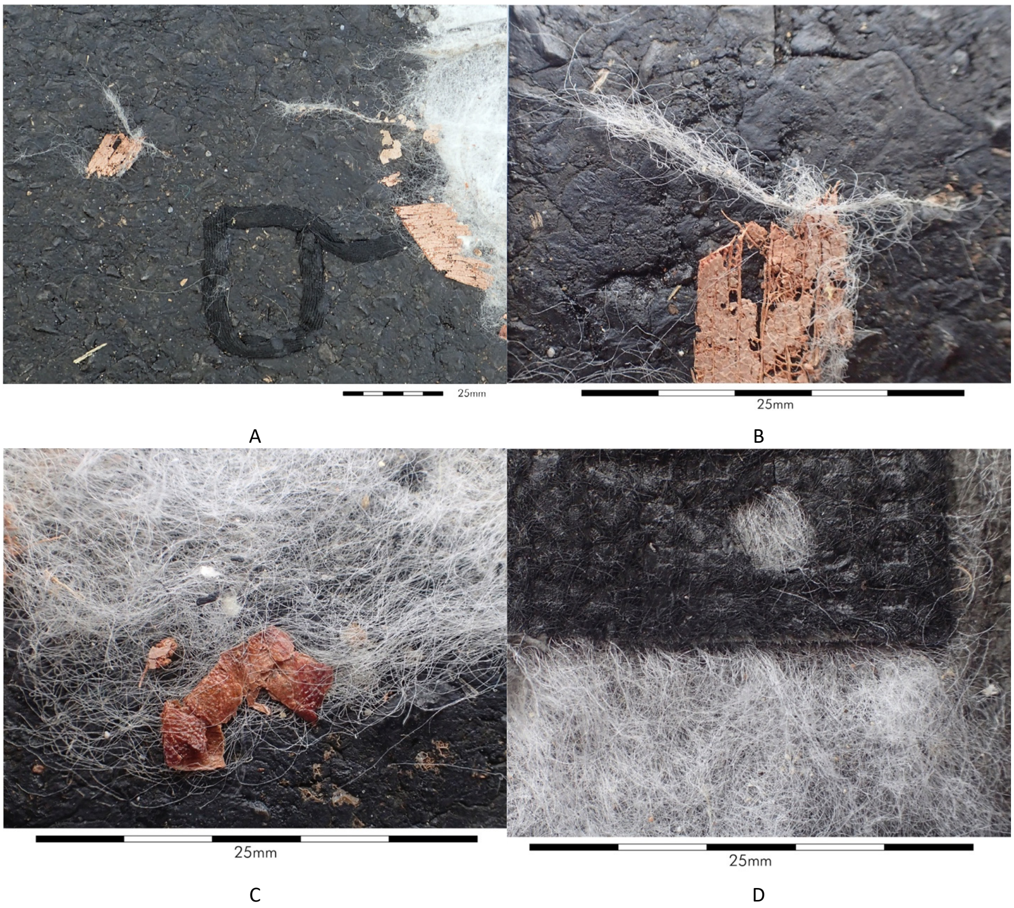

Fig. 5. Details of single use surgical-type face mask embedded in a bitumen repair patch.(Spennemann, 2022b)

Experimental Studies

The field observations were augmented by a set of experiments to simulate the response of masks to the impact of vehicle tyres under controlled conditions. Laboratory testing was both impractical as it would have required to constructed a single purpose testing rig comprised of a section of road surface and steerable wheel/tyre arrangement with the required high weight for simulation. Thus the experimental set up comprised of an outdoor setting (standard road surface in a parking lot) and a domestic sports utility vehicle (SUV, the most common type of car in the author's regional community), thereby simulating real-life situations. The experiments comprisedtwo sets of brand new masks, in a dry and in a wetted state (24 hr soak), being run over with the vehicle for a set number of times (at 241.7 kPa pressure under the wheel) (Spennemann, 2022e). Assessed variable were the state of the mask (dry or wet), the side facing the road surface (blue or white side of the mask) and whether the maks was merely run over, or whether it was also subjected to twisting action by lateral turning the tyre (simulating steering adjustement during parking).

The experiments showed that being merely run over by a vehicle has no major impact on a mask's structural integrity, certainly not for the limited number of repeats that were tested (a maximum of 30 passes). A potentially significant factor in the degradation of a mask appears to be the unevenness of the road surface and the amount of loose or loosened aggregate that may become caught between the pleats or embedded in the mask fabric (Figure 6a).

Through its penetration action, this will, over time, add to the breakdown of the thermal bonds between fibers and also the fibers themselves. Major impact was observed for masks that were subjected to the wheels of the stationary vehicle turning on top of them for two turns (full right from straight-full left-back to straight) (Figure 6a–b), simulating wheel movement during reverse parking or exiting parking spots.

Because single-use surgical type masks are made from non-woven fabric, they are more susceptible to lateral stresses, in particular rotational shear forces, than woven fabric with an interlocking multi-strand thread. The shear forces that acted on the masks during the wheel turn were caused by the friction between the rubber of the tyre and the aggregate of the asphalt. That friction was limited, however, as the mask could turn with the wheel.

While the observed damage to the spunbond fabric was low given the tested number of passes (maximum of 30), the damage would be more marked as the number of vehicle passes increases. One of the limitations of the experiment was that the masks remained stationary for the duration of the tested vehicle passes. In real-life settings, however, face masks will be moved around by wind as well as by the draught of passing vehicles. This implies that at subsequent passes the mask will be in a different position and orientation in relation to the path travelled by the vehicle. It can be posited that this will cause differential impact.

Decay Processes

To provide traction for vehicles, the urban road surfaces are not entirely smooth but are comprised of exposed gravelly aggregate of the hot mix asphalt that protrudes marginally from the bitumen in which it is embedded.

Once a mask had been run over a few times by vehicles, the surface of the mask has become 'contoured' resembling the underlying uneven road surface. Some parts of that surface are raised (where pebbles of the road aggregate protrude), and some parts are depressed (in the interstices between the road aggregate). The matting process is accelerated when the masks are wetted as a result of rainfall. The contouring is stronger at the center of the mask and less expressed at the thermally welded margins and least at the top where the nose wire is inserted. Subsequent tire action causes the fibers of the spunbond fabric to be fragmented and 'kneaded.' This leads to a matting process of the spunbonded fiber and a fragmentation of the melt-blown fabric.

Critical in this discussion is that a mask is comprised of three layers of polypropylene fabric (spunbonded–melt blown–spunbonded) that can move independently from each other but are confined in their overall movement by the lateral welded seams. When a tire presses on a mask, the friction of the tire will move that layer of fabric touching the tire, while the layer touching the road surface will remain largely stationary. This effect is increased in severity once a mask was partially embedded in the bitumen binder of the hot mix asphalt, essentially firmly fixing the

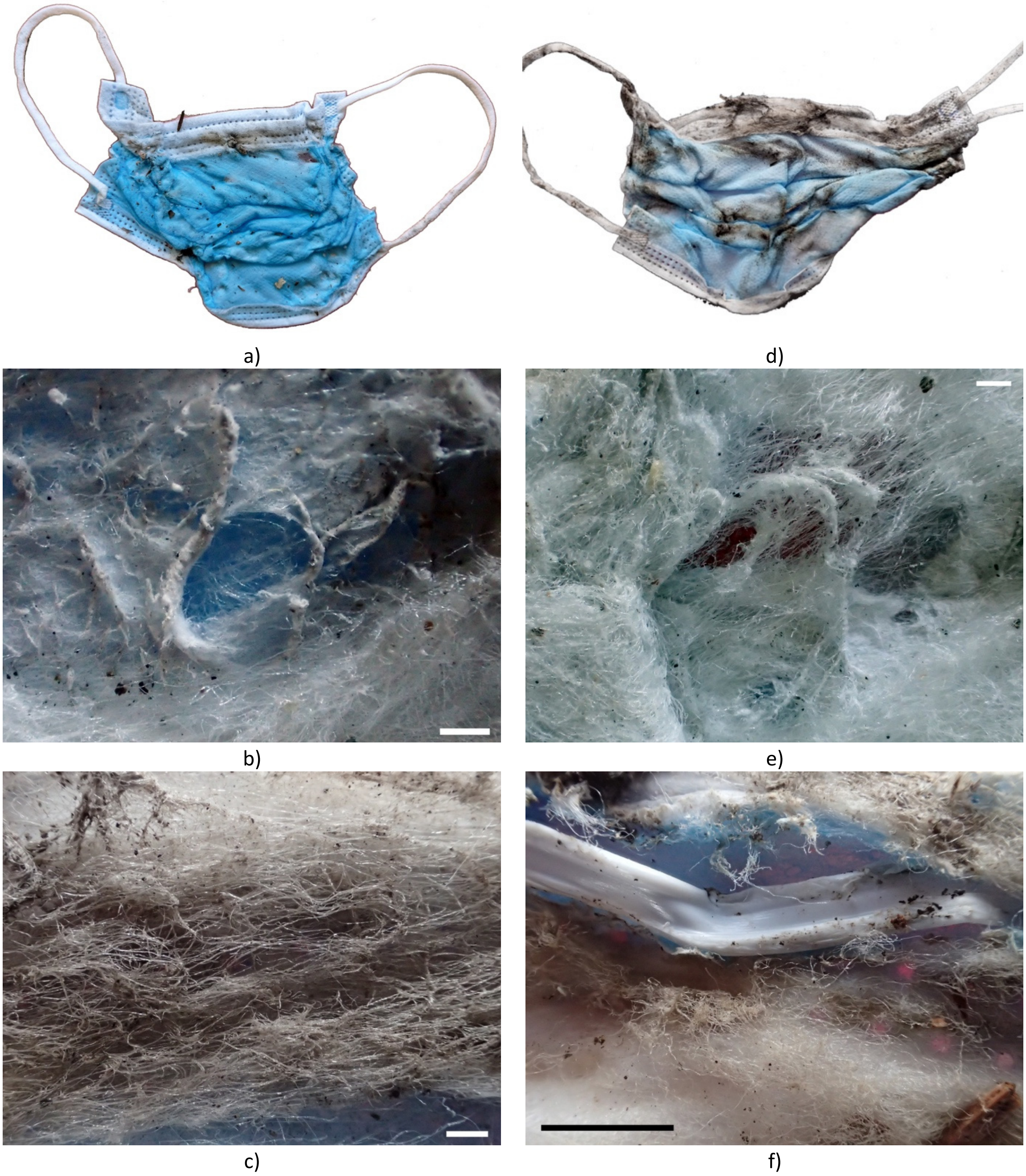

Fig. 6. Response of face masks to the impact of vehicle tires under controlled outdoor conditions. a) mask in dry state, 10 passes with additional wheel turns of a stationary vehicle (full right from straight-full left-back to straight); b–c) details of the mask showing shearing of fabric and dislocation of fibers. Scale bar 1 mm. d) mask in dry state, 20 passes with additional wheel turns of a stationary vehicle (as above); e) details of the mask showing shearing of fabric and dislocation of fibers. Scale bar 1 mm. f) details of the mask showing shearing of fabric and separation of plastic-sheathed nose wire (Spennemann, 2022e).

mask in place, yet also allowing movement of parts of the layer touching the road surface. This sets up shear forces not only between the mask face fixed in the bitumen and the rest of the mask that remained freely moveable, but also with the fabric layers themselves.(Spennemann, 2022b)

This facilitates a weakening and eventual severing not only of the already weak bonds between the fibers of the spunbond fabric but also leads to a separation of the fibers from the thermal spotwelding points. This process is further facilitated, and accelerated, by the abrasive potential of fine sandy dirt and clay particles that may have become trapped in the fiber mesh. The repeated grinding action results in a matting of both the loosened polypropylene fibers and any ancillary vegetative matter that may have also become trapped. The thicker parts of the masks, be they the welded seams or the section where the pleats still overlap will withstand the abrasive impact of vehicle tires for longer.

Once a mask has been moved by wind (or vehicle draught) and become stuck in bitumen patches which have become less viscous and thus sticky due to elevated temperatures, they will become subject to accelerated mechanical decay by vehicular movement.

In contrast to the masks stuck in the bitumen in the interstices of the asphalt road surface, masks embedded in bitumen repair patches are stuck with most if not all of one side. In consequence there is less movement in the mask fabric facing the road surface and a disproportionate movement in the other two layers. Vehicle movements set up tension and friction between the layers, largely in the direction of the movement. This leads to the rapid fragmentation of the melt blown core layer, while at the same time the weak bonds between the polypropylene fibers are loosened, essentially separating the fibers. The friction of the wheels also caused alignment of the fibers.

After repeat passes by tires these loosened fibers will detach from the fabric and will be removed from the original location through wind action or surface water flow (due to rain). Only the thicker material of the seams, which had been reenforced by weld points, are likely to resist the mechanical decay for a longer period. Likewise, the stronger components, such as the strings of the ear loops and the plastic-coated nose wire will survive.

Depending on how long a mask remains in the same location, the described decay processes can be augmented, and accelerated, by other processes such as photooxidation due to exposure to UV and high temperatures (Spennemann, 2022d). This in particular would apply to masks that had been initially lost or discarded on street verges and adjacent green spaces, and which only after a passage of time became blown onto the road surface. In such a case, the effects of mechanical action by tires would result in a disproportionately a greater effect as UV light as well thermal expansion and contraction events would have already weakened the bonds between the fibers and the fibers themselves, making them much more susceptible to shear forces.

Implications of duration of impact on mitigation

Observations of human behaviour, as well as the distribution of masks found on the ground shows that during the COVID-19 pandemic large numbers of single-use, surgical style face masks were lost or discarded in public spaces (Spennemann 2021b). The were particularly prominent on pavements along public streets and in car parking settings. Observations during windy days showed that these masks were readily blown about, with many ending up on the road surfaces where they were subjected to degradation through the tire impact of passing traffic. The residence time on the road surface depends on three main factors. The location of the mask in relation to the draught created by passing traffic, the strength of that draught (derived from the speed and size of the passing vehicle) and the nature of the road surface.

The slower the traffic, such as neighborhood or shopping street traffic, the more likely will it be that the mask will remain stationary and thus will be run over and degraded. The road surface itself plays a major role. The higher the ambient temperature, the more malleable the bitumen component of the asphalt mix will become, thereby increasing the likelihood that a mask will become stuck.

Unlike masks that have been caught in lawn mowing equipment and are, by and large, shredded into larger fragments (Spennemann, 2022a), masks that are degraded and destroyed by vehicular traffic result in an instant and continual generation of microfiber fragments of varied lengths. These fiber fragments are then displaced and distributed into the wider environment through wind action (natural or vehicle draught) and surface water flows (rainfall) as well as adherence to vehicle tires (such as being caught in the tread).

Two of the major concerns are the fact that once released, microfibers will continue to break down into smaller pieces due to mechanical action as well as photooxidation, and the persistence of microplastics in the environment. As the mechanical degradation of face masks is immediate, cumulative and progressive, mitigation measures but be swift. Thus it is incumbent of municipal authorities to ensure and implement processes that ensure the continuous and ready removal of discarded single use face masks before they can be impacted by vehicular traffic. Anecdotal observations in various communities in south-eastern Australia, both metropolitan and regional have shown that removal of face masks is often half hearted and indifferent.

CONCLUSIONS

The field observations of masks disintegrating on suburban roads as well as experiments which subjected masks to vehicular traffic in a controlled real-life situation showed that repeated passes of tires press parts of a mask's fabric into the interstices between the protruding aggregate of the hot mix asphalt. Subsequent vehicle movement, in particular the turning of wheels on top of the mask will exert shear forces on the mask fabric, weakening the bonds between the fibers leading to breakage and subsequent separation of microfibers.

This process of degradation is gradual but progressive, resulting in a continual release of microfiber fragments of various lengths onto the road surface, from which they are carried into the wider environment and are likely to end up in stormwater drains, natural water courses or on urban green spaces.

The longer a mask is subjected to tire impact, the more the mask will shed microplastics. Unlike other decay processes such as UV or mechanical shredding in lawn mowing equipment, which at least initially results in larger pieces, tire action immediately and continually generates microfiber fragments which are, effectively irretrievable as pollutnts.

Essentially, the sooner a discarded or lost mask is removed from the road environment, the better. This highlights the role of municipal agencies. Not only do they have only short window of time to remove stray face masks from the urban environment if micro-fiber pollution is to be reduced or even prevented, but there is also need for diligence in the operation and timing of street sweepers and so masks are not missed and left to degrade and decay.

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CONFLICTS OF INTEREST

The author declares that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the author.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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