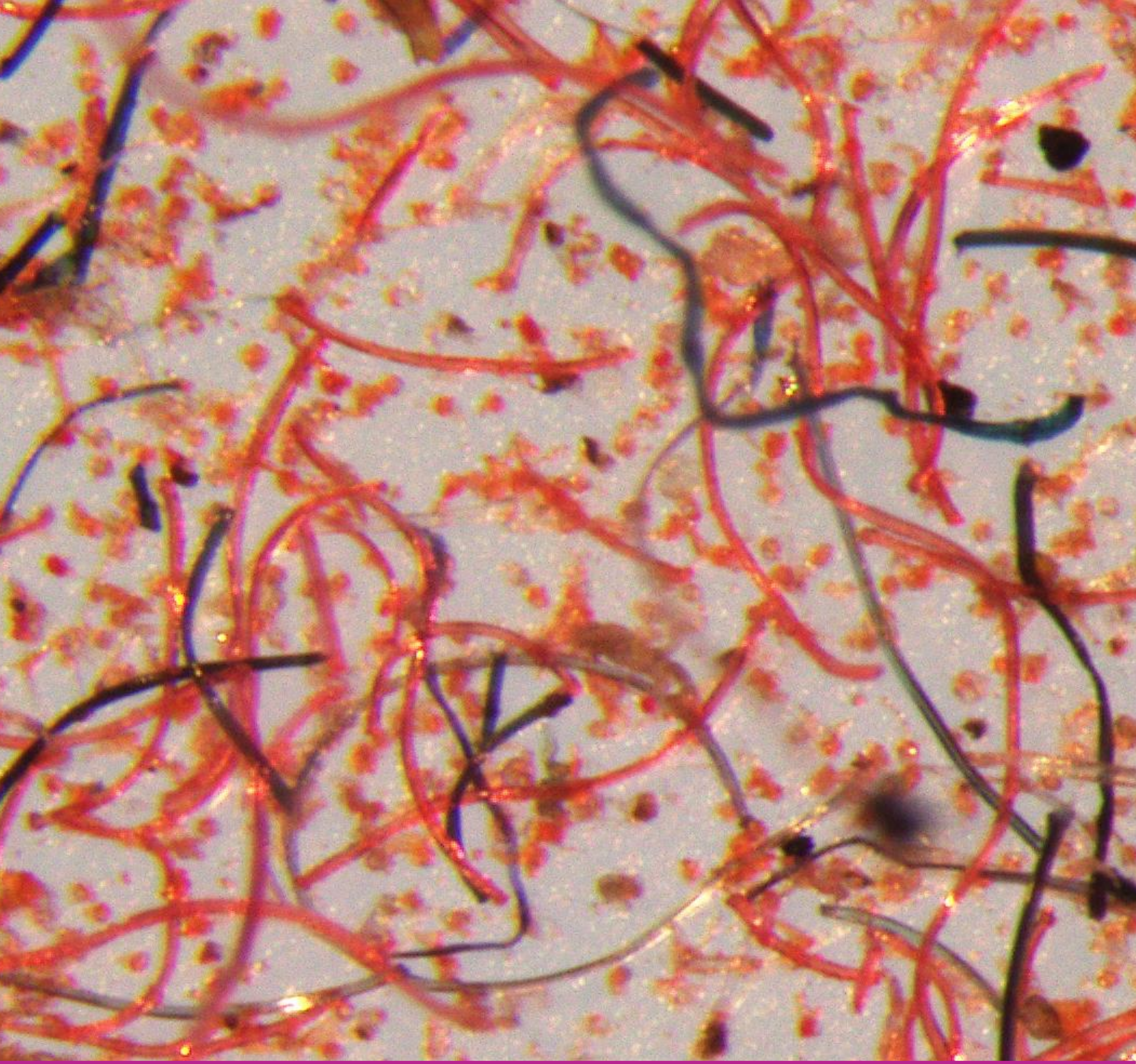

SMART WASH CYCLE DESIGN CAN REDUCE MICROFIBER SHEDDING

Acknowledgement

The Ocean Wise Plastics Lab is privileged to work on the traditional, ancestral, and unceded lands of the xʷməθkʷəy̓əm (Musqueam), Sḵwxwú7mesh (Squamish), and səl̓ílwətaʔɬ (Tsleil-Waututh) Peoples. Our microfiber research facilities are located on the shared, traditional, ancestral, and unceded territories of the scəw̓aθən (Tsawwassen), xʷməθkʷəy̓əm (Musqueam), and other Coast Salish Peoples.

We acknowledge that our work spans across the lands of many Indigenous Peoples. We understand that collaborating with Indigenous communities and intertwining Indigenous ways of knowing into our work is essential to decolonizing ocean conservation and realizing the full spectrum of benefits to people, the land, and the ocean.

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This study was conducted with financial support from Samsung Electronics, and in partnership with Patagonia, Inc.

MICROFIBER SHEDDING WITH DIFFERENT HOME LAUNDRY WASH CYCLE DESIGNS

EXECUTIVE SUMMARY

Home laundry is a major source of microplastic pollution and is endangering ocean health and, potentially, human health. In North America alone, washing machines release an estimated 3.5 quadrillion microfibers[1] into the ocean every year through a process known as microfiber shedding. This amounts to nearly 900 tonnes of microfibers – the equivalent weight of ten blue whales. Globally, the rate of microfibers being released to the ocean is estimated to be around 40,000 tonnes per year,[2] and microfibers of textile origin have been found to be pervasive in even the most pristine environments, such as the Arctic Ocean.[3] Besides threatening marine wildlife and ecosystems, recent studies have raised concerns about potential impacts on human health, after microplastics were identified for the first time in human blood and even breastmilk.[4,5]

To address this pressing concern, Ocean Wise partnered with Samsung Electronics and Patagonia, Inc. to investigate whether adjustments to wash conditions can help to reduce microfiber shedding during home laundry.

Working out of a state-of-the-art facility in Vancouver, BC, Ocean Wise's Plastics Lab conducted a series of experiments to systematically measure microfiber shed rates during different wash conditions. Over one hundred washes were conducted using loads of polyester jerseys weighing approximately two kilograms, representative of the weight of a typical consumer laundry load.

The findings from this research are conclusive: low intensity wash conditions - generally described as 'gentle' cycles - can reduce microfiber shedding by approximately 70%.

In North America alone, washing machines release an estimated 3.5 quadrillion microfibers into the ocean every year through a process known as microfiber shedding.

Ocean Wise's latest study demonstrates the opportunity for washing machine manufacturers to play a leading role in addressing growing global concerns around microplastic pollution. It also highlights several key questions for further research. We are calling on industry to partner with us as we investigate:

1. **Which specific part of the wash cycle contributes most to microfiber shedding? Can this part of the cycle be adapted or replaced, to reduce shedding?**
2. **What is the microscopic mechanism of microfiber shedding in home laundry, and how is it affected by material and wash cycle design?**
3. **How can wash conditions be designed to minimize the range of environmental impacts, including microfiber shedding as well as water usage, energy efficiency and so on?**
4. **What is the extent of microfiber shedding during tumble drying? How important respectively are air and water transport for textile microfibers?**

Figure 1 Ocean Wise Plastics Lab researchers loading washing machines in preparation for testing at our laundry research facilities.

HOW DOES A WASHING MACHINE WORK?

A common front-loading washing machine consists of an outer drum that holds water and an inner drum that is rotated by a motor, agitating the clothes inside. Machines typically run in three stages – wash, rinse, and spin. The primary difference between the wash and rinse stages is the use of detergent – since no detergent was used in this study, we refer to the wash and rinse stages together as the "wash" stage.

During the wash stage, the washing machine's motor typically runs in on-off sequences, with the direction of rotation switching at the start of every "on" sequence. The peak rotation speed of the inner drum during the wash cycle typically reaches between 40 – 60 revolutions per minute (rpm), depending on the agitation level of the wash cycle[6,7]. The percentage of time that the motor is "on" during the wash stage (referred to as motor operation rate or "op. rate") also varies depending on the cycle, from as low as 2% of the entire wash to as high as 90%. Choosing wash cycles that either increase the rotation speed of the inner drum or increase the percentage of time that the motor is "on" during the wash stage increases the level of agitation of the laundry load inside. Finally, during the spin cycle, the motor and the inner drum spin continuously at a significantly higher speed – between 500 and 1,000 rpm – to drain as much water from the clothes as possible. The research methodology for this study is designed to estimate microfiber shedding for the entire cycle – including both the wash and spin stage.

The research methodology for this study is designed to estimate microfiber shedding for the entire cycle – including both the wash and spin stage.

Wash cycles may be described as "gentle" or "intense" based on a few parameters that determine the level of agitation. For instance, a cycle tested in this study labelled "synthetics" had a motor operation rate of 82%, water temperature of 60 ℃, wash motor speed of 50 rpm, and spin motor speed of 1000 rpm, and may be considered an "intense" cycle. Conversely, another cycle labelled "delicates" had a motor operation rate of 2%, ambient water temperature (usually 15 ℃), wash motor speed of 30 rpm, and spin motor speed of 500 rpm, and may be considered a "gentle" cycle. Gentle cycles are characterized by lower wash and spin rotation speeds, and lower operating rate, namely, the relative time the motor is turned on as a fraction of the entire wash duration. [4,5].

RESEARCH METHODOLOGY

The Ocean Wise Plastics Lab, in collaboration with Samsung Electronics and Patagonia, conducted this experiment using a novel scientific methodology drawing on research methods developed with Ocean Wise's Microfiber Partnership*, a coalition of apparel retailers and government agencies that has been working to eliminate microfiber pollution since 2017.

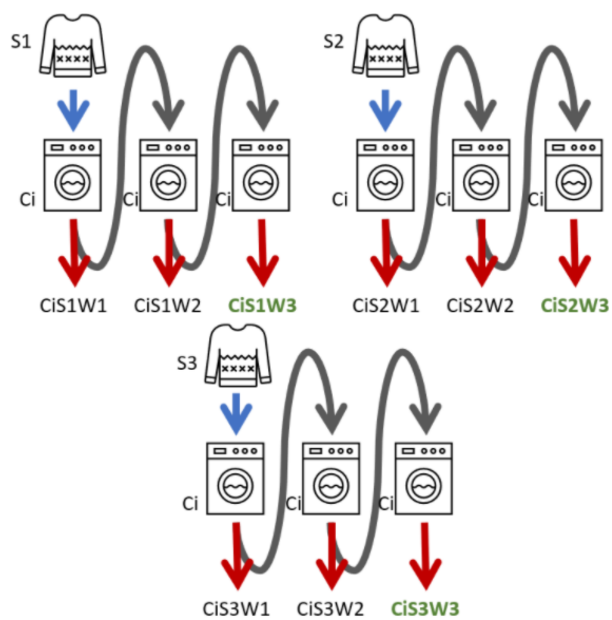

Figure 2 *Schematic for wash cycles for every selection of washing machine and condition.*

To evaluate the relative microfiber shedding rate for a given washing machine condition (C_i), three identical replicate sample sets ($C_i S_{1-3}$) were washed with each using the same condition three successive times. In total we tested 21 wash conditions (see Table 1 below). Following every wash microfiber shedding was measured by weighing dried lint collected in respective filters (see figure 1). We also measured background contamination by taking a procedural blank sample at the start of testing a new wash condition.

The detailed methodology, including measures implemented for contamination control, is included in the Appendix A. The full raw data set, including microfiber shed mass for every wash ($C_i S_j W_k$) along with procedural blanks is available online.†

The 21 wash conditions were tested with ten different washing machines during these experiments, including six made by Samsung and four made by other manufacturers. Three machines are designed specifically for the South Korean market and have 27-inch-wide drums, and seven machines are designed for the European market and have 24-inch-wide-drums.

Eight different wash conditions were tested on the South Korea style washing machines, including six conditions on Samsung machines and two conditions on machines made by other manufacturers.

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* More details at https://ocean.org/action/microfiber-partnership/

† See Appendix B for URL links to full data set, and for selected subset of data

A further thirteen wash conditions were tested on the European style washing machines, including ten conditions on Samsung machines and three conditions on the machines made by other manufacturers. More detail of the wash conditions is provided in Table 1.

Brand	Test cycle ID	Temp. ℃	Wash RPM‡	Op. rate	Spin RPM/ time	Description
Samsung (Korea, 27")	TK1	40	40	88%	1000	Conventional laundry wash condition of 27" washing machine
	TK2	cold	40	40%	1000	
	TK3	40	30	7%	500	Condition to be applied to new Samsung 27" washing machines to reduce microfiber shed
	TK4	cold	30	7%	500	
	TK5	40	40	88%	1100	
	TK6	cold	40	40%	500	
Other manufacturers (Korea, 27")	TK7	40	-	-	-	
	TK8	60	-	-	-	
Samsung (EU, 24")	TE1	60	50	82%	1200	
	TE2	40	50	82%	1200	
	TE3	cold	50	82%	1200	
	TE4	cold	30	2%	400	
	TE5	cold	50	83%	1200	
	TE6	cold	50	83%	1200	
	TE7	cold	48	81%	1400	
Samsung (EU, 24") additional tests	TE8	40	30	12%	800	
	TE9	40	30	12%	800	Condition to be applied to new Samsung 24" washing machines to reduce microfiber shed
	TE10	40	50	82%	1200	Conventional laundry wash condition of 24" washing machine
Other manufacturers (EU, 24")	TE11	40	-	-	-	
	TE12	40	-	-	-	
	TE13	40	-	-	-	

Table 1 Technical specifications of washing conditions tested

‡ The EU wash conditions are separated into two wash periods, the numbers noted here are the weighted average of the two periods.

The statistical analysis in this report is based on the data from wash numbers two and three. We have excluded data from first washes from this analysis because first washes tend to produce significant and unpredictable variation in shedding rates, as reported in our previous study.[8] The data from all washes was nevertheless recorded and is presented in this report for completeness.

PRINCIPLE FINDINGS

The findings from this series of experiments show that "gentle" cycles (as characterized above) have a significantly lower shed rate – approximately 70% – than all other cycles. On average, the lowest shedding test condition (TE4) had a shed rate of 14 mg/kg, compared to 60 mg/kg for the highest shedding condition (TE1), and 55 mg/kg for a baseline condition (TE3).[§] The shedding rate was analysed under two specific parameters – temperature and motor operation rate (see Figure 3). Of these two, motor operation rate is the only parameter that led to a statistically significant reduction in shed rate (t-test null hypothesis $p<0.05$).

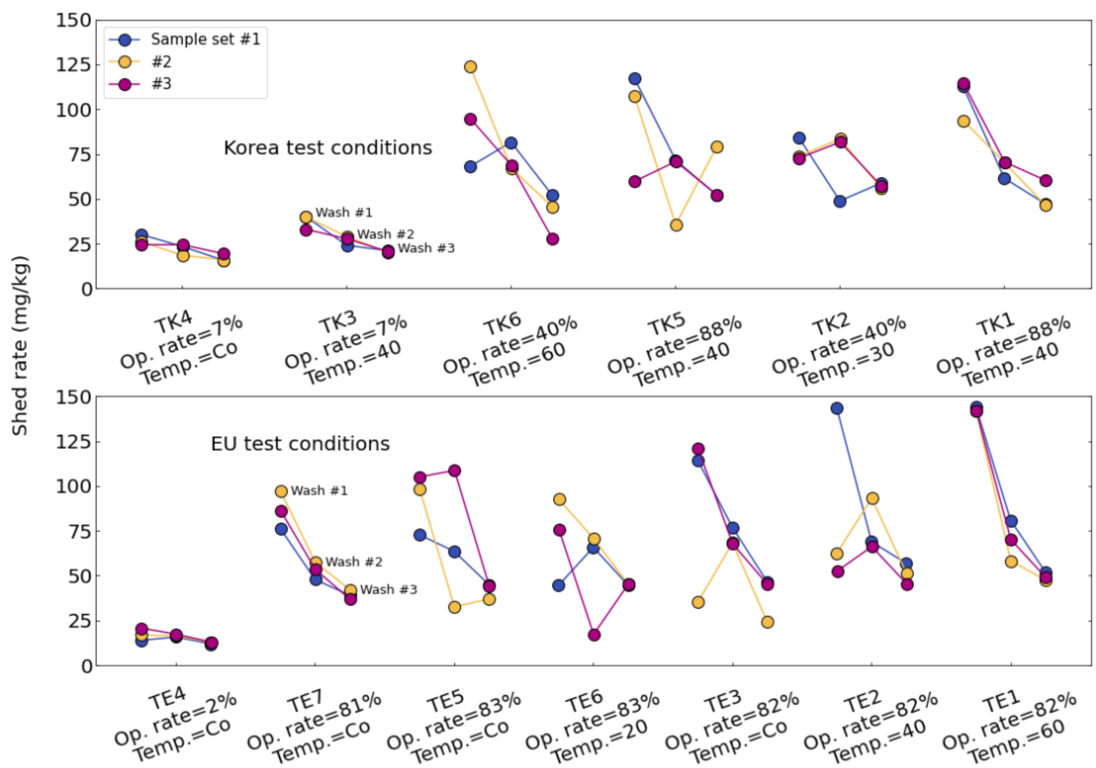

Figure 3 Shed rates for all Samsung models under Korea and EU test conditions, in approximate order of increasing average shed rate. "Gentler" shed conditions, namely, TK3, TK4, and TE4 have significantly lower shed rate than other conditions. Operating rate (Op. rate), namely, the relative time the motor is turned on as a fraction of the entire wash duration, is used as an indicator of motor agitation which is also correlated with wash speed, spin speed, and spin duration

The wash temperature did not lead to a statistically significant change (regression determinant $R^2 = 0.02$).

§The 70% reduction figure is based on conditions TE4 and TE3, chosen because TE4 had the lowest rate observed and TE3 used the same water temperature but had a different motor operation rate to TE4.

While detailed operational information for machines from manufacturers other than Samsung was not available, the observed shed rate for these wash conditions is presented in Figure 4.

TE13 - the wash condition with significantly lower shed rates – corresponds to a machine that has a pre-installed microfiber lint filter. The microfibers collected by the lint filter during all 9 washes for TE13 were dried and weighed separately. The total weight of these fibres was 3.1097 g, which corresponds to an average shed rate of 149.59 mg/kg for each of the 9 washes for TE13. The total microfiber shed rate for TE13 would thus be this value added to the values reported in Figure 4.

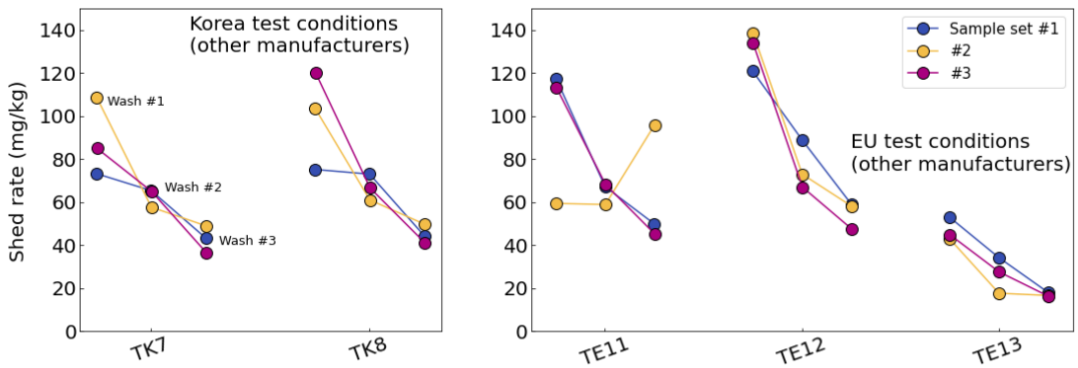

Figure 4 *Shed rates for wash conditions with machines from manufacturers other than Samsung. Note that TE13 corresponds to a machine that includes a pre-installed microfiber lint filter.*

Previous studies of microfiber shedding during home laundry have reported contrasting, but not necessarily contradictory, results. Specifically, one previous study[9] found microfiber shedding rates to increase with the use of lower agitation cycles in "tergotometer" devices, which are used in laboratories for testing purposes. While the reason for this discrepancy is not entirely clear, it is likely due to differences in performance between tergotometer devices and commercial washing machines. A separate study[11] reported that lower wash temperatures significantly reduce microfiber shedding rates. Our research neither corroborates nor contradicts this - while we did not find a significant variation in shedding rates caused by wash temperature changes, this is probably because we did not test temperature as an independent variable.

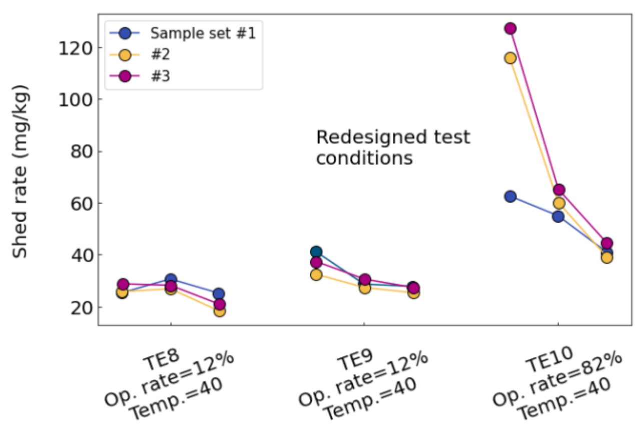

Figure 5 *Shed rates for newly programmed wash conditions showing low shed rates across some new parameters (TE8, TE9), with a conventional cycle (TE10) included for direct comparison.*

This study builds on our understanding of the impacts of wash cycle conditions on microfiber shedding, showing that gentle or low-agitation wash conditions, when tested with commercial washing machines in approximately real-world washing conditions, lead to a substantial reduction in microfiber shedding.

Following the initial round of testing of European style washing machines, and on incorporating the principal findings, additional washing machines were provided by Samsung Electronics with newly programmed wash conditions. Details of these additional test conditions are shown in Table 1, and their corresponding shed rates are noted in Figure 5. Our findings show that lower peak wash speed and lower operating rate appear to have a stronger impact on shed rate than temperature or peak spin speed.

Based on the findings from all of Ocean Wise's testing, Samsung Electronics identified the conditions TK3 (op. rate 7%, peak wash at 30pm) and TE9 (op. rate 12%, peak wash at 30 rpm) as the most effective at reducing microfiber shedding and the washing performance for the South Korea style and European style washing machines, respectively.

IMPLICATIONS

Ocean Wise's latest research highlights the opportunity for washing machine manufactures to play their part in stemming the flow of microfibers into the ocean. To date, most studies,[10] including from Ocean Wise,[8] about solutions to microfiber shedding have centered on the use of microfiber lint filters and material innovations. This research shows that, by designing gentle, low-agitation wash cycles, manufacturers can empower consumers to reduce their microfiber footprint when doing their laundry at home. Accompanied by clear labelling and messaging, these innovations could be a game-changer for ocean health. Research shows the effectiveness of labels in driving sustainable choices – Energy Star® labels, for example, have influenced adoption of front-loading washers by up to 50%.[12] Using this as a baseline, we estimate that labeling to encourage the use of low-shedding wash conditions could result in a 35% reduction in microfiber shedding in the home laundry in North America. That would prevent 200 million microfibers from entering the ocean every year.

DID YOU KNOW?

Using gentle cycles **can reduce microfiber emissions by nearly 70%** compared to conventional wash conditions.

How can I reduce my microfiber shedding footprint at home? Ocean Wise recommends that consumers take the following steps to help reduce microfiber shedding from home laundry:

1. **Say No To 'Fast Fashion'**
2. **Wash Less**
3. **Wash Cold**
4. **Wash Gently**
5. **Use A Microfiber Filter.**

ORGANIZATIONAL OUTLOOK AND OPPORTUNITIES

This study demonstrates the potential for **innovative companies to design-out microfiber shedding.** While this is an important first step, several questions remain unanswered:

1. Which **specific part of the wash cycle contributes most to microfiber shedding?** Can this part of the cycle be adapted or replaced, to reduce shedding?
2. What is the microscopic mechanism of microfiber shedding in home laundry, and how is it **affected by material** and **wash cycle design**?
3. How can **wash conditions be designed to minimize** the range of environmental impacts, including microfiber shedding as well as water usage, energy efficiency and so on?
4. What is the extent of **microfiber shedding during tumble drying**? How important are air and water transport for textile microfibers, respectively?

Ocean Wise is partnering with innovative companies like Samsung and Patagonia to drive a radical reduction in microfiber shedding from home laundry. If you have are interested in developing science-based solutions to microfiber shedding, email plasticslab@ocean.org – the oceans will thank you!

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12. Hustvedt G, Ahn M, Emmel J. The adoption of sustainable laundry technologies by US consumers. International Journal of Consumer Studies. 2013 May; 37(3):291-8

APPENDIX A: METHODOLOGY DETAILS

Methods developed based on report: Vassilenko et al., "Domestic laundry and microfiber pollution: Exploring fibre shedding from consumer apparel textiles" PLOS ONE (2021).

Testing Facility

Study was conducted at laundry test facility at Metro Vancouver's Annacis Research and Event Centre near Vancouver, BC, Canada. The machines and sampling equipment were enclosed in a dust-protective tent made from non-shedding vinyl sheets and supported by a frame made of aluminium. To further reduce airborne contamination during laundry experiments, air purifiers containing Carbon and HEPA filters (VORNADO®) were operated inside the tent during the laundry tests. All surfaces were regularly cleaned.

Testing Conditions

The purpose of this project was to identify the washing conditions that would most effectively minimize microfiber (MF) emission, to potentially develop a special set of washing algorithm.

Four European 24-inch model washing machines, including one made by Samsung and 3 made by other manufacturers, were tested with 11 washing conditions. Two South Korean 27-inch models, including one made by Samsung and one made by another manufacturer, were tested with 10 washing conditions.

Fabric Conditions

2 kg of finished goods were used for each testing condition. Finished 100% polyester clothing were chosen based on readily available supply. 21 X 3 = 63 sets of clothes were prepared for 21 tests proposed in phase 1 RAPID test.

A 100% polyester men's hoodie of interlock double knit construction has been selected as the testing clothing. Specifically the "Team 365 TT30 – Men's Elite Performance Hoodie" supplied by the Canadian clothing wholesaler Wordans in the SP Royal/white colour:

Mass per set	2kg
Number of sets	63
Extra sets	20
Total sets	83
Unit weight	7.7 oz
Number of units needed per set	9
Total number of units	760

Table A1 Fabric selection details

Laundry Conditions

1. Water for all laundry cycles was filtered with 5 µm pore-size filters.
2. Before each test wash, three spin and rinse cycles are run without samples to minimize possible background contamination.
3. n=3 standardized loads are then washed three times, and a sample from the laundry effluent was continuously collected during each laundering cycle.

Each set of finished goods was weighed at dry weights prior to each testing condition.

Effluent Sampling

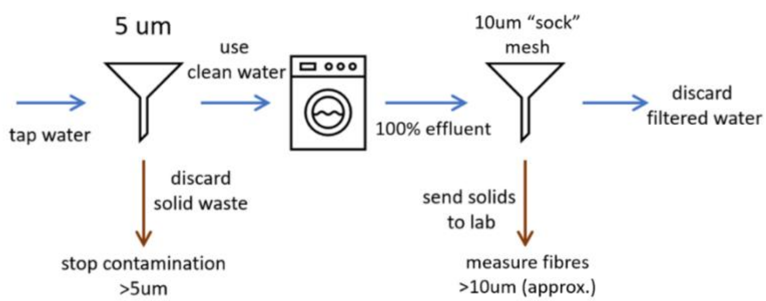

Figure A1 Schematic of filtration process

A custom manufactured stainless-steel "sock" mesh filter (fig. A1, left) was used to collect lint from 100% of all effluent from all cycles for every wash condition. Compared to using polycarbonate membrane filters, the sock mesh can collect lint from large effluent volumes efficiently, and without clogging. Following collection, the filters were dried in closed Petri dishes at 50°C overnight and then stored in individually sealed bags containing desiccant pouches. They were weighed immediately after removal from the desiccator bags.

Duplicates and Procedural Blanks

1. Duplicates were collected from a subset of samples to determine method precision.
2. Procedural blanks were collected every six washes, in parallel with the test washes.
3. The procedural blank was collected by running the same cycle, without fabric inside, and the effluent will be collected using the same method listed in Procedure 4-6.

Lint Quantification and Enumeration of Microfibers

The lint masses from wash cycle #2 and #3 (as appropriate, based on agreement between Samsung and OW) for each of 3 fabric sets were used to compare shedding among different wash conditions, since initial wash cycles often release higher amounts of fibres.

Data Analysis

1. All statistical analyses were performed using the Python 3.0 and Microsoft Excel.
2. Data for wash cycle #1, #2 and #3 were recorded and provided separately
3. Data were presented in the format as shown in the appendix.

Additional Considerations

1. The study only recorded microfiber shedding from fabric sets subjected to up to 3 washes from purchase. A typical household laundry load includes fabrics that have experienced significantly more wash cycles (Klepp et al. 2020).
2. The study can only be interpreted to report microfiber shed rates in laundry loads comprised entirely of fabrics made of polyester. Household laundry loads are more likely to include fabrics of many different material compositions and blends, which may affect their relative shed rates.
3. The study used laundry loads of approx. 2kg. Household laundry loads can be substantially heavier, from 6-10kg depending on laundry machine type (Moon et al., 2020). This may affect observed shed rates.
4. Outlier data points (identified as > 2 standard deviations or using an equivalent metric) were investigated to determine any proximate causes (e.g., instrument or operator error). After correcting proximate causes, the three-wash sequence was repeated, and data recorded.

APPENDIX B: SUMMARIZED SELECTED RAW DATA

Complete raw data for South Korea style models available at:
https://ocean.org/app/uploads/2022/10/laundry_shedding_korean_20221122_public.csv
Complete raw data for EU style models available at:
https://ocean.org/app/uploads/2022/10/laundry_shedding_EU_20221122_public.csv

Brand	Condition ID	Wash ID	Temperature	Total Load Weight kg	Shed mass g	Shed rate mg/kg	Description
Conventional laundry course of 27" washing machine	TK1	TK1S1W1	40	2.290	0.2579	112.62	Conventional laundry course of 27" washing machine
	TK1	TK1S1W2	40	2.290	0.1409	61.53	
	TK1	TK1S1W3	40	2.290	0.1082	47.25	
	TK1	TK1S2W1	40	2.269	0.2127	93.74	
	TK1	TK1S2W2	40	2.269	0.1595	70.30	
	TK1	TK1S2W3	40	2.269	0.1052	46.36	
	TK1	TK1S3W1	40	2.320	0.2654	114.4	
	TK1	TK1S3W2	40	2.320	0.1638	70.60	
	TK1	TK1S3W3	40	2.320	0.1399	60.30	
	TK3	TK3S1W1	40	2.300	0.0923	40.13	Condition to be applied to new Samsung 27" washing machines to reduce microfiber shed.
	TK3	TK3S1W2	40	2.300	0.0555	24.13	
	TK3	TK3S1W3	40	2.300	0.0486	21.13	
	TK3	TK3S2W1	40	2.345	0.0938	40.0	

	TK3	TK3S2W2	40	2.345	0.0679	28.96	
	TK3	TK3S2W3	40	2.345	0.0474	20.21	
	TK3	TK3S3W1	40	2.317	0.0766	33.06	
	TK3	TK3S3W2	40	2.317	0.0642	27.71	
	TK3	TK3S3W3	40	2.317	0.0478	20.63	
Samsung (EU, 24”)	TE9	S1W1	40	2.288	0.0944	41.26	Condition to be applied to new Samsung 24” washing machines to reduce microfiber shed.
	TE9	S1W2	40	2.288	0.0655	28.63	
	TE9	S1W3	40	2.288	0.0635	27.75	
	TE9	S3W1	40	2.341	0.0759	32.42	
	TE9	S3W2	40	2.341	0.0640	27.33	
	TE9	S3W3	40	2.341	0.0593	25.33	
	TE9	S4W1	40	2.328	0.0869	37.33	
	TE9	S4W2	40	2.328	0.0711	30.54	
	TE9	S4W3	40	2.328	0.0636	27.32	
	TE10	S2W1	40	2.319	0.1452	62.61	Conventional laundry course of 24” washing machine
	TE10	S2W2	40	2.319	0.1275	54.98	
	TE10	S2W3	40	2.319	0.0951	41.00	
	TE10	S3W1	40	2.324	0.2692	115.8	
	TE10	S3W2	40	2.324	0.1398	60.15	
	TE10	S3W3	40	2.324	0.0911	39.20	
	TE10	S4W1	40	2.312	0.2946	127.4	
	TE10	S4W2	40	2.312	0.1506	65.14	
	TE10	S4W3	40	2.312	0.1028	44.46	