様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９　（共通）

科研費 KAKENHI

科学研究費助成事業　　研究成果報告書

令和　５年　６月２４日現在

機関番号：１４３０３
研究種目：若手研究
研究期間：2020～2022
課題番号：２０Ｋ１４６３８

研究課題名（和文）Development of anti-vibration glove with 3D structured weft-knitted fabric

研究課題名（英文）Development of anti-vibration glove with 3D structured weft-knitted fabric

研究代表者
Ｙｕ　Ａｎｎｉｅ（Yu, Annie）

京都工芸繊維大学・繊維学系・助教

研究者番号：００８６３４１６

交付決定額（研究期間全体）：（直接経費）　3,200,000円

研究成果の概要（和文）：現在の防振手袋の材質と設計が着用感、振動吸収能力、手の器用さに与える影響を理解します。 さまざまな種類の編み方、素材、インレイ編み技術を使用して、振動を吸収および消散する新しい 3D 構造の横編み生地が作成されます。 また、防振手袋の試作も行い、防振性能を確認しています。
この研究は、インレイによってスペーサー生地の動的剛性を高め、快適さ、さまざまな手の部位の振動に対する手の感度、および手の人間工学を統合することにより、防振材料としての 3D ニット生地と防振手袋の開発に新しい視点を提供します。

研究成果の学術的意義や社会的意義
The creation of the novel 3D structure of knitted fabrics has research and practical significance in the textiles, protective clothing and materials engineering fields. The project provides the basis for advancing the design of hand protection products to minimize the risk of injuries for workers.

研究成果の概要（英文）：An understanding of the effect of the materials and designs of the current anti-vibration gloves on wearing comfort, vibration absorption ability and hand dexterity is achieved. A novel 3D structured weft-knitted fabric is created for absorbing and dissipating vibrations by using different types of knitting arrangements, materials and the inlay knitting technique. An anti-vibration glove prototype is also developed, and the performance in vibration isolation is confirmed.
This research provides a new perspective on 3D knitted fabrics as vibration isolation materials and anti-vibration glove development by increasing the dynamic stiffness of spacer fabric through a inlay method, integrating comfort, hand sensitivity towards vibration at different hand regions and hand ergonomics in the glove design.

研究分野：Textiles Engineering

キーワード：weft knitting　3D spacer structure　inlaid　vibration isolation　protective work glove　hand ergonomics　glove design　product evaluation

１．研究開始当初の背景

Many tasks require the use of electrical and pneumatic powered hand tools that give off vibrations, for example, ballast stop machines, chain saws, etc. Prolonged exposure of the hand to such vibrations could lead to hand-arm vibration syndrome (HAVS), which includes the following symptoms: hand pain, numbness, peripheral neuropathy, secondary Raynaud's phenomenon and musculoskeletal problems. An anti-vibration glove could serve to protect the hands during the use of vibrating hand tools. Unfortunately, the current anti-vibration gloves mainly using elastomeric materials for vibration isolation do not take the wear comfort into consideration. The gloves usually have poor thermal conductivity, air permeability and moisture transfer. It also restricts a certain degree of hand dexterity which causes safety issues and limits the usability of the gloves. Therefore, there is a need to improve the design and materials of anti-vibration gloves.

Spacer fabrics have a 3-dimensional (3D) structure with filaments in the middle connective layer holding the two outer layers together. The connective layer of the fabric contains voids which not only substantially reduce the weight of the fabric but also provide a cushioning and damping effect on vibration. With a scientific investigation and function-oriented modification, spacer fabrics provide a possibility to improve the comfort and performance of anti-vibration gloves.

２．研究の目的

The aims of this study included designing a novel 3D knitted fabric structure for vibration isolation purposes, analyzing the anti-vibration mechanism of the knitted structure and developing an anti-vibration glove with good ability to isolate vibration and offer good perceived comfort with the goal to improve work conditions and prevent injuries to workers when they are using vibrating hand tools.

３．研究の方法

The research methods involve three main parts, which are the evaluation of current anti-vibration gloves, the designing of a new fabric structure and the development of new gloves.

3.1 Evaluation of the anti-vibration glove

The design, materials and thermal comfort of four commercial anti-vibration gloves using chloroprene rubber as the vibration isolation materials and one glove made of spacer fabrics were evaluated (Fig. 1). The impact of the gloves on hand dexterity, forearm muscles activity and thermal comfort were investigated through wear trials. Surface electromyography (sEMG) of three forearm muscles was conducted during gripping, key pinching, woodblock transporting, screw inserting and screw driving tasks. The correlation between the compression properties of the gloves and hand performance was also evaluated. The subjective sensations towards the gloves were also measured. The evaluation of the anti-vibration glove samples can help to establish a thorough scientific basis for understanding the shortcomings of the current anti-vibration gloves and identifying the direction for improvement.

Fig. 1. Five types of anti-vibration gloves for evaluation

3.2 Development of novel spacer fabric structure for vibration isolation

In order to enhance the vibration isolation properties of the 3D spacer fabrics, modification on the fabric structure by means of inlay knitting was adopted. Inlay knitting is a technique that applies extra yarns into a knitted structure to provide additional reinforcement or enhance the mechanical behaviour of the fabric. The first idea was to apply elastic inlay yarn on the surface layer of a spacer fabric structure (Fig. 2). In the formation of the surface knitting course, an elastic yarn was followed and inlaid by using tuck and miss stitches. The elastic yarn facilitated the contraction of the fabric, giving a thicker structure. The alignment of the monofilament yarn used in the connective layer could also be altered, thus damping the spacer fabric.

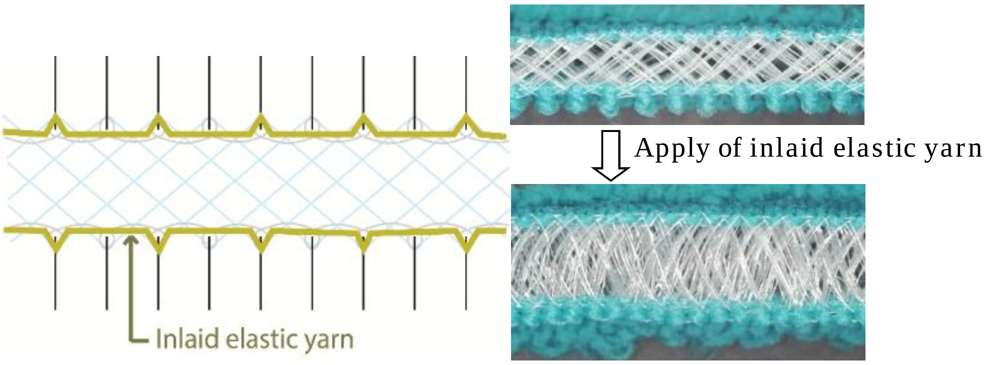

Fig. 2. Application of elastic inlay yarn in the surface layers of spacer fabric

An increase in the thickness and softness of the anti-vibration materials can help to improve their effectiveness in reducing the transmission of vibrations. However, when used as an anti-vibration glove, the vibration isolation materials would also increase difficulties in grasping and controlling hand tools, which incur safety risks. Therefore, the second idea was to integrate an inlaid silicone tube in the connective layer of spacer fabric (Fig. 3). The silicone tube can help to reinforce the fabric structure to prevent the fabric structure from collapsing due to the stress imparted by the human body. The monofilament yarn in the connective layer can be used to maintain the low stiffness and damping of the fabric. The silicone tube can be inlaid by all miss stitches forming a long float across the fabric or by tuck and miss stitches forming a zig-zag pattern.

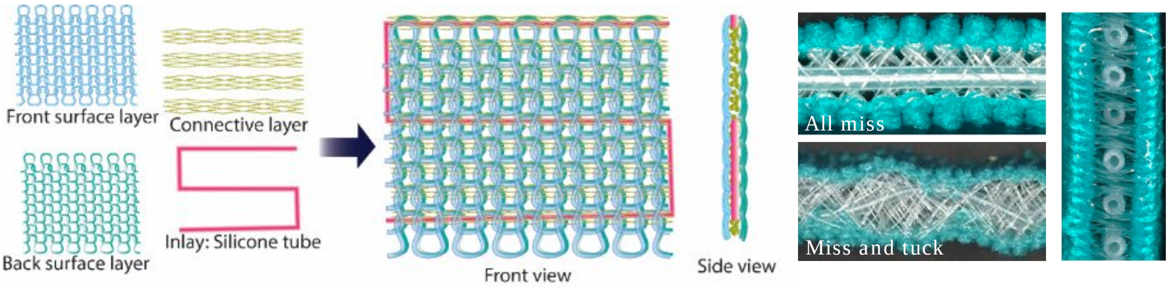

Fig. 3. Application of silicone tube inlay in the connective layer of spacer fabric

The mechanical properties, air permeability and vibration isolation properties (in accordance with ISO13753) of the developed fabrics were tested, and the effect of the inlay and fabrics parameters were investigated.

3.3 Development of anti-vibration glove prototypes

Two anti-vibration glove samples with spacer fabric paddings on the palm were developed. One sample was inserted with two layers of conventional spacer fabric, while another was inserted with two layers of silicone tube inlaid spacer fabric. Two commercial anti-vibration gloves were used for comparison. The samples were evaluated according to ISO 10819:2013, Mechanical vibration and shock – Hand-arm vibration – Measurement and evaluation of the vibration transmissibility of gloves at the palm.

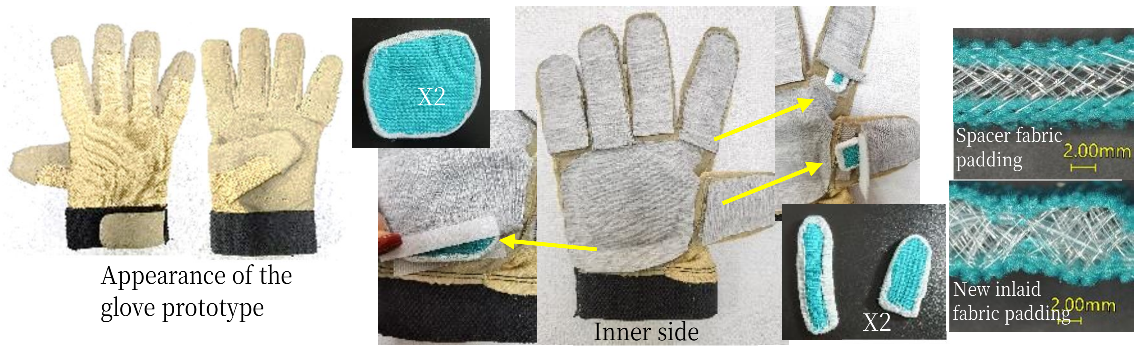

Fig. 4. Design of anti-vibration glove prototype

4．研究成果

4.1 Impact of glove parameters on performance

Different designs and materials used for anti-vibration gloves could affect hand performance when carrying out different tasks. When wearing a glove entirely made of spacer fabric without special design features, the hand dexterity is lower, and the muscle activity is higher than commercial gloves made of chloroprene rubber in carrying woodblocks. The fabric of the dorsal side is correlated to hand dexterity and a thinner fabric can facilitate finger movement and hence dexterity. Using a thin mesh fabric for the dorsal of the glove resulted in a significantly lower skin temperature than using spacer fabric or chloroprene rubber during hand activity. The different combinations and lamination of chloroprene rubber can also make a difference in compression stiffness. The palm of the glove made of spacer fabric had higher air and water vapour permeabilities than chloroprene rubber. However, the thermal sensation of human subjects showed no significant difference among the five glove samples. Apart from using highly permeable materials, the fabric thickness and design should also be considered in the development of anti-vibration gloves to provide better wear and thermal comfort. These findings can act as a reference in the development of anti-vibration gloves and the textiles paddings.

4.2 Novel fabric structure

4.2.1 Effect of elastic inlay yarn on the surface layers

The spacer fabric made by incorporating an elastic inlay can retain air permeability and a lower fabric weight than that made by the knit stitches of elastic yarns together with the surface yarns. By changing the inlay pattern, spacer fabric with different thicknesses and compression behaviour can be produced. The spacer fabrics with elastic inlay showed better vibration isolation ability having a lower natural frequency and isolated vibration in a wider frequency range than the spacer fabrics with the same structure without the elastic inlay (Fig. 5). This novel method can increase the flexibility of creating a spacer fabric with the desired properties.

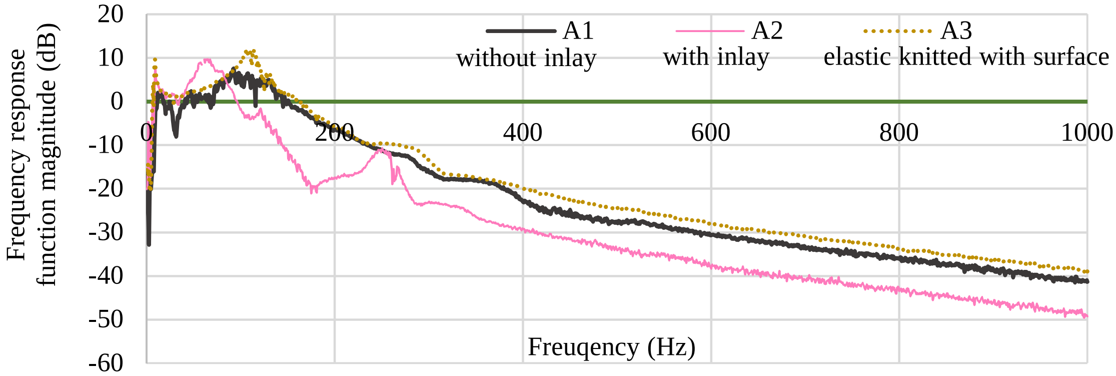

Fig. 5 The vibration transmissibility of a conventional spacer fabric sample without inlay (A1), a spacer fabric sample with elastic yarn inlaid on the surface layer (A2) and a spacer fabric sample with elastic yarn knitted with the surface yarn.

4.2.2 Effect of silicone tube inlaid on the connective layer

With the presence of a silicone inlay, the fabric thickness, weight, and stitch density are increased. The spacer fabric with a silicone inlay has higher flexural rigidity and bending stiffness but a lower degree of fabric hardness.

The compression resistance and energy absorption are also largely increased. The silicone inlay, therefore, effectively absorbs and reduces the impact forces. Compared to the spacer fabric without an inlay, the spacer fabric with an inlay constructed by using all miss stitches shows a lower compression elasticity, while the spacer fabric with an inlay that forms a zig-zag pattern through the tuck stitches has higher compression elasticity. The novel silicone inlay method can reinforce spacer fabric structures and enhance the performance of such fabrics as cushioning materials.

The effect of the type of silicone-based tubular inlay materials on the compression reinforcement has also been investigated. Different inlay materials with different Young's moduli and tensile behaviours can affect the compression energy and stiffness of the resultant fabrics. The spacer fabric inlaid with silicone foam rods, which have lower tensile strength and compression strength than silicone rods and silicone hollow tubes, can absorb more compression energy. On the other hand, the spacer fabric that is inlaid with silicone rods with high tensile strength and compression strength has the highest compressive stiffness amongst the fabric samples.

The fabric samples with a silicone inlay show poor air permeability versus those without a silicone inlay. The air resistance increased by 11% to 33%. Due to the presence of the silicone tube in the connective layer of the spacer fabrics, the air permeability of the fabrics is inhibited. Even though the air permeability of the fabric is reduced, it is still overwhelmingly higher than the elastomeric padding materials such as chloroprene rubber. The silicone inlaid spacer fabric can act as a cushioning material to improve breathability significantly.

The silicone inlay can also help to enhance the ability of the spacer fabric to isolate vibration. The tuck stitches of the inlaid tubes increase the number of resonances within the spacer structure. The tucking of the silicone hollow tubes changes not only the surface geometry (Fig. 6) but also the vibration transmissibility of the spacer fabric.

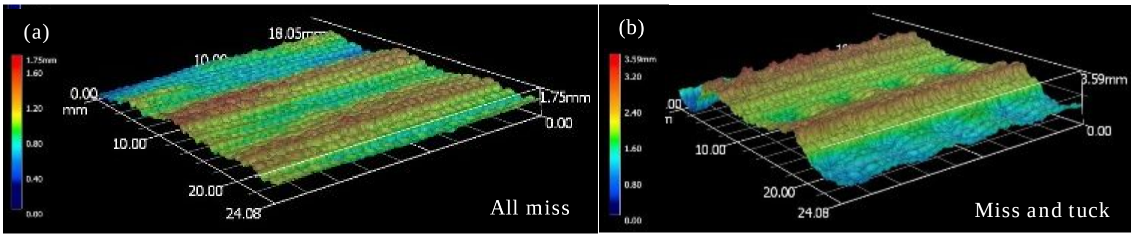

Fig. 6. The surface thickness variation (Fabric dimensions 24.08 x18.05 mm) of silicone inlaid samples by using (a) all miss stitches and (b) miss and tuck stitches

4.3 Performance of the developed anti-vibration glove

The vibration isolation properties of two commercial anti-vibration gloves (Samples M1 and M2) and two developed gloves with spacer fabric padding (Sample F1) and silicone inlaid spacer fabric padding (Sample F2) are presented in Fig. 7. F1 and F2 show better vibration isolation in magnitude than M1 but worse than M2. All the glove is not very effective in isolating the vibration at a low frequency below 150Hz. The effective frequency ranges for vibration isolation of the samples are M1: 658 – 1000Hz, M2: 135-1000Hz, F1: 138-258Hz, 400-1000Hz, and F2: 69-203Hz, 248-1000Hz. The curves of F1 and F2 are similar, which shows that silicone inlay can slightly improve the vibration isolation ability when used as the padding of a glove with the same design. The results show that the glove samples made of spacer fabric can have comparable vibration isolation properties with certain types of anti-vibration gloves in the market. The developed gloves show the ability in vibration isolation and the possibility of using spacer fabric as the padding material. Further investigation and development on the spacer fabric structure are suggested to allow the anti-vibration glove to be effective over a wider frequency range and isolate the vibration in a larger magnitude.

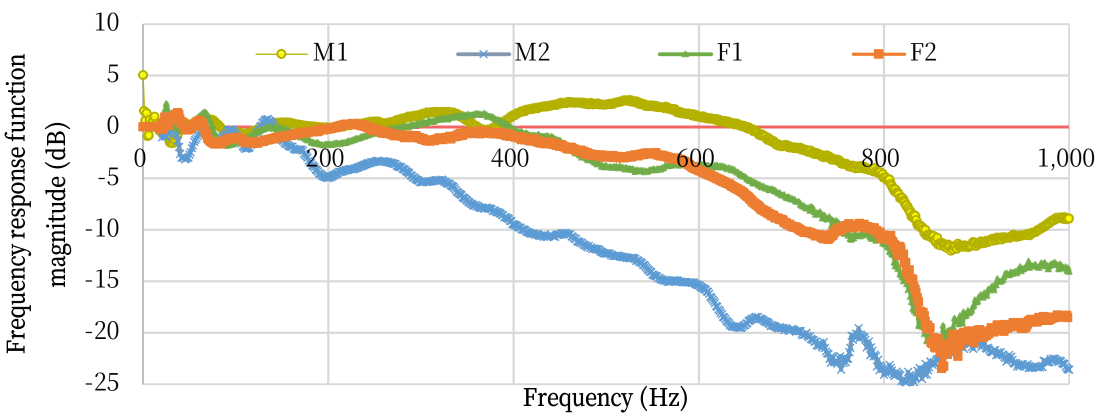

Fig. 7. Vibration transmissibility of four anti-vibration glove samples

５．主な発表論文等

〔雑誌論文〕　計6件（うち査読付論文　6件／うち国際共著　2件／うちオープンアクセス　3件）

１．著者名 Yu Annie、Sukigara Sachiko	４．巻 98
２．論文標題 Evaluation of the design and materials of anti-vibration gloves: Impact on hand dexterity and forearm muscle activity	５．発行年 2022年
３．雑誌名 Applied Ergonomics	６．最初と最後の頁 103572～103572
掲載論文のDOI（デジタルオブジェクト識別子） 10.1016/j.apergo.2021.103572	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 －

１．著者名 Yu Annie、Sukigara Sachiko、Shirakihara Miwa	４．巻 13
２．論文標題 Effect of Silicone Inlaid Materials on Reinforcing Compressive Strength of Weft-Knitted Spacer Fabric for Cushioning Applications	５．発行年 2021年
３．雑誌名 Polymers	６．最初と最後の頁 3645～3645
掲載論文のDOI（デジタルオブジェクト識別子） 10.3390/polym13213645	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 －

１．著者名 Yu Annie、Sukigara Sachiko、Yick Kit-Lun、Li Pui-Ling	４．巻 29
２．論文標題 Novel weft-knitted spacer structure with silicone tube inlay for enhancing mechanical behavior	５．発行年 2020年
３．雑誌名 Mechanics of Advanced Materials and Structures	６．最初と最後の頁 2053～2064
掲載論文のDOI（デジタルオブジェクト識別子） 10.1080/15376494.2020.1850948	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

１．著者名 Yu Annie、Sukigara Sachiko、Masuda Arata	４．巻 15
２．論文標題 Vibration Isolation Properties of Novel Spacer Fabric with Silicone Inlay	５．発行年 2023年
３．雑誌名 Polymers	６．最初と最後の頁 1089～1089
掲載論文のDOI（デジタルオブジェクト識別子） 10.3390/polym15051089	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 －

1．著者名 Yu Annie、Sukigara Sachiko、Yick Kit-Lun	4．巻 92
2．論文標題 Curvature control of weft-knitted spacer fabric through elastic inlay	5．発行年 2022年
3．雑誌名 Textile Research Journal	6．最初と最後の頁 3826～3837
掲載論文のDOI（デジタルオブジェクト識別子） 10.1177/00405175221097098	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

1．著者名 Yu Annie、Sukigara Sachiko	4．巻 10
2．論文標題 Investigation of materials for palm and dorsal of anti-vibration gloves for thermal comfort	5．発行年 2023年
3．雑誌名 Fashion and Textiles	6．最初と最後の頁 1～15
掲載論文のDOI（デジタルオブジェクト識別子） 10.1186/s40691-023-00340-0	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 －

〔学会発表〕　計2件（うち招待講演　0件／うち国際学会　2件）

1．発表者名 Yu Annie、Masuda Arata、Sukigara Sachiko、Yick Kitlun、Li Puiling
2．発表標題 Vibration Isolation and Softness of Knitted Spacer Fabric with Silicone Inlay
3．学会等名 Textile Bioengineering and Informatics Symposium 2022 (TBIS 2022)（国際学会）
4．発表年 2022年

1．発表者名 Yu Annie、Wang Yilei
2．発表標題 Investigation of anti-vibration glove made of silicone inlaid spacer fabric
3．学会等名 International Conference on Advances in Design, Materials and Manufacturing Technologies 2022 (ICADMMT 2022)（国際学会）
4．発表年 2022年

〔図書〕　計0件

〔産業財産権〕

〔その他〕

－

6．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

7．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

8．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関