Polyamide 6 fibre recycling by twin-screw melt extrusion of mixed thermoplastic polymers

Siti Zaharah Binti Kunchi Mon

Submitted in accordance with the requirements for the degree of
Doctor of Philosophy

The University of Leeds
School of Design

November, 2019

The candidate confirms that the work submitted is his/her own, except where work which has formed part of jointly-authored publications has been included. The contribution of the candidate and the other authors to this work has been explicitly indicated below. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to the work of others.

Chapter 4

Kunchimon, S.Z., Tausif, M., Goswami, P. and Cheung, V., 2019. Polyamide 6 and thermoplastic polyurethane recycled hybrid Fibres via twin-screw melt extrusion. *J. Polym. Res.* **26**. 162-175. https://doi.org/10.1007/s10965-019-1827-0

Chapters 6 and 7

Kunchimon, S.Z., Tausif, M., Goswami, P. and Cheung, V., 2019. From hybrid fibres to microfibres; the characteristic of polyamide 6/polypropylene blend via one-step twin-screw melt extrusion. *Polym. Eng. Sci*. https://doi.org/10.1002/pen.25327

The author of this thesis performed the experiment and analytical works and prepared the paper draft and co-authors provided suggestions to finalise the submission.

Acknowledgements

I would like to express my sincere gratitude to both of my awesome supervisors, Dr Vien Cheung and Dr Muhammad Tausif for the advice, time and guidance to introduce me to the world of research. Without them, my PhD journey will not be this beautiful. Not to forget, thanks to Prof Dr Parikshit Goswami, who is my first supervisor during my early years of study. His motivation, enthusiasm and criticism are incredible and keep inspired me through these years.

Deeply grateful and thanks to staff and fellow researchers at the School of Design who assist and guide me to conduct lab works; Dr Tim Smith, Dr Tom O'Haire, Dr Andrew Hebden, Mr. Jianguo Qu and Dr Matthew Clark for the TGA experiment. Thanks go to also Mr. Michael Brookes who produced the microscopy images presented in this work. Many thanks to Prof Tom Cassidy who is willing to spare his busy time to teach me to use twisting machine and Dr Jane Scott for inviting me to join her knitting class. I also want to thanks Mr. Algy Kazlauciunas from School of Chemistry for the microscopy images of PA6 and PET blend and Ms. Lesley Neve from School of Earth and Environment for the XRD experiments.

I met many beautiful souls who cherish my days in the PhD room whom directly or indirectly motivate me to complete this thesis; Najua, Soojin, Jihye, Gyeonghwa, Mia, Tian, Nani, Nicole, Bintan, Xenia, Ana, Zi, Pendo, Zohreh and many more. Thank you for sharing your hope, dreams, laughter and smile whenever I need it.

This PhD will not be possible without financial support from my employer, Universiti Tun Hussein Onn Malaysia and Malaysia Ministry of Education which I appreciated and acknowledged.

Lastly, for my family, my husband and my lovely kids, Aqil and Aqilah, who always stand by my side and keen to live abroad with me, your endless love and supports mean so much to me. For my late father whom I lost during my final year of PhD, you will always be in my heart.

Abstract

Textile wastes consist of multi-component materials are hardly recycled due to challenge to sort and separate the waste into a single component. Textile products dominantly produced from a non-renewable source that can be recycled several times before the end of life. Mixed-waste can be recycled together without sorting by thermo-mechanical process to produce hybrid fibres. The aim of this study was to investigate the potential on upcycling polyamide 6 (PA6) polymer mixed with secondary polymers via one-step twin-screw melt extrusion. Three secondary polymers were chosen in this study; thermoplastic polyurethane (TPU) which has interaction with PA6, and two polymers which do not have interaction with PA6; polyethylene terephthalate (PET) and polypropylene (PP). Different blending composition was prepared between PA6 and secondary polymers before being extruded into hybrid fibres through melt extrusion. The secondary polymers were then removed from the hybrid fibres to investigate the properties of the leftover of PA6 component. The fibres were characterised using attenuate total reflectance Fourier Transform Infrared Spectroscopy (ATR-FTIR) and microscopy techniques, the mechanical and thermal properties were investigated via tensile strength and differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA). The results showed that the blending of PA6 with interacting polymer TPU creates novel fibres morphology with multi-connected porous fibres. The mean diameter of PA6:TPU hybrid fibres when the PA6 content at 50% and 80% are 136 and 126 µm, respectively. Thermal and chemical results demonstrated strong interaction happen between PA6 and TPU. Meanwhile, the co-extrusion of PA6 with non-interacting polymer PP and PET formed PA6 micro and nanofibres in the blend, respectively. In PA6:PP blend, the SEM images show the PA6 microfibres with mean diameters of 0.76 µm and 1.13 µm developed in the hybrid fibres with PA6 content 50% and 60%, respectively. The phase inversion between PA6 and PP happened at the composition of 65% of PA6 showing the development of PA6 microfibres in a unique fibre morphology. In PA6:PET blend, PA6 nanofibres with mean diameter of 532 nm to 1026 nm were obtained. The diameter of PA6 nanofibres increase when PA6 content increase in the blend. Later, single jersey knitted fabric was produced from PA6:PP 60:40 blend composition and was treated later to remove the PP component. The treatment process exposed the development of PA6 microfibres fabric which has excellent behaviour in wicking and improved in ball burst strength compared to the untreated fabric. The success of upcycling PA6 fibres with value added properties through single-step melt extrusion can be applied to other mixed polymer waste.

Table of Contents

List of Tables

List of Figures

Chapter 1
Introduction

1.1 Overview

Textile waste has been an issue around the world with 92 million tonnes waste recorded in 2015 (Global Fashion Agenda and The Boston Consulting Group, 2017). With the increasing demand on textiles, the amount of waste generated is expected to increase up to 148 million tonnes by 2030. At the moment, only 25% of the waste is recovered via reuse and recycling route where most of it either incinerated for energy recovery or send off to landfill (Ellen MacArthur Foundation, 2017). Over two-third of textile raw materials are produced from plastic sources, hence incineration or landfill disposal has negative impacts on the environment.

Reuse and recycling can be the preferred option for textile waste. By reusing the product, the life of the product can be extended and the landfill can be avoided. However, recycling is needed for the products that are no longer useable. Four types of recycling approaches can be applied to textile waste; fabric recycling, fibre recycling, polymer recycling and monomer recycling (Ellen MacArthur Foundation, 2017; Sandin and Peters, 2018). The most widely adopted recycling approach in the industry are fabric and fibre recycling. Meanwhile for polymer and monomer recycling, the fibre production is limited to single component polymers such as polyethylene terephthalate (PET) or known as polyester fibres, Polyamide 6 (PA6), and cellulose-based fibres (Palme et al., 2017).

Even though the efforts to recycle the textile wastes into textile fibres have been in place, the conversion of textile waste into materials for clothing is extremely low (<1%) (Ellen MacArthur Foundation, 2017). The nature of textiles products that usually consists of more than one material, either by using blended yarns (e.g. polyester/cotton yarns), bicomponent fibres (core-sheath, pie-wedge, island in the sea types, etc.) or fabric coated with polymer, limits the recycling process. The mix-material products result in complex waste where component polymers cannot be practically separated by commercially relevant technologies. The sorting and separation of mix-materials waste into single component polymers is challenging and results in unsuitability of a large proportion of waste for recycling. There is a paucity of technologies and facilities to sort and separate the mixed waste materials also limits the potential of recycling multi-component products (Östlund et al., 2015).

As most of the textile products are made from plastic sources, thermo-mechanical processing can be used to recycle mixed-waste product. The mixed-waste can be directly blended, melted and re-extruded to produce blended fibres. The mixing of two different polymers is called binary blending and three different polymers is ternary blending. In polymer blends, selection of polymers, blend composition, the viscosity of the polymers and processing conditions affect the morphology and subsequently the properties of the blended fibres. In textile industry, common polymers used to produce synthetic fibres are polyethylene terephthalate (PET) (51%), polypropylene (PP) (~5%) and polyamide (PA) (5.4%) (Textile Exchange, 2018).

The possibility of mixed-waste textile product containing these polymers are high. For examples, polyamide and polyester were commercially produced as bicomponent fibres (Radici Group, n.d.). In carpet industry, polyamide was used as a face fibres and polypropylene as a bottom layer or backing fabric. Marine products such as inflatable raft and life jacket use polyamide as a base fabric and coated with polyester or thermoplastic polyurethane to make it durability against water (Erez, 2018). Complex materials exist in textiles result to the mixed-waste materials once entered the recycling centre. Even for textiles made from a single component, when collected as a waste, can also be mixed with varieties of other textile sources.

Among common synthetic polymers used for textile fibres, polyamide is considered as an expensive polymer (USD2.32-2.42/kg) compared to PET (USD1.22-1.23/kg) (YNFX, 2020).Over 4.55 million tonnes of polyamide was produced in 2014 (Wesołowski and Płachta, 2016). Two types of polyamide frequently use as textile fibres are PA6 and PA6,6 with PA6 dominates the usage in apparel industry (86%) compared with PA6,6 (14%) (Wesołowski and Płachta, 2016).

PA6 or also known as nylon 6 is widely used in many applications such as apparel, carpet, parachute fabrics, tire cord, ropes and tents (Wesołowski and Płachta, 2016). Increasing demand of polyamide products contribute to the abundance of polyamide waste too. For example, carpet which contains approximately 24% of PA6 fibres, is thrown to landfill every year. Fibre grade PA6 is a high value thermoplastic polymer that has a low rate of degradation in landfill. Therefore, to avoid landfill, another option for PA6 waste is by recycling the PA6 containing products. Several studies have shown that reprocessing PA6 fibres into several cycles can be done successfully. However, the repetitive process of melting PA6 fibres may slightly decrease the mechanical properties and stability of the polymer (Tuna and Benkreira, 2017).

Polyamide and other thermoplastic textiles polymers can be processed several times. Recycling the mixed-waste containing different thermoplastic polymers without separation process can be done by thermo-mechanical recycling. Two polymers can be melted and extruded into new hybrid fibres. Blending of PA6 with other materials such as acrylonitrile–butadiene–styrene (Aparna et al., 2017) (ABS) cellulose acetate butyrate (CAB) (Zhang et al., 2015) and chitosan (Dotto et al., 2017) into hybrid fibres were studied previously.

Blending of two different polymers can create interacting and non-interacting behaviour of the polymer blend. Amide group of PA6 and urethane group of TPU create interaction through hydrogen bonding. Non-interacting behaviour was found on the blending of PA6:PET and PA6:PP due to low chemical interaction (Hajiraissi et al., 2017). To improve the interaction on PA6:PET and PA:PP, compatibiliser was used (Aparna et al., 2017). However, the non-interacting behaviour of these polymers can benefit in the production of microfibres or nanofibres.

A study on the interacting and non-interacting behaviour of possible polymers found in textile waste was crucial. There is a paucity of reported work on the blending of polyamide with TPU as hybrid fibres when prior research focused on composite (Cai et al., 2019), injection moulding (Xu et al., 2019) and compressed moulding (Rashmi et al., 2017). Blending of PA6:PET and PA6:PA6 was studied before however focusing on addition of compatibiliser for improving of interfacial connection and the optimisation of the blend focus on PET and PP in the blend (Aslan et al., 1995; Liao et al., 2015; Aparna et al., 2017; Hajiraissi et al., 2017). With the increasing of textile waste collected and lack of technologies to separate the waste, added with high price of PA6, a study on the PA6 blending with other polymers into fibres is needed.

1.2 Research aim and objectives

The aim of this research is to investigate the effect of blending of PA6 polymer with interacting and non-interacting polymer commonly used in textile fibres production. Subsequently, the developed fibres will be processed into fabric form to evaluate their performance for apparel applications. The objectives of this research are to:

i. produce interacting hybrid fibres consisting of PA6 as main polymer blending with thermoplastic polyurethane (TPU) as secondary polymer.
ii. produce non-interacting hybrid fibres consisting of PA6 as main polymer blending with polyethylene terephthalate (PET) and polypropylene (PP) as secondary polymers.

iii. Investigate the properties of the interacting and non-interacting hybrid fibres that blended in different weight composition by:
    a. removal of secondary polymer.
    b. assess the morphology of the hybrid fibres before and after removal of secondary polymer under.
    c. characterise the properties of the fibres concerning thermal, chemical and mechanical and fibre diameter.

iv. produce fabrics made of hybrid fibres and investigate the properties of the fabrics before and after removal of secondary polymer.

Chapter 2
Literature Review

Textile waste has been considered as an environmental issue. The scenario of textile waste management and current methods on recycling textile waste are presented in this chapter. Previous studies on recycling Polyamide 6 and its properties were reported. Different types of textile fibres; single and bicomponent fibres, were also discussed, including the method to produce fibres. Finally, the blending of two polymers in producing textile fibres, with melt spinning approach that is suitable for thermo-mechanical recycling of the polymer blend, will be discussed.

2.1 Textile waste

Textile waste has been an issue all around the world. It is reported that over 92 million tonnes of textile waste generated globally in 2015 and the numbers are expected to increase up to 148 million tonnes by 2030 due to growing global population (Global Fashion Agenda and The Boston Consulting Group, 2017). In UK alone, 921,000 tonnes of textile waste collected in 2017 which end up in landfill (WRAP, 2019).

Textile waste can be divided into two categories: pre-consumer waste and post-consumer waste. Pre-consumer waste refers to by-product materials generated by textile industries such as surplus fabrics, yarns and fibres, whereas post-consumer waste is contributed by the owners of textiles including clothing and textile household such as bed linen, curtains, towels and floor covering (Echeverria et al., 2019).

Textile waste can be either reused, recycled, incinerated or sent off to landfill. Almost 55% of textile waste collected in UK was sent to landfill and only 36% was recovered through reuse and recycling process (WRAP, 2019). Most of the waste was reused domestically through second hand or charity shop or exported to developing countries. Only small proportion of the waste was recycled, currently into down-cycle application such as wiper, insulation materials and padding mattress while less than 1% of the waste was recycled back into textile fibre (Ellen MacArthur Foundation, 2017).

The route of the textile waste can be improved, to conserve the resources. The unwanted clothes, mostly exported to third-world country where there are no proper recycling and collecting facilities, will end up wasting the valuable materials into landfill. Moreover, in 2015, East African Community announced to ban an importation of used clothing that will affect the utilisation of the collected textile waste in the future (SMART Secondary Materials and Recycled Textiles, n.d.).

Over two-third of textile raw materials derived from petroleum resources have high compostable times in landfill, compost and aquatic environments. The risk of harmful gas emission to the atmosphere such as methane (CH_4) and carbon dioxide (CO_2) is also a significant concern (UNEP, 2002). Department for Environment Food & Rural Affairs (DEFRA, 2013) estimated that 3 tonnes of CO_2 can be saved with reusing or recycling of 1 ton of general waste. Sending off the waste into landfill or incinerating bring harmfulness to the environment and contribute directly to the global climate change. The more optimum option for handling the waste is either reuse until the end of product life or recycling.

2.2 Textile recycling

Textile recycling industries were developed with a target to reduce both pre-consumer and post-consumer wastes and conserve resources while minimising the amount of waste going to landfill (Echeverria et al., 2019). Moreover, most of the textile products are recyclable and have a potential to replace virgin materials. The UK government has also been promoting recycling as more and more waste has been directed towards landfills. Approximately GBP 82 million were spent on disposing the textile waste in landfill (Ellen MacArthur Foundation, 2017). Serious actions have been taken to emphasise recycling such as increasing the landfill tax. It was expected that by 2030, municipal waste including textile waste sent to landfill will reduced to 10% (Bukhari et al., 2018).

Several organisations are involved in recycling textile waste such as Waste & Resources Action program (WRAP), Department for Environment, Food & Rural Affairs (DEFRA) and Carpet Recycling United Kingdom (CRUK). WRAP has launched several plans to promote the usage of textile waste such as European Clothing Action Plan, Sustainable Clothing Action Plan (SCAP) and Love Your Clothes campaign to raise awareness of the value of clothing. CRUK focuses on carpet recycling and acts as a centre and connector for companies and organisations involved in carpet recycling. The target is to decrease the number of carpet waste that goes to landfill and develop close loop recycling of carpets.

London based company Worn Again have a collaboration with several companies to develop FIBERSORT technology with the aim to produce an automated sorting technology that can sort a variety of post-consumer textile waste (Worn Again, 2016). These show that the effort has been made by the private sector to emphasise on the recycling industry. However, these examples limit the recycling effort only onto a single component polymer. Textiles waste consists of mix-materials that encounter difficulties to be sorted and separated were send off to other easier route either landfilled or incinerated (Robert, 2016).

Textile recycling can be divided into fabric recycling, yarn and fibre recycling and polymer/monomer recycling which can be accomplished by either through mechanical, thermal, chemical processing or combination of these processing (Ellen MacArthur Foundation, 2017; Sandin and Peters, 2018).

Fabric recycling makes use of fabrics from pre-consumer waste generated by garment industries (e.g. off-cut fabrics, rejected fabrics) or post-consumer waste contributed by the users of the textiles (e.g. unwanted clothes, old clothes) and converted into new clothes or products. Tonlè, is an example of a company that produced textile products from the pre-consumer waste and managed to save 10 tonnes of waste being send to landfill in 2014 (Explorer, 2019). For fibre and polymer recycling, the methods can be simplified as mechanical recycling and chemical recycling.

2.2.1 Mechanical recycling

Fibre recycling, also referred to mechanical recycling, mechanically shredding the fabric to reclaim fibres for subsequent conversion into yarns or nonwovens. Polyester and cotton fibres, which dominantly used in textile industry were mechanically shredded during recycling process. The reclaimed cotton fibres result to shorter and lower cotton fibre quality thus produced coarser yarn count. Therefore, cotton waste was recovered into down-cycling route such as insulation materials, blankets, wipes, etc (Sandin and Peters, 2018). Pure Waste Textiles Ltd. be able to produce new 100% recycled cotton t-shirt from shredded textile cotton waste (Pure Waste Textiles, n.d.). Apart from recycling into yarn, the recycled cotton and polyester fibres were also produced into nonwoven fabrics for household application (Sharma and Goel, 2017). Low quality fibres restrict the recycling process into fibres found suitable approaches as reinforced composites(Serra et al., 2019; Meng et al., 2019), pressed into compressed mould (Dissanayake et al., 2018), sound absorption panel (Santhanam et al., 2019) or reinforced in brick or mortar (Orasutthikul et al., 2017; Kimm et al., 2018).

2.2.2 Chemical recycling

Other method for textile waste recycling is chemical recycling, either by polymer recycling or monomer recycling. Polymer recycling can be achieved by treating the fibres chemically/mechanically while keeping the polymer or oligomer intact.

Monomer recycling is a process where the polymers/oligomers are broken down to the monomer level. Textile waste consists of synthetic fibres made from thermoplastic polymers which can be chemically recycle to produce new fibres with identical properties to the virgin raw materials. ECONYL Regeneration yarn for example, was produced by recycling textile waste and fishing nets (Moorhouse and Newcombe, 2018). Some examples of regenerated fibres produced through chemical recycling were MIPAN Regen fibres, which are made by recycling PA6 post-consumer waste, REPREVE® PA6,6 fibres made of 100% recycled polyamide fabric (UNIFI, 2008) and CYCLEAD™ fabrics which are made by recycled PA6 fibres (Toray, 2007). The separation of polyester from cotton/polyester blend for example, involved chemical process such as hydrolysis and dissolving in solvent (Ling et al., 2019).

2.3 Polyamide

Polyamides are linear macromolecules containing amide (-CONH-) linkage. Two popular variances in the textile and plastic industries are PA6 and PA6,6. Other popular polyamides available commercially are polyamide 11, 12, 46 and 69. PA6 widely used in the apparel industry (86%) compared to PA6,6 (14%) (Wesołowski and Płachta, 2016). In this study, the research will concentrate on the polymer derived from PA6 which is mainly used for clothing.

PA6 or polycaprolactam is made by ring opening polymerisation of caprolactam monomer. The ring opening of ε-caprolactam monomer occurs when the monomer is heated at 250-280°C at atmosphere pressure for 12-24 hrs as shown in Figure 2.1 (Richards, 2005) and the complete process of ring opening can be seen in Appendix A. The polymerisation could be initiated by water, acid or very strong base such as sodium hydride (NaH), but water is the favoured option in the industry (Richards, 2005). The amide bonds (-CONH-) developed lactam provide hydrogen bonding between chains hence contribute to the excellent properties of PA6 such as stiffness and toughness (John and Furukawa, 2012). The H-bonds also make the PA6 categorised under hygroscopic material as water molecules can form H-bonds with the amide groups as shown in Figure 2.2 (Reimschuessel, 1998).

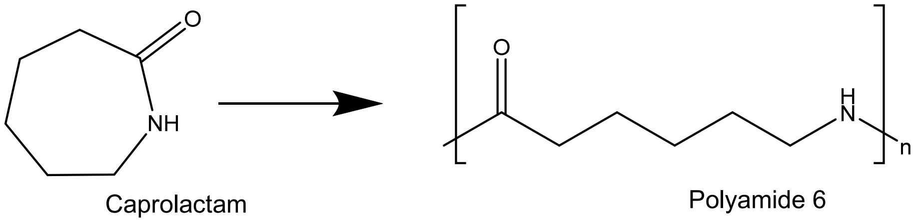

Figure 2.1 Ring opening polymerisation of PA6 (Richards, 2005).

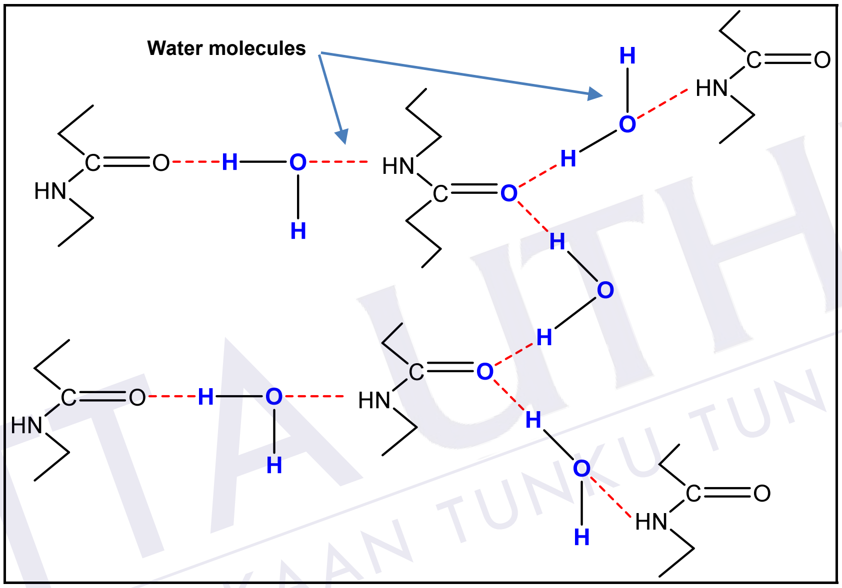

Figure 2.2 Interaction of water molecules with PA6 polymer (Reimschuessel, 1998).

The important parameter of polyamide is the molecular weight or molecular mass. Molecular weight influences the melt viscosity of the polymer namely; higher molecular weight contributed to higher melt viscosity. The melt viscosity of the polymer influences the movement of the polymer chains, namely higher melt viscosity tends to reduce the polymer chain movement (Grümer and Hopmann, 2018).

2.3.1 Polyamide 6 waste

Polyamide is a significant textile fibre with 5.7 million tonnes produced annually comprising 5.4% of the synthetic fibre market and was ranked second among all the textile fibres (Textile Exchange, 2018). The application of polyamide in textile industries is apparel, carpet and industrial filament such as tire cord and ropes (Wesołowski and Płachta, 2016).

From these applications, carpet waste can be collected easily and the amount is significant. The volume of carpet waste for disposal rose by 400,000 tonnes every year in the UK alone (Hilton et al., 2019). Carpet is classified as textiles and is extensively used in buildings and automobile as well as in aircrafts. The surface of carpet acts as a feet insulator from cold floor, sound proof and also adds to the décor of a room. 698 million m^2 of new carpets were produced in the United Kingdom in 2016 to replace the old carpets(Hilton et al., 2019). The huge quantity of fibres consumed to produce carpets lead to an enormous volume of waste, which dominant by nylon fibre (50-70%) (Mohammadhosseini et al., 2018).

2.3.2 Recycled polyamide 6 fibres

Early work on the extrusion of polyamide waste into filaments was conducted by Esfahani (1983) which reported that re-extrusion of PA6 and PA6,6 waste polymers up to 5 cycles is possible. A study conducted by Meyabadi et al. (2010) also showed that PA6 waste can be recycled into filaments. The blending of recycled PA6 with virgin PA6 showed an improvement in the tensile and thermal properties of recycled PA6. Other than the above, to the best of authors' knowledge, there is no published work on the recycling of polyamide waste into PA6 filaments or fibres. Other studies on this domain focused on the reprocessing of polyamide waste via injection moulding up to 16 cycles (Su et al., 2007; Crespo et al., 2013; Grümer and Hopmann, 2018). These studies proved that recycling the polyamide waste into multiple processing cycles are achievable. Besides, polyamide waste polymers were recycled into reinforced composites (Pan et al., 2016; Hasan et al., 2018), cement mortar and concrete reinforcement (Orasutthikul et al., 2017).

2.3.2.1 Mechanical Properties

The common tensile properties for filaments or fibres are tenacity, initial modulus, breaking elongation and work of rupture. Polyamide's relative mass, the extrusion speed, draw ratio, and heat treatment influence the tensile properties of the fibres.

Early study conducted by Esfahani (1983) on the recycling PA6 fibres found that the tenacity of PA6 fibre decreases slightly with the increasing number of cycles with 48.7 $cNtex^{-1}$ ($5.5gd^{-1}$) and 43.7 $cNtex^{-1}$ ($4.94\ gd^{-1}$) reported for the first and fifth cycle respectively. The other tensile properties (the work of rupture, Young's modulus and breaking elongation) also show a similar trend to that of tenacity. Similarly, the study done by Meyabadi et al. (2010) also suggest that the tensile strength and modulus of recycled PA6 fibres are slightly lower than the virgin PA6 fibres. The loss of the

List of References

Afshari, M., Kotek, R., Gupta, B.S., Kish, M.H. and Dast, H.N. 2005. Mechanical and structural properties of melt spun polypropylene/nylon 6 alloy filaments. *Journal of Applied Polymer Science*. **97**(2), pp.532–544.

Afshari, M., Kotek, R., Kish, M.H., Dast, H.N. and Gupta, B.S. 2001. Effect of blend ratio on bulk properties and matrix-fibril morphology of polypropylene / nylon 6 polyblend fibers. *Polymer*. **43**(2002), pp.1331–1341.

Akovali, G. 2012. Advances in Polymer Coated Textiles. *Advances in Polymer Coated Textiles*., pp.1–24.

Ali, A.M. 2019. The impact of processing conditions on the structural and optical properties of the as-spun polyamides fibers. *Microscopy Research and Technique*. **82**(11), pp.1922–1927.

Alves Fidelis, M.E., Pereira, T.V.C., Gomes, O.D.F.M., De Andrade Silva, F. and Toledo Filho, R.D. 2013. The effect of fiber morphology on the tensile strength of natural fibers. *Journal of Materials Research and Technology*. **2**(2), pp.149–157.

Aparna, S., Purnima, D. and Adusumalli, R.B. 2017. Review on Various Compatibilizers and its Effect on Mechanical Properties of Compatibilized Nylon Blends. *Polymer - Plastics Technology and Engineering*. **56**(6), pp.617–634.

Aranishi, Y. and Nishio, Y. 2017. Cellulosic fiber produced by melt spinning *In*: *Blend and graft copolymers of cellulosics*. Springer, Cham.

Arvidson, S.A., Wong, K.C., Gorga, R.E. and Khan, S.A. 2012. Structure, molecular orientation, and resultant mechanical properties in core/ sheath poly(lactic acid)/polypropylene composites. *Polymer*. **53**(3), pp.791–800.

Asiaban, S. and Moradian, S. 2012. Investigation of tensile properties and dyeing behavior of various polypropylene/amine modifier blends. *Journal of Applied Polymer Science*. **123**, pp.2162–2171.

Aslan, S., Laurienzo, P., Malinconico, M., Martuscelli, E., Pota, F., Bianchi, R., Di Dino, G. and Giannotta, G. 1995. Influence of spinning velocity on mechanical and structural behavior of PET/nylon 6 fibers. *Journal of Applied Polymer Science*. **55**(1), pp.57–67.

Ayad, E., Cayla, A., Rault, F., Gonthier, A., Campagne, C. and Devaux, E. 2016. Effect of Viscosity Ratio of Two Immiscible Polymers on Morphology in Bicomponent Melt Spinning Fibers. *Advances in Polymer Technology*. **0**(0), pp.1–8.

Ayad, E., Cayla, A., Rault, F., Gonthier, A., LeBlan, T., Campagne, C. and Devaux, E. 2016. Influence of rheological and thermal properties of polymers during melt spinning on bicomponent fiber morphology. *Journal of Materials Engineering and Performance*. **25**(8), pp.3296–3302.

Barangi, L., Nazockdast, H. and Taromi, F.A. 2008. Effect of the Melt Viscoelastic Behavior of Components on the Morphology Development of Polymer Blends in a Twin-Screw Extruder. *Journa of Applied Polymer Science*. **108**, pp.2558–2563.

Bosak, D.R. 2005. Bicomponent fibers derived from immiscible polymer blends. *Textile Research Journal*. **75**(1), pp.50–56.

Bukhari, M.A., Carrasco-Gallego, R. and Ponce-Cueto, E. 2018. Developing a national programme for textiles and clothing recovery. *Waste Management and Research*. **36**(4), pp.321–331.

Bunge, C.A., Mohr, B., Vad, T., Beckers, M. and Gries, T. 2018. Fabrication and analysis of side-emitting poly(methyl methacrylate) fibres with non-circular cross-sections. *Polymer International*. **67**(9), pp.1170–1178.

Cai, L.-F., Wang, C.-L., Chen, H.-W., Qian, H., Lin, Z.-Y. and Zhang, X.-C. 2019. Hydrogen bonding-based self-assembly technology for high-performance melt blending TPU/PA6 polymers. *Applied Nanoscience*. **10**, pp.51–59.

Chiu, H.-T. and Chuang, C.-Y. 2009. The mechanical and rheological behavior of the PA/TPU Blend with POE-g-MA Modifier. *Journal of Applied Polymer Science*. **115**, pp.1278–1282.

CIRFS European mand-made fibres association n.d. World man-made fibres production. [Accessed 2 May 2019]. Available from: https://www.cirfs.org/statistics/key-statistics.

Crespo, J.E., Parres, F., Peydro´, M.A. and Navarro, R. 2013. Study of rheological, thermal, and mechanical behavior of reprocessed polyamide 6. *Polymer Engineering & Science*., pp.679–688.

Cui, Y., Gong, H., Wang, Y., Li, D. and Bai, H. 2018. A Thermally Insulating Textile Inspired by Polar Bear Hair. *Advanced Materials*. **30**(14), pp.1–8.

Dasdemir, M., Maze, B., Anantharamaiah, N. and Pourdeyhimi, B. 2012. Influence of polymer type, composition, and interface on the structural and mechanical properties of core/sheath type bicomponent nonwoven fibers. *Journal of Materials Science*. **47**(16), pp.5955–5969.

DEFRA 2013. *Energy from Waste A guide to the debate* [Online]. Available from: https://www.gov.uk/government/publications/energy-from-waste-a-guide-to-the-debate.

Dissanayake, D.G.K., Weerasinghe, D.U., Wijesinghe, K.A.P. and Kalpage, K.M.D.M.P. 2018. Developing a compression moulded thermal insulation panel using postindustrial textile waste. *Waste Management*. **79**, pp.356–361.

Dobrovszky, K. and Ronkay, F. 2017. Effects of Phase Inversion on Molding Shrinkage, Mechanical, and Burning Properties of Injection-molded PET/HDPE and PS/HDPE Polymer Blends. *Polymer - Plastics Technology and Engineering*. **56**(11), pp.1147–1157.

Dotto, G.., Santos, J.M.N., Tanabe, E.H., Bertuol, D.A., Foletto, E.L., Lima, E.C. and

Pavan, F.A. 2017. Chitosan/polyamide nanofibers prepared by Forcespinning®technology: A new adsorbent to remove anionic dyes from aqueous solutions. *Journal of Cleaner Production*. **144**, pp.120–129.

Ďurčová, O., Gróf, I., Jambrich, M. and Mizerák, P. 1992. Fibres from polypropylene/polyamide 6 blends: Application of FT-IR Dichroism for study of fibre molecular orientation. *Polymer Testing*. **11**(3), pp.193–203.

Echeverria, C.A., Handoko, W., Pahlevani, F. and Sahajwalla, V. 2019. Cascading use of textile waste for the advancement of fibre reinforced composites for building applications. *Journal of Cleaner Production*. **208**, pp.1524–1536.

Ellen MacArthur Foundation 2017. A New Textiles Economy: Redesigning Fashion's Future. , p.150. [Accessed 20 August 2018]. Available from: https://www.ellenmacarthurfoundation.org/publications.

Eltahir, Y.A., A.M. Saeed, H., Xia, Y., Yong, H. and Yimin, W. 2016. Mechanical properties, moisture absorption, and dyeability of polyamide 5,6 fibers. *Journal of the Textile Institute*. **107**(2), pp.208–214.

Erez 2018. *2018 Technology Report for Marine Safety Textiles*.

Esfahani, S.M.H. 1983. Extrusion of waste polyamides. *Indian Journal of Textile Research*. **8**(September), pp.89–92.

Explorer, G.O. 2019. Fashion from pre-consumer waste. [Accessed 13 October 2019]. Available from: https://goexplorer.org/fashion-from-pre-consumer-waste/.

Fakirov, S. and Evstatiev, M. 1993. Microfibrillar reinforced composite from drawn poly (ethylene terephthalate) / nylon-6 blend. . **34**(22), pp.4669–4679.

Favis, B.D. 2000. Factors Influencing the Morphology of Immiscibke Polymer Blends in Melt Processing *In*: D. R. Paul and C. . Bucknall, eds. *Polymer Blends Volume I: Formulation*. John Wiley & Sons. Inc., pp.501–538.

Favis, B.D. and Chalifoux, J.P. 1988. Influence of composition on the morphology of polypropylene/polycarbonate blends. *Polymer*. **29**(10), pp.1761–1767.

Fiber Innovation Technology, I. 2015. 4DG Fiber. [Accessed 4 July 2016]. Available from: http://www.fitfibers.com/.

Frick, A. and Rochman, A. 2004. Characterization of TPU-elastomers by thermal analysis (DSC). *Polymer Testing*. **23**(4), pp.413–417.

Genovese, A. and Shanks, R.. 2001. Simulation of the specific interactions between polyamide-6 and a thermoplastic polyurethane. *Computational and Theoretical Polymer Science*. **11**(1), pp.57–62.

Global Fashion Agenda and The Boston Consulting Group, I. 2017. *Pulse of the Fashion Industry* [Online]. Available from: http://globalfashionagenda.com/wp-content/uploads/2017/05/Pulse-of-the-Fashion-Industry_2017.pdf.

Gogolewski, S. and Pennings, A.J. 1985. High-modulus fibres of nylon-6 prepared by a dry-spinning method. *Polymer*. **26**(9), pp.1394–1400.

Grümer, B. and Hopmann, C. 2018. The influence of recycling on the viscosity of polyamide 6 and a general modeling approach. *Progress in Rubber, Plastics and Recycling Technology*. **34**(3), pp.158–167.

Gun, A.D. 2011. Dimensional, physical and thermal comfort properties of plain knitted fabrics made from modal viscose yarns having microfibers and conventional fibers. *Fibers and Polymers*. **12**(2), pp.258–267.

Hajiraissi, R., Jahani, Y. and Hallmann, T. 2017. Investigation of rheology and morphology to follow physical fibrillar network evolution through fiber spinning of PP/PA6 Blend Fiber. *Polymer Engineering and Science*. **58**, pp.1–10.

Haponiuk, J.T. 1995. Dynamic mechanical thermal analysis of polyamide 6/thermoplastic polyurethane blends. *Journal of Thermal Analysis*. **43**, pp.91–101.

Haponiuk, J.T. and Balas, A. 1995. Thermal properties of polyamide 6 / polyurethane blends. *Journal of Thermal Analysis*. **43**, pp.211–214.

Hasan, M.M.B., Nitsche, S., Abdkader, A. and Cherif, C. 2018. Carbon fibre reinforced thermoplastic composites developed from innovative hybrid yarn structures consisting of staple carbon fibres and polyamide 6 fibres. *Composites Science and Technology*. **167**(August), pp.379–387.

Hasegawa, T. and Mikuni, T. 2014. Higher-order structural analysis of nylon-66 nanofibers prepared by carbon dioxide laser supersonic drawing and exhibiting near-equilibrium melting temperature. *Journal of Applied Polymer Science*. **40361**, n/a.

Heidari Golfazani, M.E., Nazockdast, H., Rashidi, A. and Yazdanshenas, E. 2012. The role of nanoclay partitioning on microfibril morphology development in polypropylene/polyamide 6 nanocomposite fibers. *Journal of Macromolecular Science, Part B: Physics*. **51**(5), pp.956–967.

Hilton, M., Daniel, R. and Lahme, V. 2019. *Review of Carpet Waste Management in the UK*.

Hiltz, J.A. 1998. *Characterization of poly(ether)urethane thermoplastic elastomers*. Canada.

Hufenus, R., Affolter, C., Camenzind, M. and Reifler, F.A. 2013. Design and characterization of a bicomponent melt-spun fiber optimized for artificial turf applications. *Macromolecular Materials and Engineering*. **298**(6), pp.653–663.

Huntsman 2010. *A guide to thermoplastic polyurethanes (TPU)* [Online]. Available from: http://www.huntsman.com/portal/page/portal/polyurethanes/Media Library/global/files/guide_tpu.pdf.

Imura, Y., Hogan, R.M.C. and Jaffe, M. 2014. *Dry spinning of synthetic polymer fibers* [Online]. Woodhead Publishing Limited. Available from: http://dx.doi.org/10.1533/9780857099174.2.187.

Iyer, S. and Schiraldi, D.A. 2006. Role of Ionic Interactions in the Compatibility of Polyester Ionomers With Poly(ethylene terephthalate) and Nylon 6. *Journal of Polymer Science: Part B: Polymer Physics*. **44**, pp.2091–2103.

Jafari, S.H. and Gupta, A.K. 1998. Crystallization behavior of polypropylene in polypropylene / nylon 6 blend. *Journal of Applied Polymer Science*. **71**(May), pp.1153–1161.

Jašo, V., Milić, J., Divjaković, V. and Petrović, Z.S. 2013. Novel elastomeric polyurethane fibers modified with polypropylene microfibers. *European Polymer Journal*. **49**(12), pp.3947–3955.

Jašo, V., Rodić, M. V. and Petrović, Z.S. 2015. Biocompatible fibers from thermoplastic polyurethane reinforced with polylactic acid microfibers. *European Polymer Journal*. **63**, pp.20–28.

Jayanarayanan, K., Thomas, S. and Joseph, K. 2011. In situ microfibrillar blends and composites of polypropylene and poly (ethylene terephthalate): Morphology and thermal properties. *Journal of Polymer Research*. **18**(1), pp.1–11.

Jaziri, M., Barhoumi, N., Massardier, V. and Mélis, F. 2008. Blending PP with PA6 industrial wastes: Effect of the composition and the compatibilization. *Journal of Applied Polymer Science*. **107**, pp.3451–3458.

John, B. and Furukawa, M. 2009. Enhanced Mechanical Properties of Polyamide 6 Fibers Coated with a Polyurethane Thin Film. *Polymer Engineering & Science*. **47**, pp.1970–1978.

John, B. and Furukawa, M. 2012. Structure and mechanical behaviors of thermoplastic polyurethane thin film coated polyamide 6 fibers part II. A solution coating method. *Journal of Polymer Research*. **19**(2), pp.1–12.

Jordhamo, G.M., Manson, J.A. and Sperling, L.H. 1986. Phase continuity and inversion in polymer blends and simultaneous interpenetrating networks. *Polymer Engineering and Science*. **26**(8), pp.517–524.

Kalyanaraman, A.R. 1988. Coefficient of friction between yarns and contact surfaces. *Indian Journal of Textile Research*. **13**(1), pp.1–6.

Kanebo 2007. Sideria. [Accessed 4 August 2016]. Available from: https://www.kbseiren.com/english/pro-sid.html.

Kegel, M., Sbarski, I., Iovenitti, P., Masood, S. and Kosior, E. 2003. In-situ reactions between recycled polyethylene terephthalate and Nylon 6 blends. *Progress in Rubber, Plastics and Recycling Technology*. **19**(4), pp.251–259.

Khanna, Y.P. 1990. Evaluation of thermal history of polymeric films and fibers using DSC/TMA/DMA techniques. *Journal of Applied Polymer Science*. **40**, pp.569–579.

Kicińska-Jakubowska, A., Bogacz, E. and Zimniewska, M. 2012. Review of Natural Fibers. Part I-Vegetable Fibers. *Journal of Natural Fibers*. **9**(3), pp.150–167.

Kim, J.M., Song, I.S., Cho, D. and Hong, I. 2011. Effect of carbonization temperature and chemical pre-treat- ment on the thermal change and fiber morphology of kenaf- based carbon fibers. *Carbon Letters*. **12**(3), pp.131–137.

Kimm, M., Gerstein, N., Schmitz, P., Simons, M. and Gries, T. 2018. On the separation and recycling behaviour of textile reinforced concrete: an experimental study. *Materials and Structures/Materiaux et Constructions*. **51**(5), pp.1–13.

Kitao, T., Kobayashi, H. and Ikegami, S. 1973. Fibers from Polyblends Containing Nylon 6 as Basic Component . I . Melt Spinning and Physical Properties of Blend Fibers. *Journal of Polymer Science*. **11**, pp.2633–2651.

Li, Y. and Shimizu, H. 2004. Novel morphologies of poly(phenylene oxide) (PPO)/polyamide 6 (PA6) blend nanocomposites. *Polymer*. **45**(22), pp.7381–7388.

Liang, B., White, J.L. and Spruiell, J.E. 1983. Polypropylene/nylon 6 blends: Phase distribution morphology, rheological measurements and structure development in melt spinning. *Journal of Applied Polymer Science*. **28**, pp.2011–2032.

Liao, H.Y., Zheng, L.Y., Hu, Y.B., Zha, X.J., Xu, X., Wen, Y.W., Tao, G.L. and Liu, C.L. 2015. Dynamic rheological behavior of reactively compatibilized polypropylene/polyamide 6 blending melts. *Journal of Applied Polymer Science*. **132**(24), pp.1–8.

Lin, X., Qian, Q., Xiao, L., Chen, Q., Huang, Q. and Zhang, H. 2014. Influence of Reactive Compatibilizer on the Morphology, Rheological, and Mechanical Properties of Recycled Poly(Ethylene Terephthalate)/Polyamide 6 Blends. *Journal of Macromolecular Science, Part B: Physics*. **53**(9), pp.1543–1552.

Ling, C., Shi, S., Hou, W. and Yan, Z. 2019. Separation of waste polyester/cotton blended fabrics by phosphotungstic acid and preparation of terephthalic acid. *Polymer Degradation and Stability*. **161**, pp.157–165.

Liu, H., Zhang, T., Cai, Y., Deng, S., Bai, D., Bai, H., Zhang, Q. and Fu, Q. 2018. Towards polylactide/core-shell rubber blends with balanced stiffness and toughness via the formation of rubber particle network with the aid of stereocomplex crystallites. *Polymer*. **159**(September), pp.23–31.

Liu, L., Wu, Y. and Zhu, Z. 2017. Internal structure and crystallinity investigation of segmented thermoplastic polyurethane elastomer degradation in supercritical methanol. *Polymer Degradation and Stability*. **140**, pp.17–24.

Liu, X., Ning, Y. and Wang, F. 2014. Deep-black-coloring effect of fabrics made of noncircular cross-section polyester filaments. *Color Research & Application*. **39**(5), pp.511–518.

Lozano-González, J., Rodriguez-Hernandez, T., Gonzales-De Los Santos, E. and Villalpando-Olmos, J. 2000. Physical–mechanical properties and morphological study on nylon-6 recycling by injection molding. *Journal of Applied Physics*. **76**, pp.851–858.

Lu, X., Zhao, J., Yang, X. and Xiao, P. 2017. Morphology and properties of biodegradable poly (lactic acid)/poly (butylene adipate-co-terephthalate) blends with different viscosity ratio. *Polymer Testing*. **60**, pp.58–67.

Meng, X., Fan, W., Ma, Y., Wei, T., Dou, H., Yang, X., Tian, H., Yu, Y., Zhang, T. and Gao, L. 2019. Recycling of denim fabric wastes into high-performance composites using the needle-punching nonwoven fabrication route. *Textile Research Journal*. (19).

Meyabadi, T.F., Mohaddes Mojtahedi, M.R. and Mousavi Shoushtari, S. a. 2010. Melt spinning of reused nylon 6: structure and physical properties of as-spun, drawn, and textured filaments. *Journal of the Textile Institute*. **101**(6), pp.527–537.

Millot, C., Fillot, L.., Lame, O., Sotta, P. and Seguela, R. 2015. Assessment of polyamide-6 crystallinity by DSC: Temperature dependence of the melting enthalpy. *Journal of Thermal Analysis and Calorimetry*. **122**(1), pp.307–314.

Mohammadhosseini, H., Tahir, M.M., Mohd Sam, A.R., Abdul Shukor Lim, N.H. and Samadi, M. 2018. Enhanced performance for aggressive environments of green concrete composites reinforced with waste carpet fibers and palm oil fuel ash. *Journal of Cleaner Production*. **185**, pp.252–265.

Moorhouse, D. and Newcombe, H. 2018. Brand interview and case study: Davy J sustainable swimwear. *Clothing Cultures*. **5**(1), pp.163–166.

Morishita, T., Katagiri, Y., Matsunaga, T., Muraoka, Y. and Fukumori, K. 2017. Design and fabrication of morphologically controlled carbon nanotube/polyamide-6-based composites as electrically insulating materials having enhanced thermal conductivity and elastic modulus. *Composites Science and Technology*. **142**, pp.41–49.

Mukhopadhyay, S. and Ramakrishnan, G. 2008. Microfibres. *Textile Progress*. **40**(1), pp.1–86.

NPTEL 2013. Smart/functional specialty fibres. *National Programme on Technology Enhanced Learning*. [Online]. [Accessed 27 July 2016]. Available from: http://nptel.ac.in/courses/116102006/19.

Oertel, R.W. and Brentin, R.P. 1992. Thermoplastic polyurethane for coated fabrics. *Journal of Coated Fabrics*. **22**(22, October), pp.150–160.

Orasutthikul, S., Unno, D. and Yokota, H. 2017. Effectiveness of recycled nylon fiber from waste fishing net with respect to fiber reinforced mortar. *Construction and Building Materials*. **146**, pp.594–602.

Östlund, Å., Wedin, H., Bolin, L., Berlin, J., Jönsson, C., Posner, S., Smuk, L., Eriksson, M. and Sandin, G. 2015. Textilåtervinning Tekniska möjligheter och utmaningar [Tetxile recycling-technical opportunities and challanges]. *Naturvårdsverket*. [Online]. (Rapport 6685). [Accessed 20 August 2018]. Available from: https://www.naturvardsverket.se/Documents/publikationer6400/978-91-620-6685-7.pdf?pid=15536.

Palme, A., Peterson, A., de la Motte, H., Theliander, H. and Brelid, H. 2017. Development of an efficient route for combined recycling of PET and cotton from mixed fabrics. *Textiles and Clothing Sustainability*. **3**(1), p.4.

Pan, G., Zhao, Y., Xu, H., Hou, X. and Yang, Y. 2016. Compression molded composites from discarded nylon 6/nylon 6,6 carpets for sustainable industries. *Journal of Cleaner Production*. **117**, pp.212–220.

Papero, P. V., Kubu, E. and Roldan, L. 1967. Fundamental Property Considerations in Tailoring a New Fiber. *Textile Research Journal*. **37**(10), pp.823–833.

Pedroso, A.G., Mei, L.H.I., Agnelli, J.A.M. and Rosa, D.S. 2002. The influence of the drying process time on the final properties of recycled glass fiber reinforced polyamide 6. *Polymer Testing*. **21**(2), pp.229–232.

Peirce, F.T., Inst.P, F. and F.T.I 1930. The handle of cloth as a measurable quantity. *Journal of the Textile Institute Transactions*. **21**(9), pp.T377–T416.

Potente, H., Bastian, M., Gehring, A., Stephan, M. and Pötschke, P. 2000. Experimental investigation of the morphology development of polyblends in corotating twin-screw extruders. *Journal of Applied Polymer Science*. **76**(5), pp.708–721.

Pötschke, P. and Paul, D.R. 2003. Formation of Co-continuous Structures in Melt-Mixed Immiscible Polymer Blends. *Journal of Macromolecular Science, Part C: Polymer Reviews*. **43**(1), pp.87–141.

Pourdeyhimi, B. and Chappas, W. 2012. United State Patent: 8129019B2 - High surface area fiber and textiles made from the same. Issued 06 Mar 2012.

Pure Waste Textiles n.d. Pure Waste Textiles. [Accessed 13 October 2019]. Available from: http://www.purewastetextiles.com/#top.

Pustak, A., Švab, I., Govorčin Bajsić, E., Denac, M., Musil, V. and Šmit, I. 2018. Polypropylene Blends with m-EPR Copolymers: Structure, Morphology and Thermal Properties. *Polymer - Plastics Technology and Engineering*. **57**(3), pp.229–241.

Qu, C., Yang, H., Liang, D., Cao, W. and Fu, Q. 2007. Morphology and properties of PET/PA-6/SiO2 Ternary Composite. *Journal of Applied Polymer Science*. **104**, pp.2288–2296.

Radici Group n.d. Polyester and Polyamide Bicomponent Yarn: Radyarn BiCo. , pp.0–1.

Rahbar, R.S. and Mrm, M. 2011. Influence of hot multistage drawing on structure and mechanical properties of nylon 6 multifilament yarn. *Journal of Engineered Fibers and Fabrics*. **6**(2), pp.7–16.

Rashmi, B.J., Loux, C. and Prashantha, K. 2017. Bio-based thermoplastic polyurethane and polyamide 11 bioalloys with excellent shape memory behavior. *Journal of Applied Polymer Science*. **134**(20), pp.1–10.

Rashmi, B.J., Rusu, D., Prashantha, K., Lacrampe, M.F. and Krawczak, P. 2013. Development of bio-based thermoplastic polyurethanes formulations using corn-derived chain extender for reactive rotational molding. *Express Polymer Letters*. **7**(10), pp.852–862.

Reimschuessel, H.K. 1998. Polyamide fibers *In*: M. Lewin and E. M. Pearce, eds. *Handbook of Fiber Chemistry*. Marcel Dekker, Inc., pp.71–152.

Richards, A.F. 2005. Nylon fibres *In*: J. E. McIntyre, ed. *Synthetic fibres: nylon, polyester, acrylic, polyolefin*. Woodhead Publishing Limited, pp.20–88.

Robert, B. 2016. To Reuse or to Incinerate? A case study of the environmental impacts of two alternative waste management strategies for household textile waste in nine municipalities in northern Stockholm, Sweden. , p.70.

S. Murase, M. Kashima, K. Kudo and M. Hirami 1997. Structure and properties of high-speed spun fibers of nylon 6. *Macromolecular Chemistry and Physics*. **198**(2), pp.561–572.

Sandin, G. and Peters, G.M. 2018. Environmental impact of textile reuse and recycling – A review. *Journal of Cleaner Production*. **184**, pp.353–365.

Santhanam, S., Bharani, M., Temesgen, S., Atalie, D. and Ashagre, G. 2019. Recycling of cotton and polyester fibers to produce nonwoven fabric for functional sound absorption material. *Journal of Natural Fibers*. **16**(2), pp.300–306.

Saunders, J.H., Burroughs, J.A., Williams, L.P., Martin, D.H., Southern, J.H., Ballman, R.L. and Lea, K.R. 1975. Biconstituent fibers from segmented polyurethanes and nylon 6. *Journal of Applied Polymer Science*. **19**, pp.1387–1401.

Savov, M., Bechev, C., Georgiev, Y. and Dimov, K. 1984. DSC studies on polyester-polyamide biconstituent fibers. *Die Angewandte Makromolekulare Chemie*. **127**(1), pp.7–26.

Schick, C. 2009. Differential scanning calorimetry (DSC) of semicrystalline polymers. *Analytical and Bioanalytical Chemistry*. **395**(6), pp.1589–1611.

Serra, A., Tarrés, Q., Llop, M., Reixach, R., Mutjé, P. and Espinach, F.X. 2019. Recycling dyed cotton textile byproduct fibers as polypropylene reinforcement. *Textile Research Journal*. **89**(11), pp.2113–2125.

Sharma, R. and Goel, A. 2017. Development of Nonwoven Fabric from Recycled Fibers. *Journal of Textile Science & Engineering*. **07**(02), pp.6–8.

Sichina, W.J. 2000. *DSC as problem solving tool: measurement of percent crystallinity of thermoplastics* [Online]. Available from: http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:DSC+as+Problem+Solving+Tool+:+Measurement+of+Percent+Crystallinity+of+Thermoplastics#0.

SMART Secondary Materials and Recycled Textiles n.d. Update on East African Community Ban on Importation of Used Clothing. [Accessed 15 October 2019]. Available from: https://www.smartasn.org/advocacy/update-on-east-african-community-ban-on-importation-of-used-clothing/.

Sotayo, A., Green, S. and Turvey, G. 2015. Carpet recycling: A review of recycled carpets for structural composites. *Environmental Technology and Innovation*. **3**, pp.97–107.

Srinivasan, J., Ramakrishnan, G., Mukhopadhyay, S. and Manoharan, S. 2007. A study of knitted fabrics from polyester microdenier fibres. *Journal of the Textile Institute*. **98**(1), pp.31–35.

Stankowski, M., Kropidłowska, A., Gazda, M. and Haponiuk, J.T. 2008. Properties of polyamide 6 and thermoplastic polyurethane blends containing modified montmorillonites. *Journal of Thermal Analysis and Calorimetry*. **94**(3), pp.817–823.

Su, K.-H., Lin, J.-H. and Lin, C.-C. 2007. Influence of reprocessing on the mechanical properties and structure of polyamide 6. *Journal of Materials Processing Technology*.

Suvari, F., Ulcay, Y. and Pourdeyhimi, B. 2019. Influence of sea polymer removal on sound absorption behavior of islands-in-the-sea spunbonded nonwovens. *Textile Research Journal*. **89**(12), pp.2444–2455.

Takahashi, T., Konda, A. and Shimizu, Y. 1996a. Effect of viscosity ratio on structure of polypropylene / polyamide 6 blend fiber. . **52**(10), pp.507–515.

Takahashi, T., Konda, A. and Shimizu, Y. 1996b. The changes of structure and tensile strength and elongation characteristics for the polypropylene/polyamide 6 blend fibers upon drawing. *Sen'i Gakkaishi*. **52**(8), pp.38–46.

Tavanaie, M.A., Shoushtari, A.M., Goharpey, F. and Mojtahedi, M.R. 2013. Matrix-fibril morphology development of polypropylene / poly (butylenes terephthalate) blend fibers at different zones of melt spinning process and its relation to mechanical properties. *Fibers and Polymers*. **14**(3), pp.396–404.

Textile Exchange 2018. Preferred Fiber and Materials Market Report 2018. , pp.1–96.

Todros, S., Venturato, C., Natali, A.N., Pace, G. and Noto, V. Di 2014. Effect of steam on structure and mechanical properties of biomedical block copolymers. *Journal of Polymer Science, Part B: Polymer Physics*. **52**(20), pp.1337–1346.

Toray 2007. Fiber and textile recycling. [Accessed 20 July 2016]. Available from: http://www.toray.com/csr/value/val_005.html.

Tran, N.H.A., Brünig, H., Auf der Landwehr, M., Vogel, R., Pionteck, J. and Heinrich, G. 2016. Controlling micro- and nanofibrillar morphology of polymer blends in low-speed melt spinning process. Part II: Influences of extrusion rate on morphological changes of a PLA/PVA blend through a capillary die. *Journal of Applied Polymer Science*. **133**(47), pp.1–10.

Tuna, B. and Benkreira, H. 2017. Chain Extension of Recycled PA6. *Polymer Engineering and Science*. **58**(7), pp.1037–1042.

UNEP 2002. Gas emission from waste disposal. *United Nations Environment Programme*. [Online]. [Accessed 6 March 2016]. Available from: http://www.grid.unep.ch/waste/html_file/42-43_climate_change.html.

UNIFI 2008. Unifi’s 100% recycled REPREVE® nylon 6,6 now available in China. [Accessed 20 July 2016]. Available from: http://unifi.com/un_news_pr.aspx?id=12.

Varma, D.. and Dhar, V.. 1988. Nylon 6/PET Polymer Blends: Mechanical Properties of Fibers. *Textile Research Journal*., pp.274–279.

Varma, D.S. and Dhar, V.K. 1987. Studies of Nylon 6 / PET Polymer Blends : Structure and Some Physical Properties. *Journal of Applied Polymer Science*. **33**, pp.1103–1124.

Vinckier, I., Moldenaers, P. and Mewis, J. 1996. Relationship between rheology and morphology of model blends in steady shear flow. *Journal of Rheology*. **40**(4), pp.613–631.

Wang, L., Guo, Z.-X. and Yu, J. 2012. Cocontinuous phase morphology for an asymmetric composition of polypropylene/polyamide 6 blend by melt mixing of polypropylene with premelted polyamide 6/organoclay masterbatch. *Journal of Applied Polymer Science*. **123**, pp.1218–1226.

Wang, M., Yu, B., Han, J., Song, W. and Zhu, F. 2017a. The influence of drawing pressure on the properties of PET/PA6 bicomponent spunbonded fibers. *Journal of Industrial Textiles*. **46**(5), pp.1281–1293.

Wang, M., Yu, B., Han, J., Song, W. and Zhu, F. 2017b. The influence of drawing pressure on the properties of PET/PA6 bicomponent spunbonded fibers. *Journal of Industrial Textiles*. **46**(5), pp.1281–1293.

Wesołowski, J. and Płachta, K. 2016. The polyamide market. *Fibres & Textiles in Eastern Europe*. **24**(6), pp.12–18.

Worn Again 2016. FIBERSORT project. [Accessed 4 July 2016]. Available from: http://wornagain.info/wp-content/uploads/TextilesPressRelease.pdf.

WRAP 2019. *Textiles Market Situation Report 2019*.

Xu, D., Zhou, Y., Guo, J., He, W., Wu, H., Qin, S. and Yu, J. 2019. Different component ratio of polyamide 1212/thermoplastic polyurethane blends: Effect on phase morphology, mechanical properties, wear resistance, and crystallization behavior. *Journal of Thermoplastic Composite Materials*.

YNFX 2020. *YnFx Monthly Pricewatch Report*.

Yoon, B.S., Joang, J.Y., Suh, M.H., Lee, Y.M. and Lee, S.H. 1997. Mechanical properties of polypropylene/polyamide 6 blends: Effect of manufacturing processes and compatibilization. *Polymer Composites*. **18**(6), pp.757–764.

Yousefi, A.M., Smucker, B., Naber, A., Wyrick, C., Shaw, C., Bennett, K., Szekely, S., Focke, C. and Wood, K.A. 2018. Controlling the extrudate swell in melt extrusion additive manufacturing of 3D scaffolds: a designed experiment. *Journal of Biomaterials Science, Polymer Edition*. **29**(3), pp.195–216.

Zainab, Z.I. and Ali, R.T. 2016. Recycled medical cotton industry waste as a source of biogas recovery. *Journal of Cleaner Production*. **112**, pp.4413–4418.

Zhang, H., Zhang, L., Jia, Q., Shi, C. and Yang, J. 2015. Preparation of porous Nylon 6 fiber via electrospinning. *Polymer Engineering & Science*. **47**, pp.1133–1141.

Zhang, P., Xu, D. and Xiao, R. 2015. Morphology development and size control of PA6 nanofibers from PA6/CAB polymer blends. *Journal of Applied Polymer Science*. **132**(27), pp.1–8.

Zhou, S., Huang, J. and Zhang, Q. 2012. Mechanical and tribological properties of polyamide-based composites modified by thermoplastic polyurethane. *Journal of Thermoplastic Composite Materials*. **27**(1), pp.18–34.

Zo, H.J., Joo, S.H., Kim, T., Seo, P.S., Kim, J.H. and Park, J.S. 2014. Enhanced mechanical and thermal properties of carbon fiber composites with polyamide and thermoplastic polyurethane blends. *Fibers and Polymers*. **15**(5), pp.1071–1077.