

Microplastic emissions from domestic laundry

A laboratory work resulting in a comparison between the amount of fibres released from different synthetic textiles

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Front page:

Pictures in order from left to right: Acrylic fibres, polyester fibres and nylon fibres. All pictures are taken with the microscope LRI, OLYMPUS BX53 with the computer program OLYMPUS cellSens Entry.

Preface

This report is the final part of the bachelor program Civil Engineering at Chalmers University of Technology, Sweden. The thesis is made during the spring of 2019 at the institution of Architecture and Civil Engineering under the division of Water Environment Technology.

We would like to thank Sebastien Rauch who has been our supervisor during this project, and our examiner Ann-Margret Hvitt Strömvall. We are grateful to Amir Mohammadi who made it possible for us to analyse the results in the lab and would also like to say thank you to the Department of Professional Languages and Communication. We also appreciate the help and inspiration we got from the company Mimby and Susanne Tumlin at Gryaab, and a last but not least, we want to thank Elin Hagman who helped us with the design of the informative sheet.

Abstract

The amount of plastic existing in the oceans today is a growing problem and the reasons to prevent the dispersion of the plastic are many. Calculations have shown that if the emissions of plastic continue in the same pace as expected there will be more plastic than fish in the oceans by the year of 2050.

Microplastics, an umbrella term for small plastic fragments, are a contributing factor to this. There are many sources to the release of microplastics and laundry of synthetic textiles is one of the bigger sources. When synthetic clothes are being washed, they are exposed to chemical and mechanical stress that causes the release of microplastic fibres which, via sewage systems, ends up in the environment.

The knowledge gaps are today big considering what parameters and materials that are assumed to be the biggest contributions to the emissions of microplastics when laundering. Temperature, detergent and the structure of the material are some examples of factors that are crucial when calculating the amount of microplastics released. To strengthen these theories made by previous research, this bachelor thesis will by conducting a laboratory work, contribute with yet another source of results. Further on, an informative sheet will be designed and the purpose of this is to spread information about how synthetic materials could be washed to minimise the amount of microplastic emissions.

Three materials were studied in the laboratory work and in the result the fibres released were presented in weight per wash. Polyester released the greatest amount of fibres, and the amount was reduced with each wash. The amount of microplastic fibres released from nylon and acrylic did not decrease with the amount of washes, but the emissions from these materials were significantly smaller compared to polyester. The gathered fibres were studied in microscope and an estimation of the amount of microplastic fibres were calculated. The result from the laboratory work was compared with the result from the previous research and the report ends with a discussion about the method, possible error sources and the final result.

Key words: microplastic fibres, synthetic textiles, laundry discharge, microplastic emissions, fibre shedding, counting microplastics, weighing microplastics

Sammandrag

Mängden plast i de sju världshaven är idag ett växande problem och det finns goda skäl att försöka stoppa det. Om utsläppen av plast fortsätter i samma takt som hittills, beräknas det redan år 2050 finnas mer plast än fisk i haven. Mikroplaster, ett samlingsnamn för små plastfragment, är en bidragande faktor till detta. Det finns ett flertal källor som leder till stora utsläpp av mikroplaster varav tvätt av syntettextiler är en av de större källorna. När syntetkläder tvättas utsätts de för kemisk och mekanisk påverkan som leder till att plastfibrer frigörs och via avloppssystem når miljön.

I dagsläget är kunskapsluckorna stora vad gäller vilka parametrar samt material som tros bidra till störst utsläpp av mikroplaster vid tvätt. Temperatur, tvättmedel och materialstruktur är några exempel på faktorer som antas vara avgörande för mängden frigjorda mikroplaster. För att stärka dessa teorier från tidigare forskning och medverka till mer belägg för påståenden syftar denna kandidatuppsats till att, genom laboration, bidra med ytterligare resultat. Dessutom kommer kandidatuppsatsen resultera i ett informationsblad vars syfte är att sprida information angående hur syntetmaterial kan tvättas för att minimera mikroplastutsläppen.

I laborationen testades tre olika material och i resultatet redovisades de avgivande fibrernas vikt per tvätt. Polyester släppte ifrån sig mest fibrer och mängden reducerades med antal tvättar. Antalet frigjorda fiber av nylon och akryl avtog däremot inte med antal tvättar men deras utsläpp var betydligt mindre jämfört med polyester. De samlade fibrerna studerades även i mikroskop och en uppskattning av antalet mikroplastfibrer togs fram. Resultatet från laborationen jämfördes med resultatet från tidigare forskning och rapporten avslutas med en diskussion kring tillvägagångssättet, eventuella felkällor och det slutgiltiga resultatet.

Nyckelord: mikroplastfibrer, syntettextilier, utsläpp från tvätt, mikroplastutsläpp, fällning av fibrer, räkna mikroplaster, väga mikroplaster

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1. Introduction

With the amount of plastic existing in the oceans of the world, actions need to be taken. The United Nations (2017) has estimated that 51 trillion plastic particles can be found in the oceans, and also that by the year 2050 it is possible that the oceans carry more plastic than fish if the emissions continue in the same rate. Swedish Environmental Protection Agency (2017) states that the amount of macro- and microplastics floating in the oceans today are around 14,400 to 268,940 tonnes. The big span shows that there are uncertainties when gathering the microplastics and collections could be made from the surface but also from sediments. Since there are no standards on how to collect the microplastics, there are big differences between studies when discussing the amount of microplastics in the oceans. Even if the plastic use in the world should stop today, there would still be accumulation of microplastics in the environment because of the slow degradation of plastic (Swedish Environmental Protection Agency, 2017).

The problem with microplastic emissions is a global issue and is connected to the global goals from the UN, and also the Swedish goals for the environment. In the Swedish goals for the environment, set in 1999, the problem with microplastic emissions are especially connected to the goal “A balanced marine environment, flourishing coastal areas and archipelagos” (Swedish Environmental Protection Agency, 2011). This goal focuses on how the ocean environment is affected by toxic waste, fishing and other activities that concerns the oceans. One of the global goals for the environment is “Life Below Water” and within this, there are targets such as “Reduce marine pollution” and “Protect and restore ecosystems” (The United Nations Global Goals, n.d.). These are connected to the issue with microplastic emissions which will affect the oceans and therefore also the ecosystems.

The reason why microplastics are a big concern relates to the fact that the degradation of plastic is slow, which facilitates the accumulation of plastic particles in the environment (Jiang, 2018). Jiang (2018) also mentions that microplastics are easily ingested by organisms due to their small size and that there is a risk of microplastics carrying pollutants on their surface area. Today, microplastics can be found in the ocean, freshwater systems and land-based environments (Swedish Environmental Protection Agency, 2017). Even in remote places as for an example the Arctic, microplastics have been detected, which brings forward the importance of this question (Napper & Thompson, 2016).

There are multiple pathways of microplastics emissions described by the Swedish Environmental Protection Agency (2017). Following are four examples:

- Tearing from plastic products when used.
- Emissions when plastics are not recycled properly.
- Pellets, small plastic fragments, used as raw material when producing plastic products.
- Small plastic grains, from cosmetics and skin care products.

The two latter sources are already in the size of microplastics when produced and are defined as a primary source of microplastics whereas the two former ones are examples of a secondary source (Swedish Environmental Protection Agency, 2017). The Swedish Environmental Protection Agency (2017) also mentions the largest sources of microplastics which is industrial production of the primary sources (pellets and grains), plastic from roads and tires, artificial grass, anti-fouling paint, littering and laundry.

Laundry is a contributing factor to the emissions of microplastics, although research show various result of just how much. Synthetic textiles have after being commercialised in the 1930's and 1940's, gradually started to replace the natural fibres, such as wool and cotton (Richards, 2005). Consequently, synthetic fibres now provide for approximately 50% of the world's production of textile (Furvik, n.d.). Whereas in Sweden today, around 140,000 tonnes of textiles per year are purchased, and 30-40% of them are made from synthetic textiles (Swedish Environmental Protection Agency, 2019). The microplastics are emitted from the textiles when used or due to mechanical stress when the clothes are washed in the machine (Swedish Environmental Protection Agency, 2017).

Textile washing is an important part of the daily domestic chores all over the world. It is influenced by social, cultural and moral issue which lead to differences between countries. The Swedish Environmental Protection Agency (2017) states that in Sweden, around 95% of the households are equipped with either a washing machine or a shared laundry room and one person generates around of 200-300 kg of laundry every year. According to Salvador Cesa, Turra and Baruque-Ramos (2017), an ordinary washing machine consume around 20 km³ water and 100 TWh every year. Nowadays, washing machines are designed to minimise the impact on the environment in terms of energy and water consumption. They are however not equipped with facilities to collect the shedding of the microplastics.

1.1 Purpose of the bachelor thesis

The main purpose of this bachelor thesis is to perform a laboratory work by washing different types of fabric. A literature study will also be made to be able to compare the results from the laboratory work with previous research, presented as background in section 3 and 4. The three materials discussed in this study are polyester, nylon and acrylic. These textiles were chosen because these are three of the biggest plastic sources within the textile industry and they are easy for the everyday person to find in garments on the market (Jönsson, et. al., 2018).

The project will result in a comparison between the different synthetic fibres and the materials will be analysed regarding to the weight and quantity of microplastics emitted during the washing. The study will also include an informative paper on how to wash clothes with the lowest microplastic emissions as possible. This will result in user-oriented guidelines which informs people about microplastics in synthetic clothes and how to wash them in the most effective way considering microplastic emissions. This might also affect consumption patterns when buying clothes and hopefully create a greater awareness of the issue of microplastic emissions from laundry.

2. General information about microplastics

Within this section, general information about microplastics, how the plastic particles reach the oceans through the wastewater treatment plants and the impacts on the environment, will be discussed. Furthermore, the laws and regulations related to microplastics will also be described.

2.1 Definition and sources

Microplastics are usually defined as plastic particles between 1 nm to 5 mm (Engström & Westholm, n.d.). The fragments are either produced as small plastic particles, pellets, often used in industry (primary source), or created by tearing of materials (secondary source). The tearing causes small particles of plastic to release themselves from the source. The pellets constructed for industrial use are not always within the definitions of microplastics but could instead be bigger than 5 mm (Swedish Environmental Protection Agency, 2017). Although, these plastic particles are still counted as microplastics. This shows that the definition of the term microplastic is not entirely clear. It is difficult to find particles as small as 1 nm in the nature and to measure such a small size, but the lower limit of 1 nm is still in the definition. OSPAR (Convention for the Protection of the Marine Environment of the North-East Atlantic) does not have a lower limit to their definition of microplastic but does instead define them as smaller than 5 mm (Swedish Environmental Protection Agency, 2017). These varying definitions lead to difficulties of collecting and measuring the amount of microplastics existing in the oceans today.

There are many sources of the plastic found in the marine, as seen in figure 1. Plastic is a low-cost material that is currently replacing glass, metal and paper for example as packaging material and single-use items and is therefore a more common material (Andrady, 2011). The microplastics in the oceans attribute from two main sources, from road runoff water and from weathering breakdown of plastic debris. One example of the latter is the fishing industry which nowadays uses tools and gears of plastic that can end up in the ocean and be broken down by the weather to microplastics. A total of 66% of the microplastics in the environment are from the runoff water from roads, and two of the sources could be degradation of tires or road marking (Boucher & Friot, 2017). Furthermore, around 32% of the microplastics from the runoff water from roads finally end up in the oceans.

Synthetic textiles are, as mentioned in the introduction, a source of the emission of microplastic and will be this study's main focus. When textiles made of plastic are being washed, they shed and release small fibres of microplastics (Boucher & Friot, 2017). After the washing, the fibres follow the outgoing sewage water to the wastewater treatment plant (WWTP). How much of the microplastics that will be released into the environment depends on the WWTPs efficiency.

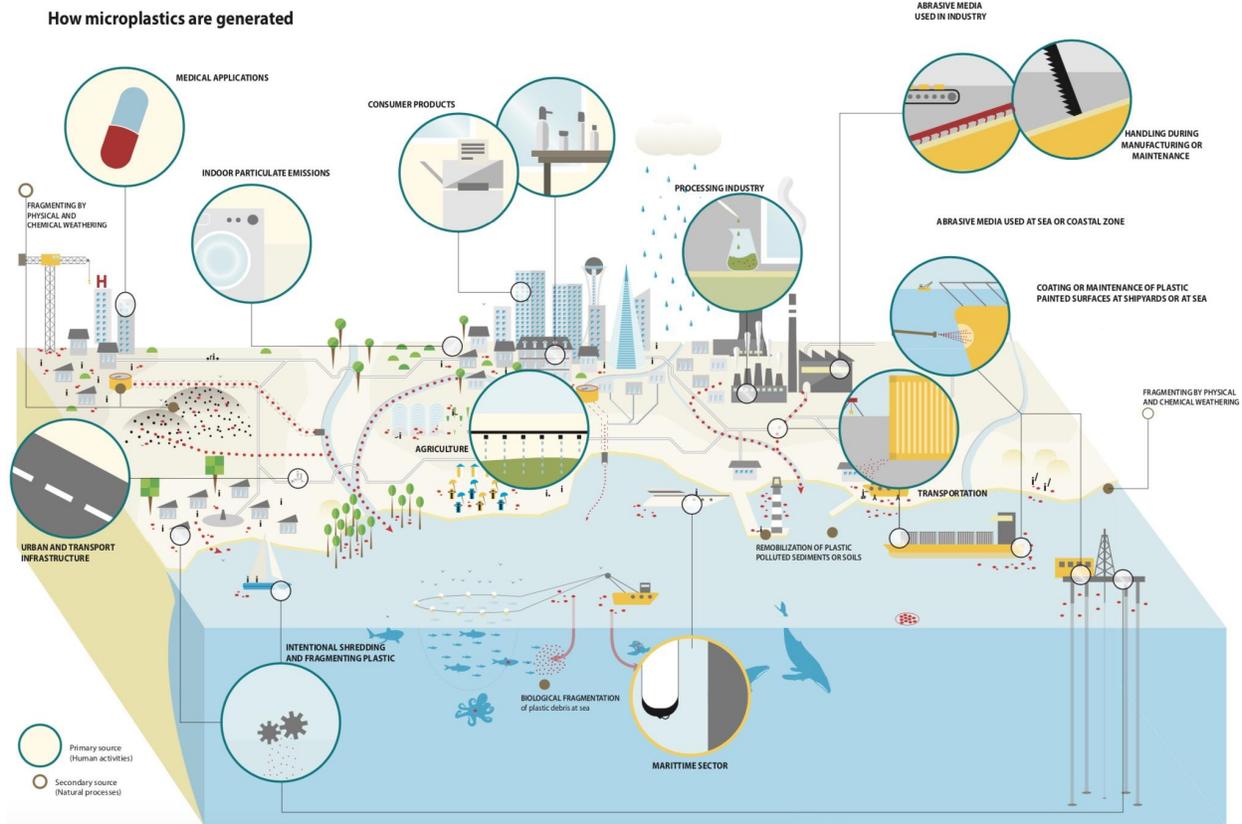


Figure 1. The picture describes how microplastics are generated and their pathways to the marine environment. (Pravettoni, 2014). Reprinted with permission.

2.2 Wastewater treatment plants

In Sweden most of the wastewater from households and some of the urban stormwater are collected and treated in wastewater treatment plants (WWTPs). Every year, 8-950 tonnes of microplastic from household laundry reach the Swedish WWTPs (Swedish Environmental Protection Agency, 2017). The Swedish Environmental Protection Agency (2017) states that laundering of textile together with hygiene products are the largest sources of microplastic emissions that reaches the WWTPs, whereas laundry contributes the most of the two.

In the treatment plants, the microplastics are removed from the water by sedimentation. The microplastics are retained in the sewage sludge which leads to the small particles becoming potential environmental pollutants since the sludge products from the first sedimentation are used in soil production (29%), spread on agricultural land (25%) or used as landfill cover material (24%). Consequently, the microplastics will return to the environment. Beyond that, 0.2-19 tonnes of microplastics each year remain in the water passing through the WWTPs. The smallest particles will not end up in the sewage sludge and are instead released directly to freshwater and marine water sources (Swedish Environmental Protection Agency, 2017).

According to Susanne Tumlin working at Gryaab, the wastewater treatment plant in Gothenburg, Gryaab receives around eight tonnes of plastic every year (Susanne Tumlin, personal communication, April 2, 2019). Around 35% of the mass originate from household water and the remaining 65% from infiltration, stormwater and other sources. Already in the first coarse bar screening, 12% of the total income of microplastic is gathered. The pores have a size of 20 mm and the primary task of the bars is to protect more sensitive components later on in the cleaning process. The next coming bar screen has a size of 2 mm and another 17% of the influent is removed. The plastic that passes through here goes to sedimentation and 73% end up in the sewage sludge. The sewage sludge is used on agricultural land (50%) and as landfill cover material (50%).

The water passes through another three cleaning steps and the very last thing the water passes through before it is released into Göta Älv is a disc filter (Susanne Tumlin, personal communication, April 2, 2019). The mesh size of the disc filter is 15 µm and the outcoming water has shown to have a removal efficiency of 99%, which means that 99% of the incoming dirt and impurities has been removed.

A challenge Gryaab and Gothenburg has to face is the fact that the city is built with combined water systems (Susanne Tumlin, personal communication, April 2, 2019). Both stormwater and household water are meant to pass through the wastewater treatment plant. During periods with a lot of rain the system is overloaded, and it therefore impossible to treat all the incoming water. A brim has to be made which means that some of the water will be released directly to Göta Älv without being treated.

2.3 Impact on marine and terrestrial life

When the plastic ends up in the ocean, animals, often fish and birds, can mistake the small particles for food and therefore get in their stomachs (UN Environment, n.d.). For example, nano-zooplanktons and whales, which are filter feeders, get the microplastic in their body when they eat. Research has shown that a minimum of 44% of marine birds have ingested plastic (Andrady, 2011). The mentioned organisms do not have the possibility to break down or absorb the synthetic polymers and microplastics should be seen as bio-inert, a material that the organisms do not respond to.

Microplastics have the ability to transport persistent organic pollutants (POPs) (Andrady, 2011) and toxic substances that attach themselves to the surface which could be harmful to humans, animals and the environment (Jönsson et al., 2018). The substances that are transported on the surface of the microplastics are hydrophobic, which means that they repel water and can therefore be carried a long way (Kjellander, n.d.). The microplastic can also contain substances from the material production, for example bisphenol A (BPA) (Andrady, 2011). BPA is a suspected hormone disrupting substance and could also affect the reproduction for humans (Swedish Chemicals Agency, n.d.). The microplastics in the ocean absorb the POPs in the sea water and the concentration of pollutants increases in the microplastics and decreases in the water (Andrady, 2011). The pollutants absorbed in the plastic could become biologically available to organisms and therefore harmful.

With the toxic substances attached to the plastic particles that travel through ecosystems, bioaccumulation will occur. This means that the amount of the substance will increase with the uptake when higher up in the nutritional chain (Swedish Agency for Marine and Water Management, 2013). Shown from a study

conducted by Zhu et. al. (2018), microplastic fibres and particles have been detected in the gut of the endangered species Chinese white dolphin, *Sousa chinensis*. There were not only the fully-grown dolphins that had plastics in their stomachs but also the calves, which indicates that the particles and fibres can be ingested unintentionally by aquatic species. Zhu et. al. (2018) are studying cetaceans and comparing their life span and their position as apex predators to humans and claims that the impact of the microplastic ingestion in cetaceans could be translated to humans as well. By studying the different fibres found in the gut of the dolphins, it was shown that the dominant source of microplastics was from ropes and fishnets, but there were also fibres originating from textiles and plastic bags. There was a larger amount of fibres compared to fragments and flake shapes, and this shows that microplastic fibres seem to remain easier in the gut of the cetaceans.

There have also been studies of the zebrafish which shows that exposure of microplastics will cause damage to the gut and alterations to the gut metabolome and microbiome (Qiao et. al., 2018). Inflammations and oxidative stress in the gut of the zebrafish were caused by accumulation of microplastics and should be considered when discussing the subject of microplastic emissions and its effect on the environment and living organisms.

There are often studies concerning microplastics conducted on aquatic species and not much focus on the terrestrial species. There are difficulties when studying bioaccumulation patterns in soils because of the complex structure (Yang, Chen, Lu & Liao, 2018). Yang et. al. (2018) have conducted an experiment where they assessed polystyrene-microplastics in mice. Since mice have a similar gene structure to humans, it is advantageous to use them in experiments to be able to draw conclusions about the impact on humans. Similar to the study with the zebrafish, the mice showed alterations in the metabolome and oxidative stress in the internal organs when exposed to microplastics. In addition to this, the liver and kidney of the mice were also affected by the microplastics. Another result from the study is the uptake of microplastics in earthworms, *Lumbricus terrestris* (Yang et. al., 2018). These worms are the base in many food chains which means that when they ingest the microplastics, these will later end up in the apex predators.

2.4 Laws and regulations

Currently, there are no obvious laws or regulations concerning microplastic emissions. Sweden has Environmental Quality Standards (EQS) that the municipalities and governments are liable to follow (Swedish Agency for Marine and Water Management, 2012). Examples of an EQS are the Environmental code (1998:808) and the Planning and building act (1992:1140). These regulations do not have specific parts that manage the microplastic emission part of the environmental problems but explains how the planned activity will have to take the EQS into account.

There has been a regulation put up against using microplastics in cosmetic products which will have a positive effect on the emissions into nature and the oceans (Government Office, 2018). The EU has decided to put a ban on unnecessary microplastic additives in cosmetics and also detergents, paints, polish and so on. This is to attempt to lower the microplastic emissions with 400,000 tonnes in 20 years (ECHA, n.d). The law focuses on banning microplastics that are added for profit and is therefore not useful when it comes to other areas, for example microplastic emissions from laundry. The amount of microplastic

emissions from laundry do not have any laws or regulations made by the Swedish government that limits the release into the nature and oceans. Since it is not clear how microplastics affect the environment, ECHA (2019) claims that risk assessment is difficult. It is still important to control the amount of plastics entering the nature and environment because of these uncertainties.

Because of the lack of knowledge about how the microplastic release affects the environment, Swedish Environmental Protection Agency (2017) have assessed that in the short-term perspective, the possibilities of decreasing the microplastic emissions are limited. Although, by applying the precautionary principle, Swedish Environmental Protection Agency (2017) still think of it as necessary to take action regarding the microplastic emissions in nature. They say that there should be guidelines when it comes to regulations about brimming and they also think that there should be information handed out to consumers about microplastic emissions from laundry. There have also been discussions with the EU about the production of textiles and how the microplastic emissions could be lowered within this area. Sweden's Government has commissioned the Swedish Environmental Protection Agency to identify sources of microplastics in the environment, to reduce the risk of microplastics ending up in the environment and to propose measurements to lower the emissions (Swedish Environmental Protection Agency, 2017).

3. Synthetic textiles - manufacturing and characteristics

This chapter contains information regarding the manufacturing of synthetic fibres in general and describes in particular the characteristics of polyester, acrylic and nylon.

3.1 History of synthetic textiles

Wallace Hume Carothers founded the first nylon fibre in 1935 at the DuPont company in the U.S., which was called nylon 6.6 (Richards, 2005). The first products, stockings in this case, was first sold in October 1939 and was the first commercial synthetic fibre product on the market. Nylon was followed closely by the commercialisation of polyester and acrylic, which took place in the 1940's. Nylon was until the 1970's the largest source of synthetic textiles in terms of volume but was afterwards outrun by polyester. Richards (2005) points out that this was a result of polyester, often blended with cotton, being a better suited material in terms of comfort for the body. This was since nylon had the characteristics of building up electric charges, being a limp fabric and transporting moisture poorly throughout the fabric. Today, polyester is still the most important synthetic fibre, with around 30% of the worlds production of textile fibres, coming in second place after cotton, which is a natural fibre (Furvik, n.d.). Approximately 50% of the world's production of textile fabrics is synthetically made.

Textiles can be made of natural and/or manufactured fibres (Furvik, n.d.). The latter is divided into two categories depending on the chemical substances' origin, if it is natural or synthetic (Block, 2014). This bachelor thesis will only focus on synthetic fibres, which are made of polymers and obtained from raw materials such as petroleum, coal and natural gas. Nylon, acrylic and polyester are examples of synthetic fibres and the raw material that they are made of is petroleum (Block, 2014).

3.2 Polymers

Polymers are long chains of smaller units called monomers, interlocked by covalent bonds creating the chainlike structure (Terselius, n.d.). The process where a polymer is created is called polymerisation (Block, 2014). When manufacturing synthetic fibres, addition polymerisation or condensation polymerisation can be used. Block (2014) mentions that there are four distinguished traits of the fibre polymer which are:

- Long chains, minimum 200 monomers.
- Strong intramolecular and intermolecular attractions.
- A capability to be arranged along the axis of the fibre.
- A capability to be arranged in crystalline form.

Block (2014) states that these characteristics “establish the properties of the fibre, such as strength, flexibility, resilience, and abrasion resistance, which contribute to their usefulness in various end uses for apparel, home furnishing, and commercial and industrial applications.” (p.3).

3.3 Manufacturing

In general, when constructing synthetic fibres, the manufacturing follows the same three steps (Block, 2014):

1. The material forming the fibres is made liquid.
2. The liquid forms tiny strands when forced through holes and is afterwards solidified when going through a medium of some kind. This is called extrusion.
3. To obtain the desired properties of the fibre, additional processes are required as the last step.

Melt spinning is a fibre production method and it is used when producing for example nylon and polyester (Mather & Wardman, 2015). Since the fibres are thermoplastic, they can withstand high temperatures without fragmentation (Block, 2014). The melted polymers are solidified into filaments when they reach cold air, after being pressed through tiny holes. Block (2014) mentions that due to this form of manufacturing, the shape of the fibre can be altered when the filament is being solidified into for example circular or square cross-sectional areas.

Acrylic is produced in a different manner, mainly by wet or dry spinning (Mather & Wardman, 2015). Since melt spinning is the simplest production method, it is preferred but because acrylic cannot be melted without being damaged by the high temperature, another method has to be used. In both wet and dry spinning, the polymer is made liquid by a solvent and is afterwards pressed through a metal plate with small holes, called spinnerets (Block, 2014). The solidification differs between the two processes whereas with dry spinning, warm gas is used which makes the solvent evaporate and filaments are formed. The process of wet spinning, on the other hand, includes a coagulation bath which the spinneret is placed in (Mather & Wardman, 2015).

After the extrusion process, the filaments are stretched (Block, 2014). Stretching, or drawing the filaments is important since it makes the molecules in the fibre rearrange in the longitudinal direction. It also makes the molecules more tightly packed, this thanks to a higher degree of crystallinity when they are drawn. This process enhances the strength and elasticity and minimises the stretch of the fibre. Mather and Wardman (2015) mention that fibres that have not been stretched do not have good mechanical properties. This can be avoided by stretching them five or ten times, or more, of their former length.

The process of giving texture to the filaments is connected to the fact that natural fibres, such as cotton or wool are less compacted containing air pockets, giving the yarn a higher surface area (Block, 2014). This gives the fabric some desired properties such as the ability to behave both as an insulator in cold temperatures and the ability to transport moisture in higher temperatures. Block (2014) mentions that these characteristics are something that is desired for synthetic fibres as well and that is the reason why irregularities, or crimp, is needed on the fibres. There are many different processes to achieve the texturing and one example is false-twisting, where the yarn is heated and twisted with an apparatus and is afterwards cooled down and the irregularities are obtained.

3.4 Polyester, acrylic and nylon

The most common polyester fibre is polyethylene terephthalate, PET, but there are also for example polybutylene, PBT, and polytrimethylene terephthalate, PTT (Mather & Wardman, 2015). Polyester consists of an ester of substituted aromatic carboxylic acid, with the minimum amount of 85% of the fabrics' weight (Block, 2014).

Polyester, and mainly PET, are by far the most common synthetic materials (East, 2005). East (2005) states that the reason why is because “They are inexpensive, easily produced from petrochemical sources, and have a desirable range of physical properties. They are strong, lightweight, easily dyeable and wrinkle-resistant, and have very good wash-wear properties.” (p.95). Block (2014) mentions that polyester fabric is often found in a combination of other natural fibres, mainly because on its own, polyester absorbs oil but not moisture. Disregarding these traits, polyester shows great strength and durability at a low cost. In general, PET fibres are very versatile and can be found in different settings such as apparel, medical and industrial (Mather & Wardman, 2015). Mather and Wardman (2015) also mentions that PET fibres, due to their high tenacity and low abrasion level, can endure dynamic washing programs. Figure 2 shows an image of polyester fibres in form of fleece.

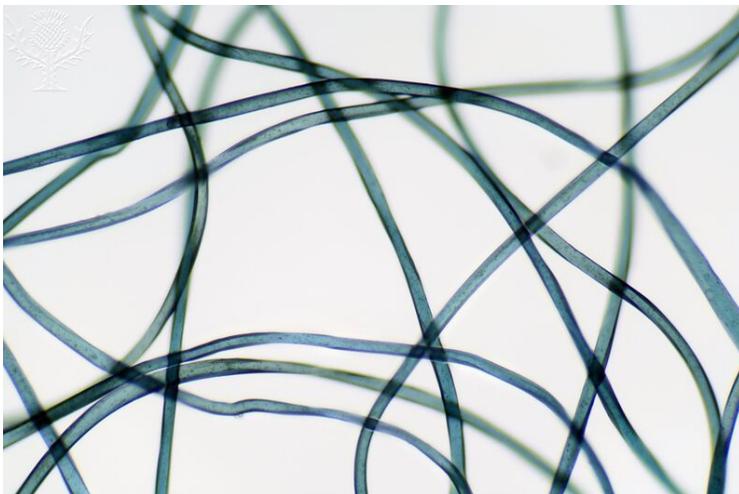


Figure 2. Polyester fibres (fleece LM - X150) (Encyclopædia Britannica ImageQuest, 2019). Reprinted with permission.

Acrylic is made of acrylonitrile units and, similar to polyester, it has to consist of at least 85% of its weight of these (Block, 2014). Mather and Wardman (2015) mention that the demand for acrylic fibres went down between the years 2012 and 2013 and one of the reasons is that the raw material acrylonitrile is expensive in comparison to other synthetic fibres' raw material.

The acrylic fibres have varying properties depending on use but Mather and Wardman (2015) states that acrylic fibres generally have a “balance of satisfactory performance in terms of appearance, ease of dyeing to heavy depths, ease of care and durability.” (p.194). Although compared to nylon and polyester, the acrylic fibres are stiff, breaks easier when stretched, but do not build-up static electricity in the same rate as nylon and polyester (Mather & Wardman, 2015). However, the acrylic fibres do lose strength under wet and warm conditions. As the temperature rises under wet conditions, the material loses its

tenacity at break and gets very extended. Mather and Wardman (2015) state that this is an issue when laundering acrylic textiles and mention that “Hand washing in lukewarm water with minimal agitation is necessary.” (p.195). Acrylic also has characteristics similar to wool, such as bulkiness and the ability to retain warmth (Mather & Wardman, 2015). Typical uses for acrylic include apparel applications, such as knitwear, and industrial applications, such as awnings which need to be resistant to mould and protect against sun. See figure 3 for an example of acrylic fibres, in form of Orlon.



Figure 3. A light micrograph of acrylic fibres (Orlon). (Encyclopædia Britannica, 2016). Reprinted with permission.

The nylon fibre, or polyamide which it is also called, is defined by amide linkages of less than 85% that is connected to two aromatic rings, making up linear macromolecules (Richards, 2005). The two most important nylon fibres are nylon 6.6 and nylon 6.

Richards (2015) mentions that nylon 6.6 and nylon 6 are more expensive to produce compared to polyester. Although the author also states that “They have, however, been able to resist competition, holding niche markets by exploiting certain characteristics. These are principally their tenacity coupled with suppleness and elasticity.” (p.84). Block (2014) also refers to the strength of nylon, which is achieved when the filaments are drawn and give them a small diameter. Other characteristics of nylon are a high abrasion resistance and ease of care, due to less soiling and staining. According to Block (2014), the negative aspect of nylon is the slick feel of the material. Due to this, nylon is often used together with other materials, such as wool, to avoid this aspect. When washed, nylon risks wrinkling and distorting due to breakage of intermolecular hydrogen bonds. This results in washing the garments of nylon in low temperatures and with low levels of agitation (Mather & Wardman, 2015). Typical applications for nylon in apparel is for example lingerie and swimwear. Other applications include carpets, often blended with wool to get appropriate properties. Figure 4 shows an optical microscope image of acrylic fibres.



Figure 4. An optical microscope image of nylon fibres. (Britannica ImageQuest, 2016). Reprinted with permission.

4. Parameters affecting the microplastic emissions from laundry

The amount of microplastic fibres that shed during washing depend on several different laundering parameters. To be able to compare the results from this bachelor thesis with other previous published experiments it is important to acknowledge mechanical and chemical parameters such as the structure and conditions of the textile.

4.1 Detergent and fabric softener

There are differences between studies when it comes to the question if the form of the detergent matters. Hernandez, Nowack and Mitrano (2017) claims that the microplastic releases will be the same if using powder detergent or liquid detergent when washing two different types of polyester (knitted interlock and knitted jersey). One conclusion from the article is that no matter what detergent, the presence of the detergent increases the microplastic emissions from laundry compared to if the laundry was conducted with only water (Hernandez et. al., 2017). Although the detergent causes an increase in microplastic releases, it also protects the fabric from mechanical stress because of the cushioning effect from the surfactant.

De Falco et. al. (2017) washes three different materials (polyester, acrylic and polyester-blend) and claim that powder detergent releases 3538 ± 664 microfibrils per gram of fabric, compared to the releases caused by liquid detergent which were stated to be 1273 ± 177 microfibrils per gram of fabric. They conclude that detergent in any form increases the emissions of microplastics. Washing with only water releases 162 ± 52 microfibrils per gram of fabric. This is a significant smaller number of microfibrils compared to the ones released within the presence of detergent and it conforms the results from the article written by Hernandez et. al. (2017). The higher emissions because of the powder detergent is, according to the Hernandez et. al. (2017), explained by inorganic compounds of the substance which creates friction with the fabrics. There might also be a correlation between higher emissions of microplastics and a higher pH of water and powder detergent. Although the increasing probability of microplastic release due to higher pH, De Falco et. al. (2017) states just like the experiment conducted by Hernandez et. al. (2017), that washing products like softener may decrease the release of microplastics that is caused by mechanical action. In the same way Salvador Cesa et. al. (2017) claims that absent of detergent and conditioner were responsible for less emissions of microplastics in all conditions.

Pirc, Vidmar, Mozer & Kržan (2016) performed a study where they washed six identical fleece blankets with three different parameters changing. One study was made without additions, the second one was conducted with detergent and the third one had both detergent and fabric softener. The tests performed had similar outcomes as the previous researches discussed in this section. They state that the laundry made without any addition was the one releasing the least amount of microplastic fibres. The test with only detergent released the highest amount of fibres but when fabric softener was present, the emissions lowered. The differences were however very low, therefore Pirc et. al. (2016) concluded that the main factor of emissions occurs because of mechanical stress from the washing machine.

4.2 Amount of washes

One conclusion made from the study conducted by Pirc et. al. (2016) was that the release of microplastic emissions decrease with the number of washes. This is also the result from research conducted by Napper and Thompson (2016) where the decrease of fibres with the amount of washes was significant. All of the textiles studied showed a steady decrease from the first to the fifth wash. Salvador Cesa et. al. (2017) get similar results from their study, where the emissions of microplastics decrease with the amount of washes. The emissions stabilise with the fifth wash and the results show that the polyester-cotton blend has the lowest amount of emissions.

Hernandez et. al. (2017) states that “In contrast to other published studies, in our tests there did not appear to be a reduction in the amount of fibres released subsequent washes, and instead there was a steady average release of approximately 0.025 mg microplastic fibres/g textile regardless of wash cycle number.” (p.7040). Worth mentioning is that the amount of microplastic released correspond to a textile with a size of 30x10 cm². Hernandez et. al. (2017) had a hypothesis that the mechanical stress of the laundering process would cause an increase in microplastic emissions. This would however lead to an increase of emissions with the increase of washing time and that was not measured in this experiment.

4.3 Washing time

Before conducting the experiments, Hernandez et. al. (2017) assumed that the emissions of microplastics were going to increase with the increasing time of the laundry. Their results after washing different materials and measuring the emissions afterwards were that the differences in emissions were very small from the two-hour laundry compared to the four-hour laundry and did not double as first imagined. They found a “fixed” amount of fibres regardless of the washing time and various mechanical stress.

When increasing the washing time, the fabric will have a longer exposure time to chemical damage caused by the alkaline detergent (De Falco et. al., 2017). This will lead to an increase in water hardness and therefore an increase of abrasive damage. De Falco et. al. (2017) also claim that industrial washing releases significantly more microplastics compared to domestic washing. This is because of the differences in washing conditions and with a more aggressive way of washing in the industry.

4.4 Fabric type and structure

Hernandez et. al. (2017) claim that the differences in fabric type also changes the amount of microplastic releases. The yarn spinning process will make small fibres attach themselves to the fabric which will later be released during laundry. This is considered to be the majority of the fibres released during laundry in this study. It is important to consider the fabric type; if it is woven, knit or nonwoven. The previous history of the fabric should also be taken into account, together with the fibre geometry.

De Falco et. al. (2017) states that the fabric characteristics matters when it comes to microplastic emissions. They studied three different materials (woven polyester, knitted polyester and woven polypropylene) and the woven polyester released the largest amount of microplastics. The phenomenon of pilling, where fibres gathers on the surface of the textile often occurs on knitted fabrics. This is a big

source of emissions of microplastics and depends on the structure of the textile. The hairiness of a textile is not a parameter that can be associated with the amount of microplastic release since this study has shown that textiles with similar hairiness have different amount of microplastic releases. Another parameter that cannot be directly connected to the microplastic emissions is the weight of the textile. Although the double-knit jersey polyester used in this study had the highest weight, it released the lowest amount of microplastics. A parameter that could be important when observing the emissions is the length of the fibres that compose the yarn. Similar to the study by Hernandez et. al. (2017), the experiment conducted by De Falco et al. (2017) shows that smaller fibres can be released from the textile and increase the amount of microplastic emissions.

One conclusion Pirc et. al. (2016) draw from their study is that the fabric structure has a major part when it comes to microplastic emissions from laundry. They also conclude that the higher amount of release of fibres in the beginning of a washing cycle is the result of loose fibres stuck in the structure of the material. In the end, they say that more research has to be made to come to understand the impact of different washing conditions when it comes to microplastic emissions from laundry.

Salvador Cesa et. al. (2017) have compared three different textile models all made of 100% polyester. The experiments comprised of a shirt, a blanket and a fleece. The study resulted in that textiles like fleece released 180% more fibres when compared to the other types.

4.5 Quantity and weight of microplastics released

To give an idea on how much fibres are shed when washed depending on material, Carney Almroth et. al. (2017) showed that polyester fleece fabrics released the most amount of fibres with $7360 \text{ fibres/m}^2/\text{L}^{-1}$ in average, which gives around 1100 fibres for a 100 cm^2 polyester fleece fabric. When compared with knitted polyester fabrics, nylon and acrylic, these materials released significantly less fibres, with around 0-20 fibres from a 100 cm^2 piece of fabric. Another study, conducted by Browne et al. (2011), showed that more than 1900 fibres per wash can be released from a single garment.

Napper and Thompson (2016) washed polyester, acrylic and polyester-cotton blend fabrics at 30°C and 40°C to estimate the amount of microplastics released, when altering different parameters such as detergent, bio-detergent, conditioner as well as no additives. For the calculations of the amount of fibres, an assumed amount of 6 kg of washing load was used. An average of 763,130 fibres/mg of dry fibres from the filter was measured for the acrylic fabric giving the largest amount of fibres compared between the different textiles. The measurements of the acrylic fibres were in average 5.44 mm in length and a diameter of $14.05 \mu\text{m}$. The polyester fabric released in average 475,998 fibres/mg of dry fibres from the filter and the polyester-cotton blend emitted 334,800 fibres/mg of dry fibres from the filter, resulting in the lowest amount. The polyester fibres were on average $11.91 \mu\text{m}$ in diameter and 7.79 mm in length and the polyester-cotton blend had an average of $17.74 \mu\text{m}$ and 4.99 mm in length and diameter respectively. Napper and Thompson (2016) states that the measuring of the fibres was done in a microscope and ten individual fibres were selected for each fabric to estimate the average length and diameter of the fibres. However, the weight of the fibres released showed a different pattern, whereas polyester had the largest amount of fibres emitted from the first wash followed by acrylic and then polyester-cotton blend.

4.6 Other parameters affecting the emission of microplastics

Concluding the results claimed by De Falco et. al. (2017), if the temperature, the water hardness, the mechanical action or the use of powder detergent increases, this results in a larger release of microplastic fibres. However, the study shows that the differences are not that significant. The increase in temperature could lead to an increase in surface hydrolysis of polyester fabrics which will therefore increase the emissions of microplastics (De Falco et. al., 2017). On the contrary, Hernandez et. al. (2017) claim that washing with different temperatures will not affect the microplastic emissions. They washed the textiles in 25°C, 40°C, 60°C and 80°C and the difference in microplastic emissions from the different washes were not noticeable.

Soutukorva et. al. (2019) conclude that parameters that affect the microfibre release could be temperature, the time washing the clothes and the intensity of the centrifugation. The report also mentions that clothes that have previously been worn and where the material is getting looser, also can increase the release. How much detergent and softener affects the release of microplastic has not been determined with affirmatively results.

Salvador Cesa et al. (2017) looked closer into how different machine model could influence the amount of fibres released. They concluded that a top-loaded washing machine led to an increase of 430% in the mass of fibres released when compared to front-loaded. It may be due to the presence of a central agitator and the fact that the top-loaded one had a higher cycle duration and a higher water consumption.

5. Method

In the process of this bachelor thesis, a laboratory work has been made. This chapter will present the materials used and how the laboratory work was conducted.

5.1 Material

In this laboratory work, nylon, polyester and acrylic were examined. The three fabrics were cut into equally big pieces, 70x100 cm. Each fabric was sewn along the sides, with a hem, to make it more comparable with clothes and to prevent loose fibres to release themselves from the raw edges of the textiles. The textiles were sewn with red thread to decrease the risk of interference of the thread with microplastic fibres when observing them in the microscope. The conditions of the textiles were new when bought, they do not have any chemical or mechanical finishing. The nylon is twill woven and the polyester and acrylic are knitted, as shown in figures 5-7. The polyester fabric is of a fleece material and both the polyester and nylon fabric is bought as textile per meter. The acrylic fabric is, on the other hand, cut from a blanket bought at IKEA.



Figure 5. The acrylic fabric used in the laboratory work.



Figure 6. The nylon fabric used in the laboratory work.



Figure 7. The polyester fabric used in the laboratory work.

The laboratory work was conducted in a shared laundry room and the same washing machines were used to keep similar conditions throughout the study, see figure 8. The washing machine is of the brand Miele Professional PW6055 and is front-loaded (horizontal axis), with a capacity up to 5.5 kg of dry laundry. An ordinary program normally uses 50 L of water and the machine can contain up to 25 L of water. There is no existing filter in the machine that collects microplastics.



Figure 8. The washing machine, Miele Professional PW6055, used in the laboratory work.

To collect the microplastic emissions from the laundry machine, a filter was used. The filters are made of nylon, they are cylindrical, open at both ends and have a pore size of 50 μm . The filters were new when bought and have not been rinsed before used.

5.2 Laboratory work

A test laboratory work was made and the purpose of it was to see if the planned execution would work and if the procedure is doable. This was made before the original laboratory work session and the procedure of this session was not as precise as the original laboratory work made later in the project.

Before the first wash, the machine was cleaned by washing an empty machine at 30°C for 38 minutes. No detergent was present in this first cleansing wash. After the machine was rinsed, each piece of fabric was washed separately five times. However, there were only measurements with filters conducted the first, third and fifth time. The reason why this was made, was to be able to analyse the decrease of the release of microplastics between the first and fifth wash and also to save time in the experiment. The weights of the textiles and the filters were measured between each wash as well as before the laboratory work, see Appendix A. This was to be able to calculate the weight of the release from the textiles and to compare these results to the fibres collected in the filters. The densities of the materials were calculated in the lab at Chalmers University of Technology, see Appendix B for the procedure of calculating the density.

Over the pipe with outgoing water, a filter was placed, see figure 9. Therefore, all water leaving the laundry machine was filtered. The filter was sealed with plastic clips to ensure that the microplastic fibres

were retained in the filter. The plastic clips were newly bought to ensure that they were straight and unbroken. The filters were fastened with cable ties and string to the pipe.



Figure 9. The picture shows the filter fastened on the end of the pipe with cable ties, and a plastic clip sealing the end.

The textiles were washed according to the fabric instructions where polyester and acrylic were washed for 58 minutes, with 1400 rotations per minute and in 40°C. Nylon were washed for 44 minutes, with 1000 rotation per minute and in 30°C. An assumption that the washing water reaches the claimed temperature of the machine was made.

The detergent that was used is called “Neutral Colour” which is a liquid detergent especially developed for sensitive skin. Therefore, there are no added perfume or colorants. It contains 15-30% non-ionic surfactants, 5-15% anionic surfactants and less than 5% enzymes, phosphonates and soap. The pH of the detergent is 8.75.

According to The City of Gothenburg (n.d), the water in Gothenburg is soft. Water hardness is a measurement of how much calcium and magnesium ions the water contains (Aqua Expert, n.d). Hard water contains high levels of these ions while soft water contains low levels of them This means that it is possible to use the lowest dosage of detergent when washing in Gothenburg (Gothenburg City, n.d). The information on the detergent recommends 40 ml for a wash loaded with 3-5 kg of laundry with soft water. Since the washing machine during this laboratory work only will be loaded with a small piece of fabric

the amount of detergent was reduced. A tablespoon of the detergent was used in each wash-cycle, which correspond to 15 ml. Apart from the detergent there have not been any other chemical product presence, no conditioner nor any other general cleaners.

Between each wash, the samples were dried in a drying cabinet until completely dry, and then the filters as well as the textiles were weighed. For the filters, a scale with four digits was used and a scale with two digits was used for the textiles. Because of the small amount of microplastic fibres, more digits were needed for the weight of the filters. The amount of fibres collected in the filters were all assumed to be microplastic fibres. When weighing the filters together with the collected fibres, a weight of the microplastics from each material was calculated. This also gave information about the decrease in microplastic fibres with each wash. To check if the substance collected in the filters were only fibres from the washed textile, the textiles were weighed as well.

To calculate the percentage emission of microplastic from the fabric, the equations below ((1) and (2)) were used. E_s is the emission per gram of fabric based on the substances collected in the filter from the outgoing water, m_e [g] is the weight of the material that is filtered from the outgoing water from the washing machine and m_b [g] is the weight of the fabric before the wash.

$$E_s = \frac{m_e [g]}{m_b [g]} \quad (1)$$

E_f is the emission per gram of fabric based on the fabrics' reduction of weight after each wash, m_a [g] is the weight of the fabric after the wash and m_b [g] is the weight of the fabric before the wash.

$$E_f = \frac{(m_b - m_a) [g]}{m_b [g]} \quad (2)$$

Between each wash where filters were used, the textiles were washed with detergent but no microplastic fibres were collected.

After the washes, the filters were brought to the lab at Chalmers University of Technology and were examined through a microscope. The filters were cut up and tape was used to collect the fibres from the filters. These collections were placed on a glass stick and put under the microscope of model LRI, OLYMPUS BX53. By looking at the fibres on the computer screen and using the computer program OLYMPUS cellSens Entry, measurements of the fibres were possible. This was made by drawing a polyline on the different fibres and the lengths of them were decided, figure 10. Pictures of the fibres were taken through the microscope and can be seen in figure 14-19. When using the microscope, the longest and the shortest fibre was observed to be able to estimate the highest and lowest amount of fibres per gram of fabric. The procedure of calculating the amount of fibres are shown in Appendix C.

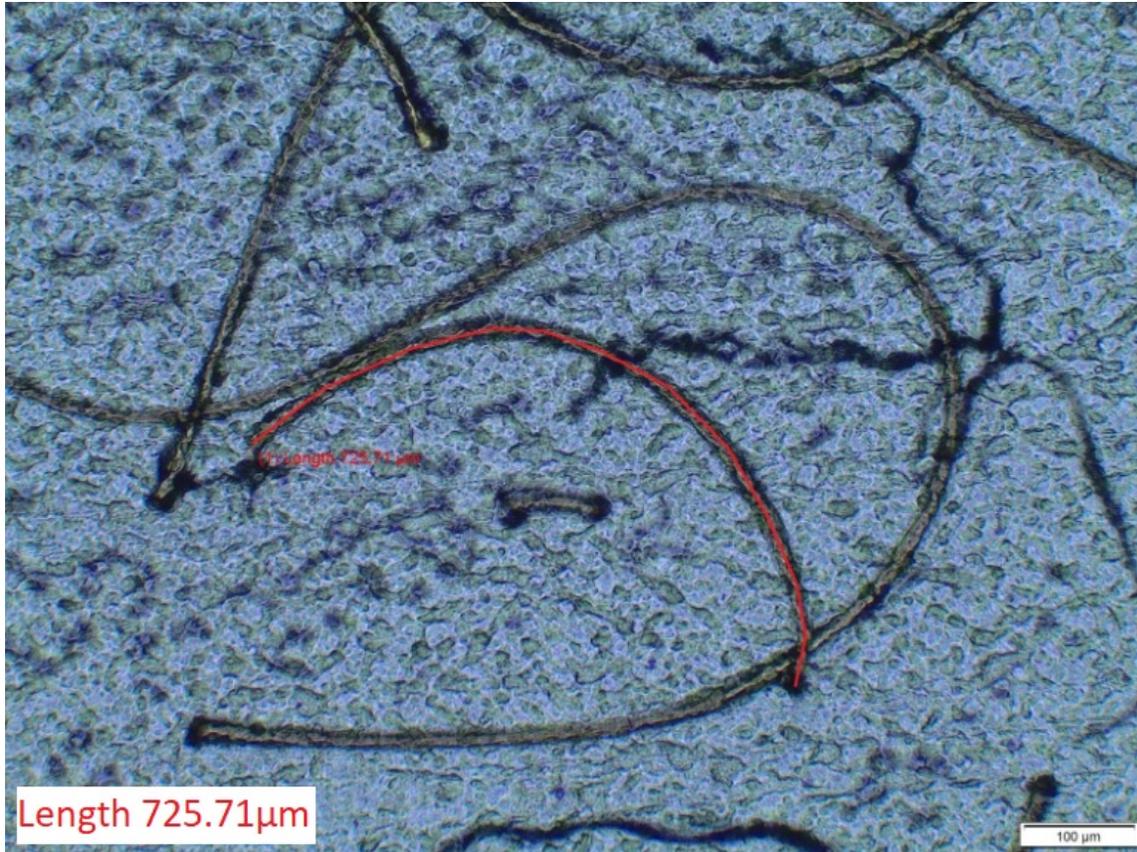


Figure 10. Measurement of polyester fibres with OLYMPUS cellSens Entry.

The densities of the materials were measured by lowering pieces of the material into water and calculating the increase of water together with the weight of the material. A glass rod was used to push at the material to prevent the presence of air bubbles. The procedure of the density calculations is shown in Appendix B.

5.3 Informative sheet

The informative sheet was made using a template from Freepik and with help from Elin Hagman, a design engineer who works at Essiq, a consultant company. It was made in Adobe Illustrator and was focused on the everyday person and to make it as easy to read as possible. These user-oriented guidelines were made to conclude the results from this bachelor thesis and to give advice on how to wash and consume synthetic clothes.

6. Result

The result from the laboratory work and the following microscopic observation will be presented in this chapter. This section also contains the result regarding the quantity of microplastics released and a proposal of the informative sheet.

6.1 Test laboratory work

The result from the test laboratory work was that the planned procedure is doable and that the gathering of the microplastics was relatively easy. The filter used in this test laboratory work was easy to connect to the washing machine. Since the materials washed in this laboratory work were mixed there were no studies made in microscopes and also no conclusions from material structure could be drawn. The differences in emissions from different materials were not examined in this experiment.

6.2 Laboratory work

The results from the laboratory work are illustrated in tables and diagrams. They describe the resulting emissions of microplastic from the fabrics. The material that is collected in the filter is called substance.

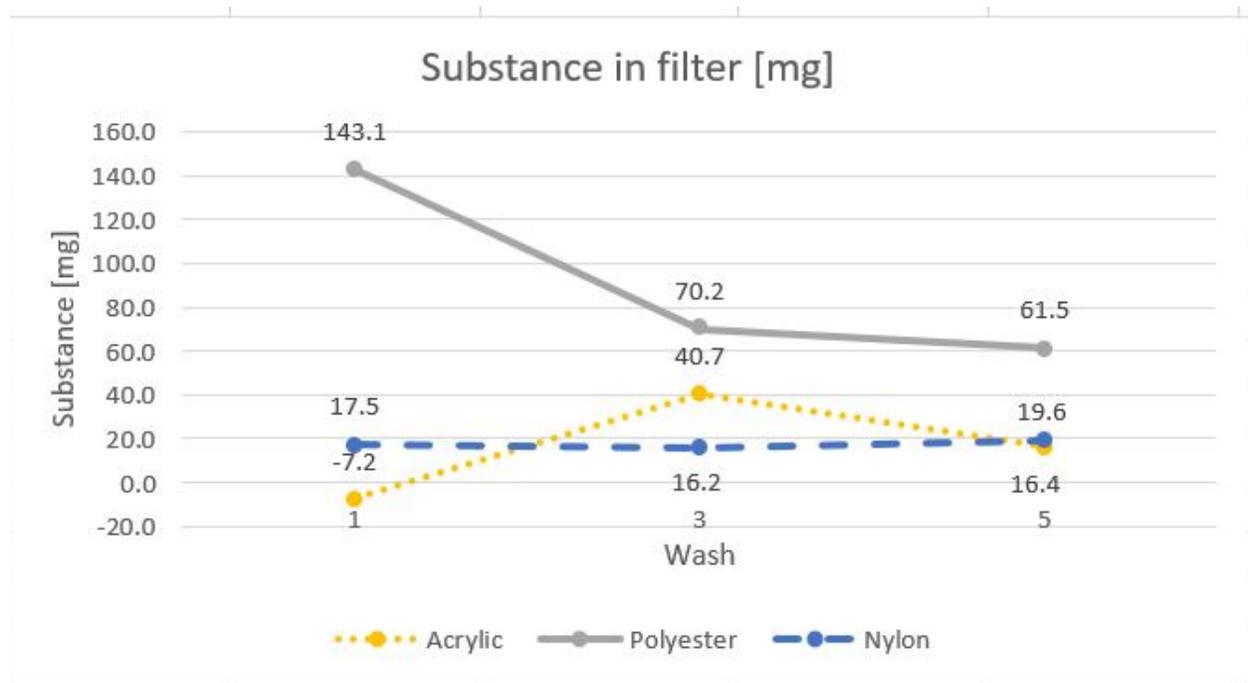


Figure 11. The diagram presents the substance that was collected from each wash for each material.

Figure 11 illustrates the substance that was collected in the filter from the outgoing water from the washing machine. Acrylic has a deviating value which is negative and between the third and fifth wash acrylic has a large decrease of collected substance in the filter. The amount of substance from polyester decreased after each wash. The substance between wash one and three has decreased with 72.9 mg and

the reduction between wash three and five is 8.7 mg. The substance collected in the filter from nylon after the first, third and fifth wash is illustrated by an almost horizontal line.

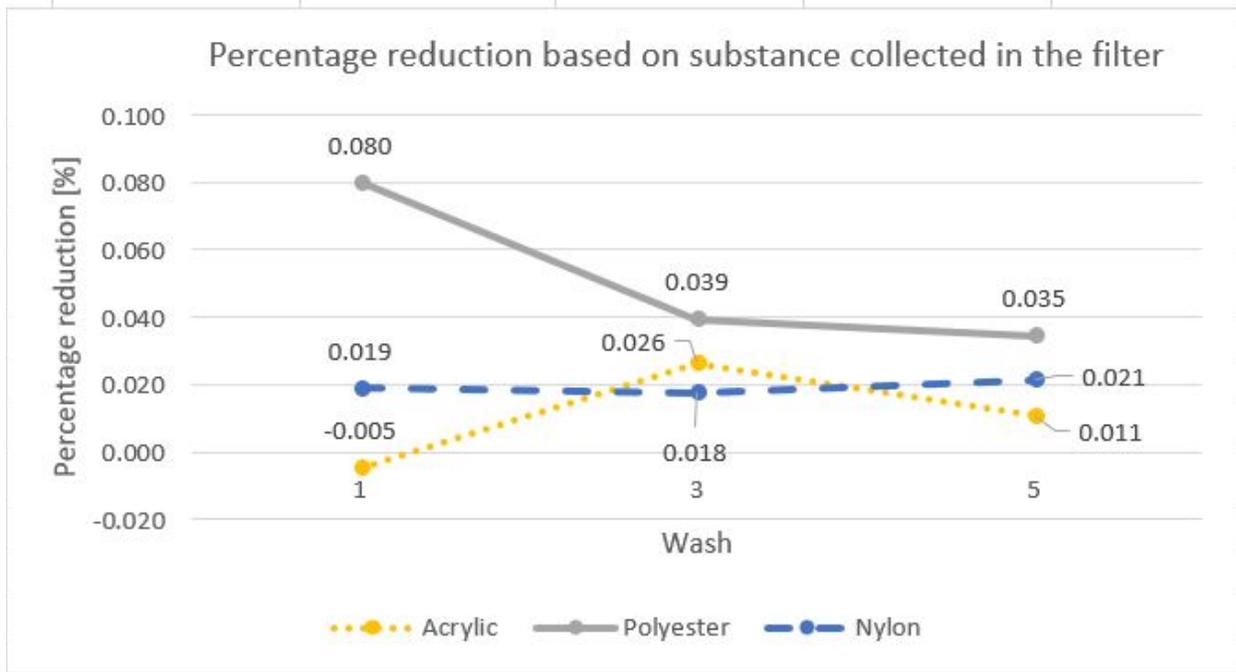


Figure 12. The diagram presents the percentage reduction of microplastics based on the substance filtered from the outgoing water.

The percentage reduction based on the substance collected in the filter is calculated with equation (1) as seen in figure 12. Acrylic has a negative value which is deviating. Polyester has a decreasing percentage reduction. The percentage reduction for nylon is decreasing and then increasing between the washes with small changes. Therefore, the material has almost the same percentage reduction based on the substance collected in the filter.

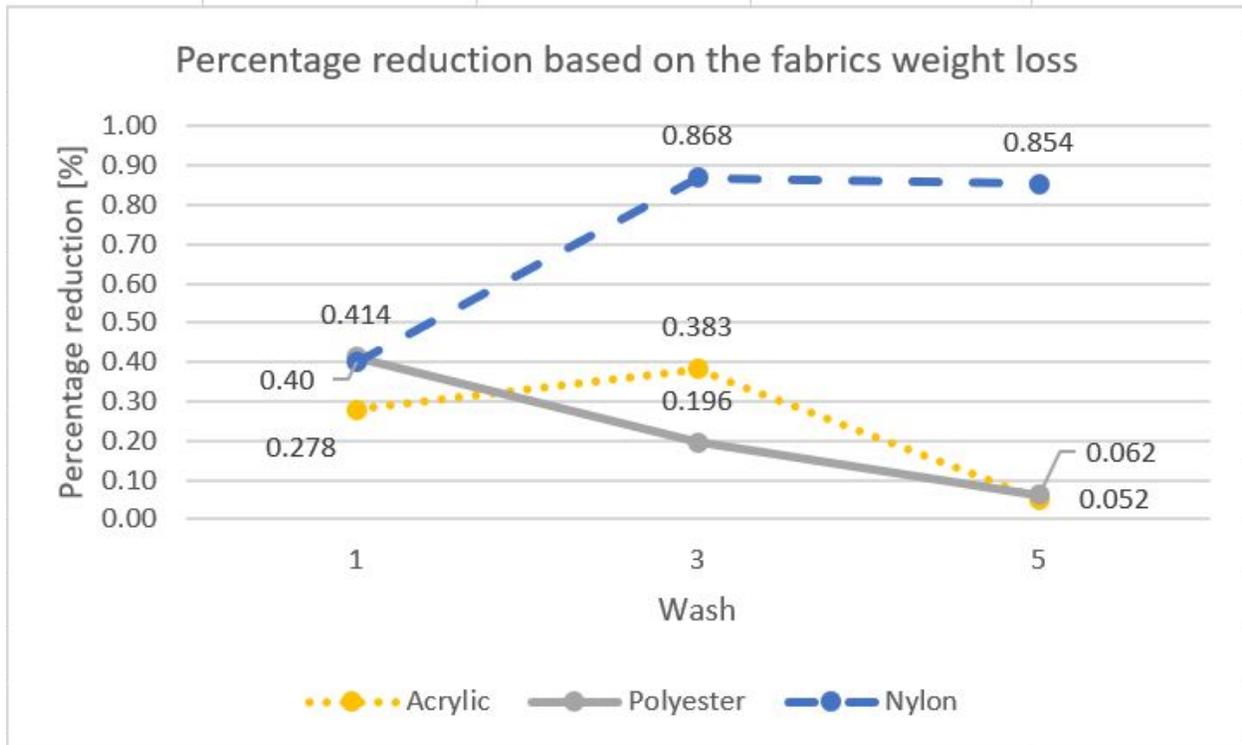


Figure 13. The diagram presents the percentage reduction of microplastics based on the weight loss of the fabrics.

Based on the weight of the fabrics, the reductions of the materials can be seen in figure 13 and are calculated with equation (2). Similar to figure 12, acrylic has the largest percentage reduction after the third wash. Polyester has a large decreasing reduction after all three washes. Nylon has a double increase between first and third wash and a small decrease between third and fifth wash.

6.2.1 Microscopic observation

By looking at the fibres collected in the filters through a microscope of the model LRI, OLYMPUS BX53, the structure of the textiles was observed. The acrylic fibres appear to have a coarse surface with a few bigger fringes as seen in figures 14 and 15. Compared to the other fibres, the mass of the acrylic fibre looks irregular and appear cluttered. The polyester fibres have a uniform diameter and a smooth surface without any fracturing as seen in figures 16 and 17. The fibres made of nylon appear with an extremely coarse structure in some pictures while on others they have a uniform diameter and a smoother surface as seen in figure 18 and 19.

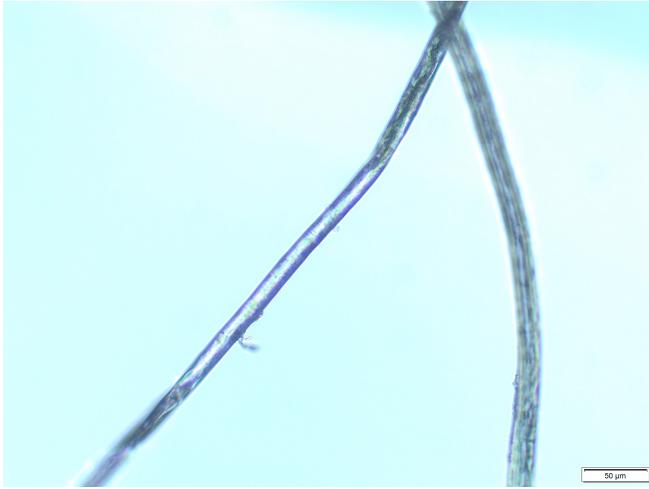


Figure 14 and 15. Acrylic fibres gathered from the first wash studied in microscope, LRI, OLYMPUS BX53.

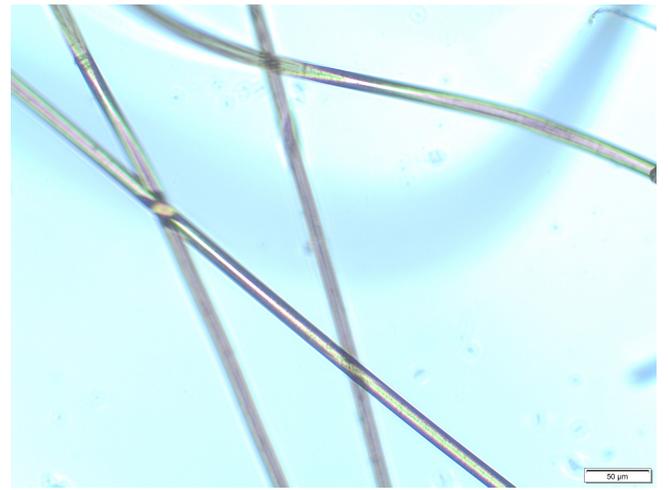
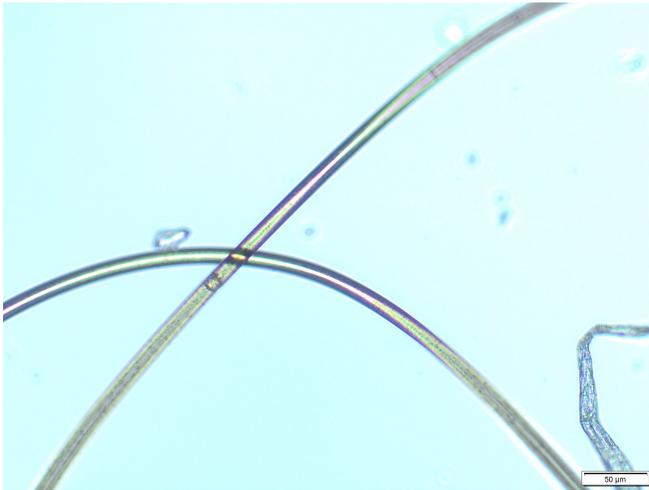


Figure 16 and 17. Polyester fibres gathered from the first wash studied in microscope, LRI, OLYMPUS BX53.

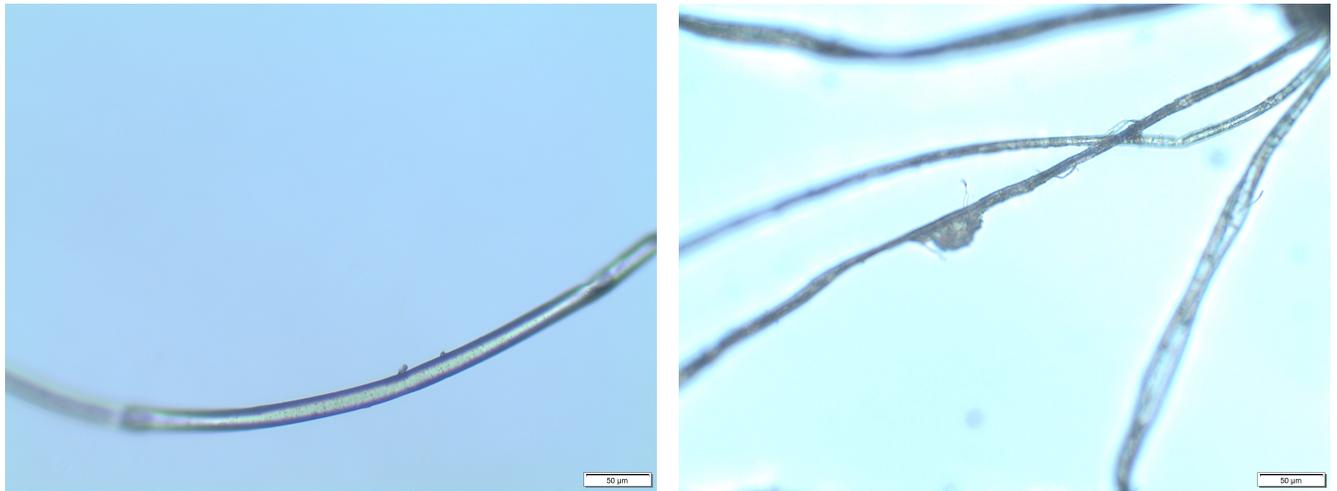


Figure 18 and 19. Nylon fibres gathered from the first wash studied in microscope, LRI, OLYMPUS BX53.

6.2.2 Counting of microplastic fibres

The calculation of the density of the different fabrics showed that polyester had the highest density, whereas nylon and acrylic had similar density as shown in table 1. In Appendix B the calculation of the density is described.

Table 1. The density of the fabrics.

	Density [g/ml]
Polyester	1.39
Nylon	1.02
Acrylic	1.06

Table 2-4 show the number of fibres per gram of fabric that is emitted, and the process of the calculation is described in Appendix C. The polyester fabric released the highest amount of microplastics per gram of fabric, whereas nylon and acrylic had similar emissions of microplastics in terms of quantity as shown in table 2-4. Polyester released between 588 and 10,186 fibres per gram of fabric, whereas the larger amount corresponds to the shorter length of 0.374 mm and the smaller amount to the length 6.687 mm. The amount of fibres per gram of fabric that acrylic released ranges between 341 and 2566, with lengths of 4.009 mm and 0.760 mm respectively. Nylon emitted 172 and 2278 fibres per gram of fabric, with corresponding lengths of 2.454 mm and 0.53 mm. Even though some of the fibres found in the samples observed in the microscope are longer than 5 mm they are still counted as microplastics. This is because of the difficulties of separating the fibres from each other.

Table 2. Calculation of number of fibres per gram of fabric released from the first polyester wash.

Polyester wash 1		
	Fibre 1 (short)	Fibre 2 (long)
Length of fibre[mm]	0.374	6.687
Diameter of fibre [mm]	0.0139	0.0137
Weight of fibres released from first wash [g]	0.1431	0.1431
Volume of one fibre[ml]	0.000000565	0.000000979
Weight of one fibre [g]	0.000000785	0.00000136
Weight of fabric before the first wash [g]	178.96	178.96
Number of emitted fibres per gram of fabric	10186	588

Table 3. Calculation of number of fibres per gram of fabric released from the second acrylic wash.

Acrylic wash 2		
	Fibre 1 (short)	Fibre 2 (long)
Length of fibre [mm]	0.760	4.009
Diameter of fibre [mm]	0.0128	0.0152
Weight of fibres released from second wash [g]	0.0407	0.0407
Volume of one fibre [ml]	0.0000000971	0.000000731
Weight of one fibre [g]	0.000000103	0.000000775
Weight of fabric before the second wash [g]	154.15	154.15
Number of emitted fibres per gram of fabric	2566	341

Table 4. Calculation of number of fibres per gram of fabric released from the first nylon wash.

Nylon wash 1		
	Fibre 1 (short)	Fibre 2 (long)
Length of fibre [mm]	0.530	2.454
Diameter of fibre [mm]	0.0140	0.0237
Weight of fibres released from first wash [g]	0.0175	0.0175
Volume of one fibre [ml]	0.0000000814	0.00000108
Weight of one fibre [g]	0.0000000830	0.00000110
Weight of fabric before the first wash [g]	92.51	92.51
Number of emitted fibres per gram of fabric	2278	172

6.3 Proposal of informative sheet

In figure 20, a proposal of the informative sheet is shown, and the intended readers are people with shared laundry rooms. This because it is easier to reach a wider audience with the higher accessibility of the shared laundry room compared to households having private washing machines. There are also more people visiting the laundry rooms which will lead to more people having the possibility of reading the informative sheet.

The informative sheet was created to be placed in laundry rooms, where people will have easy access to the information when washing their clothes. The design is simple and colourful to attract people reading it. There are also short text sections to make it easy to read. The beginning section with general information about microplastic is broad and not too long. Following this section is a text with easy and feasible proposals on how to make a difference and how to change habits when buying new clothes.

Figure 20. A proposal of the informative sheet.

MICROPLASTIC - NOT SO FANTASTIC!

DID YOU KNOW?

- Microplastics are released when you wash clothes made of plastic materials.
- Microplastics can eventually end up in the ocean and nature, and finally, on your plate!
- The emissions of microplastics are largest the first times you wash newly bought synthetic clothes.

WASH SMART!

- Use low temperatures when washing your clothes.
- Don't tumble dry your clothes.
- If you have to wash synthetic clothes, use a washing bag that prevents microplastics from reaching the environment.

YOU CAN MAKE A DIFFERENCE

- Firstly, don't buy clothes made out of plastic materials...
- ... but if you have to get synthetic clothes, buy them Second hand!

SOURCE: BACHELOR THESIS "MICROPLASTIC EMISSIONS FROM DOMESTIC LAUNDRY: A LABORATORY WORK RESULTING IN A COMPARISON BETWEEN THE AMOUNT OF FIBRES RELEASED FROM DIFFERENT SYNTHETIC TEXTILES "

By Hedda Hagman, Frida Rehnberg, Klara Lindberg and Rebecka Engström Gustafsson

7. Discussion of method and result

In this chapter the method and the result of the laboratory work together with the literature study from the background in section 4, will be discussed. Also, a proposal of solutions to minimise the emissions of microplastics will be presented.

7.1 Comparison between the materials

As presented in figure 11, the weight of the substance from polyester collected in the filter after each wash decreases. This is similar to the study made by Pirc et. al. (2016) where a reduction in the amount of fibres is connected to the wash cycle number. However, the result for acrylic and nylon is very different from the result for polyester since the curves are not constantly decreasing. The curve showing the weight of the substance collected in the filter while washing nylon has a steady average release regardless whether it is the first, third or fifth wash. This is comparable to the result that Hernandez et. al. (2017) received. Their results showed that it did not appear to be a reduction in the amount of fibres released in conjunction with the number of washes. When using clothes in everyday life they are exposed to mechanical stress when worn. The stress causes broken fibres that shed easier when washed and will result in a curve that is not decreasing similar to the result from the study conducted by Hernandez et. al. (2017).

The curve representing acrylic is more complicated since the first wash resulted in a negative number. This means that the filter weighed more before the wash than after the substance was collected. It is possible that from the beginning there was material on the outside of the filter that got released during the wash since the filters were not rinsed before the laboratory work. Another possible explanation is that the empty filter was weighed incorrectly, and once the substance was collected there was no possible way to weigh the filter separately.

Acrylic is also, as mentioned in the theory section 3.4, a fabric with fibres that are fragile and get reduced strength when washed in warm and wet conditions. According to Mather and Wardman (2015), they recommend washing this material by hand in low temperatures. Since the laboratory work was conducted according to the recommendations on the washing label, the acrylic fabric was washed in 40°C. An assumption could then be made that the acrylic fabric should have released the most amount of microplastic fibres. This was not the case, polyester released the most amount of fibres, which according to Mather and Wardman (2015) is not a delicate fabric.

An explanation why polyester releases the most amount of fibres, despite that it is not a delicate fabric, could be the density. The first wash polyester shed more than eight times as much as nylon, but it does also have 34% higher density and will therefore with the highest probability, shed more fibres in terms of weight. Another logical explanation why polyester releases a greater weight of microplastics is the structure of the fibres. It has, as mentioned when observing the fibres in a microscope, a smooth surface without any fracturing. This could increase the risk of emissions since the fibres probably slip more easily. Acrylic and nylon however have more coarse structure as seen in the microscopic observation presented in the result, and therefore the fibres are able to attach themselves to each other in greater occurrence.

Comparing the three materials with each other is complex since there are more parameters than the material of the fabric that affect the amount of microplastics released. The material composition as well as the fibre type, the fibre mix and the length of the fibres has a great influence and so does the construction of the fabric. Depending on the spinning-, weaving- and engraving technique, products of the same material releases a different amount of fibres. According to the Swedish Environmental Protection Agency (2017) textiles manufactured with loose constructions shed more than textiles manufactured with tight knitted constructions and since the three textiles compared in this bachelor thesis are constructed differently that will affect the result. This is something that should be considered when comparing the results for the three materials.

7.2 Differences between the weight of the fabrics and filters

The results from the laboratory work in figure 12 and 13 present a difference between how much the fabric has decreased in weight and the weight of the substance that was collected in the filters respectively. When the material is washed, the fibres should be collected in the filter, except for small particles that can pass through the filter with pore size 50 µm. Therefore, the weight of the substance in the filter should be almost the same as the weight loss of the textiles, but the results show a big difference. The fabrics have a bigger weight decrease than the weight of the substance collected in the filter.

The difference between the weight of collected substance and the weight loss of the fabric can depend on the transportation of the textile between the wash and the lab. The fabrics were exposed to stress and could therefore loose fibres. To avoid this error source, the washes and the weight measuring should be conducted at the same place and if that is not possible, the fabric could be transported in a paper bag with smooth surface to avoid shedding and static electricity.

Another reason for the difference between the weights could be because of the filters used in the laboratory work. They were not enclosed but were instead open at both sides, see figure 9. This meant that they had to be sealed with plastic clips. The plastic clips were bought solely for this purpose which meant that they have not been bend or broken. Although, there might have been gaps or openings that could have let out microplastic fibres. In that case, substance could have been washed out from the filter and decreased the resulted weight of substance. By using a filter with a closed edge, it would be possible to have a more accurate result of the substance's weight. The cable ties fastening the filters on the pipes could also have been loose and let out microplastic fibres. The laboratory work started with weighing the filters separately and after that they were used in the lab. The filters were not rinsed and loose material on the outside of the filters were included in the weight of the separate filter. That could have led to a greater weight of the filters than the actual weight after a wash when loose material was washed of.

The washing machines can be a reason to the difference in weight loss of the fabric and the weight of collected substance. They have been used a lot since they are situated in a shared laundry room and therefore it is a probability that fibres from earlier washes were collected in the filter and also that fibres from the laboratory work got stuck in the pipes because of deposits. An improvement to this could be to clean the machine more accurate and after the wash a rinsing program could be used to make sure that all the fibres are collected in the filter.

7.3 Weight and quantity of microfibrres

In this bachelor thesis, polyester released the largest amount of microplastic both in terms of weight and quantity. However, nylon and acrylic showed more varying results. They correspond in terms of quantity, with 172 to 2278 fibres per gram of fabric for nylon and 341 to 2566 fibres per gram of fabric for acrylic. Although, in terms of weight, acrylic shows a higher release of fibres if disregarding the first wash. The acrylic fabric released 40.7 mg from the second wash compared to the second wash for nylon which released 16.2 mg of fibres. One reason why the quantity is similar between the different fabrics is connected to the fact that the acrylic fibres that were chosen are longer and therefore gives a smaller quantity of fibres even though the weight is larger.

When comparing the results from the bachelor thesis with other reports, the different studies shows varying results in terms of the amount of fibres released. The study conducted by Carney Almroth et. al. (2017) showed similar results to this bachelor thesis, where fleece polyester released the largest amount of fibres and acrylic and nylon emitted fewer fibres. However, the study by Carney Almroth et. al. (2017) showed that the difference in the amount between the three textiles was much greater compared to the difference between the amount of released fibres from polyester, nylon and acrylic presented in this bachelor thesis. In another research conducted by Napper and Thompson (2016), the results show that acrylic released the largest amount of fibres, compared to polyester and polyester-cotton blend. Regardless, there are difficulties comparing the quantity of fibres released in their report with the results in this bachelor thesis since the amount of fibres released are presented in different ways. Napper and Thompson (2016) present it as fibres per mg of dry fibres from the filter and this bachelor thesis presents it as number of emitted fibres per gram of fabric. In the study conducted by Browne et. al. (2011), the results are presented as 1900 fibres per wash from a single garment of any material. Similarly, this results in difficulties when comparing their results with the results from this bachelor thesis, since neither the weight of the garment is specified or the type of material.

Section 4 of this bachelor thesis shows that some research (De Falco et. al., 2017; Soutukorva et. al., 2019) focuses on the quantity of fibres released whereas Napper and Thompson (2016) mention both the weight and the quantity of fibres released. De Falco et. al. (2017) used a method where the number of fibres per unit area were calculated in a small rectangle (7.8 mm^2) by visual observation. After that, the number of fibres per unit area were multiplied by the total area of the filter to get the total amount of fibres in the filter. De Falco et. al. (2017) also used a second counting method, where a larger area of the filters was used for the calculation. This was to validate the results and when compared, both methods resulted in similar values at a significant level of 0.05. Napper and Thompson (2016) have instead used a method similar to the one used in this bachelor thesis, but instead measured ten fibres and calculated the average amount of fibres released from this. Both methods use extrapolation to find out the total amount of microplastics released, which might give inconclusive results. The Swedish Environmental Protection Agency (2017) mentions that there is no standardised method when counting microfibrres. Consequently, it can be difficult comparing the results between different reports when the methods vary, and a standardised method of counting microplastic fibres could be of interest especially when comparing different types of synthetic textiles with each other.

Uncertainties were observed with the method used for calculating the quantity of fibres in this bachelor thesis. Since the fibres observed in the microscope were of a substantial amount, there were difficulties with determining the largest and smallest fibre with certainty. This result in great uncertainties when drawing conclusions about the actual quantity of fibres released. Similarly, an assumption can be made that the ten fibres chosen in the report by Napper and Thompson (2016) might not represent the actual average value of all the fibres collected. The reason why the method of choosing the largest and smallest fibres was selected in this bachelor thesis, instead of counting a selected few to get an average value, was that this gives a greater range of possible fibres released.

Assumptions are often made that the largest quantity of microplastic emissions should also result in the largest weight. Although this is not always the case since the weight and quantity of the microplastic emissions do not always correspond. This brings forward the question of which of the two parameters are of greatest importance. On one hand is it easier to get a more trustworthy result from measuring the weight, but at the same time the quantity of microplastics emitted might be of more value. For example, when discussing the amount of microplastics ingested by marine animals, it might be more relevant to know the number of microplastics ingested instead of the weight.

7.4 Further discussion of method

The results from the laboratory work are not similar to domestic washing when it comes to the mechanical parameters. De Falco et. al. (2017) as well as Hernandez et. al. (2017) use steel balls to imitate domestic washing. This is to simulate zippers, buttons and other mechanical parameters present in usual domestic washing. The materials used in this bachelor thesis were cut fabric and not clothes. This means that the results from the laboratory work are not representative for domestic washing but could instead be seen as a benchmark of the microplastic emissions from synthetic materials overall.

There are a few factors and parameters that could be improved to future research similar to this bachelor thesis. The materials studied were very different from each other when it came to fabric structure and density. It could be interesting to look at more similar materials such as Hernandez et. al. (2017) did when they observed jersey and interlocked polyester. Another example is to look at different materials with the same contexture, like knitted polyester, knitted acrylic and so on. This could lead to a more representative result.

In the laboratory work there was one wash conducted before the measurements to ensure that the washing machine was cleaned, and it is not entirely sure that all the fibres were gone. Pirc et. al. (2016) used citric acid and filtration of the outgoing water, to ensure that the washing machines were clean. There was no explanation exactly what impact the citric acid did had for cleaning of the washing machines. In further research within this area, the cleaning processes could be more specific.

Only one sample of each textile was washed. To be able to draw conclusions within a subject it is preferable to have three test opportunities. This is to get a standard deviation curve that shows deviating results that might not be representative for the experiment. For example, the measurements from the wash of the acrylic textile resulted in a deviating weight from the first wash, and this could have been prevented

by conducting more washes. In future research about microplastic emissions from laundry it is suggested to wash at least three samples of each material.

Since previous researches (Salvador Cesa et. al, 2017; Pirc et. al., 2016; Napper & Thomson, 2016) show that the emissions of microplastics seem to stabilise around the fifth wash, it might not lead to differentiating results if more washes were conducted. This means that the number of washes might not need to be more than five in number, similar to this bachelor thesis and earlier research.

7.5 Further discussion of result

When observing different reports and research within the subject of microplastic emissions from laundry it is difficult to draw conclusions because of the varying results. Different reports contradict each other when it comes to parameters affecting the emissions of microplastics from washing synthetic clothes. Likewise, the results vary when comparing different reports in relation to the quantity of fibres released. In the report by Napper and Thompson (2016) they concluded that acrylic released the largest quantity of fibres, in comparison to the study conducted by Carney Almroth et. al. (2017) which showed that polyester fleece fabric released significantly more fibres compared to the other fabrics in the experiment. However, since the studies have looked at different parameters, types of construction, area and weight of fabric washed, it is difficult to make comparisons. These completely different results show that further studies must be made within the area of microplastics, especially when it comes to microplastic emissions from laundry.

Results from previous research have shown that detergent plays a big role in the amount of microplastic releases from synthetic material (Hernandez et. al., 2017; De Falco et. al., 2017; Pirc et. al., 2016). If the washes were conducted without detergent or softener the microplastic emissions were significantly lower than if additions were present. To wash without detergent is not a realistic approach because of the advantages of using detergent for, for example, soil removal. Therefore, the results from research when washing without detergent is not something that is interesting for the everyday person. Although it could be useful when deciding how much detergent to use. If there is knowledge about how much the additives are affecting the emissions of microplastics, it could be easier to choose to wash with less detergent.

7.6 Possible solutions to the problem with microplastic emissions

Today, there are a few solutions to the problem with microplastic emissions. Guppyfriend, a company founded in Berlin through the organization Stop!Microwaste, is one solution in the form of a bag collecting microplastic fibres when washing clothes (Guppyfriend, 2019). This bag has a pore diameter of 15 μm and is made of polyamide 6.6. The material itself does not release microfibrils because of the structure of monofilaments that is more like sticks than threads. Although the bag is made out of synthetic material, it is untreated, undyed and does not contain any additives. Guppyfriend (2019) states that with the Guppyfriend washing bag, 86% fewer fibres are released compared to a wash conducted without the bag. The washing bag will also protect the clothes and extend their lifetime because of the decrease of mechanical stress. The Guppyfriend washing bag has to be used with liquid detergent and should not be tumble dried. It is important to not rinse the washing bag under running water since this will cause the microplastic fibres to end up in the environment.

In addition to the washing bags there are also another solution called Cora Ball that gathers microplastic fibres and prevent them to end up in the environment (Cora Ball, 2019). The Cora Ball is designed in Vermont, US and is made of 100% recycled and recyclable soft and stretchy plastic. Although plastic, the material is constructed to withstand the heat of a dryer. When washing clothes with a Cora Ball, 26% of the microplastic fibres per load are caught (Cora Ball, 2019). Parameters that affect the uptake of fibres are for example wash settings and wash frequency. Usually only one Cora Ball is enough with one wash but if you are a large family, up to three Cora Balls are recommended. It is important to consider what type of material is washed when using a Cora Ball. The ball could easily get tangled up in lace, tassels or similar structures. If these structures are present it is favourable to wash them in a mesh bag. The fibres collected with the Cora Ball should be put in the trash to prevent them to end up in the environment.

Mimbly, a Sweden based company consisting of students from Chalmers University of Technology, is yet another solution to the problem of microplastic emissions from laundry (Mimbly, n.d.). The Mimbox is a filter that is attached to the washing machine which filters the water and gathers the microplastic fibres. Mimbly (n.d.) states that the Mimbox also saves energy and water by analysing and reusing the clean water collected from the laundry. The Mimbox is in a pilot state and has only been tested at some hotels and tenant associations around Gothenburg.

Additionally, filters connected to the outlet of the washing machines, are another type of solution to prevent the microplastics from reaching the WWTPs. Brodin, Norin, Hanning and Persson (2018) mention both solutions that is currently available on the market and also start-ups launching microplastics filters. The filters that are commercially available now are principally made for households with under-dimensioned or individual piping systems. Brodin et. al. (2018) mention for example, Filtrol 160 by Wexco environmental. The filter is connected to the outlet of the washing machine and is supposed to remove synthetic fibres form the effluent. However, Filtrol 160 does not state to remove microplastics and therefore it is uncertain if it removes small particles. An example of a filter for a more general use, is a solution by PlanetCare which was made available in 2018 (Brodin et. al., 2018). The filter is specifically constructed for each buyer since it is placed in the drain pump filter or drain pipe in the washing machine. PlanetCare claims that 80% of the microfibrs are removed when the filters are used during washing (Brodin et al., 2018). In the study conducted by Brodin et. al. (2018) both solutions were tested to detect if the filters do retain any particles. The result showed that around 30 - 60% of the weight of particles from the effluent could be retained by using either the filter by PlanetCare or the Filtrol 160.

In all of the solutions mentioned above, the filters need to be cleaned by hand and then the fibres are supposed to be disposed in the waste bin. These solutions are suited for developed countries where the residual waste is burned. However, in countries where this is not the case, the fibres from the washing machine will instead reach the environment via deposits. This brings forward the question about implementing solutions for countries with different types of waste management which means that the solutions have to be adapted to the specific conditions for each country.

The Swedish Environmental Protection Agency (2017) suggest different solutions to minimise the emissions of microplastics, both in Sweden and in the EU. The main focus is to enhance the knowledge about microplastics for the concerned stakeholders. For example, one suggestion is to give a workshop for

textile companies, where they can share their knowledge of this issue and maybe come up with appropriate solutions to minimise the emissions. The Swedish Environmental Protection Agency (2017) also mentions information to households. They suggest that the Swedish Consumer Agency should inform the households, via forums and consumer services, about microplastics from laundry and how they can minimise the emissions. This will hopefully result in consumers making informative decisions when buying synthetic clothes and how they can wash the products to minimise the release of microplastics. It is important that Sweden spreads information about waste management and littering to prevent microplastics ending up in the environment since these are two of the biggest sources of microplastic emissions globally (Swedish Environmental Protection Agency, 2017).

8. Social and ethical aspects

A positive outcome of this bachelor thesis is making more people aware of how their microplastic emissions caused by laundry washes affect the environment. That in turn will contribute to people making more sustainable choices when consuming and while washing their clothes.

An ethical aspect to consider is that this bachelor thesis results in the production of an informative sheet that might affect textile companies. The customers can change their habits and start buying second hand and other materials instead of plastic textiles. Polyester has been found to release more microplastics compared to acrylic and nylon. This could aggravate marketing selling for companies whose focus area are on clothes made out of polyester and therefore jeopardise the concerned companies' futures. Keane and Willem te Velde (n.d.) write in their report about the importance of the textile and clothing industries in growth and developing countries. Closing down industries in developing countries which are not often as resilient to pressure and change as developed countries, could result in leaving already vulnerable people without work and salaries.

An issue with the emissions of microplastics today, is that the producers of synthetic textile do not have to take responsibility for the impact microplastics have on the environment (Swedish Environmental Protection Agency, 2017). The environmental cost, in this case the cost caused by the release of the microplastics, is not included in the final price of the textile. In Sweden there is a law called "producer responsibility" which is a framework affecting producers of packaging, giving companies a responsibility of recycling their packages and magazines (Förpackning och tidningsinsamlingen n.d). They can fulfil the law by financing the collection and recycling by packaging fees which makes the recycling a part of the final cost. An explanation why the textile companies are not held accountable for their emissions is related to the fact that microplastics from textiles, and other sources as well, is a fairly new discovery.

Acrylic and nylon have turned out to shed a smaller amount of microplastic fibres than polyester. A rebound effect of this might be that people assume that consumption and washing of acrylic and nylon is the opposite to bad, which is not the case. The best option is to not consume any of the three materials at all, since they all contain microplastics. The risk of making people stop consume synthetic clothes is that they will consume clothes made out of other materials, such as cotton. Cotton is often bleached, and hydrogen peroxide is usually used during bleaching (John & Anandjiwala, 2014). It is preferable to use non-peroxide bleaching to decrease the impact on the environment. There are also chemicals used when colouring and processing the cotton. Furthermore, around 10,000 litres of water are used when farming one kilo of cotton (Swedish Society for Nature Conservation, 2017). These numbers are big compared to the amount of water used when producing synthetic clothes, such as polyester, that only needs 6% of the amount of water used when producing clothes made out of cotton. On the other hand, the carbon dioxide equivalent (CO₂-eq) comparison between the materials are positive from the synthetic material point of view. Swedish Society for Nature Conservation (2017) claims that a polyester dress emits 17 kg CO₂-eq whereas a t-shirt made out of cotton only releases 4.5 kg CO₂-eq. It might seem environmentally friendly to buy cotton clothes instead of synthetic clothes, but it is important to consider other parameters, such as water consumption when comparing the different materials.

Another ethical aspect is how the microplastics are threatening the lives of millions of marine animals. Every year seals, whales, dolphins, seabirds and many other animals become ill because of the plastic waste in our oceans and nature. After ingesting microplastics, the animals may suffer for months or even years before they die (World Animal Protection, 2017). As previously mentioned, the microplastics might also climb the nutritional chain which will increase the risk of humans eating the plastic (Granmar, 2017). Microplastics with particles smaller than 5 µm in diameter can according to studies be taken up by fishes' tissue - in liver, gills and intestines.

8.1 Effects of the laboratory work

When conducting the laboratory work and washing clothes, a lot of water and energy will be used. As mentioned in the method, a domestic washing machine uses around 50 L of water per washing program. Since the laboratory work included 15 cycles of washes, plus one additional test laboratory washing cycle, the project has resulted in the use of around 800 L of water. As well, the filters in the laboratory work are made of a plastic material. Consequently, this could result in the emission of microplastics from the filters which can potentially reach the environment.

8.2 Potential impact of this study

The informative sheet designed in this bachelor thesis will be put in shared laundry rooms and will be read by the people washing their clothes there. This might lead to a change in their washing habits in order to minimise the microplastic emissions from their clothes and thereby lower their impact on the environment. Hopefully, people will spread the information further and increase the knowledge about microplastics emissions from laundry to a broader audience. Depending on how the information is received, it is possible to use these guidelines in other contexts such as through environmentally friendly organisations. This in order to reach households with individual washing machines.

9. Conclusion of this bachelor thesis

This bachelor thesis has resulted in a comparison between the three materials which was the aim of the project. Fleece polyester turned out to shed the greatest amount of microplastics, both in terms of weight and also quantity, while acrylic and nylon behaved more similar to each other. An informative sheet has also been made and it has been possible to study the microplastics in a microscope. In summary, the goal of the project has been reached.

However, as shown in the discussion, the method and result are worth analysing. To be able to draw further conclusions, more parameters of the textiles should be taken into account, for example how they are manufactured and constructed. That the decreasing weight of the textiles deviates from the weight of the substance collected in the filters is another proof that the method is not perfect. A conclusion from this thesis is that for a more trustworthy method, more resources are required in terms of time and money. Another two samples and measurements of each textile would have given a more accurate result and so would using a newly bought washing machine.

This bachelor thesis shows that the weight is easier to calculate compared to the quantity of the microplastics. However, the number of microplastics released might be of more interest. The other reports that have been discussed in this bachelor thesis display varying results in terms of the quantity of microplastics released and the researchers have used different methods when counting the fibres. Consequently, this makes it difficult to compare the different reports and it would be desirable to use a standardised method in the future when calculating the amount of microplastics released.

A conclusion made while writing this bachelor thesis is that the problem with the release of microplastics is something that should be taken into consideration earlier in the life cycle of the material. This because it is already difficult for consumers to make conscious choices. Producers and politicians could take responsibility for this issue, whether it is by prohibit clothes made of plastic or establish industrial pre-washes. Previous studies in this area all mention that further research has to be made. The result from this bachelor thesis will contribute to more knowledge within this area to be able to solve the problem with microplastic emissions from laundry.

10. References

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Appendix A

Appendix A.1 Klara is weighing the filters.



Appendix A.2 The scale used for weighing the filters.



Appendix B

To calculate the density of the material, the weight was divided by the increase of the water in the test tube in millilitre. A small piece of fabric was cut from each material that was washed in the laboratory work, and then weighed, see table 5. Afterwards, the small piece of fabric was put in a test tube filled with a certain amount of water and then the increase of water level was measured. The volume of water that increased is equivalent to the volume of the piece of fabric, see table 5. To calculate the density, equation (3) was used.

$$\rho = \frac{m}{V} \tag{3}$$

ρ : Density of the textile [kg/m³]

m : Weight of textile [kg]

V : Volume of water that is increasing when the textile is added [m³]

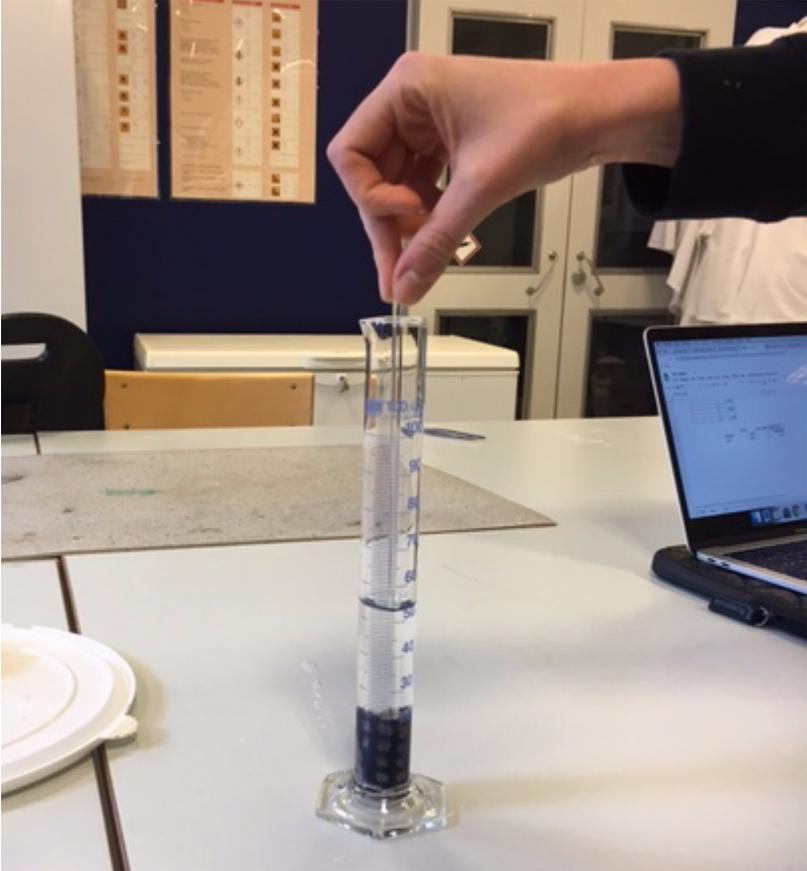
Table 5. The measurements of volume and weight, and the calculated values of the density of the three materials.

	Weight [g]	Volume [ml]	Density [g/ml]
Polyester	2.08	1.5	1.39
Nylon	2.54	2.5	1.02
Acrylic	1.59	1.5	1.06

Appendix B.1 Weighing a piece of the acrylic fabric to be able to calculate the density.



Appendix B.2 Releasing air bubbles when calculating the density of the textiles.



Appendix C

When counting the microplastic fibres, a cylindrical shape was assumed and used when calculating the volume. The shortest and the longest microfibre was observed in the microscope, and the length and diameter was measured. The weight of fibres from the first wash was observed for polyester and nylon. The weight of fibres for the acrylic sample was chosen from the second wash because of a faulty calculation when weighing the filter in the first wash. To calculate the number of fibres released, firstly the volume of one fibre was calculated by multiplying the length measured with the cross-sectional area by using the radius measured, see equation (4).

$$V_{one\ fibre} = r^2 \cdot \pi \cdot L \quad (4)$$

$V_{one\ fibre}$: Volume of one fibre [m³]

r: Radius of one fibre [m]

L: Length of one fibre [m]

The weight of one fibre of the textiles was calculated by multiplying the volume of one fibre with the density of the chosen material, see equation (5).

$$m_{one\ fibre} = V_{one\ fibre} \cdot \rho \quad (5)$$

$m_{one\ fibre}$: Weight of one fibre [kg]

$V_{one\ fibre}$: Volume of one fibre [m³]

ρ : Density of the textile [kg/m³]

Lastly, an estimation of the number of fibres emitted per gram of fabric, was made by dividing the weight of the total amount of fibres released with the weight of one fibre and afterwards dividing this amount with the weight of the textile, see equation (6).

$$n = \frac{\frac{m_{tot.\ fibre}}{m_{one\ fibre}}}{m_{fabric}} \quad (6)$$

n: number of emitted fibres per gram fabric

$m_{tot.\ fibre}$: Weight of the fibres released from the first wash (after the second wash for acrylic) [kg]

$m_{one\ fibre}$: Weight of one fibre [kg]

m_{fabric} : Weight of the fabric before the first wash (after the second wash for acrylic) [kg]