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OPEN WARP-KNITTED STRUCTURES FOR BAMBOO MOSQUITO NETS

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ABSTRACT

Mosquito nets provide protection against mosquitoes, other dangerous insects and thus against the diseases they may carry. The nets must have a specific construction to provide safe and reliable protection against mosquito bites. The required textile parameters include a defined number of mesh holes, adequate air circulation suitable for a tropical climate and specific strength, so that the mosquitoes cannot make holes in them. Since bamboo naturally contains anti-bacterial components, bamboo mosquito nets are an effective way to naturally combat and is therefore also suitable for people with allergies. This paper presents an experimental study of the functional performance properties of a various open warp-knitted structures made of bamboo fibres which are specially developed for mosquito nets. Differences in net structures and functional properties are the result of different loop constructions, different sizes of openings and different of mesh density. The physical reasons of these differences are discussed.

Keywords: Bamboo Fibers, Open Warp- Knitted Structures, Mesh Density, Mosquito Nets, , Raschel Machine, Tricot Machine .

I. INTRODUCTION

In the coming years, warp knitted fabrics will increasingly play a role in technical textiles and the warp knitted fabrics will combine the functions of medium, carrier and interface for an extremely wide range of industrial applications [1]. Warp Knitting is defined as a stitch forming process in which the yarns are supplied to the knitting zone parallel to the selvedge of the fabric, i.e. In the direction of wales. Characteristics of warp knitted fabrics include; extremely versatile in pattern effects with yarn, rigid to elastic, good air and water permeability, good crease resistance, good drapability, good dimensional stability and good strength [2].

In warp knitting machine, every knitting needle is supplied with at least one separate yarn. In order to connect the stitches to form a fabric ,the yarns are deflected laterally between the needles [3]. Net fabrics are produced in very large quantities. The warp knitting machine is equipped to produce unconnected chain lappings and is thus capable of producing a multitude of net structures. Differences in net structures are the result of different loop constructions, different sizes of openings and different types of yarns. Nets are produced for a variety of end uses, ranging from shade nets to fishing nets, and from wrapping to camouflage nets. The marquisette net structure is one of the most popular net structures, the fabric is a very open and transparent structure. Occasionally nets are formed by interlacing pillars in the structure to produce various shapes of openings [4].

Mosquito nets provide protection against mosquitoes and other insects and thus against the diseases they may carry. Examples include malaria, dengue fever, yellow fever, and various forms of encephalitis, including the West Nile virus. Some tiny insects are currently causing a great deal of concern, especially among pregnant women. The yellow-fever and tiger mosquitoes can pass on the zika virus and are suspected of causing microcephaly, a evelopmental disorder that affects unborn babies [5]. To be effective the mesh of a mosquito net must be fine enough to exclude such insects without reducing visibility or air flow to unacceptable levels. It is possible to increase the effectiveness of a mosquito net greatly by treating it with an appropriate insecticide or mosquito repellant [6]. The most frequently used pyrethroids are applied to the nets by a standard impregnation process or by long lasting impregnation (LLI). Products that have been treated by the standard impregnation process lose their effectiveness after six months and after every wash, and the insecticide has to be re-applied regularly. LLI mosquito nets, on the other hand, can be used for more than three years and washed up to twenty times [7].

Warp-knitted mosquito nets are mainly produced on two-bar tricot machines. Despite their high operating speeds, Tricot machines do not compromise on quality. The machines offer maximum precision and thus meet stringent requirements in terms of dimensional stability and uniformity of the mesh openings, tear resistance and weight per unit area. This attention to detail is definitely worth it, since any variations in the specified parameters can cost lives. In addition to tricot machines, Raschel machines having three guide bars can also be used to produce certain products [8].

There are a variety of mosquito nets available in different sizes, materials and shapes. In the 2000 meeting, three sets of specifications for netting material were discussed – for cotton, polyethylene and polyester, with a range of attributes and test methods proposed for polyester netting. However, as additional types of netting materials are being introduced into the market, the 2005 meeting recommended that generic minimum requirements for netting materials and mosquito nets should be developed. Producers can then develop materials that will possess the properties required of any type of netting. Any mosquito net should comply with the following minimum attributes: protect against insect/vector entry; be strong and durable; keep its dimensions after washing and be safe for users [9].

Bamboo fiber is a regenerated cellulose fiber, of relatively recent origin, produced from the bamboo plant. Bamboo is an important forest biomass resource [10]. A bamboo textile product has a host of incredible properties. It is breathable, cool and extremely soft; it has a pleasant luster; it rapidly absorbs water and is antibacterial. Yarns of bamboo fiber provide the desirable properties of high absorbency, antimicrobial behavior and a soft feel in textiles and made ups [11]. It is also very hygroscopic, absorbing more water than other conventional fibers, such as cotton and polyester. 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 microgaps and microholes, a characteristic that confers on the fiber-enhanced moisture absorption and ventilation [12].

Bamboo mosquito nets are unique, they are real 'eco' nets. They also have great functionality: the material breathes and ventilates exceptionally well because of the hole structure of the fiber. The fabric is cool even in hot weather. Since bamboo naturally contains anti-bacterial components, the fabric will always smell fresh and

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is therefore also suitable for people with allergies. The fabric feels very soft, is wrinkle free and does not absorb odors. The bamboo used for the production of this mosquito net is organically grown [13].

This research investigates the influence of different open warp-knitted structures made of bamboo fibres on the functional performance properties of mosquito nets.

II. MATRIALS AND METHODS

2.1. Bamboo Fibers

As a regenerated cellulose fiber bamboo fiber is 100% made from bamboo through a high-tech process. Bamboo fiber is praised as "the natural, green and eco –friendly new-type textile material of 21st century". Bamboo fiber fabric is made of 100% bamboo pulp fiber. It is characterized by its good hygroscopility, excellent permeability, soft feel, easiness to straighten and dye and splendid color effect of pigmentation. It is also a new environment-friendly raw material that enjoys a splendid prospect for application as its predecessor wood pulp fiber. Table (1) shows the physical parameters of used bamboo fibers.

Table 1 The Physical Parameters of Used Bamboo Fibers.

Dry tensile strength	(cN/dtex)	2.33
Wet tensile strength	(cN/dtex)	1.37
Dry elongation at break	%	23.8
Linear density percentage of deviation	%	-1.8
Percentage of length deviation	%	-1.8
Over length staple fibers	%	0.2
Over cut fibers	(mg/100g)	6.2
Residual sulfur	(mg/100g)	9.2
Defects	(mg/100g)	6.4
Oil-stained fibers	(mg/100g)	0
Coefficient of dry tenacity variation (CV)	%	13.42
Whiteness	%	69.6
Oil content	%	0.17
Moisture regain	%	13.03
Rate		Grade A

2.2. Open Warp-Knitted Structures

One way to produce an open warp knit structure is to knit unconnected pillars continuously while a connecting underlap by horizontal yarns is produced only every few courses. Another way to produce an open structure is to form loops continuously on the same needle and to interlace them laterally at certain intervals. open-work

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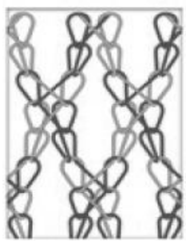
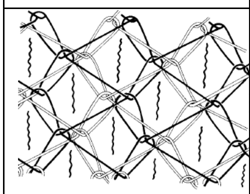
structures can be produced by using different threading techniques including leaving some guide eyelets vacant of yarn [14].

The under laps play a very important role in the pattern effects. The length or extent of these underlap floats and their direction of running cause a variety of designing possibilities. Another design tool in warp knitting is laying-in. For some design purposes, some of the guide bars do not knit the yarn into the fabric. The yarns are threaded through guide bars but the bars only insert the yarn ends into the fabric and are referred to as laid-in. This procedure is more prominent on Raschel machines. The inlaid yarn shogs only on the back side of the needle; thus, an underlap is produced but the yarn does not enter the hook of the needle. Since the laid-in yarns are not formed into loops, less yarn is needed. Laying-in allows the introduction of fancy, unusual, and/or inferior or superior yarns whose physical properties such as thickness, low strength, irregular surface, elasticity or lack of elasticity render them difficult to knit into regular intermeshed loops.

Occasionally nets are formed by interlacing pillars in the structure to produce various shapes of openings. In two-bar tricot fabrics, an opening is formed in the fabric structure when two wales do not connect. With full set threading, the only way to prevent the wales from connecting is to produce a pillar stitch. It is common practice in Raschel knitting to form nets in such a manner. Net fabrics are produced in very large quantities. The Raschel machine is equipped to produce unconnected chain lappings and is thus capable of producing a multitude of net structures. Differences in net structures are the result of different loop constructions, different sizes of openings and different types of yarns [15]. Mosquito nets for use in the tropics should have meshes large enough for air circulation but as small as possible to keep out mosquitoes. Mesh size of 1.2 mm stops mosquitoes, and smaller, such as 0.6 mm, stops other biting insects [16].

Two-bar warp knitted fabrics with three different structures were knitted on Tricot machine with 28 needles per inch using 100 denier bamboo yarns. Another three samples with different structures were knitted on Raschel machine with 28 needles per inch using 100 denier bamboo yarns. Fabrics specifications are provided in Table (1).

Table 1 Fabrics Specifications

Sample No.	Machine Model	Machine Gauge	Yarn Count	Fabric Structure	Mesh/inch^2	Fabric Thickness mm
1	HKS 2-M Tricot Machine	28	100% Bamboo yarns 100 denier		163	0.13
2					168	0.20

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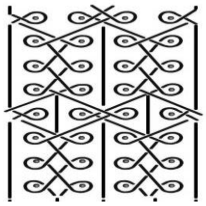
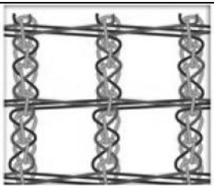
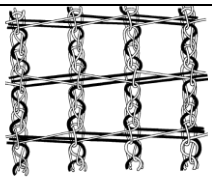
3					165	0.17
4	Multi Guide Bars Raschel Machine				166	0.18
5					170	0.22
6					160	0.12

Several tests were carried out in order to evaluate the functional properties of produced mosquito nets,:

1- Thickness test, this test was carried out according to the ASTM D1777- 96(2011) e1.
2- Weight test, this test was carried out according to the ASTM D3776 / D3776M - 09a.
3- Mesh Density test , this test was carried out according to European Norm International Standards Organization (EN ISO) 7211/2 .
4- Bursting Strength test, this test was carried out according to European Norm International Standards Organization (EN ISO) 13938-2.
5- Air Permeability test, this test was carried out according to the ASTM D737 – 04 (2012).

III. RESULTS AND DISCUSSIONS

There are specific physical textile properties that may be measured in an effort to predict the functional performance properties of mosquito nets such as ; thickness, weight, mesh density, air penetration and bursting strength.

3.1. Weight of Mosquito Nets

For a specific product (e.g., warp-knitted netting), the weight (grams per square meter) of the final netting material is closely linked to denier of the yarn and to mesh count. Lighter netting material is cheaper. Weight is not included in the minimum specification for netting materials but it should be stated on the packaging of the

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net. For the model nets, the underlap crosses and covers more wales on its way, with the result that the fabric becomes heavier, thicker and denser, as shown in Figure (1).

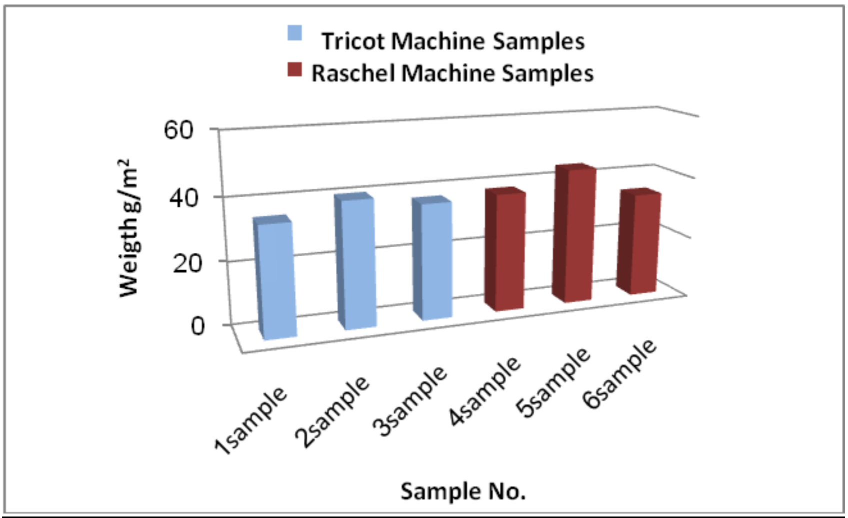

Figure 1 the Weight Values (g/m^2)

It is noticeable from Figure (1), according to the structural design sample (5) recorded the highest weight value (g/m2) while sample (6) recorded the lowest weight value (g/m2). Figure (2) represents the relation between the weight (g/m^2) and the thickness (mm) of produced samples.

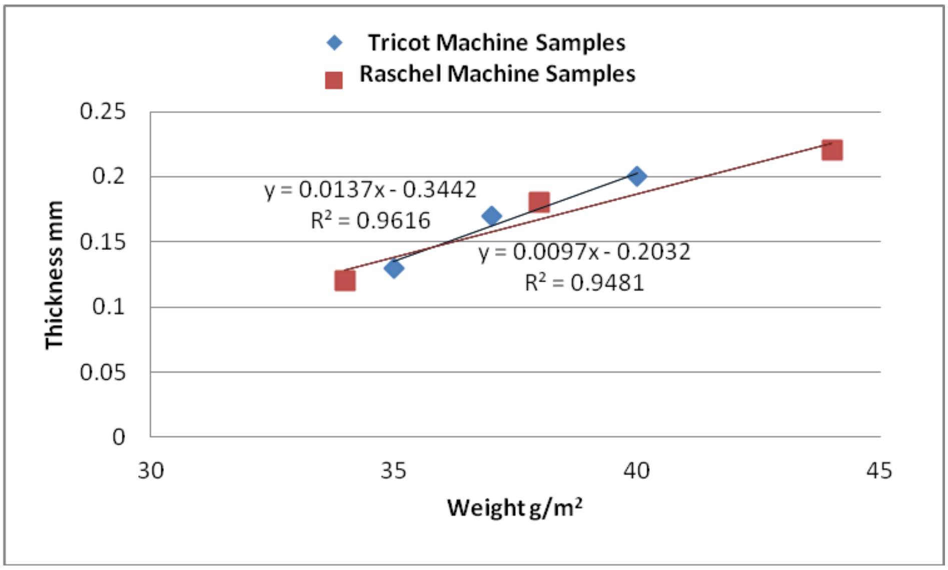

Figure 2 The Relation Between Weight (g/m^2) and Thickness (mm)

$$y = 0.0137x - 0.3442 \qquad (1)$$
$$y = 0.0137x - 0.3442 \qquad (2)$$

From equations (1) and (2), it is clear that the weight (g/m^2) is a function of knitted fabrics thickness (mm). Figure (2) shows a positive correlation between weight (g/m^2) and the thickness (mm) as the rate of fabric weight is increased by increasing the fabric thickness (R^2= 0.9616, R^2 = 0.9481) for produced samples.

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3.2. Bursting Strength of Mosquito Nets

Bursting strength measures the ability of a material to resist rupture by pressure. It is a standard method for evaluating mosquito net strength. Bursting strength is currently the only practicable test for which reliable data exist. Netting quality has improved over the past 5 years and the meeting agreed that the minimum bursting strength for acceptable netting materials is 250 kPa, when measured according to ISO 13938-1 (1999) or ISO 13938-2 (1999), using a 7.3 cm^2 sample [17]. Figure (3) shows the bursting strength values (kPa) for all experimental samples.

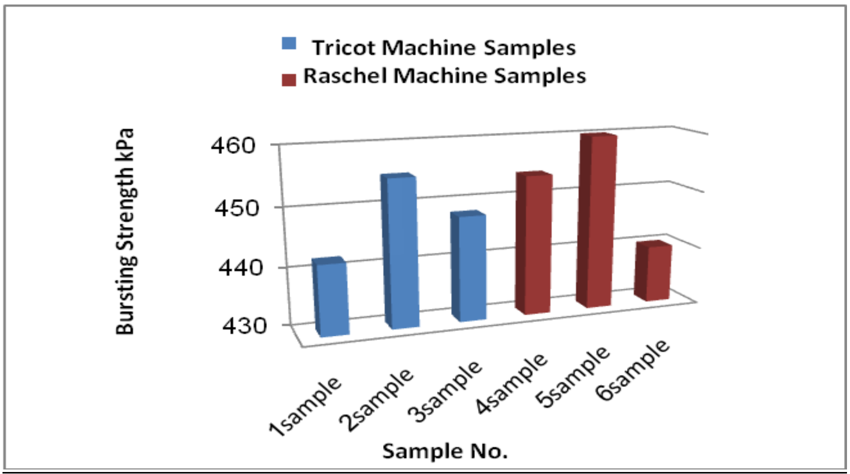

Figure 3 The Bursting Strength Values (kPa)

From Figure (3) ,sample (5) recorded the highest bursting strength values (kPa) while sample (6) recorded the lowest bursting strength values (kPa). For the model nets, higher weight and thickness provided higher bursting strength and tension strengths. Each increase in number of guide bars (using Raschel machine) tends to make the structure stronger, more opaque and heavier than structure produced in two- bar Tricot machine. For the model nets, the longer the underlap for a given warp the greater the increase in lateral fabric stability, conversely a shorter underlap reduces the width-wise stability and strength and increases the lengthways stability of the fabric. Figure (4) represents the relation **between bursting strength (kPa) and mesh density (Mesh/inch^2)**

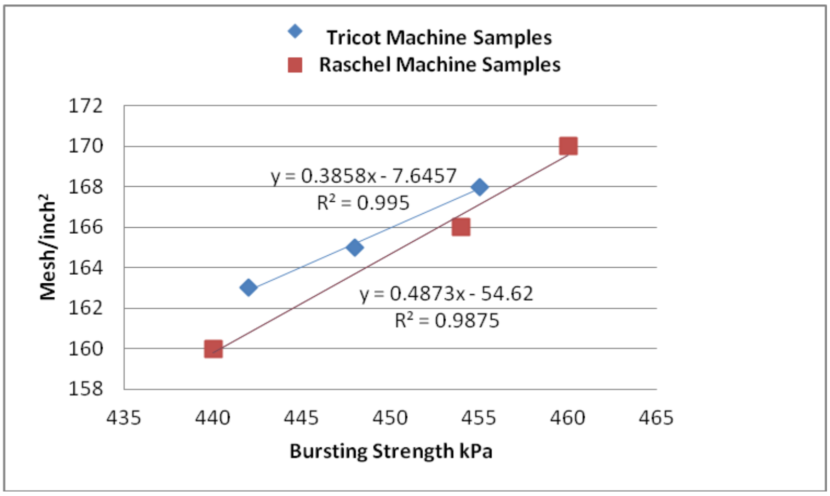

Figure 4 The Relation Between Bursting Strength (kPa) and Mesh Density (Mesh/inch^2)

y = 0.3858x - 7.6457 (3)

y = 0.4873x - 54.62 (4)

From equations (2) and (3), it is clear that the and mesh density (Mesh/inch^2) is a function of bursting strength (kPa) of knitted fabrics. Figure (4) shows a positive correlation between bursting strength (kPa) and mesh density (Mesh/inch^2) as the rate of bursting strength (kPa) is increased by increasing the mesh density (Mesh/inch^2) (R^2=1, R^2 = 0.9942) for produced samples.

3.3. Air Permeability of Mosquito Nets

Mosquito nets for use in the tropics should have meshes large enough for air circulation but as small as possible to keep out mosquitoes. A mesh size of 1.2 mm x 1.2 mm is common and recommended. The mosquito net mesh size recommended for effective malaria protection is of 120-200 mesh/square inch. The small sand fly, however, which also transmits diseases to humans, can pass through this mesh size, and can only be avoided with a small-meshed mosquito net (0.6mm x 0.6 mm), which in addition should be impregnated with insecticide [6,16].

Air permeability is a measure of how well air is able to flow through a fabric. The passage of air is of importance for a number of fabric end uses including the mosquito nets. Figure (5) shows the air permeability values (cm^3/cm^2/s) for all experimental samples.

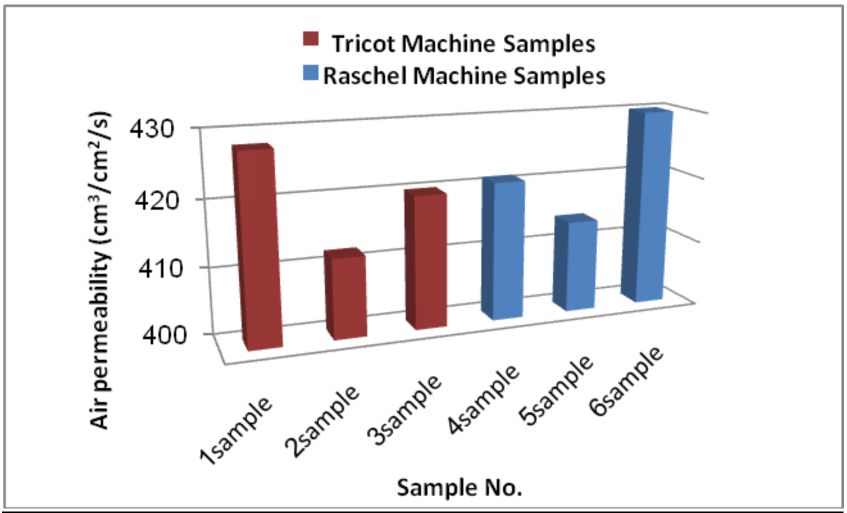

Figure 5 The Air Permeability Values (cm^3/cm^2/s)

From Figure (5) ,sample (6) recorded the highest air permeability values (cm^3/cm^2/s) while sample (2) recorded the lowest air permeability values (cm^3/cm^2/s). Figure (6) represents the relation between air permeability values (cm^3/cm^2/s) and mesh density (Mesh/inch^2).

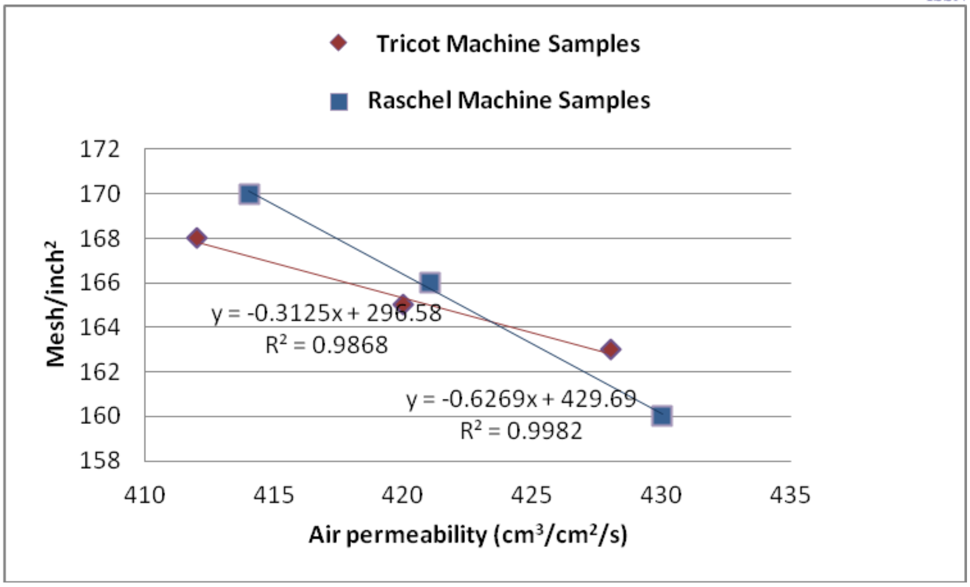

Figure 6 The Relation Between Air Permeability ($cm^3/cm^2/s$)and Mesh Density (Mesh/$inch^2$)

$$y = 0.3125x + 296.58 \quad (5)$$

$$y = 0.6269x + 429.69 \quad (6)$$

From equations (4) and (5), it is clear that the and mesh density (Mesh/$inch^2$) is a function of air permeability ($cm^3/cm^2/s$) of knitted fabrics. Figure (6) shows a negative correlation between air permeability ($cm^3/cm^2/s$) and mesh density (Mesh/$inch^2$) as the rate of air permeability ($cm^3/cm^2/s$) is increased by increasing the mesh size or decreasing the mesh density (Mesh/$inch^2$) (R^2= = 0.9868, R^2 = = 0.9982) for produced samples.

IV. CONCLUSION

Mosquito nets provide protection against mosquitoes and other insects and allow for an undisturbed night's sleep. Wide range of warp knitting machines (Tricot and Raschel machines) can perfectly meet all the technical requirements made of these nets with regard to hole size and the number of holes (120-200 mesh/square inch) over a given area. Open warp-knit structures can be produced by using different threading techniques including leaving some guide eyelets vacant of yarn. Differences in net structures are the result of different loop constructions, different sizes of openings and different types of yarns. The nets must have a specific construction to provide safe and reliable protection against mosquito bites. The required textile parameters include a defined number of mesh holes and secondly, ensures that there is adequate air circulation suitable for a tropical climate. The textile nets must also have a specific strength, so that the mosquitoes cannot make holes in them. Bamboo mosquito nets are unique, they are real 'eco' nets. They also have great functionality: the material breathes and ventilates exceptionally well because of the hole structure of the fiber. The fabric is cool even in hot weather. This research investigates the influence of different open warp-knitted structures made of bamboo fibers on the functional performance properties of mosquito nets. Well-designed open warp-knit structures, have been shown to be promising for mosquito nets. Mesh density plays an important role in the other properties evaluation, such as weight, air permeability and bursting strength. By increasing the mesh size or decreasing the mesh density the rate of air permeability is increased while the rate of bursting strength is decreases. Warp-

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knitted fabrics with unique net structures and functional properties are important elements of the mosquito nets field.

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