

‘Spacer stitching’, an innovative material feeding technology for improved thermal resistance

H Saeed¹, H Rödel¹, S Krzywinski¹ and L Hes²

¹Technical University of Dresden, Faculty of mechanical engineering, Institute of textile machinery and high performance material technology, Dresden, Germany

²Technical University of Liberec, Czech Republic

E-mail: hassan.saeed@tu-dresden.de

Abstract. This paper investigates the problems associated with heat loss occurring at the points of needle insertion. The insulation material at stitching points is compressed by sewing thread tensions and consequently the air entrapped is forced to leave its structure. It results in poor thermal insulation at the points of needle insertions. An innovative material feeding technology, ‘Spacer stitching’ is developed which addresses the state of the art of cold spots with a simpler and much efficient method. A comparison of sewing samples of conventional sewing technology with the spacer stitching is carried out in this research paper to study the improvement in thermal properties.

1. Introduction

Earth has very diverse climatic conditions. Humans have survived in extreme weather and temperatures for tens of thousands of years. As the most evolved species on the planet, humans have developed ways to keep themselves comfortable in even the harshest surroundings. To supplement what little body hair modern humans have left, our species relies on clothing, as one of the critical threats to our health and safety is extremely cold weather. In rural Oymyakon in Eastern Russia, temperatures often drop below $-50\text{ }^{\circ}\text{C}$, making it one of the coldest permanently inhabited places in the world [1]. Such places exist on almost all continents. The optimum comfortable conditions for the human body rely on the skin maintaining a temperature of 33°C to $35\text{ }^{\circ}\text{C}$. The core temperature of the human body cannot deviate from $37\text{ }^{\circ}\text{C}$ by more than 0.2 K [2,3]. Suitable clothes prevent the harmful effects of the temperature difference between the body and its environment.

With the invention of sewing machine by *Elias Howe* (1819-1867) [4], and further innovations in sewing technology with ever increasing speeds in the 20th century, mass production in the clothing industry was realized. The industrial sewing machine became more robust and specialized industrial versions of sewing machines are capable of working at higher sewing speeds. The combination of advanced automation technology and higher sewing speeds is utilized on clothing for the production of goods of longer runs, and labour-intensive work is reduced [5], [6]. Various types and forms of clothing i.e. jackets, sweaters, gloves, and sleeping bags are used to protect human beings living in extremely cold weather conditions. They are produced at mass production scale worldwide. With the advances in fabric technologies, insulating materials, and scientific knowledge of clothing comfort, these products are getting warmer and more functional than ever before.



The flow of heat through clothing is a complex process involving conduction, convection and radiation. Perceptible heat is exchanged through not only the fabric itself but also through its interstices as well as through small and large apertures of the clothing [7]. The air, which itself act as an insulator, plays a very important part in clothing insulation systems [8], [9].

In clothing products to be used in extreme weather conditions, layers of textile materials are combined with suitable insulation materials and are held together with sewing. Sewing is important to keep the insulation material at its designated place. Lockstitch is one stitch type used widely for combining layers of insulation materials with textile fabrics. The thread systems in lockstitch pull each other to locate the point of knotting in the sandwich structure of fabrics and insulation material. During the stitch formation, the outer and inner layers of textile material are brought close together during by tensions of sewing threads. Therefore, the insulation material, sandwiched between the extreme layers of fabric is compressed along the stitch line, causing a thin spot at each point of needle insertion.

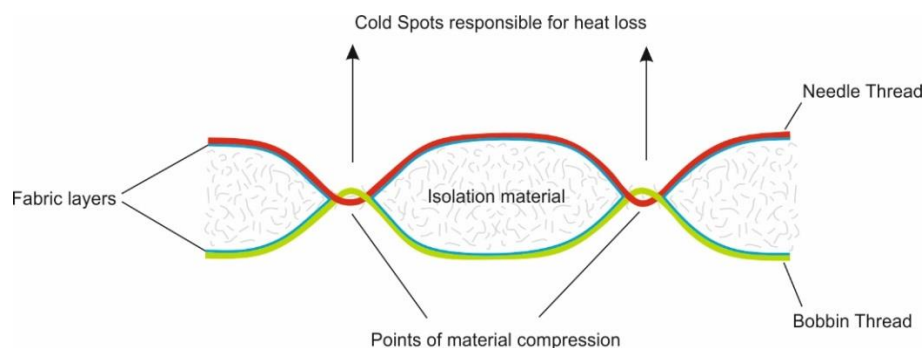


Figure 1. Graphical illustration of cold spots10(10)(10)[10]

Figure 1 shows a graphical illustration of cross-section of conventional lockstitch and the formation of cold spots. These thin spots, commonly known as ‘cold spots’, are responsible for heat loss from the human body to its outer climate. These cold spots reduce the overall insulating value of the material [11]. Due to compression along the stitch line, the air trapped inside the insulation material is forced to leave its porous structure. The thermal resistance which depends upon the thickness of insulation material and primarily on the volume of air trapped in it [12] is reduced due to localized compression at the points of needle insertions along the stitching line. The insulation materials do not exhibit their optimum performance along stitch line as in the rest of the product’s surface [13], [14]. The combination of these factors causes heat loss from the points of needle insertion. The greater the number of stitch lines, the more heat would be lost through them.

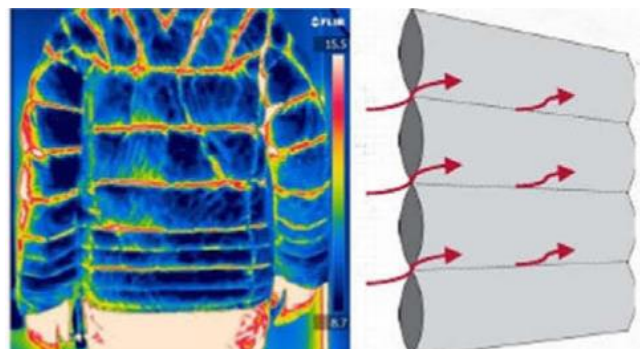


Figure 2. Heat loss through cold spots on stitching line [15]

Figure 2Error! Reference source not found. shows a thermal image of person wearing a jacket, revealing the heat loss through these cold spots [15]. In situation of extreme weather conditions, heat loss through clothing system is critically important in directing the precious body heat to escape and these cold spots present along the stitching line act as bridges between the internal climate of the body and its external climate

The traditional manufacturing methods especially with manmade insulation materials, suffer from the disadvantages of stitching lines due to formation of cold strips in the material. This is due to the fact that the thickness of the insulation along the lines of stitching is reduced merely to that of the two sheets of material. In both natural insulating materials and manmade nonwoven batting, at the point of needle insertions where the thread systems pull each other, the insulation material is compressed and heat loss occurs at these points.

The cold spots are accepted as a by-product phenomenon, inherited by sewing machine mechanisms in clothing industry. There are a number of patents registered worldwide by individuals and by renowned clothing manufacturers that counter the problem of cold spots [9], [10], [13], [14], [16], [17], [18], [19]. Most of the patents are resolving the problem with numerous material handling methods that cover the stitch line. These patents examples from the 20th and 21st century explain that the problem of cold spots and its negative impacts on product performance are well known to textile and clothing technologists. The design patents submitted by global brands until very recently prove that the problem persists despite complex material handling techniques proposed, and that a machine-based solution is not yet available.

2. Development of Spacer Stitching

The concept of spacer stitching is inspired by the spacer fabric where two parallel layers of fabric are joined to each other with the constituting fabric yarns itself and maintaining a distance between them. The concept of spacer stitching is first implemented with lockstitch sewing technology. In spacer stitching, sewing thread also join two or more layers of sewing material like any other. An innovative material feeding concept is used to maintain the distance between the extreme layers of textile material which does not compress the insulation material. Spacer stitching should not be confused with any form of loose stitches. This material feeding concept can be mounted on machines of other stitch classes. The concept is created on two level material feeding system by introducing an extra raised stitch plate, on top of original stitch plate. Lower textile layer and insulation material is fed between the raised stitch plate and lower (original) stitch plate, while the upper textile material is fed on top of raised stitch plate. The graphical illustration of spacer stitch can be seen in

Figure 3.

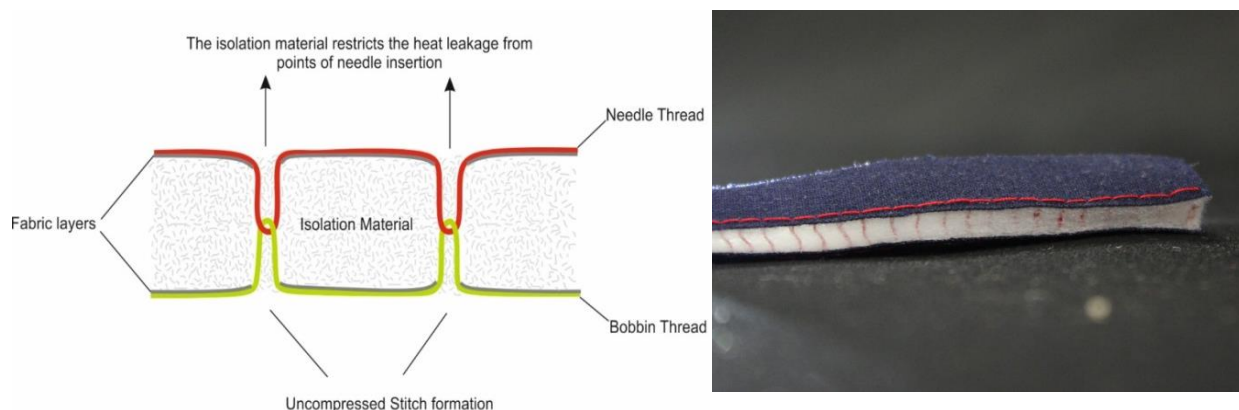


Figure 3. Graphical illustration of spacer stitching (left) and sample prepared with lockstitch (right)

The prototype was designed and mounted on conventional lockstitch sewing machine at Institute for Textile Machinery and High Performance Materials (ITM) of Technical University of Dresden. There are certain limitations in material transport while working with conventional sewing machines that will be improved in the next phase of research. The distance of raised stitch plate from machine base is flexible and it is adjusted according to required stitch height and thickness of insulation material to be sewn. The final stitch height depends on the sewing threads tensions, sewing thread type, distance between stitch plates and thickness/bulkiness of insulation material. A patent is already applied.

3. Study of heat loss through stitching

The clothing industry and garment engineers are aware of the problem presented by cold spots, yet there is lack of research available which specifies the degree of heat loss occurring through the stitch lines. There is no research work in the literature discussing the quantification of this well-known problem in detail. Historically, the clothing industry has focused on devising new material handling techniques to neutralize the problem of cold spots [20], [21]. These techniques cover the cold spots in one way or another, aiming to stop/hinder the heat passage through the weak link of stitching by adopting complex and time consuming manufacturing methods.

In the frame work of research various testing methods are used to study the effects of spacer stitching on thermal properties. However, following techniques will be discussed in this research paper.

- *Permetest*
- Sweat guard hot plate (*Skin Model*)
- X-Ray Tomography

3.1. *Permetest*

Permetest is a simpler version of the skin model developed by L. Hes and co-workers [22]. Measurements are expressed in units of R_{et} and R_{cl} as defined in *ISO 11092*. Its porous surface is continuously heated to a constant temperature. The temperature can be varied, but normally kept at a difference of 10 K to the ambient temperature. Because of this temperature difference the heat flows through the tested material [23,24].

3.1.1. Sample preparation. Testing samples were prepared for thermal resistance testing. Insulation materials of three different densities of nonwovens were used. Samples prepared are divided in 3 categories. In first category came the samples which were not sewn at all. The results from non-stitched samples served as a benchmark for comparison as they were the best case scenario. In second category the sample were prepared with conventional lockstitch. The third category of sample was prepared with spacer stitching. The samples are sewn with stitch density of 3,1 stitches/cm and sewing needle of 80 Nm. The size of sewing thread in needle and in bobbin was 100 tex made of 100 % polyester. The samples with spacer stitching are further categorized in three sub categories based upon the stitch plate distances. Spacer stitching samples were prepared with stitch plate distance (SPD) of 6 mm, 9 mm and 11 mm. A total number of 75 samples were prepared for testing with *Permetest*. Out of this number, 45 Samples were prepared for spacer stitching with different stitch plate distances, 15 for conventional lockstitch and samples without stitch were prepared for three insulation materials.

Table 1. Properties of insulation materials

Insulation Material	HO-108 (Sample 1)	HO-168 (Sample 2)	HO-297 (Sample 3)
Thickness (mm)	24.0	23.0	21.0
Fabric Mass (g/m ²)	200	200	150
Material (100%)	PES	PES	PES

3.1.2. Measurement and Results. In order to study the role of air entrapped, samples were tested in *Permetest* in three different compression states i.e. fully compressed, 50% compressed and uncompressed. These states of compressions were developed in combination to thickness of insulation materials and working principle of instrument. The instrument has a lever mechanism that moves testing diaphragm up and down. At first the samples were fully compressed between the movable lever and air flow chamber. The distance of movable measuring head was noted from base of instrument. After that the sample was placed in most uncompressed state possible in a way by making sure that the surrounding air do not get into instrument and disturbs the repeatable measurements. Again, the distance of moveable head was measured from instrument base. From these two values the 50 % compression value was calculated by dividing the difference of distances in half. This process was repeated for other two insulation materials separately.

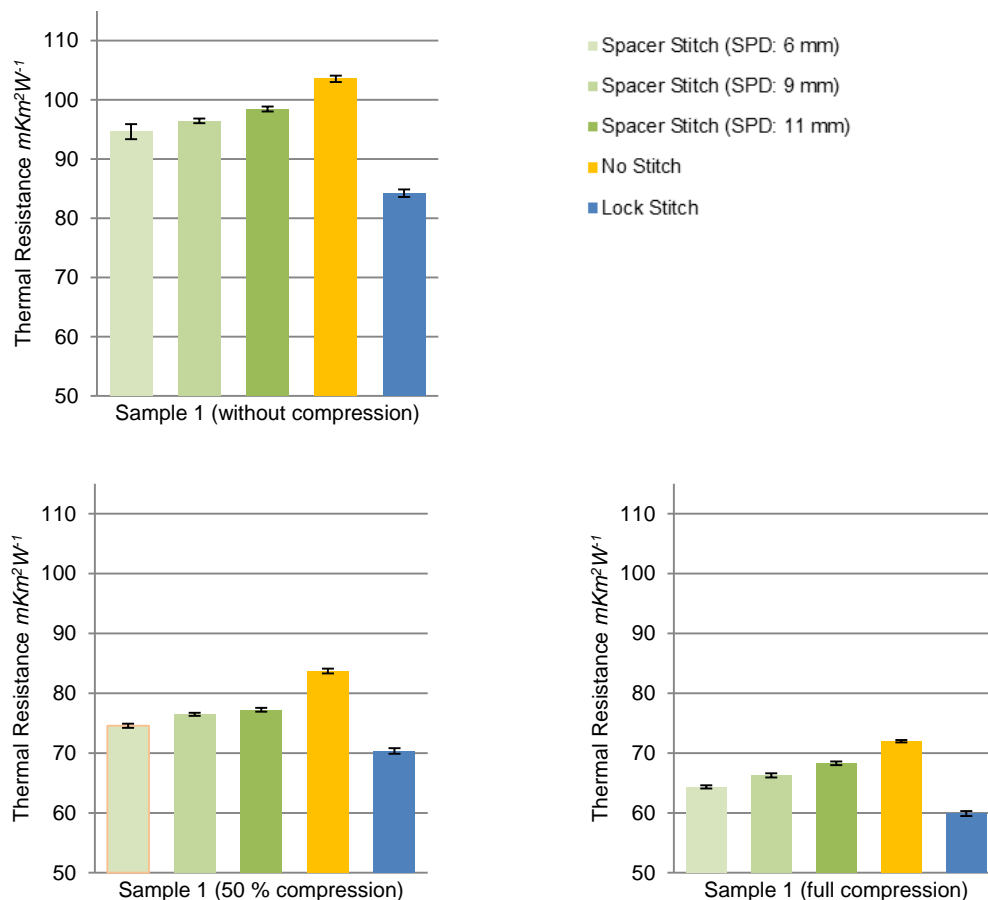


Figure 4. Thermal resistance ($\text{mK m}^2/\text{W}$) of sample 1 with Permetest

The results for sample 1 are shown in Figure 4. The tendency of thermal resistance of samples is obvious from results. The tendency of results means that the thermal resistance of samples without stitch always showed the highest thermal resistance, because there were no cold spots present due to absence of any needle penetration. The results from lockstitch showed the worst thermal resistance as expected. The reason is the maximum compression of insulation material at the points of needle insertions by the tensions of needle and bobbin thread systems. The thermal resistance of samples of spacer stitching was in between the sample without stitch and the sample sewn with conventional lockstitch. This tendency of results was also followed by other two insulation materials used in sample 2 and sample 3 in similar pattern.

A gradual increase in thermal resistance was also observed in the samples of spacer stitching with increasing stitch plate distance. With the gradual increase in stitch plate distance the stitch height was increased and so did the amount of air present along stitch line. Therefore, a gradual increase of thermal resistance was observed during measurements. It was also observed that under increasing compression state of testing, the thermal resistance decreased for all of samples. The compression forces the trapped air to leave the structure of insulation material and increase the heat flow. The tendency of compression was similar for all samples sewn or unsewn.

It became obvious from the results of *Permetest* that the spacer stitching improves the thermal properties of any insulation materials as compared to conventional sewing technology of lockstitch. The results from *Permetest* were also used for the comparison thermal properties of insulation materials. This comparison of thermal resistance explains that under same testing conditions and sampling parameters for insulation material of sample 1, spacer stitching had shown an increase in thermal resistance of up to 14 % when compared with conventional lockstitch.

3.2. Sweat guard hot plate (Skin Model)

Skin model works as per DIN (BS) EN 31092 and ISO 11092. It is also known as “Sweat Guard Hot Plate”. This device measures thermal properties and water vapour resistance of fabrics and other materials under steady state conditions. Heat and mass transfer process which occurs next to human skin are simulated during the test [25]. A reliable test results require up to 2 hours for one sample.

3.2.1. Samples preparation. The insulation material of sample 1 was studied. The stitching parameters and textile materials mentioned before for *Permetest* were followed for sample preparation. A total of 15 samples were prepared and tested on *Skin Model*. The testing methodology was the same as used for testing with *Permetest* i.e. the samples prepared were divided in 3 categories. In the first category come the samples which are not sewn at all, followed by the sample prepared with conventional lockstitch and spacer stitching. Unlike *Permetest* where three different stitch plate distances were used, only one stitch plate distance of 11 mm for samples of spacer stitching was used. The dimension of samples prepared was 300 mm * 300 mm. The sample is placed in the testing equipment in free form without any external compressional load except its own weight of gravity.

3.2.2. Measurements and results. The tendency of test results can be seen clearly in results. The thermal resistance of samples without stitch has shown the best thermal resistance. They are followed by the samples sewn with spacer stitching. Conventional lockstitch has shown the least thermal resistance.

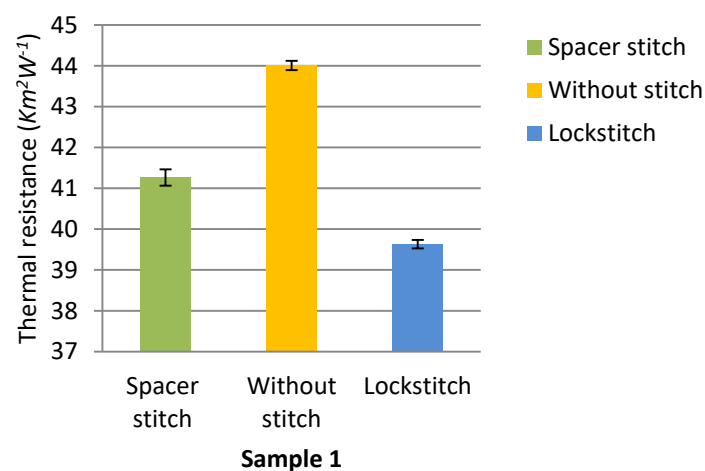


Figure 5. Thermal resistance (Km^2/W) of sample 1 with *Skin Model*

3.3. X-ray Tomography

X-Ray computed tomography is a seldom used method for studying textile structures. It is mostly used to study the internal structure of nanomaterials and electronic circuits. The advantage of X-Ray tomography is that a complete 3D internal image of any object is obtained via X-Rays. The 3D data obtained by tomography can be analysed by various imaging software for further studies. At the Center of Micro technical Manufacturing of Technical University of Dresden the ‘*Phoenix Nanotom m*’ from *GE* was used for the study.

The sample is mounted on a rotating platform. On one side of this rotating platform is the X-Rays source and on the other side is the detector. When the measurements are started, the sample is rotated on 360° about a vertical axis. The testing time can range between 60 minutes to 240 minutes depending upon precision required.

3.3.1. Sample Preparation. In order to compare the internal structure of lockstitch with spacer stitching, two samples were prepared. In the tested sample the insulation material was 100% polyester, the fabric was polyester/cotton mix and the sewing thread was 100% cotton. Different material composition of sample is later helpful during image reconstruction and distinguishment between materials. The sample measurements are 85 mm*45 mm. The sample is not meant to move during image collection. For this purpose, a frame was printed by 3D printer that can clamp the sewing sample to mount it on the platform of the tomography equipment. The frame was designed in such a way that the insulation material is not compressed.

3.3.2. Measurement and results. After mounting the sewing sample on rotating stage, the recording with X-ray was carried out. The size of one pixel in the image was 10 µm. The equipment’s own imaging software was used to reconstruct the raw data images into a 3D structure. For further processing of images open source softwares from *Volume Graphics* and *Image J* were used. By adjusting the gray values obtained, a better contrast between different set of materials/construction was made.

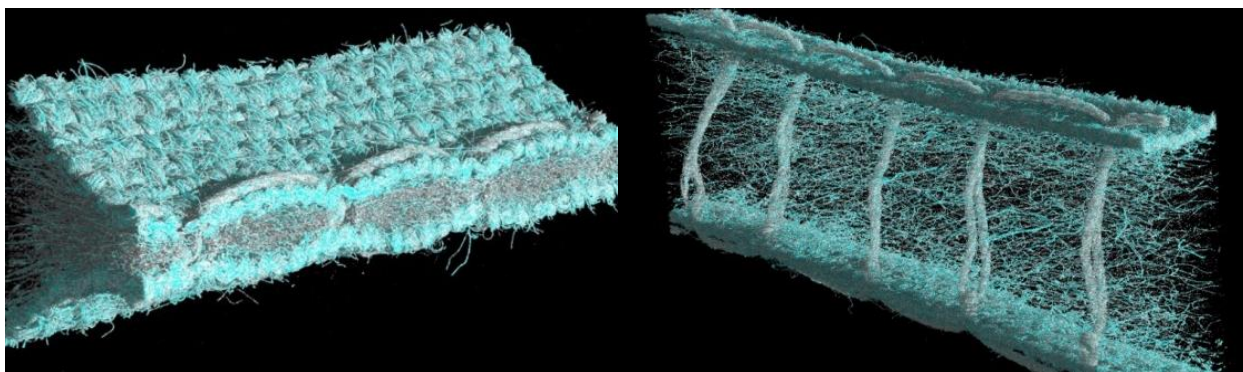


Figure 6. Cross-sectional view of lockstitch (left) and spacer stitching (right)

The cross-sectional view in Figure 6 shows how much the insulating material is compressed in lockstitch (left) at the points of needle insertions. There is no textile or insulation material present but only the lock formed by two thread systems. Furthermore, apart from the point of two needle insertions, the material present between them is in considerable compact form. Due to this compression, the air pockets are reduced and material along the stitch line behaves more densely than the rest of sandwich structure. The increase in density and removal of air pockets along stitch line lead

to increased thermal conductivity and greater heat loss. The cross-sectional view of spacer stitching (right) indicates that the textile and insulation material are in far more uncompressed state and guarantee additional volume of air in its structure. The lock formed by needle and bobbin thread can be seen near the lower side of textile material.

With X-Ray tomography results, the air trapped even inside the cross-section of sewing thread and the fabric's individual yarn can be seen. Therefore, a closer estimate of air volume existing in a unit stitch length is conceivable. To estimate the amount of air present in a unit stitch length of conventional lockstitch and spacer stitching, two dimensional images stack of top view of stitch were converted into binary images with the help of imaging software. The black pixels in the binary image mean the absence of material or the air present in material. The white pixels represent the material. This material can be the fabric, the insulation material or the sewing thread. A distance of 3 mm to either side of stitch perpendicular to the direction of stitch length is taken in study for calculation. It was observed that this 3 mm distance exhibits the most of compression. Beyond this distance, the effects of compressions start to diffuse.

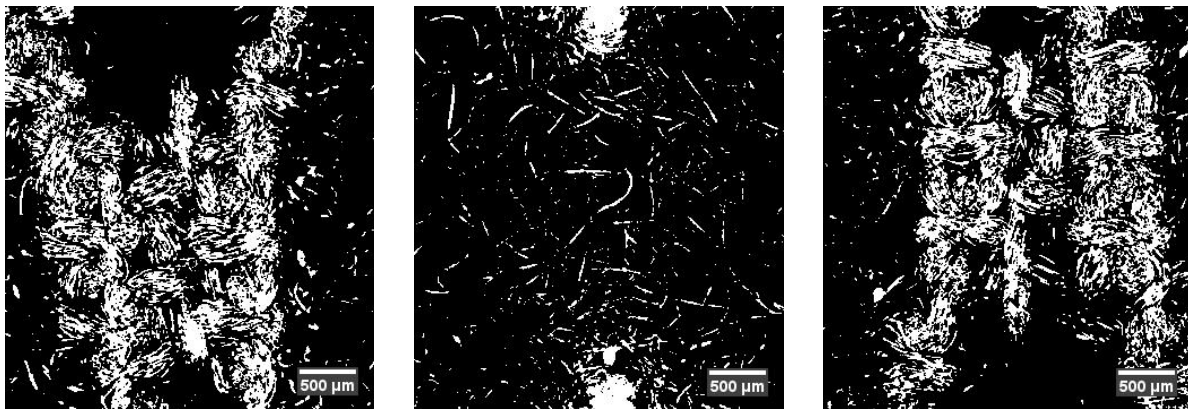


Figure 7. Substacks of lockstitch

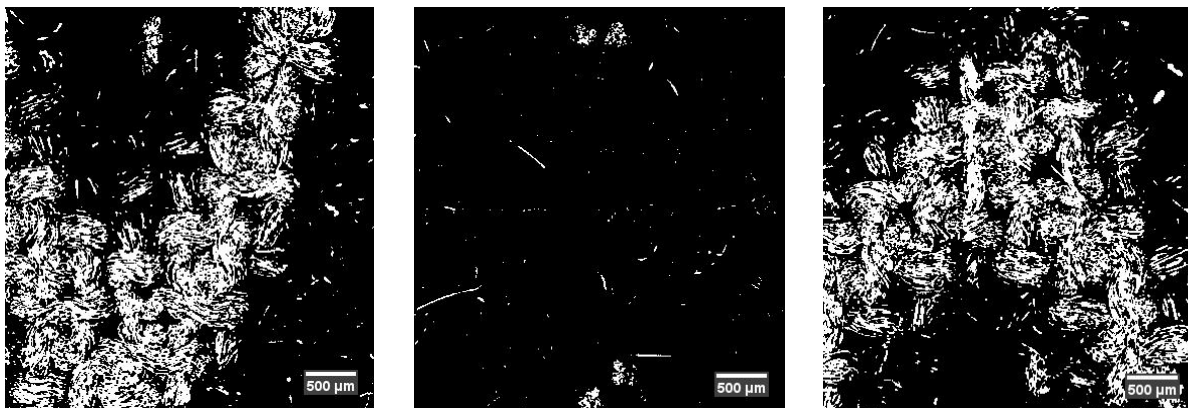


Figure 8. Substacks of spacer stitch

It is quite visible from the binary image in the middle of Figure 7 and Figure 8 that the numbers of white pixels are much more in conventional lockstitch than in spacer stitching. This shows that material density in lockstitch is greater than that of spacer stitch in a unit stitch length.

Each image was calculated on the basis of presence and absence of material. The imaging software calculates each pixel present in the 2D image stack one by one. The binary images results were later

combined to calculate the volume of air and material present in a three dimensional image. The conceptual illustration of this calculation process is shown in Figure 9.

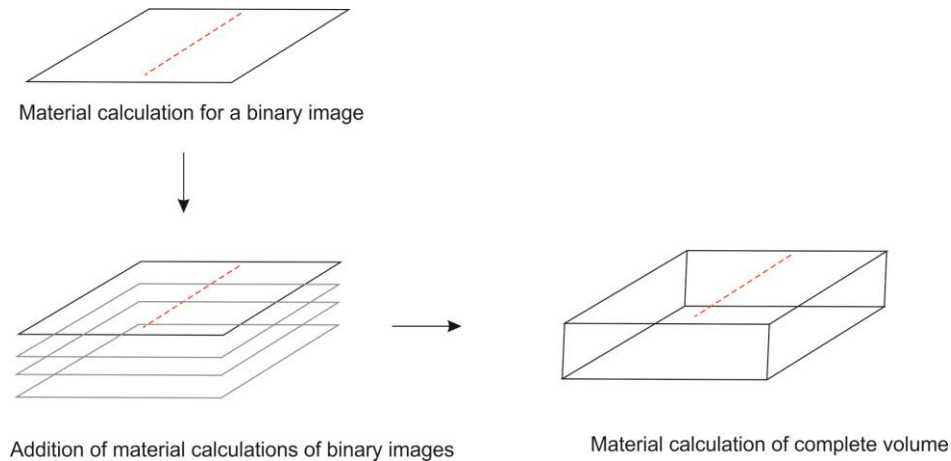


Figure 9. Concept for air and material volume calculation along stitch line

A good insulating clothing system is based not simply on the thermal properties of the textile material, rather it's the amount of air that it can encapsulate in its structure. The thermal conductivity of air is $0.025 \text{ Wm}^{-1}\text{K}^{-1}$ which is 10-20 times less than any textile material [3], [6]. Therefore, the most important factor for maintaining the temperature of human body is the insulating air trapped in fabric and insulation material. The greater the volume of air trapped in its structure, the greater the thermal insulation can be achieved. The relatively uncompressed stitch formation of spacer stitching offers lesser compression of insulation material and more volume of insulating air for improved thermal insulation. Good thermal insulation material is composed of 90-95 % of its volume of air, and very excellent ones can have more than 99 % of its volume of air in its structure [3].

With the help of imaging software, the volume percentage of material and air in a unit length of stitch was calculated and results are shown in Figure 10. Calculations from X-Ray tomography revealed that in the case of lockstitch, a unit stitch has a volume percentage of 15 % material and 85 % of the volume percentage made up by air. Here, the material includes the fabric layers, insulation material, and the sewing threads between the extreme layers of fabrics. In comparison, the spacer stitch with the same sewing and fabric parameters has volume percentage of material of 4.5 % and of 95.5 % air.

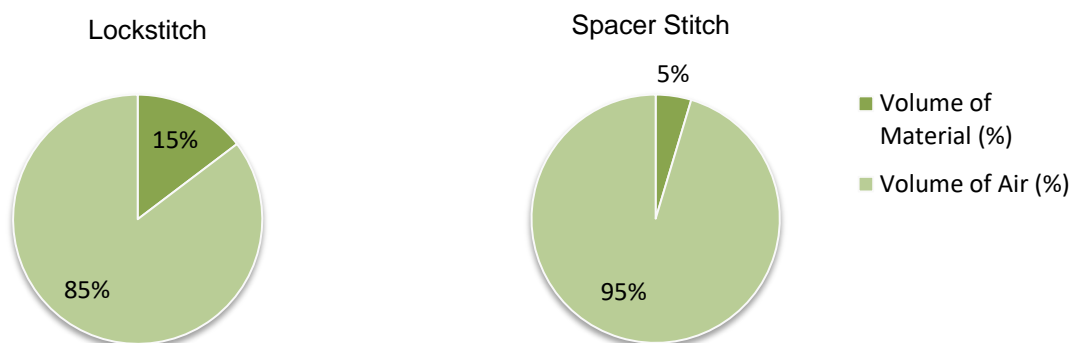


Figure 10. Comparison of volume percentage distribution of air and material in a unit stitch length

4. Conclusion

The test samples of specimens without stitch, spacer stitching and conventional lockstitch are tested with different testing equipment and following findings are observed. Three different insulation

materials with three different raised stitch plate distances for spacer stitching were studied with *Permetest*. The best results were achieved from the sample 1 along with a 1.1 cm raised stitch plate distance. Spacer stitch has shown 10-14% better thermal resistance as compared to lockstitch samples.

Independent testing was carried out in TU Liberec on *Sweat Guard Hot Plate (Skin Model)* and an improvement of 3.6% thermal resistance is measured from lockstitch to spacer stitch was observed. The purpose of this study is not to compare the thermal resistance values from two different methods of *Permetest* and *Skin Model*, rather is to understand the tendency of results. The trend of results is clear that spacer stitching shows advantage over conventional lockstitch technology. Furthermore, the gradual increase in thermal resistance with increasing stitch plate distances validates that with more uncompressed stitch formation better thermal insulation is attained.

The results from X-Ray tomography give a very clear internal picture of conventional lockstitch and spacer stitch in a unit stitch length. The unit stitch in spacer stitching has up to 10% more air volume present in its structure compared to lockstitch, when sewn under same conditions. More air volume in an insulation material pledges better thermal resistance.

In outdoor clothing, the insulation material is held along with textile materials with multiple stitch lines. The use of spacer stitching can improve the thermal insulation of products impressively. If one stitch line can improve the thermal resistance up to 14 % as measured by *Permetest* and 3.6% by *Skin Model*, more number of stitch lines can make a much greater difference. The invention can offer great prospective in industrial application of insulation. The technology can also be used for the development of advanced filtration processes. It may also be applied for the thermal protection of aircraft bodies. Spacer fabrics can also be sewn with the new technology without local compression to maximize product utilization for its desired final use. Some initial tests with spacer fabrics are by now being carried out with positive results. In the composite industry, spacer stitching can deliver positive results by reducing the localized compression problems in composite parts caused by sewing.

Acknowledgment

The author is grateful to Dr. Scharfenberger from Freudenberg Group, Mr. Oliver Albrecht from TU Dresden and Dr. Mazari from TU Liberec for their material and testing support.

References

- [1] Byrne K Photographer Captures Stunning Scenes From Coldest Inhabited Place on Earth
- [2] Longo D L, Fauci A S, Kasper D L, Hauser S L, Jameson J L and Loscalzo J 2011 *Harrison's Principles of Internal Medicine* (Newyork: McGraw-Hill)
- [3] Mecheels J 1998 Körper-Klima-Kleidung: wie funktioniert unsere Kleidung? (Berlin: Schiele und Schön) pp 15–48
- [4] Gries T and Klopp K 2007 Füge und Oberflächen Technologien für Textilien. Verfahren und Anwendungen pp 23–4
- [5] Steedman H and Wagner K 1989 Productivity, Machinery and Skills: Clothing Manufacture in Britain and Germany *Natl. Inst. Econ. Rev.* **128** 40–57
- [6] Strauchmann et al. J 1985 *Konfektionieren textiler Flächen* (Leipzig: VEB Fachbuchverlag)
- [7] Vogt J J, Meyer J P, Candas V, Libert J P and Sagot J C 1983 Pumping effects on thermal insulation of clothing worn by human subjects. *Ergonomics* **26** 963–74
- [8] Stanković S B, Popović D and Poparić G B 2008 Thermal properties of textile fabrics made of natural and regenerated cellulose fibers *Polym. Test.*
- [9] Moriarty C 2013 Thermal insulation structure and producers made therefrom
- [10] Maud T 2015 Wärmeisoliationsstruktur für ein Bekleidungsstück 1–31
- [11] Daiber O C 1949 Insulated structure
- [12] Farnworth B 1983 Mechansim of heat flow through clothing insulation *Text. Res. J.* 717–25
- [13] Reuben R 1998 Down-fill quilted fabric with combination stitched lines and tach stitches
- [14] William S and Rice E 1998 Dual Insulation Garment
- [15] Adidas FW14 Adidas Outdoor Apparel General Technology Guide *Adidas Outdoor*

- [16] Jerald W N 1990 Insulated sleeping bag
- [17] Kramer P F and Berkeley C 1992 Method of sleeping bag and construction and articles made thereby
- [18] Li Y L 2015 Insulating method and product
- [19] MaSmallish C S 1934 Sealed quilted material
- [20] Sellers B, Usher H G and Kay W L 1974 Sleeping quilt
- [21] Tesch G 1993 Quilted bed blanket
- [22] Hes L *Permetest Manual* (Liberec)
- [23] Hes L 2008 Non-destructive determination of comfort parameters during marketing of functional garments and clothing *Indian J. Fibre Text. Res.* **33** 239–45
- [24] Prof. Lubos Hes, PhD. Ds Friendly testing of comfort parameters of functional garments and clothing and its use in marketing
- [25] Machova K 2007 *Abstandstextilien als Kaminsystem für Sport- und Outdoor-Bekleidung*