International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 06 | June 2020 www.irjet.net p-ISSN: 2395-0072

Development of Eco-Friendly Sportswear using Recycled Polyester/Cotton Fibers(Part I)

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Abstract - *This project aimed at developing sportswear garments using recycled cotton and polyester fibers due to increasing awareness on the sustainability and demand of eco-friendly products in the apparel industry. Both the fibers are recycled from used materials or products, which are then processed and converted into the required form of raw material. Five types of yarns such as 1) 100% recycled polyester cotton yarn, 2) 100% recycled cotton yarn, 3)50% recycled polyester blended with 50% recycled cotton yarn 4) 65% recycled polyester blended with 35% recycled cotton yarn and 5) 35% recycled polyester blended with 65% recycled cotton yarn were spun using open-end spinning machine Oerlikon and model BD 320. All 5 yarns were spun to 16s count. The spun yarns were then tested for yarn quality parameters such as yarn count, strength, elongation, evenness, etc.as per standards. The spun yarns were made into Single jersey knitted fabrics using Mayer and Cie machine of 24-inch diameter and 26 machine gauge. The knitted fabrics were dyed with suitable dyes and finished. The finished fabrics were evaluated for fabric quality parameters such as stitch length, wales/inch, course/inch, stitch density, loop shape factor, and tightness factor. The fabrics will also also be evaluated for comfort properties such as thermal resistance, water vapor permeability, air permeability. The tested fabrics will be made into a sportswear and tested for wear trials to conclude its suitability over existing sportswear available in the market.*

Key Words: **Recycled fibers, recycled polyester fiber, recycled cotton fiber, sportswear, sustainability.**

1. INTRODUCTION

Among all the industries in the world, the fashion and/or the textile industry is determined as the major source of pollution in the world. Pollution of the textile and fashion industry is made in all forms, which is the main threat to eco-friendly and sustainable living. This threat can be controlled by using the existing materials and transforming them into another form of end-product. In the past few years, garments have become more disposable to people than mending or reusing the garment and certain brands encourage people to consume fast-fashion products, which led to more landfills pollution and large resource consumption. According to some of the statistics, about 95.6 million tons is the world's textile consumption. Among them were oil-based synthetic man-made fibers like polyester at 62.1%, natural fibers of cellulose, and protein-based like cotton at 25.2%,wood-based cellulose fibers at 6.4%, wool at 1.2% and other natural fibers at 1.5%.In account of sportswear, cotton, polyester, nylon, polyamide,etc.,. Materials are used in the production of sportswear garments and accessories. This paper focuses on reducing the cotton and polyester consumption by recycling and reusing the existing products. The natural fiber like cotton and man-made fiber like polyester is subjected in this paper for the production of the sportswear garment.

The major environmental impacts of cotton and polyester are: the comparison of natural and synthetic fibers is hypothetical since polyester cannot be substituted by cotton and vice versa[1]. These two materials have very different technical, physical, and chemical properties and their annual production volumes are so high that it is not possible to compensate one with another[1]. It should, however, be noted that cotton is, in some cases, cultivated in regions with scarce water supplies and, thus, with high requirements for irrigation[1]. Cotton growing consumes 1.65 kg CO_2 per 1 kg cotton fibers in photosynthesis, which can be deducted from CO_2 emissions, 4.7 kg, associated with cotton fiber production. This results in 3kg net CO_2 with global warming potential within cotton fiber production[1]. The increase in fertilizer use in cotton growing to boost the production, causes pollution of surface water as well as of ground-water[3]. The use of phosphate fertilizers causes accumulation of heavy metals, such as cadmium, in soil as well as surface water eutrophication in context with possible leaching[2,3]. Polyester production requires non-renewable resources, such as fossil raw materials, resulting in on the average 63% higher energy consumption than the production of cotton per 1 kg fibers. Water use in polyester production is less than 0.1% of the amount of water required in cotton growing[1]. The end products of polyester create a global threat to the environment, by not degrading and residues are left in the same for over decades, this violates the life cycle of the product to decompose.

Recycling is the process of converting the old products/materials to a new end-product, which now creates an awareness to subtly use the resources and reusing by increasing the lifespan of that end product. The current environmental

conditions drive us to lead an eco-friendly lifestyle by using biodegradable products or less resource-consuming products. As natural resources decrease, public awareness of recycling increases rapidly. Emphasis made by various media, advertising campaigns and recycling activities organized by agencies and institutes play an important role in the recent rise of awareness about recycling of materials such as glass, paper, textile, and plastic materials[5]. The textile industry generates large amounts of waste with the potential for recycling. Therefore, a special market has formed for the recycling of textile materials. This market is known as the "waste exchange system". The main purpose of this waste exchange system is to meet the supply and demand of textile materials as studied by Tereschenko[4]. Textile waste can arise at different stages of production (e.g. waste arises from yarn spinning, fabric scraps are generated within the garment industry, etc.). These used fabrics can be opened into fibers that could be used in recycled yarn production. Since recycled cotton fibers are short, it is necessary to blend the recycled cotton fibers with polyester fibers to give strength to the yarn and make it easier to spin. Blending recycled cotton fibers with polyester fibers also reduces the amount of fiber fly generated during the knitting or weaving[5].

Recycled polyester is now a major game-changer in the apparel industry, and recycled cotton is gradually gaining the attention of the public, where eco-friendly and sustainable end products are derived. Recycled polyester and recycled cotton are produced by converting the old end products or materials into new end products. Several methods have been reported to obtain recycled recipients and bottles from PET, but in general PET wastes have been traditionally used for energy recovery[7-9]. Recycled polyester fibers are obtained mostly from waste soda bottles and water bottles, and sometimes even from the old and unused polyester fabrics/garments. These are shredded and converted into small pieces, later made into yarn with the help of a melt spinning process. Recycled cotton fiber is obtained from old unused clothes, waste garments/materials, and industry waste yarns, which are ripped and shredded by the tearing machine and then a sequence of processes like carding, sliver formation, spinning are done to form recycled cotton yarn. The recycled polyester and recycled cotton yarns are made into five compositions to determine the best blend for sportswear and later they are subjected to various test parameters.

2. METHODOLOGY

2.1 Selection of Fiber

Two types of recycled fibers are used in this project for sportswear garment, which are recycled cotton fiber and recycled polyester fiber. These fibers are perfectly compatible with sportswear fabric and the main purpose is to be an eco-friendly product and achieve sustainability. r-PET stands for recycled PET, the bottles that are used for water and soda. Recycled Cotton (r-Co) includes recycled raw material, as well as used, reconditioned and remanufactured components such as old clothes, waste yarns,etc.,.

2.2 Sourcing of Recycled Polyester/Cotton fibers

Recycled polyester(r-PET) fibers are now majorly used in apparel industries to reduce carbon footprints and to achieve sustainability and Recycled Cotton(r-Co) prevents from gallons of water consumption and achieve eco-friendliness. The r-PET fibers were produced from melt spinning of PET flakes, which were purified from contaminants by sorting, washing, and drying of PET bottles/soda cans. These fibers have semi-white color during the process end. Recycled cotton(r-Co) fibers were obtained from waste clothes, old unused clothes, industry waste yarns which are ripped and shredded by the tearing machine, and then the fibers were made. Recycling of used apparels will lead to lesser carbon footprints, lower water consumption, awareness of the environment, etc.,.

2.3 Fiber Testing

For any fiber, testing is important for the analysis of its characteristics to determine the quality of the end product. For both the fibers(r-PET, r-Co); fiber fineness(dtex), fiber length(mm), tenacity(g/den), elongation(%) are tested.

Fiber fineness is a relative measure of size, diameter, or linear density. The test was done as per the ASTM D 1577-07 standard. The fineness of the fiber was tested with two specimens of recycled cotton(r-Co) and recycled polyester (r-PET) each with a weight of 5 mg were tested. The air is passed through the specimen. The finer the recycled cotton fibers, the greater is the surface area, so the drag to airflow is greater and the flow will be lesser through the finer fibers.

Fiber length of recycled cotton(r-Co) and recycled polyester(r-PET) are tested by separating the tufts of fibers of long and short lengths with the help of combs, each weighing 20mg. The tufts are placed side by side on a velvet pad, so that the free ends of tufts lie along the straight baseline. The test is done as per in house method SITRA/FP/03-2017- Single Fiber Length Measurement(BISFA).

Fiber tenacity is the ratio of load needed to break the specimen and the diameter of that specimen. The test is done as per ASTM D 3522/D 3822 M-14. Single fiber tenacity determines the accurate strength of fiber and will help to improve the quality after a series of processes.

Fiber elongation can be expressed by the percentage of increase in the length of a fiber. Elongation determines the actual strength of a fiber when in load. The test is done as per ASTM D 3522/D 3822 M-14.

2.4 Fiber Blending

From the obtained fibers, different compositions of yarn are made by blending both the recycled cotton(r-Co) and recycled polyester(r-PET). Five different blends are 100% recycled cotton(r-PET), 100% recycled polyester(r-Co), 50-50% recycled cotton(r-Co)/recycled polyester(r-PET), 35-65% recycled cotton(r-Co)/recycled polyester(r-PET), 65-35% recycled cotton(r-Co)/recycled polyester(r-PET). Blending of both the fibers are done in blow room stage or in draw frames.

2.5 Yarn Formation

After the blending of fiber in various required compositions, yarn formation is done. Yarns are made from open-end rotor spun yarn, so to withstand the recycled fibers strength and its fineness. Five different types of compositions of 100% r-PET, 100% r-Co, 50/50 r-PET/r-Co, 65/35 r-PET/r-Co, 35/65 r-PET/r-Co slivers were produced on a carding machine, with the help of draw frames. Then the slivers were spun with a BD 330 open-end spinning machine. The spinning process parameters of Oerlikon BD 320 are as follows: rotor speed of 65000 rpm, the diameter of the rotor is 43mm, opening roller OK37 NiDi at speed of 9500rpm. The yarn linear density is approximately 16s Ne, as it is made in an open-end spinning machine to maintain the strength of the recycled fibers. The formed yarn undergoes certain finishes like sizing(to even the yarn diameter for smooth and even fabric formation) before dyeing. For dyeing of yarns, for 100% r-PET yarn - disperse dye is used and for the rest of yarns like 100% r-Co, 50/50 r-PET/r-Co, 65/35 r-PET/r-Co and 35/65 r-PET/r-Co - reactive dyes are used. After the dyeing process of yarns, they are set for 24 hours in motion to avoid clogging or discoloration, and then the further processes are done.

2.6 Fabric Formation

Five different yarn compositions are taken into the next process for fabric formation. For sportswear, knit fabrics are mostly used for their comfort and extensibility. From the production perspective, it is easier to produce knit fabrics than woven. To increase fabric durability and dimensional stability, fabric structures and their properties play a vital role. Concerning the sportswear, the single jersey fabric is knitted in a flat/circular knitting machine. The single jersey fabric is made with a desired GSM and machine settings. The knitting machine is Mayer and Cie. The diameter of the respective knitting machine is 24, needle gauge is 26, the loop length of the machine is 28mm and its knitting speed is 75kg/shift(8hrs). The GSM of the fabric from the respective machine is 100-120.

2.7 Fabric Finishing and Testing

After the fabric formation, the recycled polyester(r-PET)/recycled cotton(r-Co) fabric is dyed and certain fabric finishes are given according to the requirement of the sportswear fabrics. The dyeing and the finishing should be individually done because of the different compositions of r-PET and r-Co.

Wales per Inch(WPI) and Course per Inch(CPI) represent the total number of wales and course in one inch of a linear fabric which is measured with the help of a magnifying glass. WPI and CPI are the important parameters in determining the GSM of single jersey fabric and its properties.

Loop length is the length of the yarn required to produce a complete knitted loop during fabric formation. Loop length is measured by cutting a fabric swatch of 10x10cm in wales direction and count the number of wales in 10cm of the fabric swatches.

The tightness factor is the relativity of the fabric tightness or looseness, which depends upon the loop length of the fabric. Mathematically, tightness factor = $\sqrt{}$tex/L, where L is the loop length in mm.

Stitch density in a knit fabric is the number of stitches per unit area, obtained by multiplying the number of WPI and CPI. Mathematically, stitch density = (WPIxCPI)inches - 2, where WPI and CPI are wales per inch and course per inch respectively.

Loop shape factor depends upon the yarn, and the finishing of the fabric, which determines the dimension and/or the spirality of the fabric. It is determined by dividing the courses per centimeter by the wales per centimeter. Loop shape factor (R) = CPCM/WPCM, where CPCM is courses per centimeter and WPCM is wales per centimeter[10].

3. EXPERIMENT AND RESULT

3.1 Fiber Properties of Recycled Polyester (r-PET) and Recycled Cotton (r-Co)

The recycled polyester(r-PET) fiber was produced from melt spinning of PET flakes, which were purified from contaminants by sorting, washing, and drying of PET bottles/soda cans. The recycled cotton(r-Co) fiber was produced from cotton fabric scraps, which are ripped and torn apart from waste cloth, industry yarn, and used apparels/components. The fiber properties of virgin cotton were taken from the reference journal(5) with the common factor of fiber fineness which has similar values of 4.3 mic., fiber length of 29mm, tenacity and elongation of virgin cotton is 3.51g/den and 11.2%, respectively. The fiber properties of virgin polyester were taken from the reference journal(5) with the common factor of fiber length which has similar values of 38mm, fiber fineness of 1.6 dtex, tenacity and elongation are 6.56g/den and 25.74%, respectively. The deniers of recycled polyester and recycled cotton fibers were 1.44 dtex and 4.27 micronaire, respectively. The fiber length of recycled polyester and recycled cotton fibers were 37.9 and 26mm, respectively. The strength of recycled polyester fiber was 5.90g/den, whereas recycled cotton fiber was 3.37g/den (table 1).

Table -1: Fiber Properties

Fiber Properties	Recycled Cotton (r-Co)	Recycled Polyester (r-PET)	Virgin Cotton	Virgin Polyester
Fiber Length (mm)	25	37.9	29	38
Fiber Fineness	4.27 mic.	1.44 dtex	4.3 mic.	1.6 dtex
Tenacity (g/den)	3.37	5.90	3.51	6.56
Elongation (%)	5.80	21.04	11.2	25.74

3.2 Yarn Properties of Recycled Polyester (r-PET) and Recycled Cotton (r-Co)

Five different types of compositions of 100% r-PET, 100% r-Co, 50/50 r-PET/r-Co, 65/35 r-PET/r-Co, 35/65 r-PET/r-Co slivers were produced on a carding machine, with the help of draw frames. Then the slivers were spun with a BD 330 open-end spinning machine. The yarn linear density is approximately 16s Ne, as it is made in an open-end spinning machine to maintain the strength of the recycled fibers. The yarn diameter in an indirect system of yarn count is 0.2275mm. The spinning process parameters of Oerlikon BD 320 are as follows: rotor speed of 65000 rpm, the diameter of the rotor is 43mm, opening roller OK37 NiDi at speed of 9500rpm.

3.3 Fabric Properties of Recycled Polyester (r-PET) and Recycled Cotton (r-Co)

About the sportswear, the fabric is knitted in a flat/circular knitting machine. The single jersey fabric is made with a desired GSM and machine settings. The knitting machine is Mayer and Cie. The diameter of the respective knitting machine is 24, the needle gauge is 26, the loop length of the machine is 28mm and its knitting speed is 75kg/shift (8hrs). The GSM of the fabric from the respective machine is 200. The wales per inch(WPI), course per inch(CPI), loop length(L), tightness factor, and the stitch density of the recycled polyester(r-PET) and recycled cotton(r-Co) fabrics were calculated and/or measured(table 3.3). When considering the fiber composition, the properties of the fabrics vary accordingly. The stitch density of 100% r-PET is 2468 and the 100% r-Co is 1494, when the r-PET fiber content(65%) is increased than the r-Co fiber(35%) the stitch density is 1970, when the r-PET fiber(35%) is decreased than the r-Co fiber(65%) then the stitch density is 1630 and when the fiber compositions are equal of r-PET fiber(50%) r-Co fiber(50%) the stitch density value is median of 1870.

Table -2: Fabric Properties

Fabric Properties	Wales per Inch(WPI)	Course per Inch(CPI)	Loop length (L) in mm	Tightness Factor	Stitch Density	Loop Shape Factor
100% r-PET	38	65	2.84	2.14	2468	1.71
65-35% r-PET/r-Co	34	58	2.84	2.14	1970	1.71
50-50% r-PET/r-Co	36	52	2.83	2.15	1870	1.44
35-65% r-PET/r-Co	34	48	2.82	2.15	1630	1.41
100% r-Co	34	44	2.82	2.15	1494	1.29

3. CONCLUSIONS

In this study, the properties of fiber and some physical properties of fabric produced from recycled polyester(r-PET) and recycled cotton(r-Co) were investigated. The results show the fibre strength of recycled cotton is reduced by 4.0% compared to virgin cotton and fibre elongation got reduced by 36% compared to virgin cotton. Similarly for recycled polyester the strength reduction is 10.06% compared to virgin polyester and the reduction in elongation for recycled polyester is 18% compared to virgin polyester.

The basic physical properties of recycled polyester(r-PET) and recycled cotton(r-Co) fabrics are analysed and reported. The results indicate that 100% recycled polyester and 100% recycled cotton are having the maximum stitch density. Similarly in case of blends the blend having higher recycled polyester content has higher stitch density followed by 50/50 blend of recycled polyester/recycled cotton and as the content of recycled polyester reduces the stitch density also gets reduced. The corresponding loop shape factor and tightness factors also reported in this paper.

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