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Microfibre Release Due to Domestic Washings: An Overview from Textile Fuzzing Perspective

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ABSTRACT

Microfibre release into the aquatic environment is one of the latest research interests and washing activities at home or also known as domestic washings have been claimed as one of the sources of the of this problem. Washing, textile and ageing parameters are among the factors that influence microfibre release and some approaches for MF release mitigation are discussed. The main factor of the fibre loss from the textile materials is due to the entanglement of small fibres on the fabric surface during wearing or care activities. Hence, the review from the context of textile surface fuzzing is needed to understand the phenomenon better especially for the evaluation purpose. The microfibre release from textile materials during washing is due to the detachment of the fibres either prior to or after pilling formation. In any of these situations, some amount of microfibres or fuzzing are left on the textile surface. Therefore, the evaluation on the fuzzing is proposed to see if it has a relationship with the amount of microfibres being released into the washing effluent. The evaluation of textile fuzzing is usually made by either physical test or digital image processing, which the latter offers more objective results.

Keywords: microfibre; fuzzing; pilling; washing; image processing

INTRODUCTION

Washing is a process where the textile substrates are soaked in water and agitated with the presence of detergent, which could help the soil discharge. Domestic washing has been claimed as one of the sources of microfibre (MF) release, which could cause an environmental problem [1]. The washing activities during use together with the manufacturing process is considered as the primary source of MF release, while the one which comes from the fragmentation of larger materials such as dumped garments is known as secondary source [1].

The definition of MF in general has been discussed from different textile perspectives. One of them is defined as a fibre which has less than 1 dtex but more than 0.3 dtex linear density, with half the diameter of a silk and one hundred times finer than human hair [2]. This definition has become the fundamental reason for the creation of MF cloth that is famously used for cleaning purpose owing to its capability to take up moisture up to seven times of its weight. In the context of synthetic fibre, the micro-sized of the fibre and the shape can always be controlled during manufacturing process [2]. Furthermore, the length of this MF is seldomly taken into discussion since synthetic fibres always come in continuous filament form or can be cut into staple length according to the plan of the manufacturers. Hence, the definition of MF in this context only taking the diameter and the fibre density instead of fibre length.

However, the environmental community has different view of MF definition. As the name implies, MF can be defined as any natural or synthetic fibrous materials of threadlike structure with length ranging from 1 μm to 5 mm, a diameter less than 50 μm, and length to diameter ratio greater than 100 [3]. MF can be natural; such as cotton, flax, wool and silk, synthetic fibres; comprising nylon, polyester, polyolefin and acrylic, and regenerated cellulosic; such as viscose or rayon and triacetate [3]. MF are also known as fibres at micro-sized which could be made of synthetic polymers, which are also called as microplastics. Hence, MF can be referred as any synthetic, artificial, and natural fibres with less than 5 mm in length [4]. Unlike the MF in the previous definition, MF from the environmental context originates from the fragmentation of yarns in fabric which detach due to the use including care activities like washing. As the length and basic properties of MF in previous definition can be manipulated during manufacturing process, fragments of fibres released during washings depend on the washing factors, textile parameters and the ageing of the substrates. Therefore, the MF being discussed in the current review will be the one with second definition.

MF are believed to go into the wastewater treatment plants from the washing bath of domestic washing and some countries discharge home laundering effluents directly into the environment [4]. However, there is still chance for the MF to escape from the treated wastewater considering the large volumes of effluent endlessly discharged into the aquatic ecosystem. The MF pollutants continue to go downstream and are cleared into the marine environment through rivers [3]. Ultimately, the similar size of MF as plankton in the marine ecosystem would make the particles to be easily ingested by the aquatic lives which later be the sources of protein for human consumption [5]. The presence of tiny plastics or fibres in sea salts also needs some attention in public health concern as salt is used daily in human food preparation and a long term exposure to plastic contaminated food was shown to cause some bad impacts on humans [6].

This problem seems only concerns on synthetic fibre fragments due to the perception that natural fibre will degrade quickly and will not cause any serious damage to the environment [7]. Natural fibres such as cotton, linen and wool on the other hand have a significant contribution towards this environment pollution [8]. This is due to the fact that the fast degradation of natural fibres will make the release of chemical pollutants (e.g., dye stuffs) available to the river or sea sooner to enter the food chain of aquatic lives [7]. Hence, the detachment of the fibres from textiles is the main issue regardless of the fibre types. It is said so because nothing much can be done to the environment when the MF are already emitted in the washing effluent in the long term, as the root cause comes from the textile itself where the fibre detachment still occurs. As what has been mentioned by previous researchers, inhibiting the MF emission will be the better option than controlling the MF from reaching the environment [9].

The review was made with primary aims to highlight the parameters affecting the MF release and the concept of fabric fuzzing as well as pilling which contribute to the cause of MF release. Next, the relationship of fabric fuzzing with the detachment of MF is considered with a few approaches on mitigating the MF release. Near to the end of the review, the possibility of evaluating the MF release through fabric fuzz is determined. This is because researchers always pay attention to the MF in the washing effluent rather than looking at the MF attached on the fabric itself, while the fuzz on the fabric surface might be useful to give information as such to represent MF release on the textile products.

The review was designed by collecting articles about MF release due to washing reported by researchers in the related field mostly in five recent years. The topics which focused on the washing parameters, textile parameters and other factor were then gathered and analysed. The studies which highlighted on the fabric fuzzing and pilling to cause fibre loss were taken into discussion. Apart from that, the study also includes the area in which to mitigate the MF release through textile processing, washing machine design and wastewater treatment stage which becoming in trend in the recent years. As for the MF evaluation, the authors aimed to find the possibility of representing the MF release level by looking at the fabric fuzz properties with microscopic image exploration.

Influencing Parameters on MF Release during Washing

The MF release from textile materials during washing has been discussed as due to three main factors which are the washing parameters, garment ageing and the textile parameters including fibre and fabric types [9]. In a study, the roles of detergent, temperature and fabric softener during washing were evaluated and it was found that an increase in the washing temperature from 30 °C to 40 °C has caused the polyester fibre to release more MF [10]. Nevertheless, there was no significant effect of softener as well as detergent, except that non-bio detergent made the polyester/cotton to release more MF as compared to bio detergent. However in other research, detergent was found to cause more release of MF, but there was no impact from an extended washing time [11]. According to the authors, detergent enhances the wettability of the fibre and increases the loose fibres detachment in the washing process. Other than that, the type of washer also influenced the MF release where a study conducted by Hartline et al. revealed that top loading machine created seven times more MF than front load washing owing to the stronger central agitation and mechanical abrasion in a top load washer [12].

MF release of a textile material is also influenced by the ageing factor. Hartline et al. evaluated the effect of ageing on fibre shedding of polyester garments, and found that the MF detachment increased 25 % more in the aged garments due to the changed physical properties [12]. An increment in the MF release was also observed on re-polished polyester and fleece fabric, where the re-polishing process is to mimic wear and tear as in the physical ageing process [13]. Stiffer and harder fibre with lower breaking strength due to ageing generated a higher amount of MF in the washing process [9].

In the case of textile perspective, fabric with higher compactness, thickness and grams per square area are the parameters that affect MF release [9]. The tighter the fabric structure which composed from staple yarn, the higher the number of fibres exposed to the abrasion and results in higher MF loss [13]. From the context of fibre types, polyester was discovered to shed more fibres due to the pilling nature of polyester which contributed by the fibre's increased tenacity and resiliency [10]. In a contrary, cotton was reported by Zambrano et al. to shed more MF than synthetic fibres due to the high degree of hairiness on cotton [4]. Staple yarns create more hairiness which later being slipped and removed during washing [14]. Table 1 summarizes the influencing parameters of MF release from some main studies by previous researchers.

Table 1: Influencing Parameters on Microfibre Release during Washing

Authors	Influencing Parameters			Effect on MF Release
	Textile	Washing	Ageing	
Zambrano et al, 2019 [4]	1) 100 % cotton, 100 % rayon, 100 % polyester, and 50 % / 50 % polyester / cotton.	1) 25 °C and 44 °C 2) No detergent, with detergent	-	1) Cotton at 44 °C shed more MF. 2) The use of detergent increased the MF release on cotton, rayon and polyester/cotton blend.
Napper and Thompson, 2016 [10]	1)100 % polyester, 100 % acrylic, 65 % polyester/ 35 % cotton	1) 30 °C, 40 °C 2) No detergent, bio-detergent, non-bio detergent 3)Fabric softener	-	1) Polyester released more MF with higher washing temperature, 40°C. 2) No significant effect of washing chemicals, except non-bio detergent and softener increased MF release of polyester/cotton.
Hernandez, Nowack, and Mitrano, 2017 [11]	1) 100 % polyester interlock, 100 % polyester knit jersey	1) Liquid detergent, powdered detergent 2) Extended wash time 3) Different temperatures	-	1) Both liquid and powdered increased MF release. 2) No significant difference between interlock and jersey fabric.
De Falco et al, 2018 [14]	1) Plain weave polyester, double knit jersey polyester and plain weave polypropylene.	1) Liquid detergent, powdered detergent	-	1) Plain polyester washed with powdered detergent released more MF.
Hartline et al, 2016 [12]	1) Fleece jacket of off-brand and branded name	1) Top load and and front load washer	1) New and aged jacket samples	1) Greater MF release from top washer.

Carney Almroth et al, 2018 [13]	1) Knitted polyester, microfleece and fleece polyester, acrylic and nylon with different knitting gauge.	1) Detergent 2) Lab scale washer	1) New and repolished (worn) fabrics	1) Denser fabric (higher gauge) released more MF. 2) Repolished fabrics released higher number of MF than new fabrics. 3) Use of detergent has an impact on the MF release.

Minimizing Microfibre Release

Microfibre release from textiles is suggested to be minimized at product manufacturing stage, during usage which involves wear and care, and wastewater management stage. At the manufacturing phase, it is important to come out with the new development in the design and production processing of fibres, yarns and fabrics because the shedding of the fibres occur at the source [15]. Among the things that should be considered are such as the chemical composition for synthetic fibres, fibre physical properties and the structure parameters which will directly influence the anti-pilling and abrasion characteristics of the fabric. These two properties are generally the main points in adding the life cycle and minimizing the MF release [15].

There are also efforts through coating or finishing techniques on the textile materials to inhibit the emission of the MF. De Falco et al. in their research suggested a product finishing from pectin based solution which is mixed with glycidyl methacrylate and it has reduced the MF release up to 90 %, without giving up the durability towards washing [16]. In a different study, De Falco et al. have performed a finishing treatment on polyamide by an electro fluid dynamic where a homogeneous coating of polylactic acid and poly (butylene succinate-co-butylene adipate) has been applied without affecting the hand properties and wettability of the textile [17]. However, the coatings durability on the textile surface still not be compromised for consecutive washing cycles.

The MF release during washing can also be controlled at consumer stage as the use of washing chemicals like detergent and softener, as well as the use of pulsator type of washing machine were reported to increase the emission of the MF [18], [19]. Consumers are encouraged to use lower temperature and shorter time because studies proved that these two parameters could promote higher amount of MF release [18]. However, it is not an easy task to nurture the public with an appropriate washing method because of the different background and lifestyles of the consumers which made them to choose their current washing practice. Other than consumers, washing machine producers also have their roles in reducing the MF release by imparting certain features in their washing machine design such as direct capture with filter bags which is assembled inside the washer [19]. Napper, Barrett and Thompson in 2020 revealed that the use of filtering device at the wastewater outlet namely XFiltra has reduced up to 78 % [20]. However according to the researchers, filtering device is not enough to fully prevent the fibre loss as the fibres are also released when the garments are worn in everyday use.

At the effluent management stage, a study conducted on a textile dyeing wastewater treatment plant reported that 95 % of MF are captured before being released to the ocean [21], and 85 % of MF have been filtered out from a wastewater treatment plant in a textile industrial park in China [22]. However according to the authors, despite the high MF removal rates, considerable amount of fibres will enter the environment when involving with large volume of effluent. In order to improve the MF removal rates, De Falco et al. have designed filtration system to avoid the entrance of the MF into the wastewater system with 64 % of efficiency in capturing the tiny fibres from polyester garments [23].

It is important to note that preventing the MF release at the product stage is far critical than the other phases as once the particles are released in the washing effluent, there is still probability that the detached fibres will be emitted into the aquatic ecosystem. Even if the MF can be effectively removed from the effluent in the wastewater treatment plant, the particles will be returned to the land and remain in the environment [10]. Hence, a proper product design and development is essential to ensure minimum amount of MF release and to achieve that, a product evaluation is needed to support the current approach of MF release assessment.

Fabric Fuzzing and Pilling in Relation to MF Release

Fabric fuzzing or protrusion can be known as a phenomenon when small fibres emerging on the textile surface from loose fibre ends which can happen due to fibre weakening and abrasion [24]. This situation might be caused by any physical or mechanical action during manufacturing and use including washing activities. Pilling on the other hand, can be defined as the entanglement of small fibres on the fabric surface during wearing or washing, causing the formation of fibre pills that raised on the surface of the textiles which is usually found on knitted fabrics [25], as shown in Figure 1. This situation is a result of scrubbing action on loose fibres on the surface of a fabric [26], which can occur between fabric-to-fabric or fabric-to-tub during washing process.

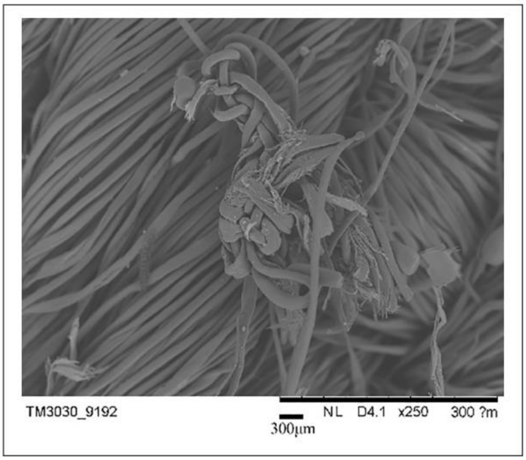

Figure 1: Scanning Electron Microscopy Image of Textile Pilling [19]

The formation of the pills was proven to be caused by the protrusion of MF or fuzzing on the textile surface and has to be known as the cause of fibre lost [10]. This phenomenon was discovered as the consequence of the formation of fuzz on the surface and the persistence of these fuzz when the fibres were entangled. Eventually, the fibres were worn out or released as MF due to the mechanical action during either washing or wear [10]. The mechanism of MF release is illustrated in Figure 2.

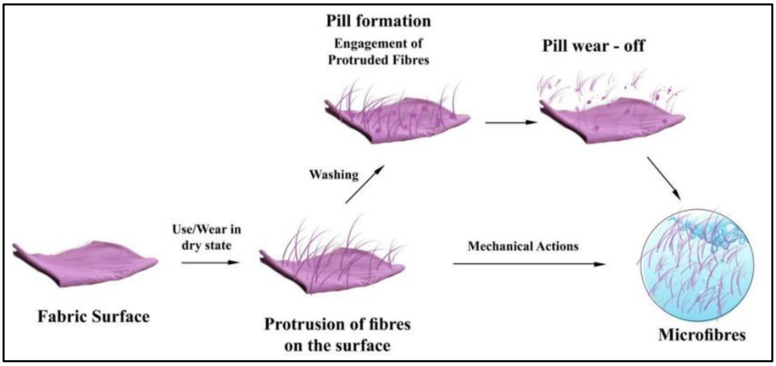

Figure 2: MF Release Mechanism during Washing [10]

Yarn protrusion was proven to formon the surface of the fabric, or from another view, the irregularities of the yarns directly influenced the irregularities on the textiles [28]. The surface abrasion during washing also was identified to cause fibres breakage and the textiles to shed fibres. The shedding of the fibres occurs when the yarn surface gets cut and the cut edges make the fibres shed. Zambrano et al. suggested that the MF release volume primarily depends on the fuzz formation step and how fragile the fibres to be broken during washing before generating the pills [4]. In other words, the fibre loss occurs even before the pilling are formed, leaving the strong fibres attached on the fabric surface.

It is therefore concluded up to this point, the formation of MF on textile surface come out under two conditions; 1) after pilling; when the fibre entanglement cause the removal of tiny fibres, and 2) before pilling; where the removal of loose fibres occurs due to the washing mechanical action leaving the strong fibres on the fabric surface. In any of these conditions, the MF residues were left on the surface after washing (Figure 3). These MF which is seen as fuzzing should give useful information such as to depict the MF which leave the fabric. The justification for this claim is that the greater the MF formation on fabric after washings, the more is the amount of MF emitted in the washing effluent. This is because the formation of fuzzing and pilling on the textile surface has to be known as the cause of fibre lost [10]. Other possible reason is that, if lesser MF formation found on the fabric after washings, it can be an indication that more amount of

MF emitted in the washing effluent. This is due to the tiny and loose fibres which have been detached from the fabric leaving a smoother surface with minimum protrusion.

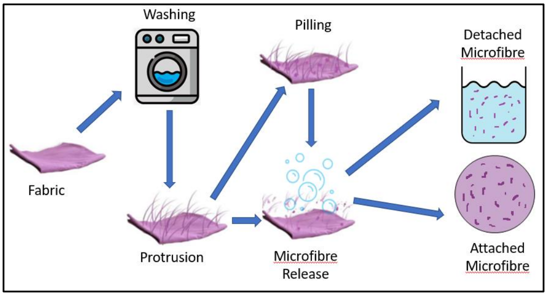

Figure 3: MF Formation and Detachment during Washing

Textile Surface Fuzzing Assessment for MF Release Evaluation

Majority of the researchers have worked on the textile MF release to the environment through the MF collection from the washing effluent. The basic method in evaluating MF release are washing, filtering and determination of MF amount. Carney Almroth et al. did sampling in a laboratory with the estimation of MF was made manually by counting and measuring the fibres under the microscope [13]. Belzagui et al. worked out on the MF collection by taking a smaller volume of washing effluent so that the number of MF could be counted and MF overlapping could be avoided [29]. The results from this study showed that the samples shed more MF in the first washing cycles, which was probably contaminated by fibres residue from the textile manufacturing process. From this point, it is shown that examining the MF from the effluent alone is not enough to represent the actual amount of MF release. There are also difficulties in comparing the results from previous studies as the accuracy is still low and the units used to express the results are different [29]. Therefore, textile surface evaluation is needed to support the findings, to see whether the surface evaluation and MF release are related.

The MF formation on the textile surface which is seen as fuzzing should give useful information as discussed in the previous section. Apart from knowing the amount of fibres leaving the textiles, the characteristic of the MF left on the fabric surface after washing would be informative to represent the MF emitted in the washing effluent. This can be measured through physical test method and digital image processing.

The protrusion or fuzzing on textile surface can be measured by pilling evaluation. Surface fuzzing and pilling are usually assessed by the use of Martindale and pilling box method [30]. All the methods for the evaluation of pilling and protrusion have in common that they are based on human judgement, which is by comparing the samples with photos, hologram or a written description for grading [31, 32]. This subjective method according to the authors is not so reliable especially when different evaluator would give different judgement on the samples observed due to the varied visual abilities. The micro-sized fibres formation on the textile surface is also not easy to be visualised, unless clear pills are formed which can be detected with naked eyes (Figure 4). Hence, assessing textile surface fuzzing objectively is another way to evaluate textile surface quality which has been explored quite extensively.

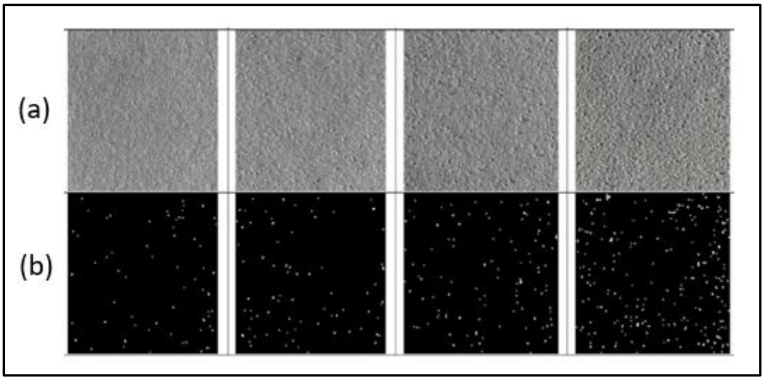

Figure 4: Fabric Pilling Image (a) Subjective Evaluation (b) Objective Evaluation [33]

Digital image processing of textile protrusion is significant as it may lead to objective surface assessment, other than by using subjective evaluation. In general, the steps involved in image processing are including image organization, image pre-processing, image segmentation, and features extraction [33, 35]. Recent study conducted by Zhi et al. reported that the MF formation extraction in textile image processing was possible based on fabric surface plane [35]. In the other article, Wang et al. have stated that the degree of fuzziness or MF formation on textiles is usually represented by the quantity of protrusions, length as well as the shape of fluffy fibres, and this could be achieved by linear region threshold segmentation [36]. Furthermore, the total pill area and the number of pills on a polypropylene nonwoven fabric could be determined using simple image evaluation from the greyscale image [30]. The determination of optimal thresholding of the image was made based on the mass loss of the materials during the abrasion test. This situation could be applied in the case of MF release where the grey value would be determined by the amount of MF collected from the washing effluent which represents the MF loss.

CONCLUSION

Environmental community has put efforts in determining the MF release in the effluent caused by domestic washing activities. Through the works, the MF release influencing parameters have been explored with the aim to find the solution how to minimize the problem. Mitigation efforts through various stages of the textiles including manufacturing, use and care, and wastewater management are important to help to reduce the release of MF to the environment. Therefore, an explanation from the context of textile evaluation is needed as past studies have suggested that preventing the MF release at the product stage is far more critical than the other two. Textile surface fuzzing characteristic can be the one aspect to be explored that relates to textile surface evaluation to represent the amount of MF being emitted during the washing process. The basis for this statement is that, for the MF which leave or detach from the textiles during washing, there are also residues or MF which are left or still intact sticking out on the textile surface. These attached MF which are seen as fuzzing, are produced as a result of the fibre cut due to abrasion when there is mechanical action either before or after fibres entanglement during washing. Hence, the fuzzing can be useful in giving information either through physical evaluation or image processing, which could be related to the MF being emitted in the washing effluent. A strong relationship between the fuzzing on fabric and the MF release during washing can be the reference for the textile manufacturers to produce materials with better fuzzing resistance towards mechanical stress during domestic care, with the ultimate hope to create a safer planet to live.

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