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Tactile Comfort Evaluation of Conductive Knitted Fabric Using KES-FB

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Abstract: Tactile comfort has a strong relation with low-stress mechanical properties of textile fabrics having close contact with the human skin. In this work, we attempt to analyse the low-stress mechanical properties of the functional knitted fabric obtained using Kawabata’s fabric evaluation system (KES-FB). The measured results were compared with those of the controlled polyester fabric. The bending ability of the product increased from 0.2448 to 0.8010gf.cm\textsuperscript{2}/cm and hence the rigidity influenced when copper yarn is introduced. However, the compressibility increased from 0.173 to 0.449gf.cm/cm\textsuperscript{2} and hence the compressibility slightly boosted. The surface roughness (SMD) highly increased from 7.196 to 14.258 μm. It was observed that the incorporation of conductive copper yarn during knitting brought an effect on the tactile comfort of the fabrics and reduced by 69%. The overall comfort properties of the conductive textile fabric were reduced due to the introduction of copper yarn during knitting operations. Focus should be given when functional fabric developed which has close contact to the human skin.

1. Introduction

Now a days, textiles are serving the human being beyond the traditional use (shelters to the skin) such as wearable smart materials [1, 2]. Smart and functional textiles are fabric which replace the functions of electronics and simultaneously behave physically like traditional textiles which enable computing, digital components; electronics to embed into wearable into them. They have wide application areas such medical, sport clothing, protection from danger, and many other uses. The smart textile fabrics can be produced in many ways such as coating [3] and incorporation of smart fibre via knitting [4]. However, most researchers have been focused on the functionality aspect only. On the other hand no or little work has been done on the interaction of the wearer to the fabric. That means a lot of work should be required to assess and evaluate the tactile comfort of the smart fabrics as customers need always comfort in addition to quality of the product. This work intended to solve the quality dimensions in terms of tactile comfort.

After the birth of the objective evaluation of textile products by Pierce in 1930 [5], a lot of works have been done such as measuring the low-stress mechanical properties of the textile product using SiroFAST (Fabric Assurance by Simple Testing) and [6] FTT (Fabric touch tester [7] for the
realization of the objective evaluation and inspection of the tactile comfort of textile products. The major advance in the objective evaluation was the work done by Kawabata and his co-workers in 1991 [8-11]. The authors addressed the quality of the textile product by measuring the mechanical properties at low-load regions. The major findings in this work was the measurement of tensile properties, shearing properties, bending properties, compressional properties and surface and frictional properties of the textile product under low-load regions. This means the mechanical properties will be analysed without damaging the sample. Hence the orders of measurement does not have much influence on the obtained results. The KES-FB measurement system has been developed primarily for the objective evaluation of textile products [12]. They are ideally suited for the tactile hand evaluation of rigid (woven) fabrics. This initiates to apply the Kawabata’s evaluation systems to rigid knitted fabric which maintains its rigidity on the applications of low-load tensile forces. A fully automatic fabric test system was employed for the measurement of low-load mechanical properties of the knitted fabric.

In this work, we attempted to measure the comfort of the functional textile product using Kawabata’s evaluation system and tried to compare the results with conventional textile product. In addition to the objective evaluation, functional textile can also be assessed subjectively using human subject [13]. In this work, the authors addressed the subjective assessment of functional fabrics using bipolar attributes and found a permissible result.

2. Experimental
2.1. Materials
Plain woven polyester fabric from Almedahl-Kinna AB, with 159 g/m² was used as a control fabric. Composite of polyester (76/47/1 Dtex; 47 filaments; 10,000 m: weigh 76 gm and 1 thread only) and copper (0.1 mm ɸ; 2.5Ω/m) was used for KES-F measurements. The surface resistance of the conductive fabric was 0.158Ω/m.

2.2. Methods
Tensile, shear, bending, compression, surface, and friction properties of the functional textile fabrics were measured using tensile and shear tester (KES-FB1), bending tester (KES-FB2), compression tester (KES-FB3), surface and friction tester (KES-FB4) with KES FB-Auto (KATO TECH CO., LTD). All low stress-mechanical properties were measured in both warp and weft directions except the compression property; the average of the two were reported. Sixteen low-stress mechanical properties were measured and reported. The measurements were made under high sensitivity conditions as of reference [14].

3. Results and discussion
An important aspect of the current work is to observe the effect of incorporating conductive copper yarn on the tactile comfort of the functional fabric. All the low-stress mechanical properties of the knitted conductive fabric and controlled fabric were measured using Kawabata’s evaluation systems under controlled environment and the results are discussed as follows:

3.1. Tensile properties
The load elongation graph obtained by Kawabata’s evaluation system is shown in Figure 1. As shown in the figure, the results are displayed up to elongation of 51%. The conductive sample can extend beyond this limit. This could be attributed to the knitting structure introduced. We only compared the results up to this limit.

The load-elongation curves of the controlled fabric in this figure is a clear indication of the knitted fabrics show a maximum elongation even with at low load applications at low-load regions. This is a clear indication of how much sensitive is the Kawabata’s evaluation system to detect the change in the tensile properties at low stress regions.
Furthermore, there can be shown there is great difference between the warp and the weft yarn behaviours under load-extension curve for the tow fabric samples. This could be attributed to the structure difference between the fabrics.

Other low-stress tensile properties are displayed in Figure 2. Under this, extensibility, EMT [-], linearity, LT [-], tensile energy, WT [gf.cm/cm²], and tensile resilience, RT [%] were measured using KES-FB1 and analysed. As shown in the figure, the linearity values (LT) of the conductive sample is a little bit lower than that of the reference sample. This indicates that the incorporation of copper fabric has no any effect on the linearity of the conductive sample. As the value approaches to 1, the sample becomes harder. As shown in the figure, the fabric extensibility in the initial strain range is high in the cases of conductive fabrics. Theoretically, the lower the linearity is, the higher the comfort of the fabric in wearing. However, in our cases the low elongation recorded at low load is due to the structure of the fabric. Therefore, practically, the incorporation of the copper fabric reduces the comfort. Hence, linearity (LT) did not show the variation in the comfort of the samples.

On the other hand, incorporation of conductive copper to polyester fabric during knitting brought a great influence on the tensile energy (WT) of the conductive sample. The value for the conductive sample is higher than that of the reference sample. This could be attributed to the conductive sample in produced using knitting operations. Therefore, the stretchability increases when compared to that of weaving.

Similarly, the tensile resilience (RT) of the conductive sample is highly influenced due to incorporation of conductive copper fabric. As the value approaches to 100%, it becomes highly resilience, hence comfortable.

Figure 1. Tensile properties of (a) conductive and (b) reference samples.
Figure 2. Low-stress mechanical properties of conductive and reference samples.

As per this conclusion, the tactile comfort of the conductive sample reduces by 69% when compared to the reference sample. The strain (EMT) value of the conductive sample is much higher than that of the reference sample. This could be attributed to the increase in tensile energy due to its structure (Knitting structure). Therefore, for these samples, results of the tensile properties does not support the idea theoretical conclusions about the tactile comfort of textile product due to structure difference.

3.2. Shearing, bending, compression, and surface friction properties
Other mechanical properties of the samples measured under low-load regions using Kawabata’s evaluation are illustrated in Table 1 and Figure 3.

Figure 3. Bending and shearing property results.
In the compression measurement, the compressional energy (WC) is related to the comfort of the textile product. The higher the compressional energy is, the easier the compressibility. The compressional energy of the sample increased from 0.173 to 0.449. This indicates that the textile material becomes softer when copper fabric is introduced. This may be due to the structural change from woven to knitted product.

In the measurement of the surface frictional properties of the samples, the mean deviation of surface friction (MMD) is highly related to the comfort of the product. It tells us about whether the fabric is rough or smooth. The higher the MMD is, the harder the sample. The MMD result confirmed that the reference sample is rougher than that of the conductive sample. This is an indication of incorporating the conductive yarn using knitting operation does not have an effect on tactile comfort.

Finally, the control sample and the conductive knitted sample were tested if they can fit for some purpose by calculating the total hand value (THV) and by drawing and calculating the hand values for respective application areas. The control sample was tested for men’s summer suit, while the conductive knitted sample was tested for knit outwear (winter) and the results are shown in Figure 4.

As shown in the figure, the primary hand values (KOSHI, SHARI, FUKURAMI, and HARI) are within the range of values for men’s winter suit in the case of control fabric. Similarly, the primary hand values for conductive sample for knit outwear are also within the range for its specific applications. The calculated total hand value (for which THV: 5; excellent and THV: 1; poor) is another indication for which the product can fit for purpose or not. In this case, the total hand value for

### Table 1. Low-stress mechanical properties of the conductive and reference sample.

<table>
<thead>
<tr>
<th>Mechanical properties</th>
<th>Reference</th>
<th>Conductive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LC [-]</td>
<td>0.29</td>
<td>0.179</td>
</tr>
<tr>
<td>WC [gf.cm/cm²]</td>
<td>0.173</td>
<td>0.449</td>
</tr>
<tr>
<td>RC [%]</td>
<td>60.93</td>
<td>66.99</td>
</tr>
<tr>
<td>Surface friction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIU [-]</td>
<td>0.181</td>
<td>0.232</td>
</tr>
<tr>
<td>MMD [-]</td>
<td>0.070</td>
<td>0.067</td>
</tr>
<tr>
<td>SMD [μm]</td>
<td>7.196</td>
<td>14.238</td>
</tr>
</tbody>
</table>

![Figure 4. Primary and THV values.](image-url)
conductive fabric (2.73) is higher than that of control (1.98) even though they have different application due to structure difference.

4. Conclusions
At low-load regions, polyester knitted fabrics with copper incorporated are rougher than that of the pure polyester fabric. This could be due to copper yarns property. In similar way, the bending ability of the knitted fabric was improved due to the characteristic features of the knitted fabrics. The results of the shearing test also indicate that the conductive sample with copper yarn incorporated was highly deformable due the change in structure from weaving to knitting. The tensile test result showed that the tactile comfort reduced by 69% due to the incorporation of the copper yarn during knitting. The overall result confirmed that it is possible to make an analysis on the comfort of the functional fabric based on the results of the low-stress mechanical properties obtained by Kawabata’s evaluation system. To the end, we can conclude that tensile, shearing, and bending properties are very difficult to compare the comport properties of fabric which have different structure. However, other low-stress properties such as surface friction and compressional properties are used to distinguish the tactile comfort properties of textile products with different fabric structures.

5. References

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