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THERMAL COMFORT STUDY OF ACRYLIC AND COTTON KNITTED FABRICS USING STATISTICAL ANALYSIS

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Abstract: *Yarn made from natural cellulose and man-made polymer fibres are contemporaneously used in virtually all ramifications of textiles. It is ostensible that different raw materials and fabrics structures affect the characteristics of the finished textiles. This paper presents a comparative analysis of the thermal comfort idiosyncrasies, scilicet, thermal conductivity, thermal diffusivity, thermal absorptivity and thermal resistance of knitted fabrics made of 100% acrylic and 100% cotton yarns with the same nominal linear density. Using a combination of miss, knit and tuck stitches, 27 fabrics were designed and knitted for each respective yarn composition, with each fabrics having distinct surface configuration. The fabrics porosity was measured on the basis of image processing. Furthermore, the Alambeta instrument was used to determine the thermal comfort properties and thickness of the fabrics. The results were statistically and graphically depicted. In parametric statistical testing, the* R^2 *was determined hinged on simple regression analysis. Because low correlations were observed between porosity-thickness and thermal comfort parameters, Parametric Plots (P-P) in conjunction with non-parametric test methods viz. Anderson-Darling, Cramér-von Mises, Kolmogorov-Smirnov, Mardia Combined, Shapiro-Wilk and Watson* U^2 *were conducted using hypothesis test of their p-values using Wolfram Mathematica software. All the test results exhibited failure to reject the null hypothesis.*

Key words: *Comfort, Textile, Knitting, Thermal insulation, Statistics*

1. INTRODUCTION

Thermal comfort is among the utmost salient characteristics of textiles for consumers [1]. Generally, transfer of heat from human body to a fabric layer occurs by radiation, conduction and convection simultaneously [2]. Fabrics perform an adjustment role and their properties of heat transmission sway the wearing comfort. As such, thermal insulation ascertains the rudimentary function of clothing by maintaining a cosy microenvironment between clothing and human body in fluctuating atmospheric surroundings [3]. Cotton has been the most commonly used natural fibre for thousands of years. Attributable to their thermal comfort properties and easy laundering, knitwear constitutes for the highest use of cotton. Acrylic are synthetic fibres made from the organic polymer resin polyacrylonitrile. Acrylic knitted fabrics possess easy-care properties, good shape retention and durability. A plethora of textile products are manufactured and marketed using acrylic [4].

Weft knitting is the most common fabric manufacturing process and can be produced using tuck, knit and miss stitches [5]. By dint of their freedom of movement, soft feel and high elasticity, knitted fabrics are much desired for garments. Also, knitted fabrics are favoured for summer and winter as the next-to-skin wear in which requirement for comfort is essential.

Porosity is the physical characteristics indicating the difference between the total fabric area and the estimated area covered by the yarns [6]. Knitted textile fabrics are considered as open porous structures. Hence, determining knitted fabric porosity is critical because it affects heat transport from the body to the environment. Computational digital image analysis has gained ground as an accomplished approach to measure knitted fabrics porosity [7].

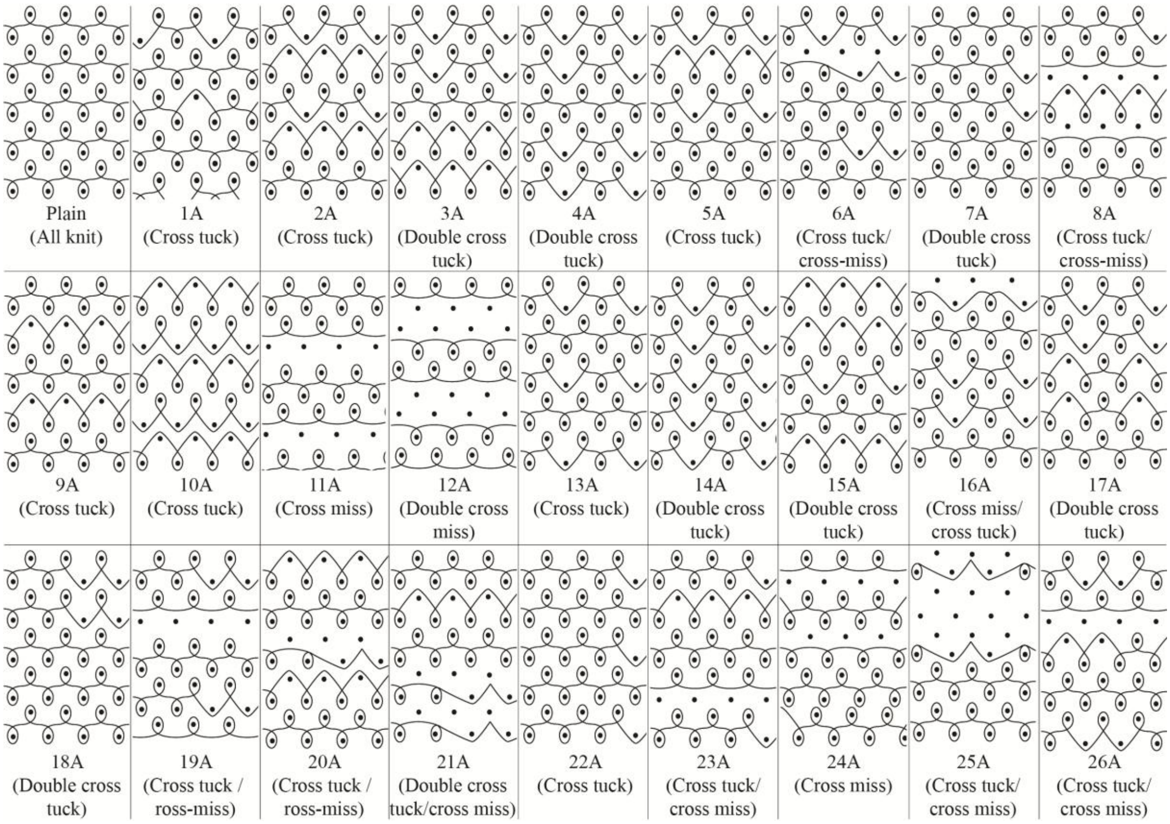
Hes (1995) broached the notion of thermal absorption as an estimate of the warm-cool sensation of textiles [8]. Thermal properties of textiles are the cornerstones underlying for comfort during hot and cold weather. The contact temperature between two materials is determined by the thermal absorptivity. This warm-cool feeling property imparts whether an individual feels cool or warm at the initial succinct touch of the human skin to a fabric. Its avail causes the particularity that thermal absorptivity does not rely solely on the experimental conditions, it is allied with thermal properties such as thermal diffusivity and conductivity [9]. It is well known that thermal properties are the functions of many factors such as fabric porosity, thickness, fibre types and structure [10]. Porosity of the fabrics improves the breathability and thickness improves the thermal insulation. In this purview, umpteen investigations conducted have been dedicated to examine thermal comfort of knitted fabrics [11, 12]. In the alluded references, the Alambeta device, manufactured by the Czech company Sensora has been used to measure the thermal comfort properties of fabrics [13].

Au fait with the review of literatures, erstwhile studies were reckoned to be limited mainly to knitted structures such as single jersey, ribs or interlock. Scant perusals are pertained on the thermal comfort properties of variation of knitted fabric structures. Practically, it is presumed that during shopping, customers do not plump for to buy a specific type of knitted fabric apparel structure [14]. Hardly or few researchers have scouted cellulosic and man-made knits under all types of thermal comfort exposures. Drawing from these insights, the objective of this work is to design and produce assorted weft knitted fabrics structures using acrylic and cotton yarns and to comparatively study their thermal comfort characteristics.

2. MATERIALS AND METHODS

The notations of the knitted fabrics were designed, Fig. 1, which were used to produce the fabrics on a 5-gauge V-flat bed manual knitting machine set with stitch cam 15 mm. 100% cotton and 100% acrylic yarns were used for knitting, both bearing linear density 236.2 tex (2.5 Ne) to maintain consistency during the analysis. Weft knitted fabrics can be created by either: knit + miss loops; knit + tuck + miss loop; all knit loops and or knit + tuck loops. Firstly, a plain fabric was produced consisting only of knit stitches. Combinations of knit, tuck, and miss stitches were incorporated during knitting to produce 27 different fabric structures both with 100% acrylic and 100% cotton yarns respectively. The aftermath of this operation yielded a total of 54 fabrics for both yarn compositions. The knitting notations are given in Fig. 1.

Conditioning of fabrics was done at 21 ± 1°C (70 ± 2°F), and 65 ± 2% relative humidity for 48 hours, following the ASTM D1776-04 standard. Images of fabrics were captured in the constructed light box designed as reported by Imrith et al. (2019) [15]. The porosity was evaluated using digital image processing and analysis routine in Wolfram Mathematica. The Alambeta apparatus was used to determine the thermal properties of the fabrics.



Plain (All knit); 1A (Cross tuck); 2A (Cross tuck); 3A (Double cross tuck); 4A (Double cross tuck); 5A (Cross tuck); 6A (Cross tuck/ cross-miss); 7A (Double cross tuck); 8A (Cross tuck/ cross-miss)

9A (Cross tuck); 10A (Cross tuck); 11A (Cross miss); 12A (Double cross miss); 13A (Cross tuck); 14A (Double cross tuck); 15A (Double cross tuck); 16A (Cross miss/ cross tuck); 17A (Double cross tuck)

18A (Double cross tuck); 19A (Cross tuck / ross-miss); 20A (Cross tuck / ross-miss); 21A (Double cross tuck/cross miss); 22A (Cross tuck); 23A (Cross tuck/ cross miss); 24A (Cross miss); 25A (Cross tuck/ cross miss); 26A (Cross tuck/ cross miss)

Fig. 1. *Kntting notations were designed to knit the fabric structures*

3. RESULTS AND DISCUSSIONS

3.1. Structural parameters of fabrics and thermophysiological comfort

The porosity *(p_o)* of acrylic fabrics pans out to be higher than cotton, ranging from 38.88% to 52.80%. Double cross tuck structures exhibit larger porosity and fabric thickness. A conceivable explanation was due to the tuck stitches that produce less elastic and wider fabrics. On the other hand, miss stitches resulted in thinner and tighter fabrics. In general, both acrylic and cotton followed tantamount tendencies in thickness and porosity.

Acrylic fabrics depict lower thermal absorptivity and higher thermal resistance than cotton due to their smooth and regular fibrous structure, which create tortuous paths that scatter and absorb heat. The increased porosity in acrylic fabrics decreased heat transfer by entrapping air, consequently promoting insulation. Cotton is endowed with its elliptical fibre cross-section and it can be pointed out that this results in low fabric cover factor. Hence, the cotton fabrics have higher thermal absorptivity as heat passes more easily through its ribbon-like fibre surfaces. Generally, the fibrous surfaces of acrylic fabrics bring about higher thermal insulation related to cotton, emphasising their aptness for applications calling for retention of heat.

Cotton's rough surface increases contact area, enhancing thermal absorptivity and producing a warmer sensation. The acrylic fabrics had smooth surface, thereby decreasing contact area with the skin. With regards to thermal conductivity, cotton and acrylic show high differences for all samples, in that order with mean 57.02 W/mK and 110.29 W/mK. As it is cellulosic fibrous material, cotton has polar groups at its molecular level and will have a higher moisture regain than the acrylic [16].

Albeit the linear density of the yarns was same, cotton fabrics have less thermal insulation than the acrylics. This is because the acrylic fabrics were thicker than that of the cottons. At the same time, twist adds bulkiness to the yarn, and hence the resulting cotton fabrics macrostructures with higher thermal conductivity were obtained.

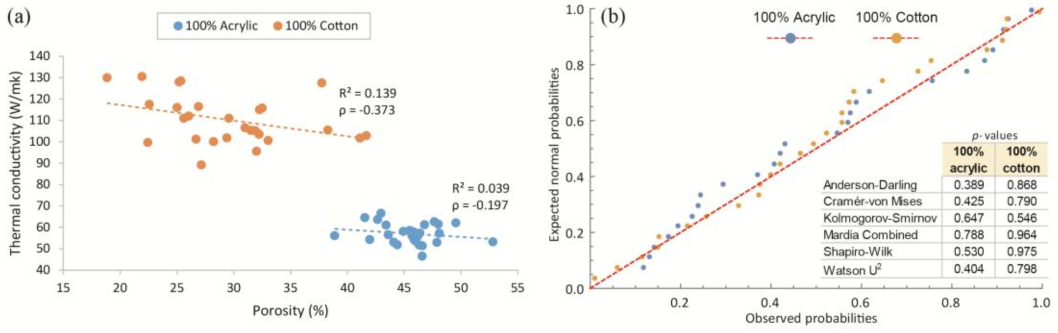
3.2. Statistical methods to evaluate experimental results

Linear regression was used to estimate the relationship between the thermal comfort variables and fabric porosity and thickness. The correlation hypothesis was defined that porosity and thickness would show good correlation with the thermal comfort properties. Pearson's correlation *(ρ)* analysis was conducted to analyse the correlation between thermal comfort and fabric parameters.

3.3. Porosity of 100% acrylic fabrics and 100% cotton fabrics

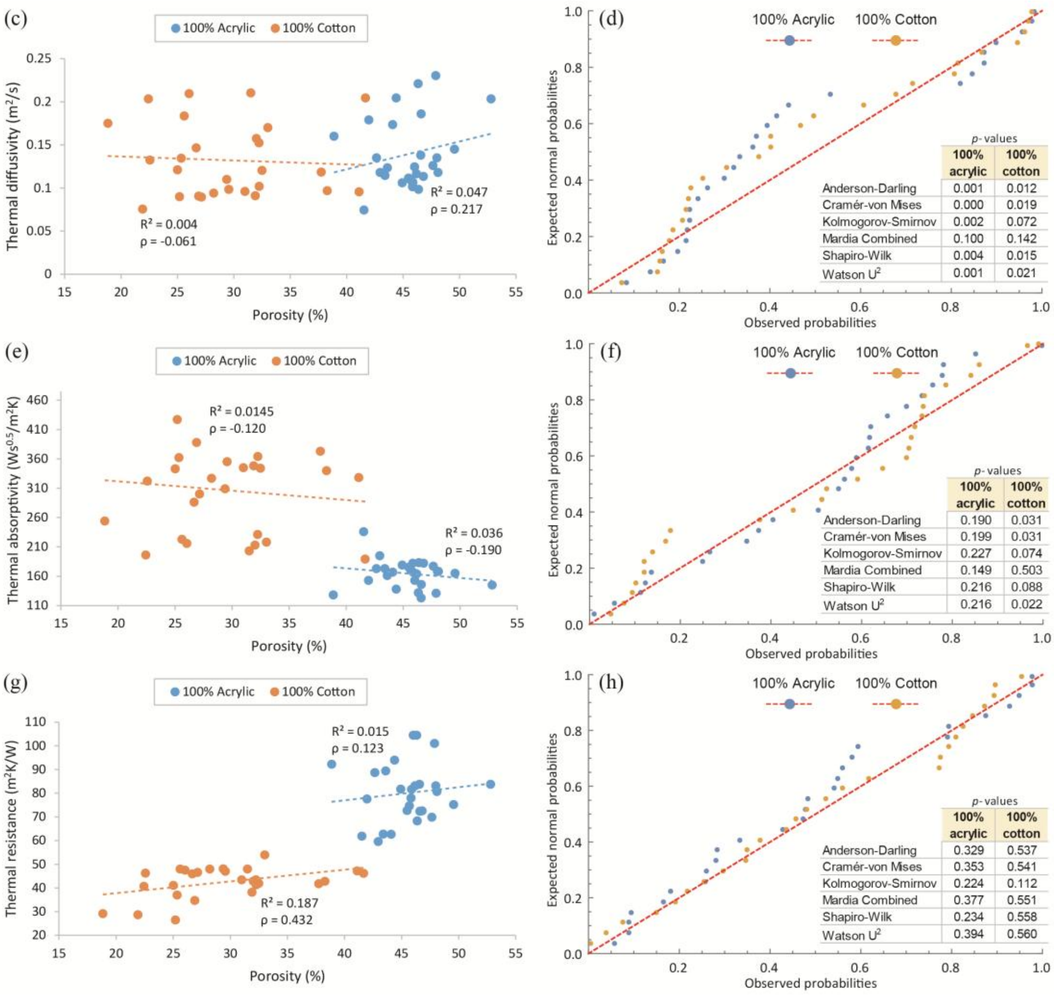
Fig. 2 (e) shows the variation of the coefficient 0.036 of thermal absorptivity as a function of the porosity. The decrease or increase in fabric porosity led to the inverse proportional effect between thermal absorptivity and thermal resistance as also supported by the respective negative and positive *ρ*. Still, the %ratio coefficient of correlation of the regression equation for the dependencies between thermal absorptivity and porosity and between thermal resistance and porosity are 29:71. Fig. 2 (a) shows the negative contemplated trend between thermal conductivity and porosity. From these R^2 values, it can be deduced that porosity of the 100% acrylic macrostructures has low influence on the thermal properties.

The coefficients of the linear regression for thermal conductivity and resistance are higher, compared with equivalent dependences for the 100% acrylic. The R^2 between porosity and thermal absorptivity is 0.0145, that is, 29% compared to 71% for 100% acrylic. Between thermal diffusivity and the porosity, the $R^2$is 0.0047, implying only 7% of influence compared to only 93% for the 100% acrylic fabrics. The correlation coefficients are 0.0037 to 0.1868 for thermal comfort of the 100% cotton, and still they are low so that the statistical linear reliance to be contemplated strong enough. For 100% acrylic, the influences of thermal comfort properties are 0.0151 and 0.00473. In this case, these values ascertained the hypothesis that thermal comfort properties of knitted macrostructures expressed low correlation with attributes such as fabric thickness and porosity.



p-values

	100% acrylic	100% cotton
Anderson-Darling	0.389	0.868
Cramér-von Mises	0.425	0.790
Kolmogorov-Smirnov	0.647	0.546
Mardia Combined	0.788	0.964
Shapiro-Wilk	0.530	0.975
Watson U^2	0.404	0.798



(d)

p-values	100% acrylic	100% cotton
Anderson-Darling	0.001	0.012
Cramér-von Mises	0.000	0.019
Kolmogorov-Smirnov	0.002	0.072
Mardia Combined	0.100	0.142
Shapiro-Wilk	0.004	0.015
Watson U^2	0.001	0.021

(f)

p-values	100% acrylic	100% cotton
Anderson-Darling	0.190	0.031
Cramér-von Mises	0.199	0.031
Kolmogorov-Smirnov	0.227	0.074
Mardia Combined	0.149	0.503
Shapiro-Wilk	0.216	0.088
Watson U^2	0.216	0.022

(h)

p-values	100% acrylic	100% cotton
Anderson-Darling	0.329	0.537
Cramér-von Mises	0.353	0.541
Kolmogorov-Smirnov	0.224	0.112
Mardia Combined	0.377	0.551
Shapiro-Wilk	0.234	0.558
Watson U^2	0.394	0.560

Fig. 2 (a - h). *Scatter plots with R^2, ρ and P-P with non-parametric results between porosity and thermal properties*

3.4. Thickness of 100% acrylic fabrics and 100% cotton fabrics

Each of Fig. 3 (a - h), respectively, depicts scatter plots with R^2 and ρ and probability plots with non-parametric tests results between thickness and thermal comfort characteristics. Thickness is a conspicuous characteristic of textiles structure and which can be held for the thermal comfort properties of the fabrics. In this sense, it is reckoned to be an evident elevated relationship between thermal resistance and thickness. Fig. 3 (a) shows a high linear correlation between thickness and thermal resistance, $R^2 = 0.723$.

The appreciation in fabric thickness effected a wane in the thermal absorptivity whereas an equivalent opposite trend was seen for the thermal resistance. The linear relationship of thermal resistance and thickness have high correlation coefficient $R^2 = 0.495$. Both fabrics compositions show high dependence of thermal resistance on the thickness of the knits. At the same time, thermal absorptivity and thickness shows very low correlation of $R^2 = 0.010$, practically it is 6% compared to 94% for the 100% acrylic structures. It proves that the increasing fabric thickness, the thermal insulation also increases.

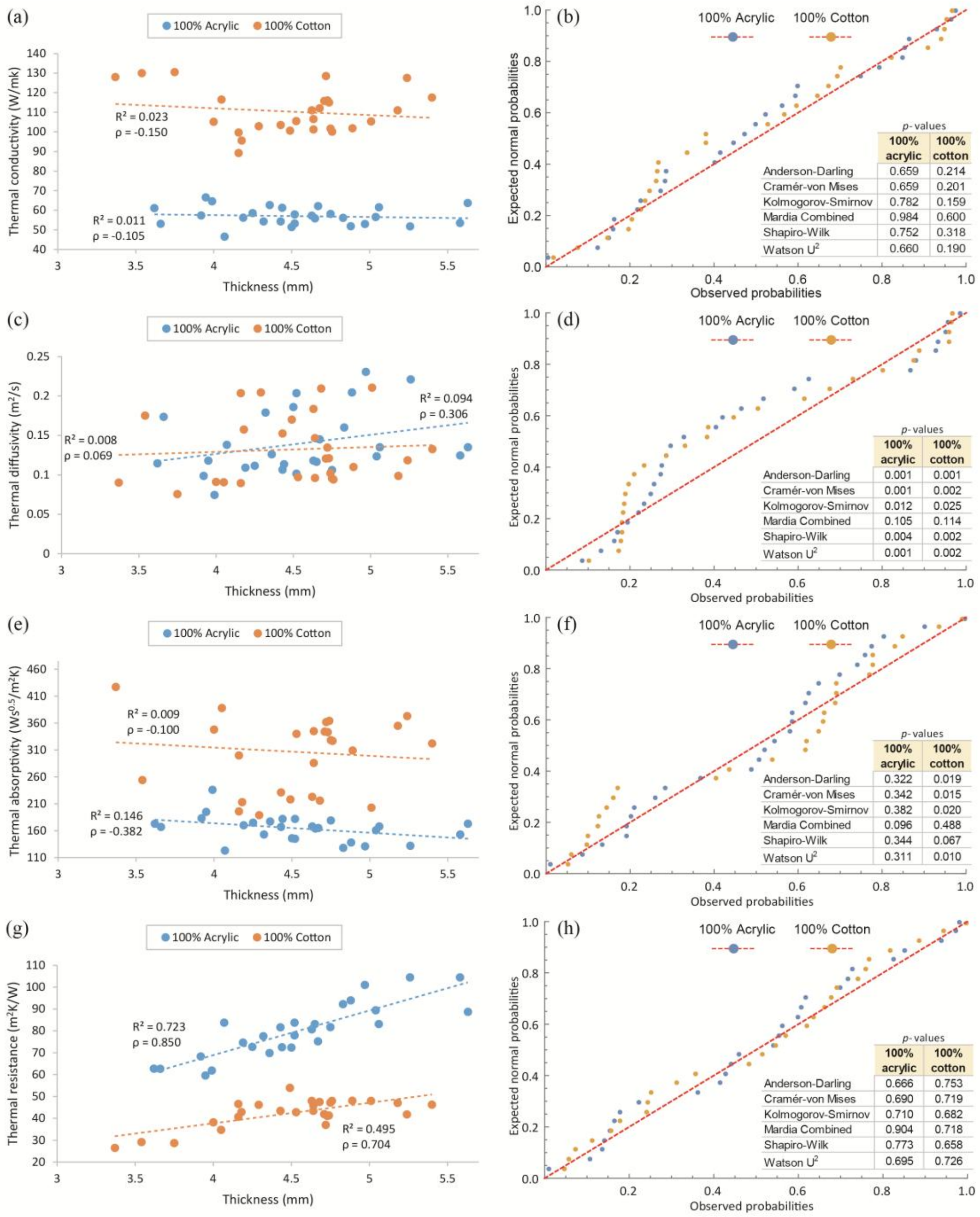


Fig. 3 (a - h). *Scatter plots with R^2, ρ and P-P with non-parametric results between porosity and porosity*

3.5. Analysing results using *p*-value

The normality of residuals was formally assessed based on hypothesis tests of *p*-values from non-parametric test statistics. The research question: whether fabric porosity and thickness influence the stipulated thermal comfort characteristics significantly. The null hypothesis *(H_0)* and alternate hypothesis *(H_a)* were defined:

H_0 : $p \geq 0.01$: Data are not statistically significant

H_a : $p < 0.01$: Data are statistically significant

With significance level of $\alpha = 0.01$, the null hypothesis states that the anticipated *p*-value is equal to or greater than 0.01. The assessment of the significance level and *p*-value allowed deciding whether or not to reject the null hypothesis. If the *p*-value is smaller than the significance level, it is made out that the null hypothesis is rejected, otherwise the null hypothesis is true. On that score, to decrease the probability of the type I error rate, the significance level was set to 0.01, akin to confidence level of 99%. This is the non-rejection region in the normal distribution. This connotes that 1% would be expected to be either below or above the rejection region. For this reason, it was acceptable with the likelihood of committing a type I error 1% of the time. The test samples *p*-value must be inside the critical region, 99% of the time. The current sampling distribution is a one-tailed test. Although it was shown that the majority of the correlation test have low R^2 values, all non-parametric tests, Fig. 2 (b, d, f, h) and Fig. 3 (b, d, f, h), showed that the *p*-values are higher that the significance level, then it was assume to be underlying the null hypothesis. Excepting thermal diffusivity against thickness and also against porosity, Anderson-Darling, Cramér-von Mises, Kolmogorov-Smirnov, Shapiro-Wilk and Watson U^2 resulted in $p < 0.01$. It is inferred that there is enough evidence to reject the null hypothesis. Accordingly, the smaller the *p*-value obtained from these five test methods, it was improbable that H_0 can be true. It was marked that there was significant difference between the means of all groups of the paired data using critical value of 0.01. Though, the non-parametric results concluded that the null hypothesis was rejected in favour of the alternative hypothesis (*p*-value < 0.01).

The smaller the *p*-value, the stronger the indication against H_0 provided by the data. Therefore, it indicated a type II error because the non-parametric test showed that porosity, thickness to thermal diffusivity is statistically significant. Contrarily, the Mardia Combined test for both fabrics' compositions has (*p*-value ≥ 0.01) for thermal diffusivity against porosity and also against thickness. The null hypothesis is that the porosity-thickness against thermal diffusivity is normally distributed and is not rejected at the significance level 0.01 depending on the Mardia Combined test. Here, it indicated failure to reject the null hypothesis, meaning that the data are not statistically significant. The fabrics areal porosity and thickness against the thermal comfort properties have $p \geq 0.01$ for both sets of fabrics. Non-parametric tests resulted in $p < 0.01$. In 100% cotton and 100% acrylic, thermal conductivity, thermal absorptivity and thermal resistance have $p \geq 0.01$ in all six statistical tests, substantiating the normality of the data.

4. CONCLUSION

Acrylic fabrics show maximum thermal resistance and porosity. The combination of cross tuck / cross miss for both fabric compositions lead to lower thermal comfort properties than only double cross tuck and cross tuck fabrics. Double cross tuck fabrics are characterized by higher values of porosity and thermal resistance as compared to other structures. There is akin agreement of Pearson correlation for all thermal comfort between porosity and thickness respectively. Moreover, to support the relationship among the variables statistically, this work applied non-parametric tests to evaluate the normality of the residuals. In a nutshell, low R^2 were observed and it can be concluded that if parametric tests give unsatisfactory results, then non-parametric test methods can be employed. The points of all the models in the P-P plot are clustered along the 45° line, signifying that the normality assumption is practically satisfied. The spreads of thermal comfort characteristics residuals are moderately equal around the line. And so, linearity of errors is not violated. Hence, the conclusions garnered from this reconnaissance can abet textile technologists or individuals to wend their path towards the selection of germane fabrics to manufacture or choose clothings depending on the climatic conditions for optimum thermo-physiological comfort. Future works will entail the use of various types of fibre compositions, including warp knitted, woven and non-woven fabric structures with the application of mathematical optimizing tools for predicting the thermo-physiological comfort of textiles.

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