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Investigation of the Functional Performance Properties and Anti-microbial Behavior of Sports Socks Knitted from Eco-Friendly Materials

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ABSTRACT

The material components of the sports sock provide; impact protection, injury avoidance, anti-frictional, absorption and anti-bacterial properties. The quality of socks can vary depending on many factors. These can be summarized as the type and properties of the used yarns, knitting conditions and machine properties, finishing method and the used finishing materials and the form giving operation applied on socks. With the growing demand for more com-fortable, healthier and environmentally friendly products, efforts in research and development in the textile industry have focused on the utilization of renewable and biodegradable resources. This study comprised an experimental investigation to determine the functional performance properties and anti-microbial behavior of socks manufactured using not only traditional cotton or polyester yarns but also yarns made of new kinds of eco-friendly fibers like bamboo. This paper studies the influence of different sports socks compositions on the functional performance properties and anti-microbial behavior of knitted fabrics made of two types of structures (Rib- Jersey) knitted from elstane yarns with eco- friendly fibers effect. The results demonstrated that all tested properties influenced by both material and knitted structure parameters. These findings are an important tool in the design of healthy comfortable sports socks.

Key words: *Anti-microbial Behavior, Eco-Friendly Materials, Functional Performance Properties, Hosiery Machines*.

1. INTRODUCTION

A sock is an item of clothing worn on the feet. The foot is among the heaviest producers of sweat in the body, as it is able to produce over 1 US pint (0.47 l) of perspiration per day. Socks help to absorb this sweat and draw it to areas where air can evaporate the perspiration. In cold environments, socks decrease the risk of frostbite [1]. For a runner, moisture is the foot's worst enemy. Moisture causes painful/race-ending blisters, Athlete's Foot, odor causing bacteria and over-all discomfort. Runners' feet are going to get wet either from sweat, puddles, wet grass, rain, or by getting splashed at a race water station. In cold/freezing weather, moisture pulls heat away from the skin 23 times faster than air, reducing the temperature so rapidly that wet feet become painfully cold and much more susceptible to frostbite or Non-Freezing Cold Injury [2].

One thing should be kept in mind when selecting material and designing sports socks structure is that the blood circulation does not affected or resisted. Weather and the season conditions are also under consideration when buying or manufacturing sports socks. The sports socks outlook is also an important part of sock selection, because the overall appearance of sports socks makes comfortable to the user [3].

Sports socks can be created from a wide variety of materials. Some of these materials are cotton, wool, nylon, acrylic, polyester, olefins, (such as polypropylene), or spandex. To get an increased level of softness other materials that might be used during the process can be silk, bamboo, linen, cashmere, or mohair [4]. The quality in sports socks can vary depending on many factors. These can be summarized as; the type and properties of the used yarn, knitting conditions and machine properties, finishing method and the used finishing materials and the form giving operation applied on socks [5].

Elastane (Spandex) was invented in 1937, but is often known by trade names such as Lycra (launched by DuPont in 1958 and now owned by Invista) and Dorlastan. Stretch fibers are readily adopted in sports socks in addressing overall comfort, shape and fit, freedom of movement, support and compression[6]. There are two principal methods used in processing elastane. One is to wrap the elastane fiber in a non-elastic thread, either natural or man-made when the resulting yarn has the appearance and feel of the outer fiber used. The second method involves using pure elastane threads being knitted or woven into fabrics made from other fibers[7].

In the past decade the term eco-friendly has been used to describe the confluence of products and technology in the twenty – first century. through the term remains nebulous as it continues to evolve. Eco friendly can refer to three related things. Most commonly it is understood as material product, specifically a garment or accessory worn on the body. second it can refer to category of creative praxis, encompassing the diver range of scientific and creative processes undertaken by the artist, fashion designs, technologists and hobbyists who make the product of wearable technology[8]. Eco friendly fabrics are made from fibers that do not require the use of any pesticides or chemicals to grow. They are naturally resistant to mold and mildew and are disease free. Hemp, linen, bamboo and ramie are eco-friendly fibers [9].

Bamboo is a highly renewable grass, and it is probably this property that has resulted in its being classified as "eco-friendly". Bamboo is one of nature's most sustainable resources. Bamboo is chemically, by regenerating the cellulose fiber, which make Bamboo Viscose. All fabrics manufactured with cellulose, whether its bamboo, plants or trees are rayon (viscose). Bamboo Viscose is considered eco-friendly, as the primarily source is naturally regenerative. Bamboo fabrics can be produced without any chemical additives but ensure that it is eco certified look for Oeko-Tex, Soil Association, Skal, Krav or similar organic or sustainable certification body [9]. Bamboo fabric is naturally anti-microbial, hypoallergenic and thermal regulating. It is also resistant to mold [10]. Bamboo breathes and wicks moisture away due to its porous nature. Bamboo also has an excellent drape and a silky-cashmere feel. What is notable of bamboo fiber is its unusual ability to breathe and its coolness. Because the cross - section of the bamboo fiber is filled with various micro-gaps and micro-holes, it has much better moisture absorption and ventilation. It is never sticking to skin even in hot summer [11].

The last few years have witnessed a growing interest in knitted fabrics due to their simple production techniques, low cost, high levels of clothing comfort and wide product range. Knitting fabrics, due to comfortable stretch, freedom of movement and good air-permeability, and water vapor permeability characteristics are preferred for sports socks [12]. For centuries the production of hosiery was the main concern of the knitting industry. Nowadays, hosiery production is centered almost exclusively on the use of small-diameter circular machines [13]. The term 'hosiery' specifically refers to knitted coverings for the feet and legs, but it may be generically (but confusingly) applied to all types of knitted goods and fabric. Most hosiery articles are knitted with integral tubular legs and feet. The welts and top are usually knitted first, the foot and toe last. Closing the toe also produces a secure finish [14]. The machines have a master machine control that automatically times and initiates the mechanical and electronic operations, and changes of stitch length necessary to produce the garment-length knitting cycle. Later making-up, such as toe-closing and finishing operations, off the machine may still be required (15). Sports socks is type of cloth manufactured by

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the knitting technique, it covers the foot and leg complete or partial. There are many types of sports socks. Sports Socks are available in various colors, sizes and materials [16].

The main goal of this study is to reach the best methods of hosiery machine adjustment for sports socks by using different types of raw materials (cotton- bamboo- nylon-elstane) with various ratio and structures to achieve the required functional performance properties and anti-microbial behavior.

2. MATERIALS AND METHDS

In the experimental study, Twelve samples of sports socks were knitted from cotton and regenerated cellulosic bamboo blend with nylon and elastane in different ratios. All socks were knitted on the same hosiery machine by controlling the machine adjustment and using different constructions.

2.1. Yarns Specifications

2.1.1. Bamboo Yarns

Table (1) shows the technical specification of used bamboo yarns.

Table (1) Technical Specification of Used Bamboo Yarns

Material Blend %	Bamboo 100%	Standard, Equipment
Material yarn	30/1 Bamboo	
Count ne	29.64	ASTM D 1907-97
Ne CV%	1.04	
Uster irregularity CV%	12.4	ASTM D 1425-96
Imperfections in 1000m		
Thin places (-40)	69	ASTM D 1425-96 USTER TESTER 3
Thin places (-50)	1	
Thick places (+35)	169	
Thick places (+50)	15	
Neps (+140)	280	
Neps (+200)	46	
Neps (+280)	10	
Hairiness	5.14	V 400m/min
Strength CN/Tex	14.71	ASTM D 2256 97 USTER TENSPRAPID 3 V 5000m/min
Strength CV%	9.18	
Elongation	13.88	
Twist /m	809	ASTM D 1422-98 ZWEIGLE D 312
Twist /inc	20.54	
Twist factory (ALFA)	3.75	
Twist CV%	1.9%	
Cone angel	5° 57´	
Wax	Yes	

DOI: 10.31695/IJASRE.2020.33680

Test conditions	CONES, 24 HOUR CONDITIONED	TEMP(°C):20.0+/-2.0 HR (%): 6.5+/-2.0
	ISO 9001 : 2008 Registration No: 12 100 3674 TMS	

2.1.2. Cotton Yarns

Table (2) shows the technical specification of used cotton yarns.

Table (2) Technical Specification of Used Cotton Yarns

Material Blend %	*Cotton 100%*	*Standard, Equipment*
Material yarn	*30/1 Cotton*	
Count ne	*29.76*	*ASTM D 1907-97*
Ne CV%	*1.35*	
Uster irregularity CV%	*9.50*	*ASTM D 1425-96*
Imperfections in 1000m		
Thin places (-40)	*56*	*ASTM D 1425-96 USTER TESTER 3*
Thin places (-50)	*0*	
Thick places (+35)	*168*	
Thick places (+50)	*16*	
Neps (+200)	*28*	
Neps (+200)	*37*	
Neps (+280)	*8*	
Hairiness	*6.70*	*V 400m/min*
Strength CN/Tex	*14.71*	*ASTM D 2256 97 USTER TENSPRAPID 3 V 5000m/min*
Strength CV%	*9.18*	
Elongation %	*4.60*	
Elongation CV%	*8.50*	
Twist /m	*756*	*ASTM D 1422-98 ZWEIGLE D 312*
Twist /inc	*19.08*	
Twist factory (ALFA)	*3.75*	
Twist CV%	*1.8%*	
Cone angel	*5° 57´*	
Wax	*Yes*	
Test conditions	*CONES,24HOUR CONDITIONED*	*TEMP(°C):20.0+/-2.0 HR (%): 6.5+/-2.0*
	ISO 9001 : 2008 Registration No: 12 100 3674 TMS	

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2.1.3. Nylon Yarns

Table (3) shows the technical specification of used nylon yarns.

Table (3) Technical Specification of Used Nylon Yarns

Material Blend %	*100% polyamide*
Yarn Count	*70/1 Dtex polyamide*
Dtex Various %	*0.6*
Tensile strength CN/dtex	*4.3*
Tensile strength CV %	*3.5*
Extension at Break %	*22.4*
Extension at Break CV %	*4.2*
Oil Content %	*2.4*
Tenacity (CN)	*3.80*
Deviation of denier (Dtex)	*±1.5*
Variation of elongation (CV %)	*4.5*

2.1.4. Elastane (Lycra)

Table (4) shows the technical specification of used elastane (Lycra) yarns.

Table (4) Technical Specification of Used Elastane (Lycra) Yarns

Material Blend %	***100 % Lycra***	***100 % Lycra***
Yarn Count	*40 Dtex*	*70 Dtex*
Tenacity (CN)	*36.4*	*63.8*
Deviation of denier (Dtex)	*±6.0*	*±6.5*
Elongation (%)	*590*	*610*
Stress at elongation 300%	*8.0*	*11.0*
Elastic recovery at elongation 300%	*95*	*95*
Boiling water shrinkage (%)	*12*	*11*
Oil content (%)	*3.0-7.0*	*3.0-7.0*

2.2. Sports Socks Design and manufacturing

Regarding to theoretical modeling, it is assumed that various fabric structures demonstrate different mechanical and functional properties. This matter is base of sample preparation and plan of experiments. Twelve Calf length weft knitted sports socks samples were produced using two different structures with various raw materials in the same hosiery machine. Table (5) shows the hosiery machine specification that used to produce sports socks samples under study while Table (6) shows the sports socks samples specification.

DOI: 10.31695/IJASRE.2020.33680

Table (5) The Hosiery Machine Specification

Company		*Lonati*
Machine's type		*Single*
Machine's Model		*GL 615 S*
Made in		*Italy via Francesco Lonati*
Year of made		*2013*
Serial. No		*14275*
Construction		*Plain or terry*
Machine gauge (Needle / Inch)		*14*
Needle Thickness		*0.70 – 0.60 MM*
Cylinder diameter (Inch)		*3 3/4"*
Needle number		*168*
Machine Dimension		*94.5*103.3*180 CM*
Machine weight		*230 KG*
Number of feeders		*1*
Tracks	***Cylinder***	*1*
	Dial	*2*
Max speed	***RPM***	*350*

Table (6) The Sports Socks Samples Specification

Sample No.	***Elastane count (Dtex)***	***Structure***		***Bamboo 85% Nylon 4% Elastane 11%***	***Cotton 85% Nylon 4% Elastane 11%***	***Bamboo 81% Nylon 4% Elastane 15%***	***Cotton 81% Nylon 4% Elastane 15%***	***Bamboo 43% Cotton 42% Nylon 4% Elastane 11%***	***Bamboo 41% Cotton 40% Nylon 4% Elastane 15%***
		Jersey	*Rib*						
1.	*40*								
2.									
3.	*40*								
4.									
5.	*70*								
6.									
7.	*70*								
8.									
9.	*40*								
10									
11	*70*								
12									

2.3. Measurements of Manufactured Samples

Several tests were carried out in order to evaluate the functional performance properties anti-microbial behavior. of produces sports socks, these tests include mechanical and physical properties tests.

2.3.1. Weight Test

This test was carried out by using Mettler H 30 apparatus according to the D3776 / D3776M - 09a..

DOI: 10.31695/IJASRE.2020.33680

2.3.2. Thickness Test

The thickness samples were measured by the Teclock tester under a pressure 0.2 kg f/cm2 according to the D1777- 96(2011) e1.

2.3.3. Air Permeability Test

This test was carried out for all samples, according to the ASTM D737 - 04(2012).

2.3.4. Spray Test

This test was carried out for all samples, according to the ISO 4920 and BS EN 24920.

2.3.5. Bursting Strength Test

This test was carried out for all samples by using the strip method according to the ASTM D3786 / D3786M – 13.

2.3.6. Fabric Weariness or Abrasion Tester

This test was carried out for all samples, according to the ASTM D3884 - 09(2017).

2.3.7. Pilling Resistance Test

This test was carried out for all samples, according to the ASTEM D4970/D4970M-16e3.

2.3.8. Determination The growth rate of bacteria (E. coli and S. aureus) and fungi (T. Viridae and A. niger) Test

This test was carried out for all samples, according to the ATCC Method 147-2004.

3. RESULTS AND DISCUSSION

Since the main purpose of this research was to optimizing the functional properties of sports socks by using elastane yarns with eco-friendly materials. Regarding to theoretical modeling, it is assumed that various fabric structures demonstrate different mechanical and functional properties. This matter is base of samples preparation and plan of experiments. Different socks structures (jersey and rib structure) with various constructions parameters were made.

Twelve samples of Calf length sports socks in different ratios of Bamboo yarns (0%- 41%- 43%- 81%-85%) were produced in hosiery weft knitting machine by using various fabric compositions for both used structures (Jersey-Rib) according to the research plan to determine the best specification.

3.1. The Effect of Bamboo Ratio % on Sports Socks Weight

Figure (1) shows the effect of bamboo ratio % (from 0% to 85%) on sports socks weight by using various fabric compositions for both used structures (Jersey-Rib).

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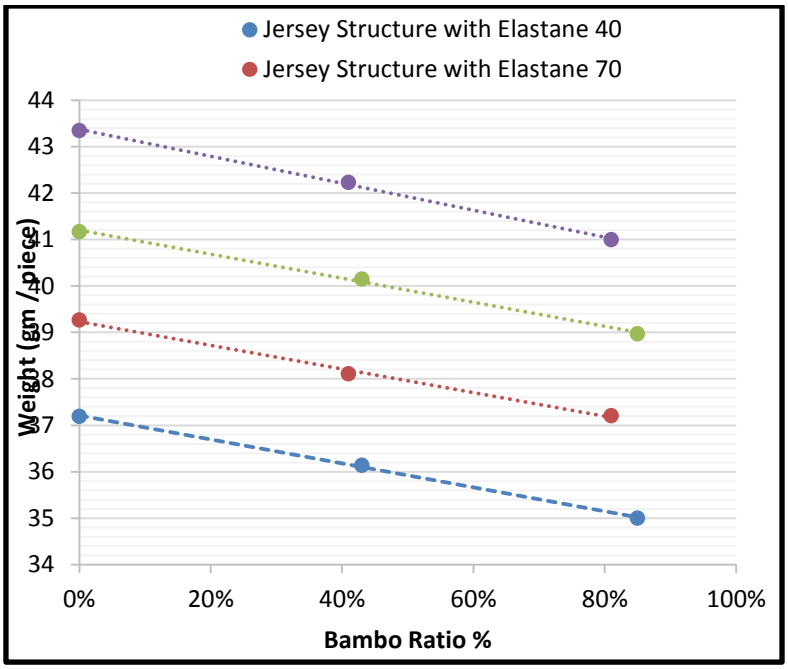

Fig. (1) The Relationship between Bamboo Ratio% and Sports Socks Weight (gm/piece)

It was obvious from Figure (1) that, there is indirect relationship between bamboo ratio % and sports socks weight. The bamboo ratio % has a significant effect on the sports socks weight (gm/piece) for all structures and elstane yarns count, as the bamboo ratio % increases, the sports socks weight was decreased, this means that the higher the bamboo ratio %, the lower the sports socks weight because bamboo fiber has smaller molecular mass and degree of polymerization than other best fibers.

To get a mathematical relationship between the bamboo ratios % on sports socks weight (gm/piece) values, a linear regressions techniques were used to get this relationship.

Table (7) Mathematical Relationship Between the Bamboo Ratios % on Sports Socks Weight (gm/piece) Values

y = -2.5759x + 37.209	R^2 = 0.9991	Jersey Structure with Elstane 40
y = -2.5444x + 39.231	R^2 = 0.9957	Jersey Structure with Elstane 70
y = -2.5874x + 41.201	R^2 = 0.9976	Rib Structure with Elstane 40
y = -2.9005x + 43.373	R^2 = 0.9988	Rib Structure with Elstane 70
Where : Y = Weight (gm/piece)		
X = Bamboo ratio %		

The correlation is considered too high which means that the regression equation is reliable for prediction of the bamboo ratio percentage values in sports socks weight (gm/piece) values range by using various fabric compositions for both used structures (Jersey-Rib).

3.2. The Effect of Bamboo Ratio % on Sports Socks Thickness

Figure (2) shows the effect of bamboo ratio % (from 0% to 85%) on sports socks thickness by using various fabric compositions for both used structures (Jersey-Rib).

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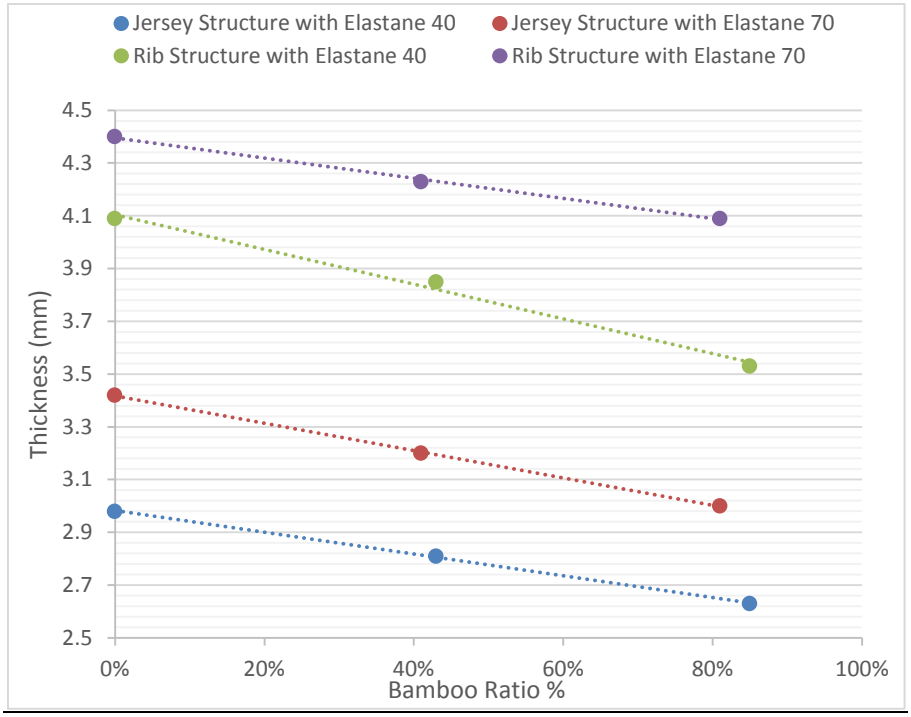

Fig. (2) The Relationship between Bamboo Ratio% and Sports Socks thickness (mm)

It was obvious from Figure (2) that, there is indirect relationship between bamboo ratio % and sports socks thickness. The bamboo ratio % has a significant effect on the sports socks thickness (mm) for all structures and elstane yarns count, as the bamboo ratio % increases, the sports socks thickness was decreased, this means that the higher the bamboo ratio %, the lower the sports socks thickness because bamboo fiber resembles cotton in its natural form, reminiscent of a puff ball.

To get a mathematical relationship between the bamboo ratio percent on sports socks thickness (mm) values, a linear regressions techniques were used to get this relationship.

Table (8) Mathematical Relationship Between the Bamboo Ratios % on Sports Socks Thickness (mm) Values

y = -0.4117x + 2.9823	R^2 = 0.9995	Jersey Structure with Elstane 40
y = -0.5186x + 3.4176	R^2 = 0.9996	Jersey Structure with Elstane 70
y = -0.6584x + 4.1043	R^2 = 0.9921	Rib Structure with Elstane 40
y = -0.3828x + 4.3957	R^2 = 0.9976	Rib Structure with Elstane 70
Where : Y = Thickness (mm)		
X = Bamboo ratio %		

The correlation is considered too high which means that the regression equation is reliable for prediction of the bamboo ratio % values in sports socks thickness (mm) values range by using various fabric compositions for both used structures (Jersey-Rib).

3.3. The Effect of Bamboo Ratio % on Sports Socks Air permeability

Figure (3) shows the effect of bamboo ratio % (from 0% to 85%) on sports socks air permeability ($cm^3/cm^2.sec$) by using various fabric compositions for both used structures (Jersey-Rib).

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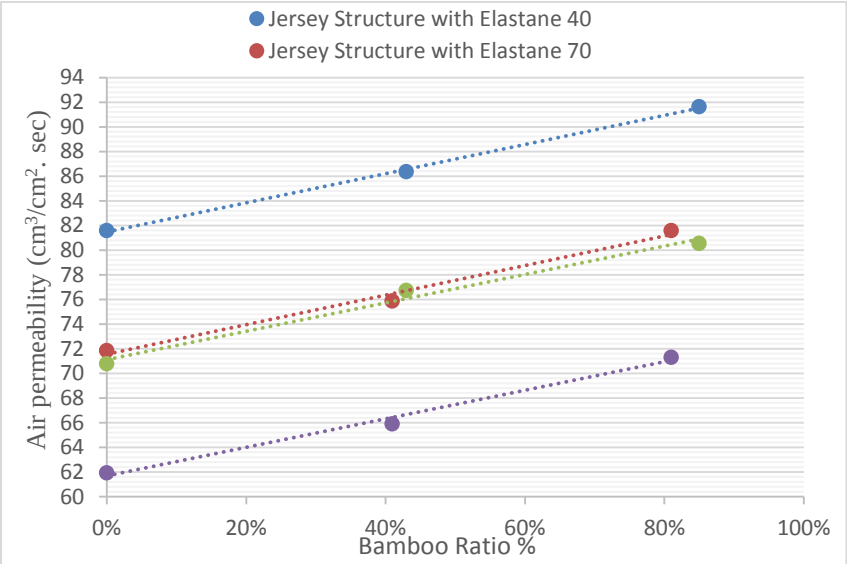

Fig. (3) The Relationship between Bamboo Ratio% and Sports Socks Air permeability (cm^3/cm^2. sec)

It was obvious from Figure (3) that, there is direct relationship between bamboo ratio % and sports socks air permeability. The bamboo ratio % has a significant effect on the sports socks air permeability (cm^3/cm^2.sec) for all structures and elstane yarns count, as the bamboo ratio % increases, the sports socks air permeability was increased, this means that the higher the bamboo ratio %, the higher the sports socks air permeability because the material breathes and ventilates exceptionally well because of the hole structure of the fiber. The most prominent attribute of bamboo material is its remarkable ability to breathe and its inherent coolness.

To get a mathematical relationship between the bamboo ratio percent on sports socks air permeability (cm^3/cm^2.sec) values, a linear regressions techniques were used to get this relationship.

Table (9) Mathematical Relationship Between the Bamboo Ratios % on Sports Socks Air permeability (cm^3/cm^2. sec)

y = 11.821x + 81.48	R^2 = 0.9988	Jersey Structure with Elstane 40
y = 12.003x + 71.552	R^2 = 0.9886	Jersey Structure with Elstane 70
y = 11.515x + 71.11	R^2 = 0.9862	Rib Structure with Elstane 40
y = 11.572x + 61.677	R^2 = 0.9911	Rib Structure with Elstane 70
Where : Y = air permeability (cm3/cm2.sec)		
X = Bamboo ratio %		

The correlation is considered too high which means that the regression equation is reliable for prediction of the bamboo ratio % values in sports socks air permeability (cm^3/cm^2.sec) values range by using various fabric compositions for both used structures (Jersey-Rib).

3.4. The Effect of Bamboo Ratio % on Sports Socks Absorption

Figure (4) shows the effect of bamboo ratio % (from 0% to 85%) on sports socks absorption by using various fabric compositions for both used structures (Jersey-Rib).

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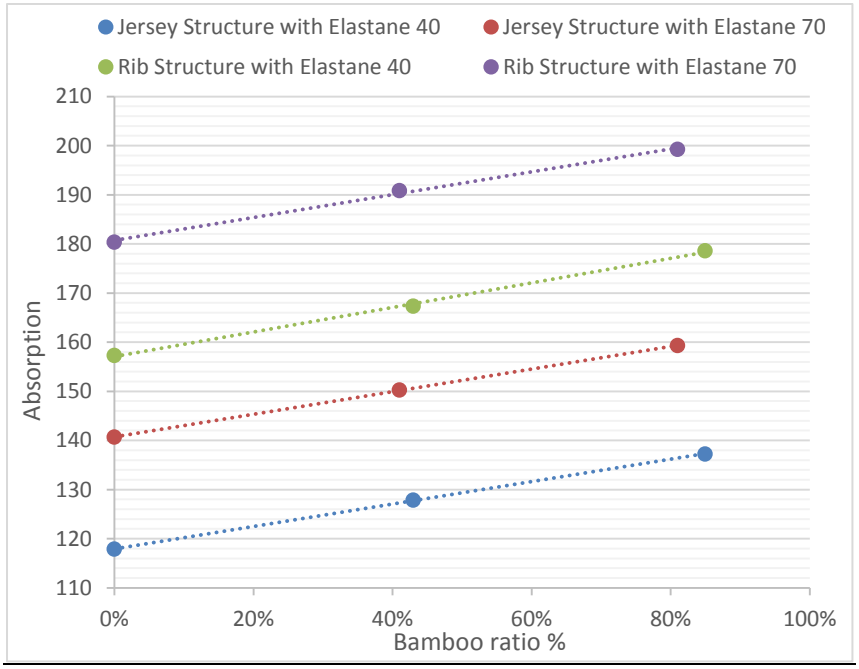

Fig. (4) The Relationship between Bamboo Ratio% and Sports Socks Absorption

It was obvious from Figure (4) that, there is direct relationship between bamboo ratio % and sports socks absorption. The bamboo ratio % has a significant effect on the sports socks absorption for all structures and elstane yarns count, as the bamboo ratio % increases, the sports socks absorption was increased, this means that the higher the bamboo ratio %, the higher the sports socks absorption because bamboo is very hygroscopic, absorbing more water than other conventional fibers, such as cotton. The transverse section of bamboo fiber is predominantly filled with innumerable micro gaps and micro holes, a characteristic that confers on the fiber-enhanced absorption.

To get a mathematical relationship between the bamboo ratio percent on sports socks absorption values, a linear regressions techniques were used to get this relationship.

Table (10) Mathematical Relationship Between the Bamboo Ratios % on Sports Socks Absorption

y = 22.79x + 117.95	R^2 = 0.9999	Jersey Structure with s Elstane 40
y = 22.989x + 140.74	R^2 = 0. 9999	Jersey Structure with Elstane 70
y = 25.04x + 157.06	R^2 = 0.9985	Rib Structure with Elstane 40
y = 23.305x + 180.7	R^2 = 0.997	Rib Structure with Elstane 70
Where : Y = absorption		
X = Bamboo ratio %		

The correlation is considered too high which means that the regression equation is reliable for prediction of the bamboo ratio % values in sports socks absorption values range by using various fabric compositions for both used structures (Jersey-Rib).

3.5. The Effect of Bamboo Ratio % on Sports Socks Bursting Strength (Kpa)

Figure (5) shows the effect of bamboo ratio % (from 0% to 85%) on sports socks bursting strength (Kpa) by using various fabric compositions for both used structures (Jersey-Rib).

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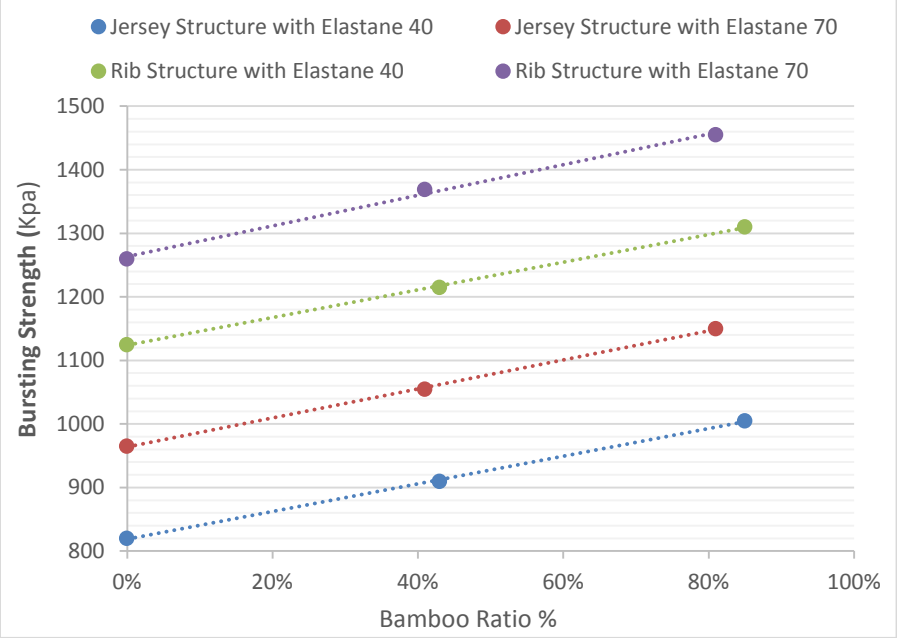

Fig. (5) The Relationship between Bamboo Ratio% and Sports Socks Bursting Strength (Kpa)

It was obvious from Figure (5) that, there is direct relationship between bamboo ratio % and sports socks bursting strength. The bamboo ratio % has a significant effect on the sports socks bursting strength for all structures and elstane yarns count, as the bamboo ratio % increases, the sports socks bursting strength was increased, this means that the higher the bamboo ratio %, the higher the sports socks bursting strength because bamboo fiber consists of more than 70% cellulose; we know that lignin is responsible for the stiffness and yellowness of natural bamboo fiber.

To get a mathematical relationship between the bamboo ratio percent on sports socks bursting strength (Kpa) values, a linear regressions techniques were used to get this relationship.

Table (11) Mathematical Relationship Between the Bamboo Ratios % on Sports Socks Bursting Strength (Kpa)

y = 217.61x + 818.82	R^2 = 0.9995	Jersey Structure with Elstane 40
y = 228.36x + 963.8	R^2 = 0.9995	Jersey Structure with Elstane 70
y = 217.61x + 1123.8	R^2 = 0.9995	Rib Structure with Elstane 40
y = 240.85x + 1263.4	R^2 = 0.9963	Rib Structure with Elstane 70
Where : Y = bursting strength (Kpa)		
X = Bamboo ratio %		

The correlation is considered too high which means that the regression equation is reliable for prediction of the bamboo ratio % values in sports socks bursting strength (Kpa) values range by using various fabric compositions for both used structures (Jersey-Rib).

3.6. The Effect of Bamboo Ratio % on Sports Socks Abrasion Resistance (The Lose in weight %)

Figure (6) shows the effect of bamboo ratio % (from 0% to 85%) on sports socks abrasion resistance (The Lose in weight %) by using various fabric compositions for both used structures (Jersey-Rib).

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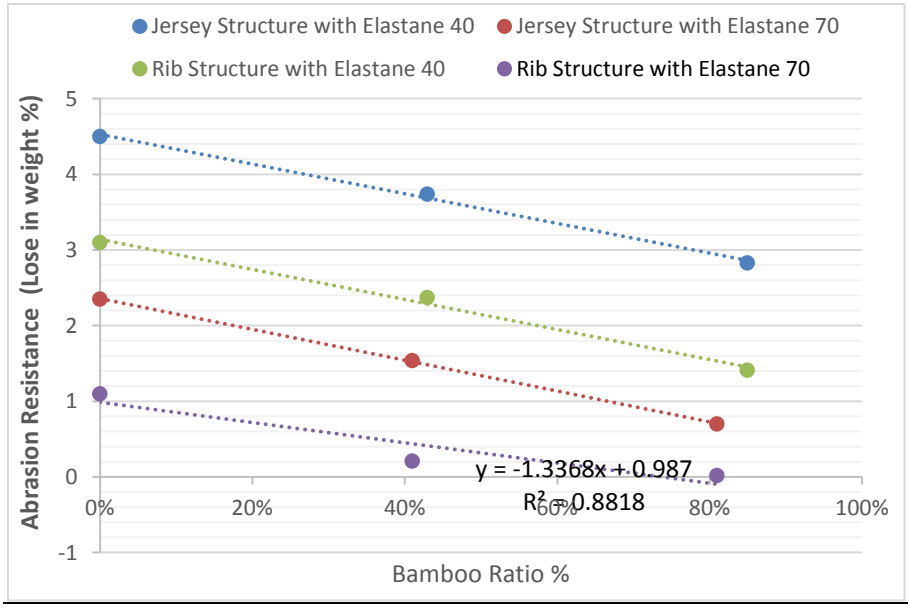

Fig. (6) The Relationship between Bamboo Ratio% and Sports Socks Abrasion Resistance (The Lose in weight %)

It was obvious from Figure (3.20) that, there is indirect relationship between bamboo ratio % and the loss in weight %. The bamboo ratio % has a significant effect on the sports abrasion resistance (The Lose in weight %) for all structures and elstane yarns count, as the bamboo ratio % increases, the sports socks abrasion resistance was increased, this means that the higher the bamboo ratio %, the lower the loss in weight % because bamboo fibers have good mechanical properties with this unique microstructure.

To get a mathematical relationship between the bamboo ratio % on sports socks abrasion resistance (The Lose in weight %), a linear regressions techniques were used to get this relationship.

Table (12) Mathematical Relationship Between the Bamboo Ratios % on Sports Socks Abrasion Resistance (The Lose in weight %)

y = -1.9639x + 4.5279	R^2 = 0.9966	Jersey Structure with s Elstane 40
y = -2.0368x + 2.3583	R^2 = 0.9997	Jersey Structure with Elstane 70
y = -1.9871x + 3.1412	R^2 = 0.9928	Rib Structure with Elstane 40
y = -1.3368x + 0.987	R^2 = 0.8818	Rib Structure with Elstane 70
Where: Y = abrasion resistance (The Lose in weight %)		
X = Bamboo ratio %		

The correlation is considered too high which means that the regression equation is reliable for prediction of the bamboo ratio % values in sports socks abrasion resistance (The Lose in weight %) range by using various fabric compositions for both used structures (Jersey-Rib).

3.7. The Effect of Bamboo Ratio % on Sports Socks Pilling Resistance (Grade)

Figure (7) shows the effect of bamboo ratio % (from 0% to 85%) on sports socks pilling resistance (grade) by using various fabric compositions for both used structures (Jersey-Rib).

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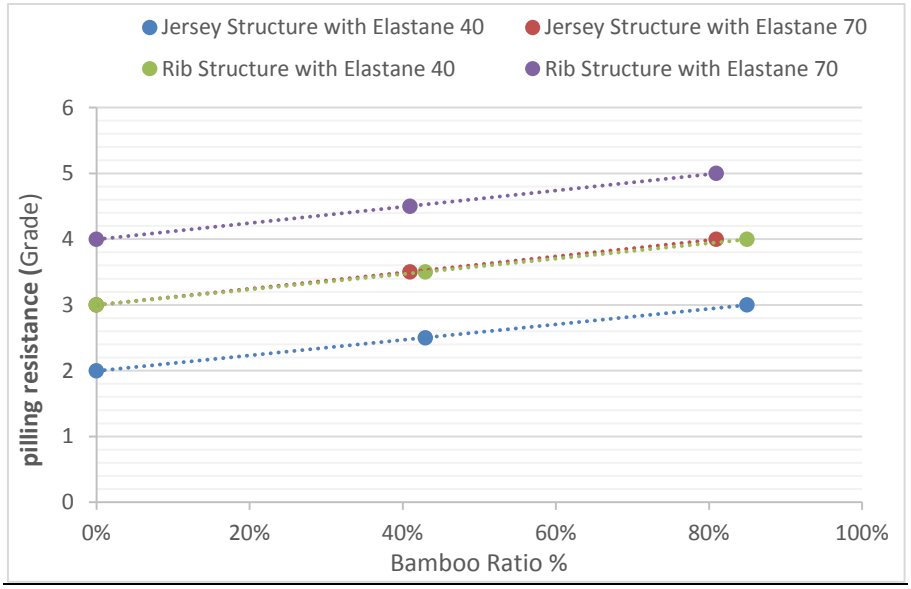

Fig. (7) The Relationship between Bamboo Ratio% and Sports Socks Pilling Resistance (Grade)

It was obvious from Figure (7) that, there is direct relationship between bamboo ratio % and the pilling resistance (grade). The bamboo ratio % has a significant effect on the sports pilling resistance (grade) for all structures and elstane yarns count, as the bamboo ratio % increases, the sports socks pilling resistance (grade) was increased, this means that the higher the bamboo ratio %, the higher the pilling resistance (grade) because bamboo fibre is characterized by its good hydroscopicity, soft feel, easiness to straighten.

To get a mathematical relationship between the bamboo ratio percent on sports socks pilling resistance (grade), a linear regressions techniques were used to get this relationship.

Table (13) Mathematical Relationship Between the Bamboo Ratios % on Sports Socks Pilling Resistance (Grade)

$y = 1.1764x + 1.9981$	$R^2 = 1$	Jersey Structure with Elstane 40
$y = 1.2345x + 2.998$	$R^2 = 0.9999$	Jersey Structure with Elstane 70
$y = 1.2345x + 3.998$	$R^2 = 0.9999$	Rib Structure with Elstane 40
$y = 1.1764x + 2.9981$	$R^2 = 1$	Rib Structure with Elstane 70
Where : Y = pilling resistance (grade)		
X = Bamboo ratio %		

The correlation is considered too high which means that the regression equation is reliable for prediction of the bamboo ratio % values in sports socks pilling resistance (grade) range by using various fabric compositions for both used structures (Jersey-Rib).

3.8. The Effect of Bamboo Ratio % on Sports Socks Antimicrobial Activity

Table (14) shows the Antimicrobial activity of sports socks by using various fabric compositions for Jersey structures.

DOI: 10.31695/IJASRE.2020.33680

Table (14) Antimicrobial Activity of Sports Socks

Sample No.	*Zone of inhibition (mm)*			
	Escherichia coli	*Staphylococcus aureus*	*Candida albicans*	*Aspergillus niger*
1	*27*	*30*	*22*	*25*
3	*24*	*28*	*19*	*21*
5	*20*	*24*	*17*	*18*
7	*10*	*20*	*14*	*15*
9	*26*	*29*	*20*	*19*
11	*26*	*27*	*18*	*17*

The highest antimicrobials activity was observed with all bamboo samples. The growing rate of bacteria for bamboo is small against cotton. The normal antimicrobial influence of bamboo does not permit the growing of organisms, where bamboo actually repels the colonization of both E. coli and S. aureus, which is a symptom of bamboo's antimicrobial resistance merits. The bactericide properties is primarily related to the existence of a bio-agent ''bamboo Kun" in the fiber, which bonds tightly with bamboo cellulose molecules. The growth rate of micro-organisms on 100% cotton is the highest.

From Table (14), it is clear that using a small percentage of Elastane in sports socks affects a little bit its antimicrobial property negatively. It is reasonable that adding Elastane decreases bamboo and cotton percentage inside the fabric which as a result decreases the antimicrobial activity.

Survivability of Bacteria

Table (15) shows the Survival of bacteria - Escherichia coli of sports socks by using various fabric compositions for Jersey structures while Table (16) shows the Survival of bacteria - Staphylococcus aureus of sports socks by using various fabric compositions for Jersey structures.

Table (15) Survival of Bacteria - Escherichia Coli

Fabric Composition	*Initial 0.1 ml inocula*	*No. of Colonies (10^3 cfu/ml)*				
		Day - 1	*Day - 2*	*Day - 3*	*Day - 4*	*Day - 5*
Bamboo 85% Nylon 4% Elastane 11%	*12×10^5 cfu/ml*	*5*	-	-	-	-
Bamboo 43% Cotton 42% Nylon 4% Elastane 11%		*12*	-	-	-	-
Cotton 85% Nylon 4% Elastane 11%		*60*	*35*	*3*	-	-

DOI: 10.31695/IJASRE.2020.33680

Table (16) Survival of Bacteria - Staphylococcus Aureus

Samples (Socks)	*Initial 0.1 ml inocula*	*No. of Colonies (103 cfu/ml)*				
		Day - 1	*Day - 2*	*Day - 3*	*Day - 4*	*Day - 5*
Bamboo 85% Nylon 4% Elastane 11%	*16×105 cfu/ml*	*100*	*15*	-	-	-
Bamboo 43% Cotton 42% Nylon 4% Elastane 11%		*150*	*20*	-	-	-
Cotton 85% Nylon 4% Elastane 11%		*TNTC*	*250*	*25*	-	-

TNTC - Too Numerous To Count

From Tables (15)&(16), The results indicate that the survivability of bacteria on cotton was more lasting compared to bamboo. The survivability of bacteria on mixed Bam/co is similar to bamboo. The general survivability of the test organism E. coli, was less compared to S. aureus. This analysis indicated that bamboo potentially resists the colonization of both E. coli and S. aureus from the second day of incubation, which is an indication of bamboo's antimicrobial resistance characteristic.

Survivability of Fungi

Table (17) shows the Survival of fungi - Aspergillus niger of sports socks by using various fabric compositions for Jersey structures while Table (18) shows the Survival of fungi - Candida albicans of sports socks by using various fabric compositions for Jersey structures.

Table (17) Survival of Fungi - Aspergillus Niger

Samples (Socks)	*Initial 0.1 ml inocula*	*No. of Colonies (102 cfu/ml)*				
		Day-1	*Day-2*	*Day-3*	*Day-4*	*Day-5*
Bamboo 85% Nylon 4% Elastane 11%	*7×102 cfu/ml*	*7*	*3*	-	-	-
Bamboo 43% Cotton 42% Nylon 4% Elastane 11%		*5*	-	-	-	-
Cotton 85% Nylon 4% Elastane 11%		*6*	*1*	-	-	-

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Table (18) Survival of Fungi - Candida Albicans

Samples (Socks)	*Initial 0.1 ml inocula*	*No. of Colonies (102 cfu/ml)*				
		Day-1	*Day-2*	*Day-3*	*Day-4*	*Day-5*
Bamboo85% Nylon 4% Elastane 11%	*19×102 cfu/ml*	*34*	*15*	-	-	-
Bamboo 43% Cotton 42% Nylon 4% Elastane 11%		*29*	*10*	-	-	-
Cotton85% Nylon 4% Elastane 11%		*38*	*20*	*3*	-	-

From Tables (17)&(18), Results indicate that the survivability of fungi was more or less the same on all tested samples. From this test, it can be concluded that the antifungal resistance of bamboo, cotton and mixed bam/cot are equally efficient. Generally, all the tested samples resisted the growth of A. niger and Candida albicans.

4- CONCLUSIONS

Bamboo fiber is cellulose based fiber with good water absorption capacity, breathability, as well as it is environmental friendly and has a fast drying behavior. It is produced from bamboo plant, which is a renewable, degradable, abundant and cheap natural resource. Twelve samples of Calf length sports socks in different ratios of Bamboo yarns (0%- 41%- 43%- 81%-85%) were produced in hosiery weft knitting machine by using various fabric compositions for both used structures (Jersey-Rib) according to the research plan to determine the best specification.

It was obvious that, there is indirect relationship between bamboo ratio % and functional properties of produced sports socks. As the bamboo ratio % increases, the sports socks weight and thickness were decreased because bamboo fiber has smaller molecular mass and degree of polymerization than other best fibers. In other wise, As the bamboo ratio % increases, the sports socks absorption, bursting strength, air permeability, abrasion and pilling resistance values increase because of the hole structure of the fiber. The most prominent attribute of bamboo material is its remarkable ability to breathe and its inherent coolness. The transverse section of bamboo fiber is predominantly filled with innumerable micro gaps and micro holes, a characteristic that confers on the fiber-enhanced absorption. Bamboo fibers have good mechanical properties with this unique microstructure.

Wearing sports socks without appropriate antibacterial footwear, leads to severe foot irritation and discomfort. The foremost target of anti-bacterial sports socks is to reject bacteria growing in the existence of heat and moisture that give rise to infections of the body and cause allergies. The growing rate of bacteria for bamboo is small against cotton. The normal antimicrobial influence of bamboo does not permit the growing of organisms, where bamboo actually repels the colonization of both E. coli and S. aureus, which is a symptom of bamboo's antimicrobial resistance merits. The bactericide properties is primarily related to the existence of a bio-agent ''bamboo Kun" in the fiber, which bonds tightly with bamboo cellulose molecules. The growth rate of micro-organisms on 100% cotton is the highest. It is clear that using a small percentage of Elastane in sports socks affects a little bit its antimicrobial property negatively. It is reasonable that adding Elastane decreases bamboo and cotton percentage inside the fabric which as a result decreases the antimicrobial activity.

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The general survivability of the test organism E. coli, was less compared to S. aureus. This analysis indicated that bamboo potentially resists the colonization of both E. coli and S. aureus from the second day of incubation, which is an indication of bamboo's antimicrobial resistance characteristic. It can be concluded that the antifungal resistance of bamboo, cotton and mixed bam/cot are equally efficient. Generally, all the tested samples resisted the growth of A. niger and Candida albicans. These findings are an important tool in the design of healthy comfortable sports socks.

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