# Progress Report for R&D Project - LITD 0064

| | |
|---|---|
| **Title:** | *Study of Performance and Safety Parameters of Wearable Compression E-Textile Products Used for Massaging Applications* |
| **Project Code:** | LITD 0064 by BIS |
| **Name of the proposer:** | Dr. Tribeni Roy |
| **Organization:** | Birla Institute of Technology and Science, Pilani (BITS Pilani) |
| **Date:** | 25/06/2024 |

## 1. Introduction

Globally, more than 600 million people experience severe body pain due to lifestyle-related health issues, and this number is projected to rise beyond 800 million by 2050 [1]. These issues often develop into chronic disorders, and their treatment, on average, costs USD 1000 per person. To address this, e-textiles offering biomedical functions have emerged as a promising solution for pain relief. E-textiles, or electronic textiles, are an emerging technology that integrates electronic devices into textiles, creating innovative products for various applications, including healthcare [2]. Integrating electronics into textiles creates smart textiles that can sense, react, and adapt to stimuli, opening new opportunities for personalized healthcare solutions [3]. The wearable e-textiles product market is projected to exceed growth of USD 780 million by 2033 [4]. In 2023, the global smart clothing market was valued at USD 3.95 billion and is projected to expand at a CAGR of 27.2% from 2024 to 2030 with advancements in sensors, actuators, and conductive fibers [5]. In 2022, the Indian medical textiles market was valued at approximately US$ 9.71 million and is projected to grow by 15%, reaching US$ 22.45 million by 2027 [6].

Among various e-textile innovations, one of the most promising areas is the development of e-textiles for massaging, where these fabrics incorporate functionality such as pressure variations, vibration, or heat generation to provide therapeutic benefits [7]. Massage is a well-known therapeutic practice for relieving stress, reducing muscle tension, and promoting well-being [8]. With advances in fabric development, e-textiles have become a promising solution for delivering automated massage therapy more conveniently, and they have the potential to revolutionize traditional methods by offering portability, comfort, and even programmability to deliver targeted and efficient therapeutic care [9]. Further, these e-massagers are particularly appealing because they offer the potential to provide massage therapy without bulky equipment or dedicated spaces, thereby increasing accessibility for people with busy lifestyles or limited mobility. Currently, e-textile massagers are commonly used in orthopedic pain management, and international research efforts are focusing on advancing more biomedical applications. Notable work includes innovations at, where integrating electronics into textiles (University of Nottingham, [10]), digital knitting technology to develop smart fabrics that sense body posture (MIT, [11]), etc. Researchers in India, including those at IIT Delhi [12], IIT Bombay [13], and IIT Kharagpur [14] and other prominent institutions, are also making progress in wearable e-textile technologies for healthcare, from antiviral clothing to gesture-tracking devices for stroke rehabilitation [15].

The Indian market for e-textile massagers is steadily growing, driven by consumer demand for more convenient and customizable solutions [16]. Companies are increasingly exploring how to incorporate e-textiles into their products, leveraging textile's lightweight and flexible nature to design products that fit comfortably and discreetly within everyday clothing or accessories. However, despite progress, there are limited studies on the quality and performance of the e-textile massagers sold in India, and this hinders understanding of the quality, type, and functionality of the e-textile massagers in the country. Hence, the proposed project aimed to conduct a review and evaluate available e-textile massagers sold in the Indian market and asses their performance and quality. Based on the proposal, a comprehensive study of the different e-textile massagers sold in India was conducted over the last three months (first phase), and the findings are discussed in this report. We have also listed the standards related to e-textile massagers in this report. Test methods were also developed to evaluate e-textile massagers in this study. Further, the current status of other objectives mentioned in the proposal is described in consecutive sections of this first phase report.

## 2. Objectives of the Proposal

The main objectives of the project (for 6 months) are listed below:

- To conduct a review of literature and collect data from industries concerning e-textiles for massaging.
- To collect e-massagers available from the market and conduct various tests (durability, abrasion, stiffness, and power) in the lab.
- To prepare a comprehensive report about the data collected and the performance of the various e-textiles-based massagers available in the market.

Out of the proposed objectives, in the last 3 months (first phase), the following tasks are completed:

- Reviewing the literature on e-textiles for healthcare applications, specifically massaging.
- Procuring different e-textile massagers from the market.
- Preparing a comprehensive report about the literature on the various e-textiles-based massagers and related standards. Further test methodologies to access the performance and safety parameters of the wearable compression e-textile products for massaging applications were also developed.

## 3. Progress

### 3.1 Literature Review

E-textile massagers are cutting-edge technology that integrates mechanical and electronic components into fabrics, creating innovative products for diverse applications like healthcare, physical wellness, therapeutics, etc. Current studies emphasize that e-textile massagers effectively relieve pain from the full body or specific parts (neck, waist, legs, knee, etc.). This section details a comprehensive review of the literature to understand existing e-textile massagers and their applications. E-textile massagers incorporate pressure controllers, actuators, motors, sensors, etc., within textile layers to apply mechanical force or heat to the body, thereby providing a massaging effect. Hence, the research and development in e-textile massagers focuses on developing better massaging mechanisms (pressure, actuators, heat, etc.), followed by their integration with textiles and monitoring.

The initial phase of e-textile massager development was based on pressure-based fabric, which can provide a massaging effect to the body. Dias et al. invented a pressure garment (patent number

US7043329B2) designed to apply controlled pressure to body parts for medical treatments like compression therapy [17]. This garment incorporated a knitting structure that uses specific yarn tensions to ensure proper pressure distribution. However, such garments have the problem of loosening their elasticity due to continuous wear with no extra benefits of massaging for elderly or inactive patients. To compensate for the loss of elasticity of the fiber, Ahmad et al. employed polyurethane-based shape-memory polymer (SMPU) actuators for medical pressure bandages, focusing on gradient pressure application for leg ulcers [18]. The SMPUs, optimized for flexibility (800% strain) and a transition temperature of 45°C, could generate controlled pressure through heat activation after retailing their elastic nature, making them better e-textile massagers than the former. Further, Papadopoulou et al. developed an affective sleeve that provided sequential compression and warmth for promoting calmness using shape memory alloys to deliver massage and warmth, showcasing how e-textiles can be designed for physical therapy and emotional comfort [19]. The work integrated haptics into wearable fabrics, which was important for developing e-textile massagers for therapeutic and emotional well-being. However, challenges like pressure decay due to stress relaxation require further optimization for long-term use in e-textiles. In this regard, Kumar et al. modified the textile structure to control the external pressure with temperature [20]. The work aimed to control the pressure exerted on the limb, which is beneficial for chronic venous disorders. Their work represented a significant step toward smart compression therapy. Despite the innovation, the work highlighted challenges such as pressure relaxation over time, leading to a loss of sustained compression and the need for dynamic control over the pressure. This necessitated further optimization of the structure to dynamic control and minimize pressure loss while retaining the flexibility of the fabric. In this regard, Harishkumar et al. designed advanced e-textile massagers based on dynamic pressure control using stress-memory polymeric fabrics (polyurethane and nylon) [21]. The team developed an empirical relationship based on Laplace's law and optimized fabric parameters like loop length, stitch density, & float length to obtain precise pressure for massaging needs. The results indicated that the fabric could control the blood velocity based on massage function, making it suitable for compression therapy (for venous ulcers & varicose veins) and customized needs. Along similar lines, Yu et al. explored the development of therapeutic compression textiles focusing on improving precision and user compliance [22]. The work optimized minute variables, like yarn feeding velocity and loop size, to improve the product's precision, mechanical properties, and pressure behavior.

From the above details, it can be noted that pressure-based garments have aided in the development of massaging products. However, these have limited massaging effects, making them not applicable to wide applications. In this regard, researchers started building e-textile massagers based on actuators, which can provide better massaging effects than pressure garments. Zhou et al. employed a series of elastic actuators (SEA) to control the massaging effect when integrated into textile systems [23]. The SEA mechanism regulated the massage pressure dynamically, and the motors used in the device aided in adjustable massage intensities, making the device suitable for varied rehabilitation needs, stress management, and circulation improvement. Once the actuators were proven better than pressure garments, researchers started integrating more electronics to control the actuators and bring more control over the massaging effect. In this direction, Suarez et al. developed a system for electronic lymphatic drainage using pneumatic bending fabric actuators [24]. Their work focused on using pneumatic actuators to generate compression and lateral fluid movement for lymphatic drainage. The system's actuators were flexible, allowing them to conform to the human body, making it highly applicable for e-textile massagers for treating lymphedema. Mengjia et al. developed a wearable system using fluidic fabric muscle sheets for dynamic compression and massage therapy to promote blood flow using a limb model, where it demonstrated the capability to induce fluid flow via peristaltic compression, making it suitable for treating blood and lymphatic circulation disorders [25]. The work showcased how electronic systems can be integrated into textiles to programmatically deliver therapeutic compression and massage. Yoo et al. designed Z-folded pneumatic actuator modules that generate normal and shear forces for massaging for lymphedema [26]. These actuators were also able to apply dynamic forces to affected areas, providing targeted massage therapy in a flexible, wearable format.

Once the programmatic control of the e-textile massagers was developed, the focus was to build a closed-loop system capable of monitoring the body conditions and automatically changing its massaging effects. In this direction, Payne et al. explored force control of textile-based soft wearable electronics for mechanotherapy [27]. This study emphasized the importance of precise force control in wearable systems, critical for ensuring safe and effective massage therapy in e-textile applications. Zhao et al. introduced a programmable dynamic pressure delivery system with a matrix of soft sensors, which can adapt to the user’s needs for intermittent pneumatic compression therapy [28]. This technology allowed real-time pressure adjustments, providing a customizable therapeutic experience in wearable applications. In e-textile massagers, such a system could enable adaptive pressure control, enhancing the comfort and efficacy of compression garments. Chaitanya et al. developed a device that integrated EEG sensors and massage motors into a headband, focusing on anxiety detection and relief [29]. The system detects emotional states, such as relaxation, focus, and anxiety, by analyzing beta wave activity in the brain's frontal lobe. These kinds of massagers demonstrate how textile-integrated sensors and actuators can provide real-time feedback and targeted therapy based on physiological data. Using biofeedback to activate massage therapy provided a foundation for creating next-generation smart textiles that monitor user health and respond automatically to alleviate stress, pain, or discomfort. Another mechanism that is under development is the use of heat to give massaging effects. Repon et al. developed an electro-conductive compression garment using silver-coated polyamide yarns [30]. These garments are designed to provide heat for orthopedic support and compression therapy. The study investigates the effects of stretching and frequent washing on heat generation and durability. These insights are highly relevant for e-textile massagers by enhancing dynamic heating and compression for therapy applications.

Thus, e-textile massagers incorporate actuators or sensors within textile layers to apply mechanical force or heat to the body. By integrating vibration motors, pressure sensors, and heating elements, these textiles offer customizable functionalities that can be adjusted to individual needs. This personalized approach allows users to target specific discomfort or muscle tightness with adjustable intensity and duration, making it significant in massage therapy. However, e-textile massagers are limited by the different mechanisms and sensors employed. Advancements in sensor design and computing offer opportunities for improved sensor usage and data assimilation. New mechanism development also can aid in improving the e-textile massagers. The field also lacks significant clinician involvement, leading to an emphasis on engineering and technical processes. Future technology development requires collaboration among engineers, biophysicists, designers, and therapists to assess efficacy, reliability, and validity in populations with central nervous system lesions to create a proper standard and make it available in the market. For e-textiles to be easily used daily, rehabilitation therapists, designers, engineers, and consumers must work together to develop standardized, effective assistive technology and actuation functions.

### 3.2 Standards related to wearable compression e-textile products for massaging applications

Wearable compression e-textile products (WCETs) for massaging applications represent a fast-growing sector of the e-textiles industry. Given the significance of these technologies in health and wellness, a range of international and national standards are emerging to ensure product safety, efficacy, and quality. The standards are critical in ensuring these wearable products are safe, reliable, and effective for end users. The standards governing these devices cover multiple aspects, including textile quality, electronic integration, safety regulations, and performance assessment. At the international level, organizations like the American Society for Testing and Materials (ASTM), the International Electrotechnical Commission (IEC), and the International Organization for Standardization (ISO) etc. are developing standards for WCET products as listed in ***Table 1***.

Table 1. List of International/National Standards related to wearable compression e-textile products used for massaging applications

| Sl. No | Standard | Description |
|---|---|---|
| 1 | IEC/CD 63517 [31] | This standard focuses on wearable, electric heating textile products, specifically outlining the test methods for the performance of heating products. The key area of focus includes test procedures for the heating temperature and power consumption of wearable heating textile products. (***Status: Under development***) |
| 2 | IEC 63203-204-1 [32] | The standard specifies household washing durability test methods for e-textile products. It includes testing procedures for e-textile products with electrically conductive components and sensors to collect the user's data. (***Status: Published***) |
| 3 | IEC 60335-2-32:2024 [33] | This deals with the safety of electric massage appliances for household and similar purposes, with their rated voltage not more than 250 V for single-phase appliances and 480 V for other appliances, including direct current (DC) supplied and battery-operated appliances. Examples of appliances within the scope of this standard are massage beds, belts, massage chairs, and massage pads. (***Status: Published***) |

| | | |
|---|---|---|
| 4 | ASTM D3884-09 [34] | The standard deals with determining the abrasion resistance of textile fabrics using the Rotary Platform, Double-Head (RPDH) tester. The guides the evaluation of how well textile fabrics resist wear and tear due to frictional forces, helping to assess their durability. (***Status: Published***) |
| 5 | IEC 63203-401-1 [35] | The standard specifies a method to measure tensile strain for stretchable, resistive strain sensors. This also describes characterization procedures for evaluating unimodal tension sensors' gauge factor, linearity, response characteristics, and hysteresis. (***Status: Published***) |
| 6 | IEC 63203-406-1 [36] | This standard defines the terms, definitions, symbols, configurations, and test methods to specify the standard measurement conditions and methods for determining the contact-surface temperature of wearable electronic devices. (***Status: Published***) |
| 7 | ASTM D8248-19 [37] | This standard covers terms related to smart textiles, technical textiles, electronic textiles, and wearable electronics, including fibers, yarns, and end products. (***Status: Published***) |
| 8 | ISO 24584:2022 [38] | This standard describes the methods for determining the sheet resistance of conductive textiles or conductive structures using eddy current technology in a reflection mode setup. The test applies to conductive textile structures intended for application in sheets of textiles (woven fabric, knitted fabric, nonwoven, coated fabric) where intersecting surfaces with conductive textile material form the area. (***Status: Published***) |
| 9 | ISO/TR 23383:2020 [39] | This standard defines "smart" textiles and textile products and categorizes different types of smart textiles. It briefly describes the current development stage of these products and their application potential and gives indications on preferential standardization needs. (***Status: Published***) |

| | | |
|---|---|---|
| 10 | ISO/AWI 25242 [40] | This standard provides an environmental test to determine the ability of the smart textile systems (e.g., electrically heated garments) to withstand rapid changes in ambient temperature. It applies to the jacket, vest, jumper, etc., which includes the electrically operating part. (***Status: Under development***) |
| 11 | EN 17673:2022 [41] | This standard applies to garments and the assembly of garments that protect against heat and flame, with integrated smart textiles and non-textile elements for enhanced health monitoring. (***Status: Published***) |
| 12 | CEN/TR 17512:2020 [42] | This standard lists terms and definitions related to core terms in smart garments. It is intended to facilitate communications, for example, between organizations and individuals in industry and those who interact with them. (***Status: Published***) |
| 13 | ASTM WK58009/WK61478 [43] | The standard defines new terminologies for smart textiles (***Status: Under development***) |
| 14 | ASTM WK61480 [43] | The standard gives a test method for the durability of smart garment textile electrodes after laundering. (***Status: Under development***) |
| 15 | IEC 63203-201-2 [43] | The standard measures the basic properties of conductive fabric and insulation materials. (***Status: Under development***) |
| 16 | IEC 63203-401-1 [43] | The standard evaluation method of stretchable resistive strain sensor. (***Status: Under development***) |
| 17 | IPC-8941 [43] | This standard defines guidelines for connectors for e-textiles. (***Status: Under development***) |
| 18 | IPC-8952 [43] | This standard is for printed electronics on coated or treated textiles and e-textiles. (***Under development***) |
| 19 | IPC-8981 [43] | This standard will establish required testing and reliability expectations for e-textile wearables. (***Status: Under development***). |

| | | |
|---|---|---|
| 20 | ASTM D4032 [44] | This standard gives a test method to evaluate fabric stiffness by determining its resistance to compression using a circular bend procedure. This test applies to various textiles, including clothing and industrial fabrics, measuring their flexibility and handle. It helps manufacturers and buyers assess material performance regarding comfort and durability. (***Status: Published***) |
| 21 | IPC-8971 [45] | This standard establishes requirements for electrical testing printed electronic e-textiles, including selecting the test analyzer, test parameters, test data, and fixturing requirements to perform electrical testing. This standard provides e-textile manufacturers guidance for electrical test setup, techniques, and equipment. (***Status: Published***) |
| 22 | IPC-8952 [46] | This standard outlines specific requirements for designing printed electronic applications and their forms of component mounting and interconnecting structures on coated or treated textile substrates. (***Status: Published***) |
| 23 | IPC-8921 [46] | This standard defines industry test methods and guidance for providing performance data on key characteristics and durability of woven and knitted e-textiles integrated with conductive fibers, yarns, and/or wires. This standard also establishes classifications for e-textiles made with e-fiber, e-yarns, and e-wires. Additionally, these standards highlight the key characteristics and test methods for e-textiles. (***Status: Published***) |
| 24 | IPC/JCPA-8911 [46] | This standard identifies e-textile categories and establishes a classification system, quality control requirements, and test methods for conductive yarns. This standard also touches on best practices for conductive materials production. (***Status: Published***) |
| 25 | IS 7137 [47] | This standard covers portable, hand-held mains-operated electric massagers designed for connection to supplies at a voltage not exceeding 250 V AC single-phase 50 Hz or DC. (***Status: Published***) |

### 3.3 Market Analysis and data collection from vendor/seller (Status: Ongoing)

A market survey was also conducted to identify commonly available products and their specifications in the Indian market. Different types of e-textile massagers are available for the healthcare domain based on various studies and research works, like the electric hand massager, a versatile rehabilitation device designed to aid stroke patients and individuals with hand disabilities by enhancing motor recovery [48]. The massager uses air pressure to relieve hand spasms and stiffness while promoting functional hand and finger training. Equipped with wireless, portable, and easy-to-use features, including an intelligent touch button, the device integrates advanced flexible electronics and neuroscience. This allows patients to engage in motor relearning exercises, making it suitable for home-based rehabilitation after strokes, brain injuries, or surgeries. Details about a few more e-textile massagers available in the Indian market are given in ***Table 2***.

Table 2. Types of e-textile massagers available in the Indian market.

| Sl. No | Massagers Name | Available Information | Precaution |
|---|---|---|---|
| 1 | Knee Massager with Heating & Vibration Technology | • Temperature range: 0˚-50˚C<br>• Humidity: < 80% RH<br>• Atmospheric pressure: 70 - 106 kPa | • The power cord should be properly conditioned, and the battery should be plugged in before use. |
| 2 | Cervical, neck, shoulder, & Back Pain Relief Massager | • Thermal protection device<br>• Infrared light produces warmth<br>• 16 massage head<br>• Skin-friendly coverage with a soft touch | • Not usable for temperature sensitive person<br>• Pregnant women require doctor's advice<br>• Malignancy patient required doctor's advice |
| 3 | Full Body massagers | • 10 invigorating massage motors for full-body massage<br>• 1 Heating pad for full-back<br>• variable massage modes<br>• 3 selective vibration intensity | Not available |

| | | | |
|---|---|---|---|
| | | • Polyester knitted fabric | |

Based on the ongoing market survey, the work will continue to gather more detailed information about more e-textile massagers available in the Indian market. Discussions with various vendors have revealed that the Indian market (for e-textiles) is predominantly import-based, with products sourced from China, South Korea, USA and Japan. The products were chosen to cover a range of designs, functionalities, usability, and price points. More details will be provided in the final report.

### 3.4 Test methods to evaluate the performance and safety parameters

***3.4.1 Durability*:** Evaluation of the product's longevity and ability to withstand continuous pressure, wear and tear.

***3.4.1.1 Wear Test***

*Scope*: This test method outlines a laboratory procedure to assess the wear of e-textiles using a pin-on-disk apparatus. The method provides insights into their wear resistance and frictional behavior in controlled laboratory settings. The test will be conducted under non-abrasive conditions.

*Related Standards*: DIN 50324-07, ASTM G99-05, ISO 18535

*Test Procedure:*

1. Before testing, using non-chlorinated, non-film-forming cleaning agents and solvents, to remove all dirt and foreign matter from the specimens (e-textile).
2. Measure appropriate textile dimensions to the nearest 2.5 µm or weigh the specimens to the nearest 0.0001 g.
3. Securely insert the disk into the holding device, ensuring it is fixed perpendicular (±1°) to the axis of resolution.
4. Securely insert the pinned textile into its holder and adjust, if needed, to ensure it is perpendicular (±1°) to the disk surface upon contact, maintaining proper contact conditions.
5. Add the proper mass to the system lever to develop the selected force by pressing the pin against the disk
6. Start the motor and adjust the speed to the desired value while holding the pin textile out of contact with the disk.
7. Set the revolution counter (or equivalent) to the desired number of revolutions.

8. Begin the test with the textile in contact under load. The test is stopped when the desired number of revolutions is achieved. Tests should not be interrupted or restarted.
9. Remove the textile and clean off any loose wear debris. Note the existence of features on or near the wear scar, such as protrusions, displaced metal, discoloration, microcracking, or spotting.
11. Remeasure the textile dimensions to the nearest 2.5µm or reweigh the specimens to the nearest 0.0001 g, as appropriate.
12. Repeat the test using different pin materials, such as alumina and steel, for comparative analysis.

### ***3.4.1.2 Tear Test***

*Scope:* A tear test is important for textile devices because it measures the strength and resistance of the fabric to tearing. The tear test helps ensure that the fabric won't easily rip or degrade over time, which is critical for both the longevity and safety of the device. This test method specifies the procedure for determining the force required to propagate a single-rip tear from a pre-cut in various fabrics using a falling-pendulum (Elmendorf-Type) apparatus.

*Related Standard*: ASTM D-1424

*Equipment specification:*

1. A stationary clamp is a clamp carried on a pendulum that is free to swing on a bearing.
2. A knife will be mounted on a stationary post for the initial slitting of the textile centered between the clamps and adjusted in height to give a tearing distance of 43.0 ± 0.15 mm; that is, the distance between the end of the slit made by the knife and the upper edge of the specimen is 43.0 ± 0.15 mm when the lower edge of the 63.00 mm wide textile rests against the bottom of the clamp.
3. With the pendulum in its initial position ready for a test, the two clamps are separated by a distance of 0 ± 0.5 mm and are aligned such that the clamped textile lies in a plane parallel to the axis of the pendulum, the plane making an angle of 0.480 rad with the perpendicular line joining the axis and the horizontal line formed by the top edges of the clamping jaws. The distance between the axis and the top edges of the clamping jaws is 104 ± 1 mm. The clamping surface in each jaw is at least 25 mm wide and 15.9 ± 0.1 mm deep.
4. Calibration Weight(s) for the graduation of 50 % of the full-scale force range or other means as described by the manufacturer of the test apparatus.

5. Cutting Die has essentially the shape and dimensions. The die provides the basic rectangular specimen 100 ± 2 mm long by 63 ± 0.15 mm wide, along with additional fabric at the top edge of the textile to help ensure the bottom portion of the textile will be torn during the test. The critical dimension of the test specimen is the distance 43.0 ± 0.15 mm which is to be torn during the test.
6. Air Pressure Regulator, capable of controlling gauge air pressure between 410 kPa and 620 kPa, when applicable, for air clamps.
7. Setting Gauge for Cutting Blade that will provide a cut slit that leaves a 43 ± 0.15 mm specimen tearing distance for a 63 ± 0.15 mm wide specimen, or equivalent.
8. Jaw Spacing Gauge 2.5 ± 0.25 mm width, or equivalent.

*Test Procedure:*

1. Test the conditioned specimens in the standard atmosphere for testing textiles, which is 21°C and 65 % relative humidity, unless otherwise directed in a material specification or contract order.
2. Position the pendulum to the starting position and the force recording mechanism to its zero-force position.
3. Place the long sides of the textile centrally in the clamps with the bottom edge carefully set against the stops and the upper edge parallel to the top of the clamps. Close the clamps, securing the specimen with approximately the same tension on both clamps. The textile should lie free with its upper area directed toward the pendulum to ensure a shearing action.
4. Using the built-in knife blade, cut a 20 mm slit in the textile extending from the bottom edge and leaving a balance of fabric 43.0 ± 0.15 mm remaining to be torn.

***3.4.2 Abrasion Resistance:*** Testing the e-textile's resistance to abrasion and its ability to maintain functionality.

*Scope:* This test method determines the abrasion resistance of textile fabrics using the Martindale abrasion tester. It applies to knit, woven, and nonwoven fabrics but may be limited by the material's thickness due to the capacity of the specimen holder. The procedure evaluates how well fabrics resist wear and tear from friction, making it suitable for various materials, including those used in apparel and upholstery. The method ensures consistent testing conditions for reliable results, helping assess the durability of fabrics across various industries.

*Related Standard*: This international standard (for textiles) was developed following globally recognized standardization principles, as outlined in the World Trade Organization's Decision on Principles for the Development of International Standards, Guides, and Recommendations by the Technical Barriers to Trade (TBT) Committee.

*Equipment Specifications*: Martindale Abrasion Testing Process - Governed by ISO 12947 2

- Martindale Tester: Uses a Lissajous figure of 60 mm equipped with a 38 mm sample holder.
- Standard Felt: Mass: 750 g/m² ± 50 g/m² (22 oz/yd² ± 1.5 oz/yd²), Thickness: 3 mm ± 0.3 mm (0.12 in. ± 0.01 in.).
- Polyurethane Foam Backing: Thickness: 3.00 mm ± 0.01 mm, Density: 29–31 kg/m³, Hardness: 170 N to 210 N.
- Fabric Punches or Press Cutters: Diameter: 38 mm and 140 mm

*Sample Specifications*:

Cut three circular specimens, each 38 mm in diameter, from each swatch in the laboratory sample.

Test Procedure:

1. Place a 140 mm felt and abradant e-textile on the table. Flatten and secure them with the mounting weight. Inspect for tucks or ridges. Weigh the specimen to the nearest milligram.
2. Place the specimen face down in the holder. For e-textiles under 500 g/m², insert a 38 mm polyurethane foam disk. Assemble the holder as per the manufacturer's instructions.
3. Position the holder on the machine above the e-textile/felt.
4. Apply the required weight of 9 - 12 kPa Set the machine counter for the desired movements and start the machine.
5. Periodically check progress, reducing movements as the endpoint nears. Cut off any pills.

**3.4.3 Material Stiffness:** Measurement of the textile's stiffness and material fatigue

*Scope:* This test method determines the stiffness properties of e-textile by measuring their bending behavior. The key parameter measured is the bending length, which indicates how far the e-textile extends horizontally before bending under its weight. Using the principle of cantilever bending, where the e-textile acts as a beam supported at one end, the bending length is recorded. Flexural rigidity, a measure of the e-textile's resistance to bending, is calculated from the bending length. This method provides insight into the e-textile's stiffness by analyzing its ability to support itself, which is essential for understanding drape and handling characteristics.

*Related Standard*: This international standard (for textile) was developed by following globally recognized principles of standardization, as outlined in the Decision on Principles for the Development of International Standards, Guides, and Recommendations by the World Trade Organization's Technical Barriers to Trade (TBT) Committee.

*Equipment Specifications*:

- **Horizontal Platform**: A flat, smooth, low-friction surface, such as polished metal or plastic, with minimum dimensions of 38 mm by 200 mm.
- **Bend Angle Indicator**: Positioned at an angle of 41.5° ± 0.5° below the surface plane of the horizontal platform. **Movable Specimen Slide**: A metal bar at least 25 mm by 200 mm and approximately 3 mm thick, with a mass of 270 g ± 5 g. An optional motorized specimen feed unit, set at 120 mm/min ± 5% will be used.
- **Scale**: For measuring the overhang length.
- **Cutting Die (optional)**: Dimensions of 25 mm ± 1 mm by 200 mm ± 1 mm.

*Sample Specifications:* Cut the test specimens to 25 mm by 200 mm with the longer dimension aligned to the machine direction (MD) for MD measurements, and to the cross-machine direction (CD) for CD measurements. Label each specimen to ensure proper identification.

**Test Procedure:**

1. Place the tester on a level surface and adjust the platform to horizontal.
2. Ensure the bend angle indicator is set to 41.5°.
3. Remove the movable slide and place the specimen (e-textile) on the platform, aligning its edge with the appropriate reference point.
4. Carefully place the slide on the specimen without disturbing its position.
5. For automatic testers, turn on the machine and stop it when the specimen touches the bend angle indicator.
6. For manual testers, smoothly advance the slide at 120 mm/min (±5%) until the specimen edge touches the bend angle indicator.
7. Measure and record the overhang length to the nearest 1 mm.
8. Repeat the procedure for both the face and back of each specimen end, recording four readings per specimen.

**3.4.4 Wear Comfort:** Evaluation of the product's comfort during extensive wear.

*Scope*: This test accurately measures surface texture that influences wear comfort, such as softness, flexibility, surface roughness, and elastic recovery. It provides insight into how fabrics interact with the skin and body movement. These measurements help optimize fabric design for better comfort and offer detailed insights into how textiles interact with the skin and accommodate body movements.

*Test procedure*:

1. Cut a fabric sample to at least 3 centimeters long and ensure it is under preset tension.
2. Position the surface tester so both electronic sensors are aligned and in direct contact with the fabric surface.
3. Set the contact pressure of the sensors to standard levels for consistent measurements.
4. Start the fabric movement under the sensors in the forward direction and record the roughness measurements.
5. Reverse the fabric movement under the sensors and record the roughness and coefficient of friction measurements again.
6. Analyze the obtained parameters, including the coefficient of surface friction, mean deviation of coefficient of friction, and index of surface roughness in μm.

**3.4.5 Power consumption**: Measuring the energy efficiency and power requirements of the product.

*Scope*: This test method aims to conduct a comprehensive analysis of the power consumption associated with the electronic components integrated into a e-textile based massager. The massager operates with multiple vibration modes, each mode is expected to exhibit varying levels of energy consumption. Therefore, detailed monitoring of power usage across these modes is essential to understand operational behavior, energy efficiency, and the projected lifespan of the device. Understanding power requirements for each function will help improve the performance of massagers and guide ways to make them last longer and be more sustainable.

*Test procedure*:

Type 1:

1. For the massagers that are directly connected to a power source via a cord, a small incision will be made in the wiring to isolate the positive and negative connections to the circuit board.

2. This separation will allow for the precise measurement of electrical current using a digital multimeter (DMM).
3. Based on these current readings, the power consumption of the device will be accurately calculated.

This approach ensures a reliable assessment of energy usage, facilitating a better understanding of the massager's electrical efficiency.

Type 2:

1. For massagers powered by a rechargeable battery, the outer casing will be carefully removed to access the internal components.
2. An ammeter will then be used to monitor the current flow through the device during operation across various modes.
3. This measurement will provide critical data on the energy consumption in each mode, enabling a detailed analysis of the device's power usage and performance characteristics in battery-powered configurations.

**3.4.6 Interoperability:** Tests to ensure that the wearable massaging e-textile components from different manufacturers can work together seamlessly. This test method is only feasible by changing the battery. We attempted other components, but the electronic circuit board is so specifically designed that interoperability is highly challenging.

**3.4.7 Fall test:** A fall test to be formulated to evaluate the product's safety in scenarios where users might trip or fall while wearing compression e-textile products. This test will assess whether the product poses any risks in such situations.

*Scope:* A fall test is important for e-textile based massager devices to assess their durability and performance when dropped or impacted. In real-life situations, if someone wearing a textile-based massager device falls or collapses, the device could be exposed to significant impact. The fall test helps determine whether the internal components of the device and the textile material can withstand such force without breaking or malfunctioning. It ensures that the device remains functional and intact, providing reliability and safety for users, especially in critical situations where the device may need to keep working after a fall.

*Related Standard*: MIL STD 810G

*Equipment Specification:*

- Dropping height: Maximum 1800mm, minimum 300 mm

- Maximum dimension of the specimens: 500x500x500 $mm^3$
- Maximum weight: 60 kg
- Base dimension of floor: 1200x900 $mm^2$

*Test procedure:*

1. First, adjust the height of the platform by rotating the wheel which is provided on the side of the device in an upward direction or downward direction.
2. Now, place the device on the platform.
3. Ensure that the device is placed in the center of the plate to get correct test results.
4. Then, drop the device from a set height using the help of the handle.
5. Observe the device for any kind of damage to check the drop strength of the corrugated box.

**3.4.8 Electrical safety:** An electrical safety test is to be prescribed to evaluate of the product's electrical safety. This test shall involve assessing insulation materials, wire integrity, and protection against electrical hazards.

***3.4.8.1 Insulation of wire:***

*Scope:* An e-textile-based massager device gets sweaty while wearing it. As a result, the electronics' internal parts can be damaged, or electric shocks or burns may happen. So, proper insulation is essential for wearable devices to ensure user safety and comfort as well as it will improve the durability and performance of the devices. Additionally, good insulation keeps the device functioning efficiently while maintaining skin comfort during extended wear.

*Equipment Specification:*

- Megger insulation tester (MF 1741) is a small, portable instrument that gives a direct reading of insulation resistance in ohms or megohms.

*Test procedure:*

1. Before testing, make sure the equipment you're testing is powered off, and any stored energy is discharged.
2. Check that the Megger tester is functioning correctly and calibrated. Make sure all connections, probes, and leads are intact.
3. Attach the Megger's positive and negative leads to the insulation being tested. Choose the appropriate test voltage on the Megger based on the equipment specifications or standard testing guidelines. Common test voltages include is 500V.

4. Start the Megger by either cranking it (if it's a hand-operated model) or pressing the button for an electronic model. The tester applies a high DC voltage to the insulation. The Megger will measure the small leakage current through the insulation.
5. Monitor the reading on the Megger's scale, which measures the insulation resistance in ohms or megohms. For good insulation, you should see a high reading in the megohms range.
6. All the experiments should be conducted at same temperature. A record of the relative humidity near the equipment at the time of the test is also helpful in evaluating the reading and trend.

***3.4.8.2 Wire Integrity:***

*Scope:* Several techniques now used or under development to detect wiring problems mostly involve reflectometry. Common to all these methods is the sending of a signal (a pulse, sine wave, or the like) down the wire and sensing the reflection that returns from the wire's end. They are most useful for detecting so-called hard errors, such as short circuits, but have not proven as useful for less obvious wire problems.

*Test procedure:*

- Turn on the reflectometer and calibrate the device as per manufacturer instructions to ensure accurate readings.
- Set the distance range to an appropriate value based on the expected length of the transmission line or distance to the fault.
- Connect one end of the transmission line to the output terminal of the reflectometer and the other end to the textile base massager device.
- Ensure that all connections are secure to avoid signal loss. Set the test voltage or signal type (usually a step pulse or square wave).
- Appropriate pulse width, length, and type of cable or material being tested.
- Send a test signal down the transmission line. The reflectometer will automatically send the signal and measure reflections. Watch for the reflected signal or waveform on the reflectometer display.
- The reflected signal indicates a change in impedance, such as a fault, splice, or other anomaly. Identify the points where reflections occur. These could represent cable faults, impedance mismatches, or connectors.

- Compare the reflected signal with the transmitted signal and record the data.

***3.4.8.3 Protection against Electrical Hazards***

*Scope*: Understanding the hazards of electricity, primarily electrical shock and fire. Electrical shock occurs when the body becomes part of an electric circuit, with severity determined by factors such as current, exposure time, and whether the skin is wet or dry.

*Related Standards:* The Faculty of Engineering and Natural Science of Sabanci University, Turkey has reported a guideline for preventing Electrical Hazards.

*Test procedure:* There are several ways to protect against electrical hazards, including guarding, grounding, and protective devices. To reduce risks, follow these precautions:

- Inspect device wiring before each use; replace damaged cords immediately.
- Use safe practices whenever operating the device.
- Know how to operate shut-off switches and circuit breakers in emergencies.
- Limit extension cord use to short-term, temporary needs.
- Use multi-plug adapters with circuit breakers or fuses.
- Shield exposed electrical conductors.
- Avoid water or chemical spills near the device.
- The device with two-prong plugs should be used in the laboratory. These plugs provide a grounding path for internal electrical short circuits, protecting users from potential electrical shocks.
- Keep away from the energized or loaded circuits.
- Sources of electricity and exposed circuits must be guarded.
- Disconnect the device from the source in the period of service or maintenance of the device.
- Disconnect the power source before servicing or repairing electrical equipment.

**3.4.9 Pressure safety:** Ensuring that the product exerts the intended pressure safely without causing discomfort, injury, or skin-related issues

*Scope*: The Per Pressure test ensures that the massager provides effective pressure for muscle relaxation or pain relief without crossing the threshold where the pressure becomes painful or uncomfortable.

*Related Standard*: IS:11056, ASTM D:737

*Equipment Specifications*:

- Specification: ALGO-AN
- Capacity : 20Kg
- Units : kg, N
- Load Division Value: 200gm
- Accuracy : ±0.5%
- PC Connectivity and Software: No

*Test Procedure:*

1. Ensure the pressure algometer (PA) is calibrated correctly. Select an appropriate probe size, typically 0.5 or 1 $cm^2$, depending on the depth of tissue that you want to assess.
2. Expose the area of tissue to be measured.
3. Hold the PA perpendicular to the tissue surface at the designated measurement site (e.g., muscle, joint, or skin). Ensure the probe is positioned flat on the skin to avoid uneven pressure distribution
4. Apply pressure steadily and gradually at a constant rate. The rate of pressure application should be consistent. Suggested rates range from 0.05 N/s to 20 N/s, but it is recommended to use slower rates to allow the subject time to react.
5. For handheld devices: Read the peak pressure from the gauge (in Newtons or kilo pounds).
6. Reset the PA (tare) to prepare it for the next measurement.
7. Perform the measurement 2–3 times at each site for accuracy. Allow brief rest periods between measurements to avoid tissue fatigue or adaptation.

**3.4.10 User guidelines:** Recommendations to be prescribed for safe usage and maintenance of wearable compression e-textile products

*User Guideline*:

1. Before use, consult an orthopedic and physiotherapist.
2. Pregnant women should consult a gynecologist, as the device's vibration may affect them.
3. Avoid using the massager on open wounds or cuts.
4. Select the correct device size (S, M, L, XL); ensure it is not too tight to avoid restricted blood flow or irritation.
5. Clean the skin area before using the device.
6. Read the instructions or manual very carefully before use.
7. Avoid prolonged use of the device.

8. Prevent exposure to extreme heat.
9. Familiarize yourself with the warranty period.
10. If using a rechargeable device, check that the battery is in good condition.
11. Use caution with damaged or malfunctioning devices; discontinue use and contact support if necessary.
12. If discomfort or health issues arise during or after use, contact a healthcare professional immediately.

**List of e-textile massagers purchased (Status: Ongoing)**

Different e-textile massagers were purchased (***Table 3***) as part of the work, and based on the test procedures mentioned in section 3.4, these massagers will be evaluated.

Table 3. List of e-textile massagers purchased

| Sl. No | Company/Product Name | Purpose of Use | Quantity |
|---|---|---|---|
| 1 | AGARO 33621 M6542 Massager | Full body | 1 |
| 2 | Dr Physio electric heat Shiatsu Massager | Neck, Shoulder & Back | 1 |
| 3 | Carefit BJM-253 Korean Jade Massage Therapy Bed | Full Body | 1 |
| 4 | Manibam Impex Electric Foot Massager | Leg | 1 |
| 5 | PREMIUMLI Knee Massager | Knee, Calves, Thighs, Elbow & Shoulder | 2 |
| 6 | Vihan Knee Massager | Knee | 2 |
| 7 | Beurer EM29 knee and elbow electric massager | Knee | 2 |
| 8 | Arg Healthcare knee massager | Knee | 2 |
| 9 | KG INDIA | Full leg | 1 |
| 10 | Prira Wellness Solutions | Knee | 2 |
| 11 | Myalkaran Creation | Full body | 1 |

**3.5 Visiting existing facilities for testing on medical fabric (Status: Ongoing)**

We visited the South India Textile Research Association (SITRA) facility in Coimbatore on 23rd September 2024 to enhance our knowledge of e-textile parameters relevant to massagers. The visit provided valuable insights into the textile testing methods and equipment, facilitating a comprehensive understanding of formulating the test methodologies to address the performance and safety parameters of the wearable compression e-textile products for massaging applications. The visit enabled us to understand more about the facilities available at SITRA, which can be used to test the e-textile massagers. As mentioned in *section 3.4*, we will send e-textile massagers to the SITRA facility to test as per the formulated test methodologies.

### 3.6 User Trials (Initiated)

Initial testing of purchased products has started, focusing on electrical safety and compression efficiency. Preliminary results indicate variations in performance across different products, highlighting the need for standardized benchmarks. A detailed data regarding this will be provided in the final report.

### 3.7 Equipment procurement (Under process)

Based on the first released funds, a purchase order has been raised for equipments like a 45˚ flammability tester & bursting strength tester. It is expected to be installed by October 2024.

## 4. Timeline and Milestones

| | Work packages/Tasks | 6 Months | | | | | |
|---|---|---|---|---|---|---|---|
| | | Completed | | | Pending | | |
| | | 1 | 2 | 3 | 4 | 5 | 6 |
| WP1 | WP1: Review of literature, data collection and device procurement | ■ | ■ | ■ | | | |
| | Task 1.1: Literature review | ■ | | | | | |
| | Task 1.2: Data collection | | ■ | | | | |
| | Task 1.3: Device procurement | | | ■ | ■ | | |
| WP2 | WP2: Testing of devices | | | | ■ | ■ | |
| WP3 | WP3: Preparation of comprehensive report | | | | | | ■ |

| Milestones | Expected date of completion |
|---|---|
| Literature survey | Completed |
| Data collection from industries | October 2024 |
| Visit to existing facilities | September 2024 |
| User trial | November 2024 |
| Initial Data Analysis and Reporting | September 2024 |
| Equipment Procurement | October – November 2024 |
| Conducting experiments | October – November 2024 |
| Final Data Analysis and Reporting | December 2024 |

## 5. Conclusion

The advancement of e-textile massagers represents a significant step forward in integrating smart textiles into healthcare and therapeutic applications. In the initial phase of this study, we focused on understanding the significance and necessity of e-textiles, particularly their applications in healthcare. A literature review was conducted to gain a comprehensive understanding, and commercially available textile-based massagers were procured for analysis. While early inventions like pressure garments have provided essential insights, newer developments in actuator-based massagers can potentially deliver more targeted and effective therapeutic benefits, such as pain relief and improved circulation. However, challenges such as maintaining long-term functionality, pressure control, and sensor integration remain key areas for further exploration. Future collaborations between engineers, medical professionals, and designers will be crucial in optimizing these technologies for widespread use, ensuring they meet the diverse needs of users, especially elderly and inactive patients. The review also helped me understand the existing standards related to this field. Further, test methods to evaluate e-textile massagers were also formulated in this project's first phase.

## 6. References


[1] M. L. Ferreira *et al.*, "Global, regional, and national burden of low back pain, 1990–2020, its attributable risk factors, and projections to 2050: a systematic analysis of the Global Burden of Disease Study 2021," *Lancet Rheumatol.*, vol. 5, no. 6, pp. e316–e329, Jun. 2023, doi: 10.1016/S2665-9913(23)00098-X.

[2] A. Libanori, G. Chen, X. Zhao, Y. Zhou, and J. Chen, "Smart textiles for personalized healthcare," *Nat. Electron. 2022 53*, vol. 5, no. 3, pp. 142–156, Mar. 2022, doi: 10.1038/s41928-022-00723-z.

[3] Y. Zhang, J. Zhou, Y. Zhang, D. Zhang, K. T. Yong, and J. Xiong, "Elastic Fibers/Fabrics for Wearables and Bioelectronics," *Adv. Sci.*, vol. 9, no. 35, p. 2203808, Dec. 2022, doi: 10.1002/ADVS.202203808.

[4] A. Komolafe *et al.*, "E-Textile Technology Review-From Materials to Application," *IEEE Access*, vol. 9, pp. 97152–97179, 2021, doi: 10.1109/ACCESS.2021.3094303.

[5] "Smart Clothing Market Size Report, 2030." https://www.grandviewresearch.com/industry-analysis/smart-clothing-market-report (accessed Sep. 29, 2024).

[6] "Textile Industry in India, Leading Yarn Manufacturers in India - IBEF." https://www.ibef.org/industry/textiles (accessed Sep. 29, 2024).

[7] "E-TEX: the smart textile venture." https://iit-techambit.in/e-tex-the-smart-textile-venture/ (accessed Sep. 29, 2024).

[8] M. Alves, M. H. de A. G. Jardim, B. P. Gomes, M. Alves, M. H. de A. G. Jardim, and B. P. Gomes, "Effect of Massage Therapy in Cancer Patients," *Int. J. Clin. Med.*, vol. 8, no. 2, pp. 111–121, Feb. 2017, doi: 10.4236/IJCM.2017.82010.

[9] J. H. H. Kim, J. Stilling, M. O'Dell, and C. H. L. Kao, "KnitDema: Robotic Textile as Personalized Edema Mobilization Device," *Conf. Hum. Factors Comput. Syst. - Proc.*, Apr. 2023, doi: 10.1145/3544548.3581343/SUPPL_FILE/3544548.3581343-VIDEO-FIGURE.MP4.

[10] "Novel 3D stretchable electronic strip could spark new possibilities for wearable e-textiles | Nottingham Trent University." https://www.ntu.ac.uk/about-us/news/news-articles/2024/06/new-3d-stretchable-electronic-strip-could-spark-new-possibilities-for-

wearable-e-textiles (accessed Sep. 29, 2024).

[11] "3DKnITS: Three-dimensional Digital Knitting of Intelligent Textile Sensor for Activity Recognition and Biomechanical Monitoring — MIT Media Lab." https://www.media.mit.edu/publications/3dknits-three-dimensional-digital-knitting-of-intelligent-textile-sensor-for-activity-recognition-and-biomechanical-monitoring/ (accessed Sep. 29, 2024).

[12] "IIT Delhi Establishes SMITA Research Lab Centre of Excellence in Smart Textiles : IIT Delhi." https://home.iitd.ac.in/show.php?id=99&in_sections=News (accessed Sep. 28, 2024).

[13] "Towards Hazard-free Wearable Health Monitors | IITBombay." https://rnd.iitb.ac.in/node/1134 (accessed Sep. 28, 2024).

[14] "IIT-Kharagpur Team Develops Wearable Technology From Silk." https://www.ndtv.com/india-news/iit-kharagpur-team-develops-wearable-technology-from-silk-1712252 (accessed Sep. 29, 2024).

[15] I. Wicaksono, D. D. Haddad, and J. Paradiso, "Tapis Magique: Machine-knitted Electronic Textile Carpet for Interactive Choreomusical Performance and Immersive Environments," *ACM Int. Conf. Proceeding Ser.*, pp. 262–274, Jun. 2022, doi: 10.1145/3527927.3531451.

[16] "E-Textile Market Expected to Reach $721.8 Million by 2031." https://www.alliedmarketresearch.com/e-textile-market-A16100 (accessed Oct. 01, 2024).

[17] Dias, "Pressure garment," May 2004.

[18] L. A. Parkinson *et al.*, "Feasibility study of polyurethane shape-memory polymer actuators for pressure bandage application," *Sci. Technol. Adv. Mater.*, vol. 13, no. 1, p. 015006, Feb. 2012, doi: 10.1088/1468-6996/13/1/015006.

[19] A. Papadopoulou, J. Berry, T. Knight, and R. Picard, "Affective sleeve: Wearable materials with haptic action for promoting calmness," *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 11587 LNCS, pp. 304–319, 2019, doi: 10.1007/978-3-030-21935-2_23/FIGURES/10.

[20] B. Kumar, J. Hu, and N. Pan, "Smart medical stocking using memory polymer for chronic venous disorders," *Biomaterials*, vol. 75, pp. 174–181, Jan. 2016, doi: 10.1016/J.BIOMATERIALS.2015.10.032.

[21] H. Narayana, J. Hu, B. Kumar, S. Shang, M. Ying, and R. J. Young, "Designing of advanced smart medical stocking using stress-memory polymeric filaments for pressure control and massaging," *Mater. Sci. Eng. C*, vol. 91, no. May, pp. 263–273, 2018, doi: 10.1016/j.msec.2018.05.026.

[22] Y. Shi, R. Liu, J. Lv, and C. Ye, "Biomedical therapeutic compression textiles: Physical-mechanical property analysis to precise pressure management," *J. Mech. Behav. Biomed. Mater.*, vol. 151, p. 106392, Mar. 2024, doi: 10.1016/J.JMBBM.2024.106392.

[23] Z. Zhou, Y. Wang, C. Zhang, A. Meng, B. Hu, and H. Yu, "Design and Massaging Force Analysis of Wearable Flexible Single Point Massager Imitating Traditional Chinese

Medicine," *Micromachines 2022, Vol. 13, Page 370*, vol. 13, no. 3, p. 370, Feb. 2022, doi: 10.3390/MI13030370.

[24] E. Suarez, J. J. Huaroto, A. A. Reymundo, D. Holland, C. Walsh, and E. Vela, "A Soft Pneumatic Fabric-Polymer Actuator for Wearable Biomedical Devices: Proof of Concept for Lymphedema Treatment," *Proc. - IEEE Int. Conf. Robot. Autom.*, pp. 5452–5458, Sep. 2018, doi: 10.1109/ICRA.2018.8460790.

[25] M. Zhu, A. Ferstera, S. Dinulescu, N. Kastor, M. Linnander, and R. O. Jun, "A peristaltic soft , wearable robot for compression and massage therapy," pp. 1–10, 2022.

[26] H. J. Yoo *et al.*, "Wearable lymphedema massaging modules: Proof of concept using origami-inspired soft fabric pneumatic actuators," *IEEE Int. Conf. Rehabil. Robot.*, vol. 2019-June, pp. 950–956, Jun. 2019, doi: 10.1109/ICORR.2019.8779525.

[27] C. J. Payne *et al.*, "Force control of textile-based soft wearable robots for mechanotherapy," *Proc. - IEEE Int. Conf. Robot. Autom.*, pp. 5459–5465, Sep. 2018, doi: 10.1109/ICRA.2018.8461059.

[28] S. Zhao, R. Liu, X. Wu, C. Ye, and A. W. Zia, "A programmable and self-adaptive dynamic pressure delivery and feedback system for efficient intermittent pneumatic compression therapy," *Sensors Actuators A Phys.*, vol. 315, p. 112285, Nov. 2020, doi: 10.1016/J.SNA.2020.112285.

[29] M. N. Chaitanya, S. Jayakkumar, E. Chong, and C. H. Yeow, "A wearable, EEG-based massage headband for anxiety alleviation," *Proc. Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. EMBS*, pp. 3557–3560, Sep. 2017, doi: 10.1109/EMBC.2017.8037625.

[30] M. R. Repon, G. Laureckiene, and D. Mikucioniene, "The influence of electro-conductive compression knits wearing conditions on heating characteristics," *Materials (Basel).*, vol. 14, no. 22, 2021, doi: 10.3390/ma14226780.

[31] "IEC/CD 63517 - Wearable electronic textiles — Test method for performance of heating products." https://www.iso.org/standard/86639.html (accessed Oct. 20, 2024).

[32] "IEC 63203-204-1:2023 | IEC." https://webstore.iec.ch/en/publication/74088 (accessed Oct. 20, 2024).

[33] "IEC 60335-2-32:2024 ED6." https://genorma.com/en/standards/iec-60335-2-32-ed6 (accessed Oct. 20, 2024).

[34] "D3884 Standard Guide for Abrasion Resistance of Textile Fabrics (Rotary Platform, Double-Head Method)." https://www.astm.org/d3884-09r17.html (accessed Oct. 20, 2024).

[35] "IEC 63203-401-1:2023 | IEC." https://webstore.iec.ch/en/publication/62631 (accessed Oct. 20, 2024).

[36] "IEC 63203-406-1:2021 | IEC." https://webstore.iec.ch/en/publication/62634 (accessed Oct. 20, 2024).

[37] "D8248 Standard Terminology for Smart Textiles." https://www.astm.org/d8248-19.html (accessed Oct. 20, 2024).

[38] "ISO 24584:2022 - Textiles — Smart textiles — Test method for sheet resistance of conductive textiles using non-contact type." https://www.iso.org/standard/78999.html (accessed Oct. 20, 2024).

[39] "ISO/TR 23383:2020 - Textiles and textile products — Smart (Intelligent) textiles— Definitions, categorisation, applications and standardization needs." https://www.iso.org/standard/75383.html (accessed Oct. 20, 2024).

[40] "ISO/AWI 25242 - Textiles — Smart textiles systems — Test method of temperature change." https://www.iso.org/standard/89551.html (accessed Oct. 20, 2024).

[41] "EN 17673:2022 - Protective clothing - Protection against heat and flame - Requirements and test." https://standards.iteh.ai/catalog/standards/cen/b69e9073-ca46-4bab-8f5f-30410172cbda/en-17673-2022?srsltid=AfmBOooHHX1HNJBaaLqSM_M239XazOWgwkcQP8oN561Q0mPknDpwOJC1 (accessed Oct. 20, 2024).

[42] "CEN/TR 17512:2020." https://genorma.com/en/standards/cen-tr-17512-2020 (accessed Oct. 20, 2024).

[43] K. Le *et al.*, "Electronic textiles for electrocardiogram monitoring: A review on the structure–property and performance evaluation from fiber to fabric," *Text. Res. J.*, vol. 93, no. 3–4, pp. 878–910, Feb. 2023, doi: 10.1177/00405175221108208/ASSET/IMAGES/LARGE/10.1177_00405175221108208-FIG8.JPEG.

[44] "D4032 Standard Test Method for Stiffness of Fabric by the Circular Bend Procedure." https://www.astm.org/d4032-08r16.html (accessed Oct. 20, 2024).

[45] "IPC-8971 - Standard Only Requirements for Electrical Testing of Printed Electronics E-Textiles." https://shop.ipc.org/ipc-8971/ipc-8971-standard-only/Revision-0/english (accessed Oct. 20, 2024).

[46] "New IPC Standards for E-Textiles — LOOMIA Soft Electronics | E-textiles." https://www.loomia.com/blog/new-ipc-standards-for-e-textiles (accessed Oct. 20, 2024).

[47] B. of Indian Standards, "IS 7137 (1973): Portable, hand held mains-operated electric massagers".

[48] "Multiple Functional Electric Hand Massager for Stroke Patient Hand Rehabilitation." https://www.syrebo.com/showroom/multiple-functional-electric-hand-massager-for-stroke-patient-hand-rehabilitation.html (accessed Sep. 30, 2024).

**--x--**