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Development and performance of jacquard woven retro-reflective textiles with African design patterns

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Abstract

Retro-reflective materials are important for safety purposes, such as enhancing the visibility of pedestrians at night when they wear garments with reflective materials and therefore reducing pedestrian fatalities. This has challenged different manufacturers to produce effective materials that provide the best retro-reflection. Most of these materials are applied as stripes on clothing, but can also extend to artisans using reflective yarns in their creations. Nevertheless, there is a lack of research and the synthesis of reflective yarns and African design patterns (due to its symbolic value for the African people) to create effective textiles that have the necessary properties for visibility at night. In this research work, a new approach is adopted by using a design process that combines jacquard weaving technology, reflective threads and African design patterns to produce retro-reflective textiles. The subsequent reflective effects captured in a darkroom show the retro-reflective ability of the samples. The testing carried out by using the Kawabata Evaluation System for Fabrics shows that the total hand value (THV) of the samples makes them suitable for men's winter dress shirts and women's thin winter dresses (with positive values) but not suitable for the summer garment (with negative values) counterparts respectively. This new approach might extend the ideation to produce retro-reflective textiles that can be applied for many different uses.

Keywords: Retro-reflective textiles, Visibility, African design patterns, Jacquard weaving, Total hand value

Introduction

Pedestrian fatalities comprise a larger percentage of all the deaths and injuries on the road (Damsere-Derry et al., 2010; Schlottmann et al., 2017). In Africa, cases are particularly high with 35% of all deaths attributed to pedestrian accidents in South Africa in 2021 (Stoltz, 2021) and 35% in Kenya in 2020 (Kimuyu, 2021). These high percentages of pedestrian fatalities according to World Health Organization (2013) report accounted for about 38% of the total road traffic accidents in Africa in 2010. The average rate of road death in Africa increased to 40% or 26.6 per 100,000 individuals in 2013 (World Health Organization, 2018).

A study by Ackaah et al. (2020) to examine road traffic crashes at night in Ghana during 2013–2017 revealed the severity of pedestrian fatalities with 44% of the accidents happening at night. This is because some of the roads in both the urban and rural areas lack the needed lighting systems and road markings. These are major road safety concerns or problems since pedestrians walk along the roads or cross them at night. Other attributable factors for pedestrian accidents in Africa especially in Ghana includes, illegal road crossing, driver fatigue (Tulu et al., 2013), speeding, drunk drivers or drunk pedestrians (Ackaah & Adonteng, 2011; Cho et al., 2017), visual impairment, low or no lighting system at night (poor street lighting), poor road infrastructure, use of electronic gadgets while driving or walking and low visibility of the pedestrian (Ackaah et al., 2020; Kouabenan & Guyot, 2004; Mphela et al., 2021; Schwebel et al., 2012). The latter coupled with low lighting conditions at night, leads to poor visibility of the road users or pedestrians hence an increase in night vehicle-pedestrian collisions after dark (Sullivan & Flannagan, 2002). A key reason has been the type of clothing that pedestrians normally wears, which are not reflective and according to Green (2021) makes it difficult for drivers to visually detect pedestrian to avoid possible collisions. Additionally, the poor visual perception in most cases makes it difficult for drivers to see pedestrians at night (Fylan et al., 2020), hence increasing the risk of an accident.

In fact, a recent article by the Ghana News Agency (GNA, 2021) stated that, Sgt Timinka Richard of the Motor Transport and Traffic Department (MTTD) in Ghana urges pedestrians to wear reflective clothing to ensure safety and curb road knockdowns at nights. Even though many pedestrians in the developed economies can afford to purchase these reflective clothing, the unavailability, low aesthetics appeal and increased cost of such clothing have made it difficult for pedestrians in the developing countries in Africa to afford them (Wood et al., 2012). Nevertheless, considering the increase in pedestrian accidents in Africa especially in Ghana, recommendations have been made for road users to wear reflective clothing (Ackaah et al., 2020; Green, 2021; Tyrrell et al., 2004) to enhance their visibility. This is imperative since most of the streets are dark and there is the lack of lighting infrastructures so that they can be seen by approaching vehicles.

Although there are benefits from wearing clothing with reflective properties to ensure safety at night, there needs to be incentive and motivation to wear them. African patterns are cherished by the indigenes which can be applied creatively to enhance the aesthetics, and their interest and use of reflective fabrics. This research therefore aims to use modern jacquard weaving technology to produce African-inspired reflective textiles with cultural patterns to reignite local interest and reinforce the need for reflective clothing to ensure safety at night. A new approach of using reflective threads in materials that can be used in everyday wear during the day and night is proposed. This jacquard weaving technology is environmentally friendly, fast, and efficient as compared to the more time consuming and labour-intensive traditional weaving production methods widely practiced by craftsmen to produce the textiles. The production process from jacquard weaving produces no effluent or toxic waste that are potentially hazardous when released into the environment. These however do not come with functional performance to ensure the safety of the wearer especially at night.

As such, this study poses the following research questions: (i) how can the performance of African inspired textiles be improved for night use? (ii) which eco-friendly approach or technique can be used in the creative process that can incorporate African elements and retro-reflective threads in textiles? and (iii) what are the performance properties of these retro-reflective textiles using African cultural motifs as its design elements?

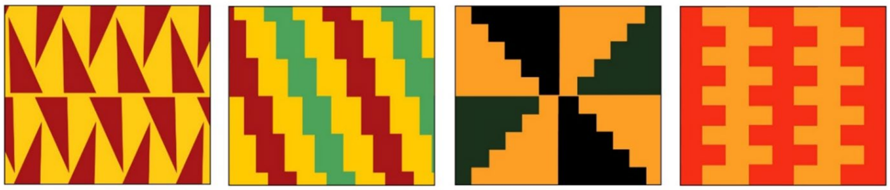
The significance of the study is the use of a design approach to expand the availability of reflective materials with cultural elements or patterns that not only reduces the high pedestrian fatalities at night but further showcases the rich heritage of the African culture to the World. This practical design approach broadens the scope of creative ideas for other cultures to produce reflective materials for their residents towards a more sustainable goal of road safety as inscribed in targets 11.2 of the United Nations 17 Sustainable development Goals (SDGs) in the 2030 Agenda for Sustainable Development. These textiles would improve the interest of the people to providing materials that ensures a personal safety at night-time due to their retro-reflection properties.

African patterns

The African art forms produced by skilled craftsmen in the second largest continent in the world incorporate indigenous symbols in their patterns. These art forms are found on different items like textiles, sculptures, pottery, architecture, baskets and jewellery amongst others. They carry significant messages or have meanings that tells a unique cultural history of events or happenings. African patterns are commonly cherished by the people because of their cultural values as a means of identity, personal adornment and an effective means to communicate messages to the viewers. Traditionally, the indigenous people use these patterns on different medium to communicate for example the human history, events or happenings in the community. In addition to the colour types used, these patterns further gives the individual's sense of mood either sad or happy for a funeral or a naming ceremony respectively. This visual communication method of the African patterns gives the religious and social insights of their culture. The wealth of patterns in Africa are generally grouped into two types; geometric and figurative patterns. They are a visual expression of the history, belief and philosophy of the culture (Evans, 2017). Depending on the cultures, their patterns may vary in terms of the style, shapes and colours. These African patterns are used by craftsmen to produce simple to complex visual forms through different techniques like weaving, carving, dyeing, sewing, painting and hand printing.

African geometric patterns are composed of rectangles, triangles, squares and circles which are incorporated into textiles, painted on walls of buildings amongst others. These geometric patterns carry significant cultural value. Notable examples are the Ndebele wall paintings in South Africa, and Kente cloth and Sirigu wall paintings in Ghana. Figure 1a and b show these geometric patterns which are either painted on walls or woven into traditional type of fabric. The patterns of the Ndebele wall paintings are created by women who use earth colours to paint the walls of buildings. Patterns are grouped together based on the five main colour choices (pink, green, sky blue, yellow to gold, red to dark red) from interesting design structures that reinforce their message to viewers (Jcroman, 2015; Rose, 2013). In the Sirigu wall paintings, *Agurinuuse* motif in Fig. 1a(i)

[a] Sirigu wall paintings in Ghana. Adapted from Asmah et al. (2013).



[b] Geometric motifs on Asante Kente cloth in Ghana. Adapted from Essel (2019), (CC BY 4.0).

Fig. 1 African geometric patterns

means linked hands, *Zaalin daa* motif in Fig. 1a(ii) symbolises male essence and *Zaalin nyanga* motif in Fig. 1a(iii) symbolises female essence. These last two symbols are collectively called *Zaalinga* or net, which draws on the importance of netted containers or fish or calabash nets to saveguard their calabashes from breaking (Wemegah, 2013). Finally, there are the geometric motifs on Asante Kente cloth in Fig. 1b. The *Nkyemfre* motif in Fig. 1b(i) means a pot shed, and symbolises service, knowledge, healing power, recyclability and history. The *Fa hia kɔtwere Agyeman* motif in Fig. 1b(ii) means lean your poverty on or carry your poverty to *Agyeman* (a noble individual who was known to be generous when this pattern emerged) symbolises faith and hope (Essel, 2019). *Apremo* motif in Fig. 1b(iii) means canon and symbolises resistance against foreign domination, and Achimota *Nsafoa* motif in Fig. 1b(iv) means Achimota keys, symbolises harmony, unity in diversity, knowledge (Asibey et al., 2017).

Figurative patterns are composed of images of animals and humans that depicts the historical signifcance of the culture. These types of patterns are found commonly on the Fon Applique cloth of Benin (West Africa) which are produced by men who cut out images that depict animals, humans, plants and objects which are then sewn onto a traditional woven fabric (Kimani, 2018) and the Adire cloth of Nigeria which resists starching and dyed an indigo colour. In terms of textile forms, simple to complex figurative patterns are either woven, sewn, embroidered, dyed or painted directly on the surface of the fabric. Figure 2a and b show some of the African figurative patterns that are used in textile applications.

Retro-reflective textiles

While retro-reflective materials have been developed for applications in different areas, nevertheless, they are specially used on clothing to produce products that improve the visibility of individuals at night thus reducing fatalities. Retro-reflective effects are imported onto the surface of a material by using one of two system technologies:

embedded glass beads and corner cubes or prismatic reflectors (3M, 2014; Önlü & Halaçeli, 2012), which differ in structural composition. Retro-reflective textiles are made by coating the surface of a base cloth with adhesives and embedding glass beads onto the cloth. This manufactured structure creates an additional layer on the base fabric which may influence its eventual thickness and tactile feel. Alternatively, retro-reflective inks can be used to imprint design patterns onto a base fabric to impart reflective effects. These inks enhance the ability to reflect light back to its source without scattering the light. Lloyd (2008) further added that, three key principles are found for retro-reflection or bouncing light back to its origins without absorbing the light: specular reflection, refraction, and total internal reflection. The most basic retro-reflector are glass beads. Their refractive index is an imperative property (Taek et al., 1999) which dictates the visibility and reflection distribution of light back to its source without scattering the reflected light in different directions. Retro-reflective textiles are used for reflective clothing, and backpacks and used as stripes on construction vests, cycling wears etc.

Methods

Design models or frameworks are widely used by designers to produce a sequence of events or activities within a creative process especailly when utilising technology with cultural elements to produce innovative products. As such, Arslan et al. (2020) developed a design process for culturally inspired jacquard fabrics from the stories of the Ottoman Sultans in the community. The design process maps out the chain of activities from adopting relevant sketches in the initial stages to importing them into digital software (Nedgraphics) for effective colour selection for jacquard weaving. Alternative models were proposed by Mathur (2018) on the design sequence for transferring artworks through a computer aided design (CAD) system for colour and weave selections for jacquard weaving. All of these frameworks provided the necessary reference materials for this study to create an ideal design process for the weaving of retro-reflective

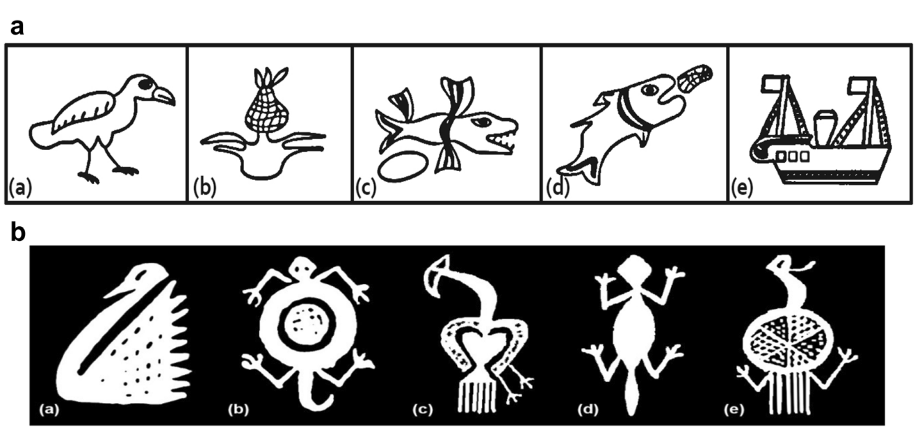


Fig. 2 **a** African figurative motifs found in Fon Applique cloth in Benin. (a) *Kpengla* (the sparrow), (b) *Agonglo* (the pineapple), (c) *Behanzin* (the shark and the egg), (d) *Houegbadja* (the fish and the wicker fish trap) and (e) *Agadja* (the ship). Adapted from Akrofi et al. (2016), (CC BY-NC-ND 4.0). **b** African figurative motifs used for Adire cloth in Nigeria. (a) Eye (bird), (b) Alangba berekete (fat lizard), (c) Adan (bat), (d) Alangba (lizard) and (e) Oobe (smaller specie of bat). (Adapted from Areo and Kalilu (2013), (CC BY 3.0))

fabrics inspired by African cultural patterns. This is vital because a special type of yarn is used and the cultural patterns require different weave structures and parameters.

The aim of the study was accomplished after completing multiple activities captured in the research methodology (Fig. 3). This features four vital activities that connects well to provide appropriate solutions for the stated research questions (RQ).

Activity 1: Problem (RQ1)

Textiles inspired from African culture are made using different techniques such as batik, printing, knitting amongst others that provide materials with aesthetic values for the consumers. These textiles are undoubtedly colourful and used for different occasions. Aside the aesthetic values, they are limited to providing the necessary functional property that can ensure personal safety most especially at night. Studies captured in the "Introduction" section clearly highlights the increase in road traffic accidents at night in Africa and the need for wear functional textiles to ensure safety. Therefore, in identifying the problem, this study clearly stated in RQ1 "how can the performance of African inspired textiles be improved for night use?" for possible solution. One possible adopted in this study is the use of retro-reflective threads (inherent with the ability to retro-reflect lights back to its source) to produce textiles with African cultural elements.

Activity 2: Ideas (RQ2)

The jacquard weaving technology was brainstorm as an eco-friendly approach capable of producing figurative textiles to solve RQ2 "which eco-friendly approach or technique can be used in the creative process that can incorporate African elements and retro-reflective threads in textiles?".

Activity 3: Design development and production (RQ2)

Figure 4 involves a synchronisation of the stages in design development and production with the use of materials and design parameters to produce the final woven reflective textiles. The design process begins with a selection of yarns and cultural elements as the CAD patterns (Adobe Photoshop 2022). The created design patterns which have a resolution of 200 dpi ensure an effective weaving process and reduces image distortions. Subsequent parameters were selected for the jacquard weaving and on ArahWeave software (for different weave structures of the fabric face and back). These efforts have led to the production of reflective woven textiles with different weave combinations.

Stage 1: This details the careful selection of the materials and African cultural elements for use in the design concepts.

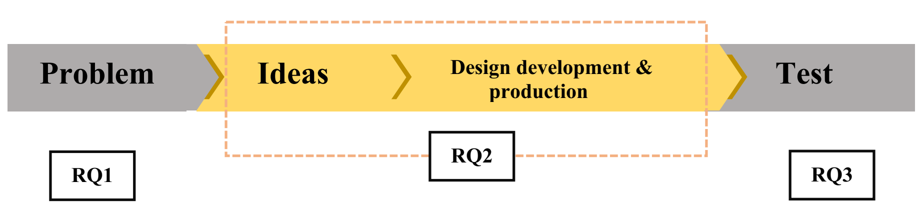


Fig. 3 Activities in the research methodology. (RQ means Research Question) (Authors Own production)

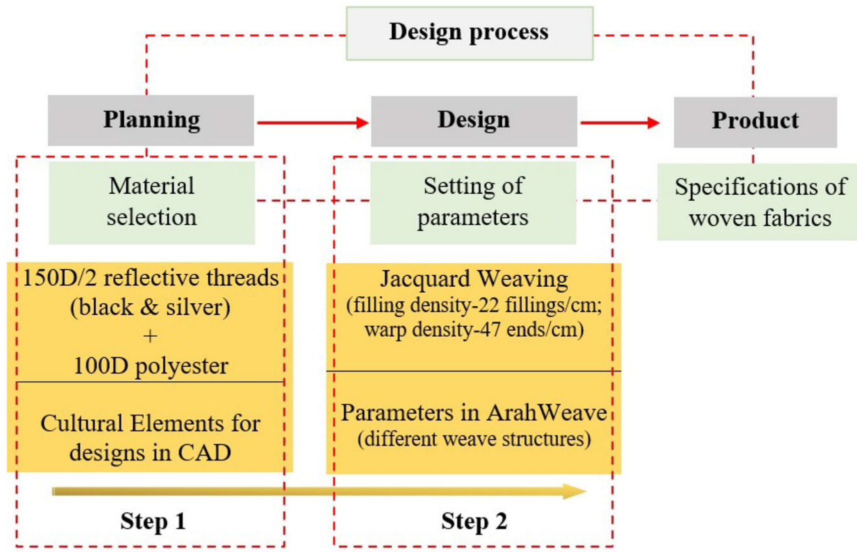


Fig. 4 Stages for jacquard weaving of reflective woven textiles inspired by African art forms (Authors Own production)

Materials. In this study, two types of yarn were used with the following specifications: 150D/2 reflective threads (either silver or black colour) with a filling density of 22 picks/cm for the weft yarns and 100 denier polyester yarns (white colour) with a density of 47 ends/cm for the warp yarns. The 150 D/2 reflective threads were purchased from Dongguan Cheng Wei Reflective Material Co., Ltd in China.

Using African design patterns. Three graphic images from the Sirigu wall paintings were used in the designing process. These have symbolic values that highlights certain activities or events or individuals in the communities. Figure 5a, shows the *Ligipela* motif which means cowry or shells (symbolise the role of cowries during trading or used to seek the hand of a woman in marriage). Figure 5b is *Wanzagsi* motif which means broken calablash which is the shell of a gourd (their value is highlighted in use as pottery). Figure 5c is *Zaalinga* motif which means fiber net (used to secure and prevent the calabashes or cooking utensils from damage). The images were processed into graphic patterns by using Adobe Photoshop CC as shown in Fig. 5d–f.

Sirigu wall paintings are traditional murals created on the walls of indigenous mud houses built in the Sirigu community located in the Kassena Nankana West District in the Upper West Region of Ghana. These paintings are created by grinding earth and rocks which are mixed with water, and cow dung "nambeto" (in the local Nankam language) is used as a binder. Sometimes these wall paintings are called mural paintings. They have existed through centuries and the technique is passed on through apprenticeship from the women to their daughters in the community. Geometric and figurative patterns with symbolic connotations are drawn on the walls by the indigenous women to send coded messages (Wemegah, 2013). This artistic female art form predominantly utilises white, red, black and ochre as the hues of the art patterns on the walls. These patterns were chosen for the design creation due to their great historical insights on how

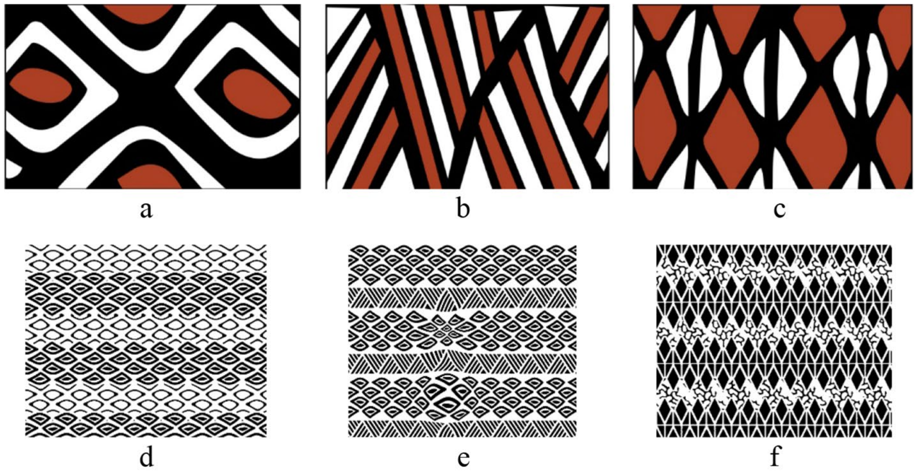


Fig. 5 **a**–**c** African design patterns in Sirigu wall paintings, and **d**–**f** Graphic patterns for designs 1–3 (Authors Own production)

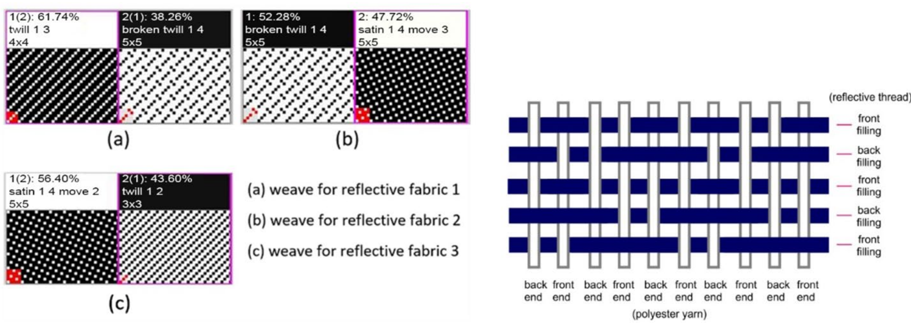


Fig. 6 Weave structure: design on front face and reversed design at back face (Authors Own production)

cowry, broken calabash and fiber net played an important role in the lives of the indigenous people.

Stage 2: The parameters are set for the various weave structures for the selected cultural element and parameters for Jacquard weaving of the fabric samples. The resultant graphic patterns were uploaded unto ArahWeave to isolate the design into weave structures for ease of recognition by the jacquard loom. The experiment utilised two colour schemes, i.e., black and white, with the former representing the design patterns or weft yarns and the latter the warp yarns. This format typically creates a reversed design pattern on the back of the textile, which makes it possible to use either side of the textile. The weave structures are one weft face to a one warp face and a one weft back to a one warp back (Fig. 6).

Reflective threads and polyester yarns were used to weave three reflective textile samples with African themed patterns on a Dornier/PTV 8J Jacquard weaving loom at a loom speed of 300 rpm, warp density of 47.1 ends/cm and 8167 warp ends. All of the woven fabrics have assume dimensions of 160 cm (width) by 90 cm (length). Table 1 shows the specifications of the woven textiles. The sample labelled as RF 1 has a weave structure 1/3 twill and ¼ broken twill; RF 2 has ¼ broken twill and ¼ satin, move 3; and RF 3 has ¼ satin, move 2 and ½ twill.

Experimental

The three woven samples with different weave structures and design patterns were subjected to physical and mechanical test, and their retro-reflective effects were also tested. These testing procedures are relavant to provide the performance properties which influences its end-use application. The samples were conditioned at a relative humidity (RH) of 65 ± 2% for 24 h and under a standard atmospheric temperature of 21 ± 1 °C. The testing methods are as follows:

Reflective effects

To test the reflective effects, images of the samples were taken with a digital camera to capture them in the day light and then in the dark at a distance of 1.5 m.

Fabric weight and thickness

An electronic balance (BX300, Shimadzu Corp.) and a digital thickness gauge with a fixed pressure of 4 g/cm^2 were used to determine the thickness and weight of five specimens of each of the three types of fabrics in accordance with the testing method ASTM D1777-96 and ASTM D3776 respectively. The average of the five specimens was calculated and recorded accordingly.

Structure morphology

The structure of the samples was observed under a magnification of 500 µm with an optical microscope (Leica M165 C).

Low stress mechanical property

The bending, compression, surface, shear, and tensile properties of the fabric samples were tested by using the Kawabata Evaluation System of Fabric (KES-F) testing instruments (Kato Giken Co., Ltd. Japan), i.e., tensile and shear tester (KES-FB1), pure bending tester (KES-FB2), compression tester (KES-FB3) and surface tester (KES-FB4). The testing of samples were measured and cut into standard dimensions 20 × 20 cm, and then conditioned under standard atmospheric air and humidity.

Table 1 Specifications of the woven reflective textiles

Sample	Composition	Weave	Yarn colour	Ends/inch	Picks/inch
RF 1	100 denier polyester yarn (warp yarns)	1/3 twill 1/4 broken twill	white (warp) silver (weft)	120	54
RF 2	150 D/2 reflective thread (weft yarns)	1/4 broken twill 1/4 satin, move 3	white (warp) black (weft)	120	54
RF 3		1/4 satin, move 2 1/2 twill	white (warp) black (weft)	120	54

RF means Reflective fabric

Air permeability

The permeability and breathability of the samples in air were measured by using an air permeability tester (KES F8 AP1; Kato Giken Co., Ltd. Japan), to record the resistance R in kPa s/m in accordance with ASTM D737-04. The test was conducted by using 5 specimens of each of the three textiles of which their average was calculated and recorded.

Thermal conductivity

The thermal conductivity was evaluated by using the KES FB7 Thermo Labo Tester (Kato Giken Co., Ltd. Japan) with the dry contact method. The specimens were placed on the water box with a circulating temperature of 25 °C and the BT-box (area of 25 cm^2 and pre-set at 30.3 °C) was then placed onto the fabric specimen. This transferred the heat from the BT-box through the fabric to the water box. The heat loss (watt) was displayed on the digital panel of the tester. The thermal conductivity k was calculated in (W/cm °C) by using $k = W \cdot D/A \cdot \Delta T_o$. (where, W denotes the—heat loss and is the unit of the readings on the digital panel; D is the—thickness of the specimens; A is the—area of the BT-box and ΔT_o is the temperature difference). After obtaining the values in (W/cm °C), they were converted to the SI unit of W/mk.

Tensile strength

The tensile strength of the specimens was measured by using an Instron 411 tester in both the warp and weft directions in accordance with the grab test methods in ASTM D5034. Five specimens were cut from each of the three woven textiles with dimensions 10 by 20 cm. The top and bottom jaws of the tester were firmly centred on the specimens. The gauge length for testing was set at 75 mm at a speed rate of 300 mm/min.

Primary hand and total hand value

The primary hand value (PHV) and total hand value (THV) of the three samples were measured in koshi (stiffness), fukurami (fullness and softness), shari (crispness), hari (anti-drape) and numeri (smoothness) hand values in accordance with the Kawabata Evaluation System for Fabrics (KES FB). The low mechanical stress properties of the samples were calculated to obtain the tactile comfort which is the total hand value (Kawabata & Niwa, 1975).

Results and Discussion

This section provides the test results of the woven fabric samples to answer the third research question of the study.

Reflective effects

The woven samples produced with reflective threads were examined in day light and a dark room. Images were taken from a distance of 1.5 m using a digital camera to identify the retro-reflectivity of the woven samples, which are shown in Fig. 7. Figure 7a–c show visible patterns on the three woven samples with the reflective threads in silver colour in Fig. 7a and black colour for Fig. 7b and c. Subsequently, after capturing the reflective effects of the woven samples with the digital camera and using a flash (Fig. 7d–f) the retro-reflective ability of the textiles is evident even though the visibility of the

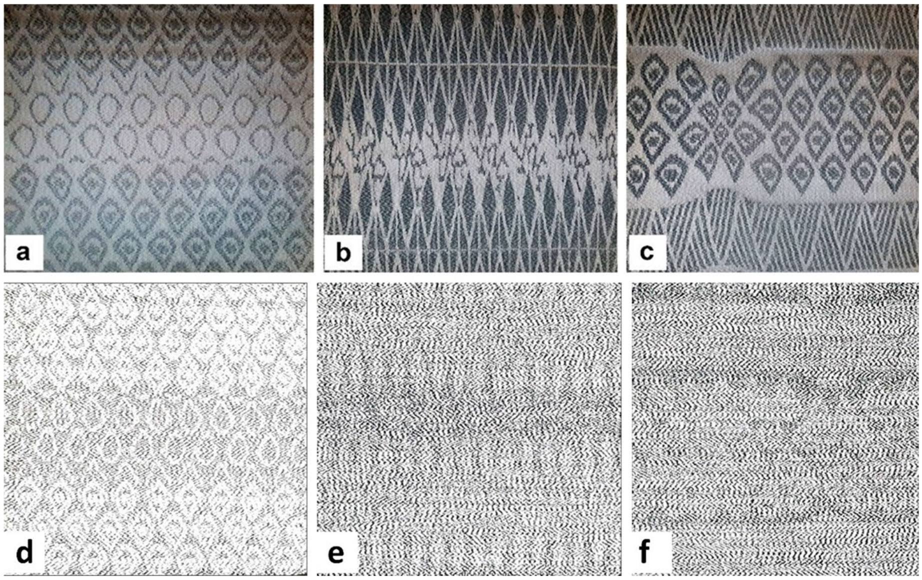


Fig. 7 Images taken during the day: **a** RF 1, **b** RF 2 and **c** RF 3. Images taken in a dark room: **d** RF 1, **e** RF 2 and **f** RF 3. *RF* Reflective fabric

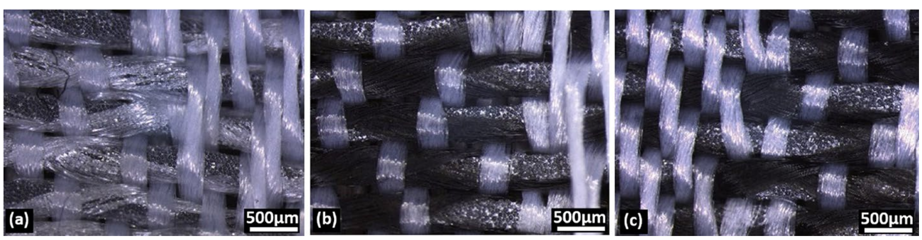


Fig. 8 Microscopic images of sample surfaces at 500 µm: **a** RF1 with silver reflective threads as weft, **b** RF2 with black reflective threads as weft and **c** RF3 with black reflective threads as weft, all in the horizontal plane. *RF* Reflective fabric

patterns in the RF 1 (Fig. 7d) is less blurred as compared to RF 2 and RF 3 in Fig. 7e and f respectively.

Fabric weight and thickness

The results from the testing showed that the fabric weight of RF 1 is 272.08 g/m^2, RF 2 is 276.28 g/m^2 and RF 3 is 272.5 g/m^2. Their fabric thickness (mm) is as follows: RF 1 is 0.75, RF 2 is 0.67 and RF 3 is 0.62 hence RF 1 is thicker than RF 2 and RF 3.

Structure morphology

All of the woven textiles were observed under a magnification of 500 µm (Fig. 8). The images in Fig. 8 show that, the reflective threads are imbedded with small glass beads that have retro-reflective ability to bounce light back in the same path without scattering.

Bending property

The bending rigidity (B) and bending hysteresis (2HB) values of the woven samples were recorded. They are shown in Fig. 9a and b respectively. The results of B in Fig. 9a in both

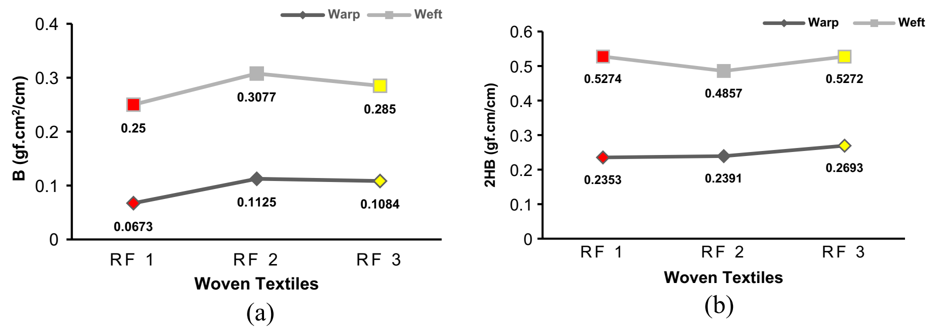


Fig. 9 **a** Bending rigidity—B (gf.cm^2/cm) and **b** bending hysteresis—2HB (gf.cm/cm). *RF* Reflective fabric

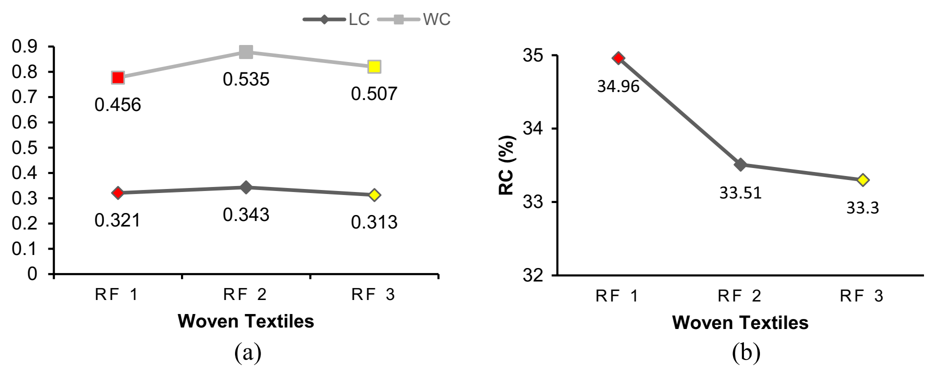


Fig. 10 **a** Linearity of compression (LC) and compressional energy (WC—gf.cm/cm^2) and **b** compressional resilience (RC—%). *RF* Reflective fabric

the warp-wise and weft-wise directions show that RF 1 has the lowest values as compared to RF 3 and then RF 2. This indicates the inability or RF 1 to resist bending during handling as compared to RF 2 which has the highest resistance to bending. The weave combination of RF 2 (¼ broken twill, ¼ satin, move 3) contributed to its resistance to bending. The results of 2HB in Fig. 7b show that, RF 1 has the lowest value in the warp-wise direction as compared to RF 2 and RF 3. Therefore, RF 1 has a better recovery after bending. RF 2 has a different design pattern and weave combination (¼ broken twill, ¼ satin, move 3) and has the lowest 2HB value in the weft-wise direction, and hence can better recover after bending.

Compression property

The plots in Fig. 10a show the linearity of compressional (LC) and compressional energy (WC) values where RF 3 has a slightly higher LC value as compared to RF 1, thus indicating higher compressional behaviour, which is influenced by the compressional properties of the weft and warp yarns of the textiles (Mukhopadyhay et al., 2002). On average, LC values have a similar range which denotes the relative hardness of the samples with the different weave structures and design patterns. As such, the high WC values of RF 2 means that this sample requires a slightly higher compressibility or higher energy for compression as compared to RF 3. This may be attributed to the weave combination pf ¼ broken twill and ¼ satin (move 3) of RF 2 versus the ¼ satin (move 2) and ½ twill for RF 3. However, RF 1 is constructed with similar weave combination as that of RF 2 with

1/3 twill and ¼ broken twill, so a lower compression energy is necessary. In terms of the compressional resilience (RC), RF 1 has a better recoverability as compared to RF 2 and RF 3 which have fairly similar value ranges. Özgüney et al. (2009) indicated that variations in the weft float, significantly affect the fabric properties like compression, and bending rigidity. The recoverability of RF 1 may be attributed to the similar twill weave structure used to produce the sample.

Surface properties

The coefficient of friction (MIU), fabric mean deviation (MMD) and fabric roughness (SMD) were measured to determine the surface properties of the samples, and the results are shown in Fig. 11a and b. In terms of the MIU values in the warp-wise direction, the higher MIU values of RF 2 show that this sample is not as slippery or has more friction force compared to RF 1 and RF 3 even though the values are within similar ranges. In the weft-wise direction, RF 3 has higher MIU values as compared to RF 1 and RF 2. This shows the resistance of RF 3 to movement when rubbed against an object or between the fingers. Atalie et al. (2021) indicated that resistance to movement is determined when the surfaces of fabrics comes into contact. Such resistance may be attributed to the type of yarn used. In this study, polyester is used for the warp and reflective thread for the weft and the yarns were interlaced to form the weave structures.

The MMD values reflect the roughness of the fabric surfaces, where a higher value denotes a higher surface roughness. RF 2 has a higher MMD value followed by RF 1 and RF 3 in the warp-wise direction as shown in Fig. 9b. In the weft-wise direction however,

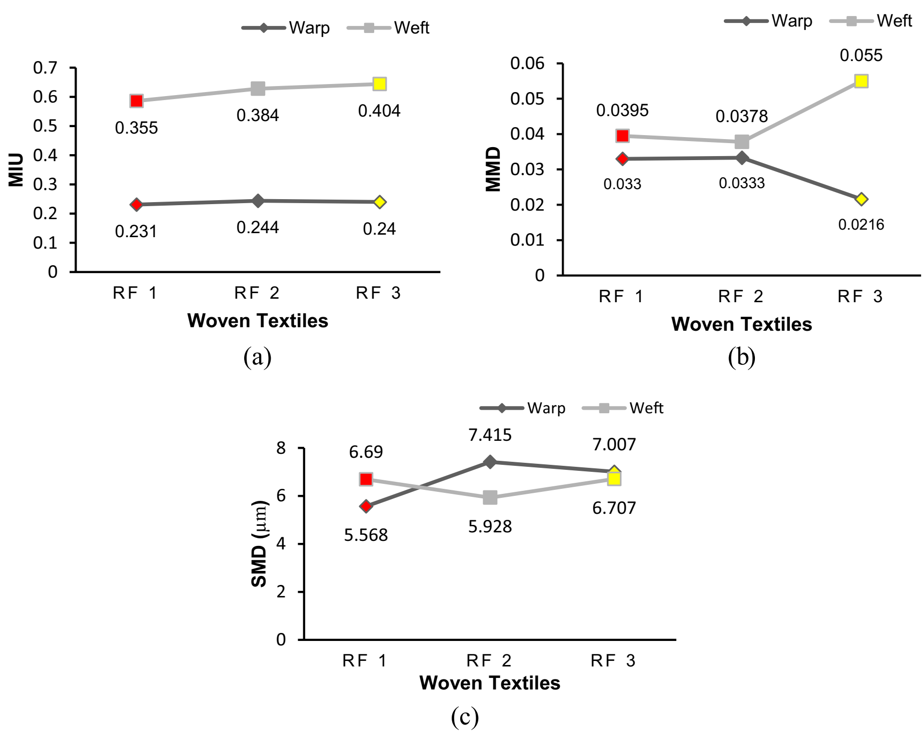


Fig. 11 **a** Coefficient of friction (MIU), **b** fabric mean deviation (MMD) and **c** fabric roughness (SMD—μm). *RF* Reflective fabric

RF 3 has the highest MMD values followed by RF 1 and RF 2. The SMD values were measured to determine the evenness of the fabric surface.

RF 2 has the highest SMD value as opposed to RF 1 and RF 3 as shown in Fig. 11c which indicates the uneven surface of RF 2 in the warp-wise direction. In the weft-wise direction, RF 3 has a higher SMD values than RF 1 and RF 2. The surface of RF 2 and RF 3 in the warp-wise and weft-wise directions have a higher MIU value, which indicates that they are less slippery. The latter factors may also be attributed to the weave combinations (i.e., ¼ broken twill and ¼ satin, move 3 for RF 2; ¼ satin, move 2 and ½ twill for RF 3) and the design patterns of these two woven textiles.

Shearing properties

The samples were measured to determine their shearing properties (recovery after shear) by using the shear rigidity (G) values, hysteresis of shear force at 0.5° (2HG) and hysteresis of shear force at 5° (2HG5). The G, 2HG and 2HG5 values of the woven textiles are reduced in RF 3, RF 1 and RF 2 in both warp-wise and weft-wise directions respectively, see Fig. 12a–c. The higher G values of RF 3 show that this sample is less deformable as compared to the lower G values of RF 2 which can easily deform. The lower 2HG and 2HG5 values of RF 2 in both directions show that this sample has better recoverability or resilience, to a poor recoverability of RF 3 which has a higher 2HG values after shearing.

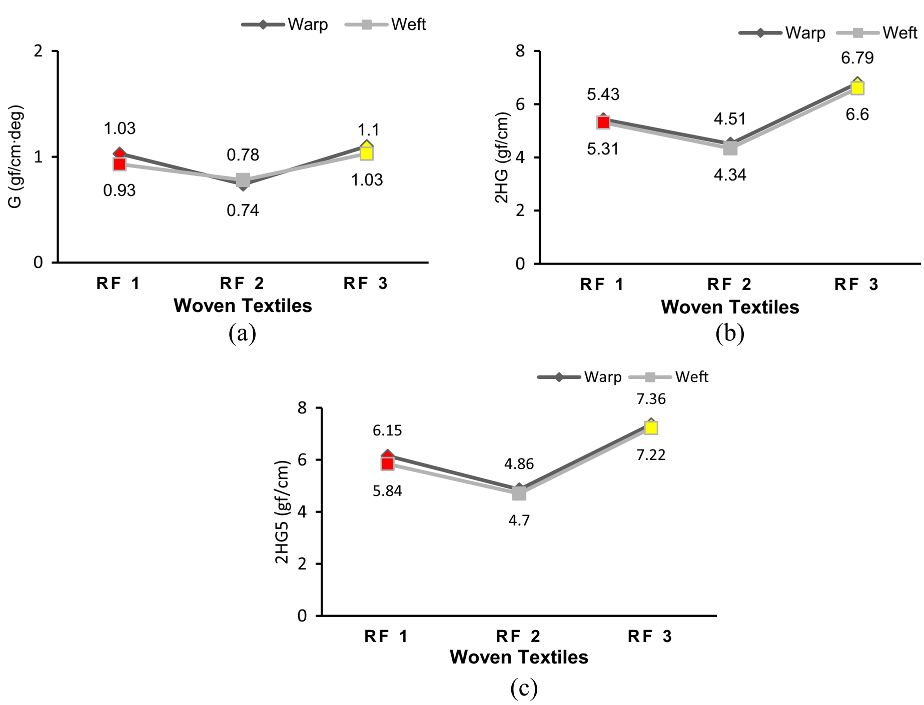


Fig. 12 **a** Shearing rigidity (G—gf/cm·deg.), **b** hysteresis of shear force at 0.5° (2HG—gf/cm) and **c** hysteresis of shear force at 5° (2HG5—gf/cm). *RF* Reflective Fabric

Table 2 Tensile properties of samples in this study

Sample	Direction	Tensile properties			
		LT	WT (gf cm/cm^2)	RT (%)	EMT (%)
RF 1	Warp	0.135*	1.6*	55.67	0.96
	Weft	0.128*	0.08*	130.00	0.25
RF 2	Warp	0.131	0.38	55.71*	1.16
	Weft	0.096	0.05	140.00*	0.21
RF 3	Warp	0.11	0.39	52.22	1.42*
	Weft	0.123	0.05	100.00	0.82*

RT tensile resilience, *WT* tensile energy, *LT* tensile linearity, *EMT* extensibility, *RF* reflective fabric

(*) Denotes higher values in warp-wise and weft-wise directions

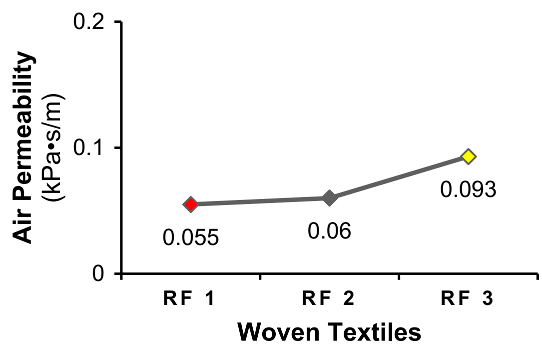


Fig. 13 Air resistance (kPa·s/m) of the woven textiles with different weave structures. *RF* Reflective fabric

Tensile properties

The tensile resilience (RT), tensile energy (WT), tensile linearity (LT) and extensibility (EMT) were measured to determine the tensile properties of the woven textiles. As seen in Table 2, RF 1 has the highest LT and WT in both the weft-wise and warp-wise directions. The higher LT means that RF 1 is more robust and harder than RF 2 and RF 3. For the WT, the higher WT of RF 1 shows that this sample can easily to stretch and can withstand external stress during extension as compared to the two other samples.

In contrast to the LT and WT values, RF 2 and RF 3 have the highest RT and EMT in the warp-wise and weft-wise directions respectively. The higher RT of RF 2 shows that the sample has good recoverability after being subjected to tensile stress. RF 3 however has the greatest EMT thus indicating good extensibility or elongation.

Air permeability

The recorded results as plotted in Fig. 13 show the air resistance (kPa s/m) values of the three samples with different weave structures. Lower values indicate good breathability or permeability of the textile. As such, RF 1 has the lowest R value as compared to RF 2 and RF 3 and is hence more permeable to atmospheric air which would ensure wear comfort. The different weave structures of the samples could affect the air permeability which would eventually impact wear comfort. The results show that the weave structure of RF 3 causes lower fabric porosity.

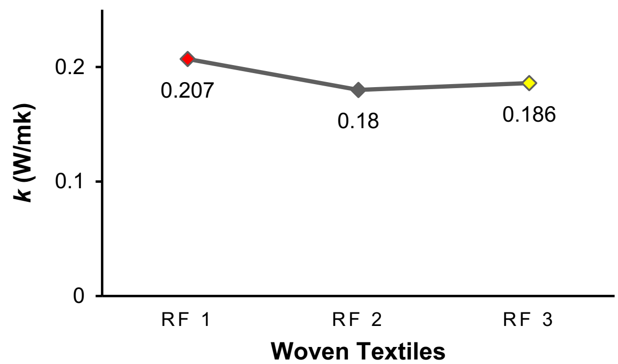


Fig. 14 Thermal conductivity of samples—k(W/mk). *RF* Reflective fabric

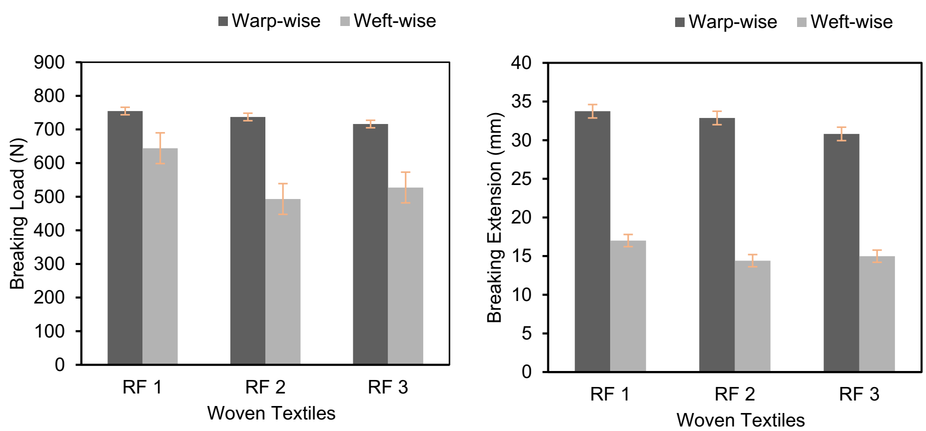


Fig. 15 Tensile strength of samples. RF means reflective fabric, RF 1 has a weave structure 1/3 twill and ¼ broken twill; RF 2 has ¼ broken twill and ¼ satin, move 3; and RF 3 has ¼ satin, move 2 and ½ twill

Thermal conductivity

The *k* values for the thermal conductivity of the samples in Fig. 14 indicates that RF 2 has the lowest *k* value followed by RF 3. This reveals that the structure of RF 2 cannot readily release heat from the body to the atmosphere. Fabrics like RF 2 can be used in the cold weathers since body heat is trapped longer before being released to the atmosphere. RF 1 has the highest *k* values which shows that this sample readily release more heat into the atmosphere. This clearly indicates that the fabric structure can influence the thermal conductivity and hence the eventual wear comfort (Musa et al., 2021).

Tensile strength

The tensile strength is an imperative property of woven textiles that determine how much extension or elongation a fabric can bear under maximum force. This factor further influences according to Ko and Lee (2003) human movement either easing or restraining movement when wearing a garment constructed from this sample. With this, the results plotted in Fig. 15 shows a reduction in force required to break the woven textiles, with RF 1 having the highest force followed by RF 2 and RF 3 in the warp-wise direction. This translates into greater extension at break for RF 1 followed by RF 2 and RF 3. In the weft-wise direction however, the force and extension at break are reduced in

RF 1 followed by RF 3 and RF 2. A greater force is required for extension of RF 1 which may be attributed to its weave combination which implies that a twill weave combination gives woven textiles good tensile strength.

Primary hand and total hand value

The PHV and THV of the three samples were measured by using koshi, fukurami, shari, hari and numeri as listed in Table 3. The samples were evaluated for both winter and summer men's dress shirts. The results showed that RF 1 has the highest stiffness followed by RF 3 and RF 2. This may be attributed to the high shearing, bending and compression properties. These largely influence the springiness and stiffness of any given fabric (Sun & Stylios, 2006). Overall, the samples have adequate stiffness for men's winter dress shirts even though the PHV and THV of RF 2 were less than average. The values of all the three samples for crispness are negative hence there is no crisp feeling. The subsequent results are positive for fullness and softness and anti-drape stiffness all of the samples. RF 3 has the highest fullness and softness value and RF 1 with the highest crispness, hence there is a crisp feeling. Thus, THV showed all three samples are good for men's winter dress shirts, with RF 3 showing the highest THV, followed closely by RF

Table 3 Primary and total hand values of samples

Properties	Primary hand value		
	RF 1	RF 2	RF 3
Men's dress shirt (winter)			
Koshi	7.68	4.98	6.33
Shari	− 0.37	− 2.05	− 0.83
Fukurami	13.40	13.39	13.99
Hari	5.07	3.85	4.81
Total hand value (THV)	7.76	7.15	7.98
Men's dress shirt (summer)			
Koshi	7.68	4.98	6.33
Shari	− 0.37	− 2.05	− 0.83
Fukurami	13.40	13.39	13.99
Hari	5.07	3.85	4.81
Total hand value (THV)	− 1.70	− 1.38	− 1.76
Women's thin dress fabric (winter)			
Koshi	8.00	6.65	6.56
Numeri	6.09	4.62	5.80
Fukurami	9.83	8.57	9.19
Total hand value (THV)	3.17	3.47	4.00
Women's thin dress fabric (summer)			
Koshi	8.00	6.65	6.56
Numeri	6.09	4.62	5.80
Fukurami	9.83	8.57	9.19
Total hand value (THV)	− 1.53	0.46	0.20

Hand value (HV); 1—weak to 10—strong

Total hand value (THV); 1—poor to 5—excellent

RF 1 has a weave structure 1/3 twill and ¼ broken twill; RF 2 has ¼ broken twill and ¼ satin, move 3; and RF 3 has ¼ satin, move 2 and ½ twill

RF reflective fabric

1 and RF2. These textiles are however not suitable for men's summer dress shirt since the THV values are all negatives.

The three samples were also evaluated for thin dresses for both the winter and summer, with the results showing that RF 1 has the highest stiffness, smoothness and fullness and softness followed by RF 3 and RF 2. Thus, all three samples have a positive THV for all of the samples with RF 3 having the highest value. Hence, RF 3 is suitable for thin winter dresses. For the summer however, the THV values show negative values for RF 1 and positive values for RF 2 and RF 3 even though they are given a poor rating for use. From the THV values, RF 1, RF 2 and RF 3 fabrics are suitable for both men's winter dress shirt and women's winter thin dress. Subsequent results show that RF 2 and RF 3 are suitable for women's thin dress for summer.

Conclusions

Reflective textiles in this study are prepared by using reflective threads and polyester yarns via jacquard weaving where patterns are sourced from Africa (specifically from the Sirigu wall paintings). In all, three reflective woven textile samples are evaluated based on standard testing procedures. The design process utilise different weave combinations and colours on the reflective woven textiles which influence the physical and mechanical properties. Subsequent testing procedures show variations in the low stress mechanical properties, air permeability, thermal conductivity, tensile strength and THV of the fabrics. Results of the total hand value by using the KES-FB system show that on average, the woven textiles with positive values are suitable for men's dress shirts and women's thin dresses for the winter. Relatively, the developed retro-reflective textiles have good physical and mechanical properties, air permeability, tensile strength, retro-reflective ability, thermal conductivity, and African patterns (which highlights the cultural values of the indigenous people in Sirigu, Ghana).

By examining the performance of the fabric samples produced using the reflective threads on a jacquard loom, the academic significance is that this study further contributes to the literature on retro-reflective textiles through design approach. This experimental practice extends the influence of weave, yarn combination and pattern type to the performance of retro-reflective textiles for appropriate end-use. For industrial or practical implications, the design approach in the study provides some insights for designers and producers to develop and improve the performance of these textiles made from reflective threads or other creative methods to ensure not just aesthetic values but personal safety of the wearer. This would advance efforts to ensuring safety of pedestrians on the road at night-time.

Limitations of the study

Even though we presented data on relevant performance properties of the fabric samples, the study had some few limitations. There was no established relationship between different yarn combinations, patterns, and weaving methods to their mechanical and physical properties. Additionally, the retro-reflective properties were not included due to the unavailability of the appropriate instruments to test the fabric samples for some quantitative data. As such the qualitative data was presented in the study. Therefore, subsequent relationship and retro-reflective properties could be developed and presented in future research work.

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Author contributions
RKS established conceptualization, conducted the experimental work and data analyses, and original draft preparation under supervision by SJ and SYC who have contributed to the manuscript writing. All authors read and approved the final maunscript.

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Availability of data and materials
The datasets used and/or analysed during the current study are presented in this paper.

Declarations

Competing interests
The authors declare that they have no competing interests.

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