

Some Significant Advances in Spacer Fabric Technology for Newer Areas of Applications

Narayan Gokarneshan* and Velumani K

Department of Textile Technology, Park College of Engineering and Technology, Coimbatore, Tamil Nadu, India

Abstract

Knit spacer fabrics have gained popularity in varied functional applications. Some important types of these fabrics are highlighted. One such is in medical applications, wherein the weft knit spacer fabrics have been attempted in treating pressure ulcer. The results show that the air permeability, thermal conductivity and water vapor permeability of weft knitted spacer fabrics are comparable with the existing wound dressings. The compressional resistance and resilience of them are good for providing protection as wound dressing. The absorbency of them is somewhat better than some wound dressings; however, they are suitable for pressure ulcer wounds with no heavy extrude. Warp knit spacer fabrics offer a better option over polyurethane foam in car seats owing to their advantages such as better recovery to compression, thermal properties and breathability. Flat-knitted spacer fabrics offer a strong potential for complex shape preforms, which could be used to manufacture composites with reduced waste and shorter production times. This article focuses on the improved strength and stiffness of woven three-dimensional (3D) spacer fabrics used in fiber reinforced plastics. The spacer fabrics were manufactured using E-glass/polypropylene (GF/PP) hybrid yarns and are intended for lightweight engineering applications. Flat-knitted spacer fabrics offer a strong potential for complex shape preforms, which could be used to manufacture composites with reduced waste and shorter production times.

Keywords: Automotive; Spacer fabric; Compression; Thermal property; Pressure ulcer; Wound; Dressing

Introduction

A good deal of research has been done in the area of spacer fabrics. Spacer fabrics can be of woven, nonwoven, and knitted types. Of these the knit spacer fabrics are the most prominent and find many and varied applications in technical textiles. When considering medical applications, pressure ulcer is one such. Pressure ulcer is the damage of skin or underlying tissue caused by prolonged pressure or pressure integrated with shear and friction over a bony prominence which heel is one of the most common sites for pressure ulcer development [1-5]. In a new product development, designers must pay increased attention to environmental issues. In the motorcar industry, materials recycling have become a very important requirement. Fabrics and carpets inside cars are often composed of several layers of different materials, usually a polyester fabric laminated to a soft polyurethane foam backing by an adhesive. This type of construction makes disassembling virtually impossible, and the combination of different polymer chemistries for the fabric and backing makes recycling of the assembly extremely difficult. Furthermore, there is effluent emission from the flame bonding process, which is used to combine the different layers. As a result, the use of polyurethane foam in car interiors is environmentally hazardous both in terms of production and recycling [6]. Owing to their excellent mechanical properties, woven fabrics have numerous applications in the field of technical textiles. Some of their outstanding mechanical properties include high stiffness, strength, and dimensional stability. With the weaving process, dense woven structures with a load-compatible yarn orientation composed of high-performance materials (e.g., glass, carbon, aramide, polyethyleneterephthalate) can be achieved, which in turn provide the basis for function-integrated, near-net shaped, and stiff spacer fabrics to be used as semi-finished products for fiber-reinforced plastics (FRPs) in lightweight engineering applications [7]. Spacer fabrics are complex three-dimensional (3D) constructions made of two separate fabric layers connected vertically with pile yarns or fabric layers. The conventional spacer fabrics composed of two surface layers bound with pile yarns are generally

manufactured using weaving and knitting technologies. However, due to inferior mechanical properties, such as elasticity and deformability under applied loads, conventional spacer fabrics are not suitable for high-performance composite applications. Moreover, the restricted distance between the plane layers contributes to the drawbacks of such spacer fabrics. One solution is to connect the planes by means of vertical fabric layers instead of pile yarns. This type of 3D spacer fabric with multi-layer reinforcements in the fabric structures is expected to show superior mechanical properties and be especially suitable as textile preforms for lightweight composite applications [8-21].

Weft Knit Spacer Fabrics for Treatment of Pressure Ulcers

Despite the existence of wound dressings over the years, the management of wound is assuming greater complexities [22,23]. The modern wound dressings are designed to enhance wound healing [24-26]. Moreover, the prevention and treatment of pressure sores need a significant amount of time and care. This not only greatly affects the lives of patients and their caretakers, but also the hospital services and costs of government as prolonged and expensive hospitalizations are required. Previous research has proven that the health costs of pressure ulcers are undoubtedly high [3,27,28]. It is difficult for pressure ulcers to heal and wound dressings that provide both good absorption and a cushioning effect are rare.

*Corresponding author: Narayan Gokarneshan, Professor and Head, Department of Textile Technology, Park College of Engineering and Technology, Coimbatore, Tamil Nadu, India, Tel: +91-892626783; E-mail: advaitcbe@rediffmail.com

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Spacer fabrics is a kind of three-dimensional knitted fabrics composed of top and bottom fabric with filament yarn in between to connect them together by tuck loop stitching [1,29,30]. Recently, weft knitted spacer fabric has gained great attention due to their versatile physical properties [31]. Based on the previous research, physical properties of spacer fabrics can be easily adjusted by adopting various types of spacer yarn, fabric density, thickness and fabric structure [32,33]. Therefore, it has been proven to have a wide area of applicability, including in medical products, due to their versatile physical, mechanical and thermal properties [34-36]. Their excellent ventilation and cushioning properties are also important for pressure ulcer prevention and the healing process [37]. The required physical properties of the absorbent layer of wound dressings, including air permeability, thermal conductivity, water permeability, absorbency and compression, are examined in 3-dimensional weft knitted spacer fabrics, and then evaluated and compared with those of wound dressings from the market. It aims to have a deeper understanding of the particular physical properties of weft knitted spacer fabrics tailored for use as the modern wound dressings.

The critical and necessary requirements of wound dressings for pressure ulcer are considered. Being a good wound dressing for pressure ulcer, not only require good absorbency property, but also breathability, thermal regulation and cushioning properties [37]. Therefore, the air permeability, thermal conductivity, water vapor permeability, absorbency and compression of weft knitted spacer fabrics are investigated and compared with existing wound dressings in order to evaluate whether the former can be used as a substitute for the latter. Based on the results, it proves that both air permeability and water vapour permeability of spacer fabrics are much better than that of wound dressings due to their structure. Although the thermal conductivity of spacer fabrics is not as good as all dressings, they are still comparable with one group of dressings. This is also true for the absorbency performance. Their absorbency property is comparable with another group of dressings. The results also prove that both compression resistance and compression resilience of some weft knitted spacer fabrics are better than that of wound dressings.

Warp Knit Spacer Fabrics for Automotive Uses

Besides ecological problems, car seats of present day should satisfy many needs. The car seats should not only appear attractive but should also very good mechanical properties with regard to durability and be able to protect passengers in the event of accident. Car seats must be comfortable too. This comfort must include both the mechanical support that the seat gives to the body as well as good climatic conditions, which are paramount for a driver's performance. Climatic comfort means good thermoregulation, which can balance the body's energy and offer good microclimate around the human skin. Studies have been conducted to measure the driver's rectal temperature with different types of car seats. With car seats offering good thermoregulation, after several hours of driving, the subject can still stay in the comfort region, i.e., below 37.5°C even in warm temperatures (25°C).

On the other hand, some types of seats, which offer poor climatic comfort, will make the driver feel uncomfortably warm very quickly, as the rectal temperature rises to 37.5°C in approximately 40 min. After 2 h, the rectal temperature may rise to 38.2°C, which is the limit of endurable strain for a normal person. Driving in such an uncomfortable seat, the driver must have a break; otherwise, he may have an accident caused by impaired physical and mental stress [38]. In recent years, the use of technical textiles has grown very fast. These fibrous materials,

which have a variety of technical end uses, may also substitute some conventional materials with advantage in specific applications [39]. Warp-knitted spacer fabrics belong to this class, and they are very interesting structures due to their unique three-dimensional (3D) configuration. Their thickness may vary between 2 and 60 mm with good compressibility and breathability. A standard spacer fabric consists of two independent fabrics connected by spacer yarns, which complete the whole assembly [40]. To sustain the space between the two independent fabrics and to obtain the required compressive properties in the thickness direction, monofilament yarns are normally used as the spacer yarn. The material used may be polyamide, polypropylene and especially polyester. Moreover, the two independent fabrics may be knitted into any kind of mesh or plain structures to get the required dimensional, mechanical and comfort properties. Spacer fabrics present good resilience to compression, high bulk with relatively lightweight and very good moisture permeability for thermoregulation [41]. In addition, spacer fabrics are good at pressure relief [42,43].

Warp-knitted spacer fabrics have compression properties different from those of normal fabrics because of the spacer yarn. Warp-knitted spacer fabrics show very good linear elastic compressibility in the first compression phase, which is of great interest for seats. The limit of the first compression phase varies with the bending rigidity and structure of the spacer yarn and with the thickness of the fabric. In this context, it is easy to design adequate WK spacer fabrics with suitable compression characteristic for use in car seats. Furthermore, warp-knitted spacer fabrics are better at reducing peak pressure than polyurethane foam. Using thicker warp-knitted spacer fabrics with appropriate spacer yarn structure and material, pressure can be much reduced.

Since there are limits to the thickness of warp knitted spacer fabrics, several layers may be used to get higher thicknesses and increased pressure relief [44]. Car seats with cushions of the warp-knitted spacer fabric are better at reducing peak pressures than seat cushions from polyurethane foam. In this context, the former will make drivers feel more comfortable. Air permeability of warp-knitted spacer fabrics is much better than polyurethane foams. Air permeability depends on the structure of the warp-knitted spacer fabrics. Therefore, these fabrics are more breathable substrates for car seats than polyurethane foam ones. Warp-knitted spacer fabrics have higher thermal conductivity and lower thermal resistance than polyurethane foams. Therefore, warp-knitted spacer fabrics can transfer heat more effectively away from the driver's body and so these fabrics have better thermoregulation properties than polyurethane foams for warm climatic conditions. Warp knitted spacer fabrics have good and comparable stability on thickness with polyurethane foams. Generally speaking, car seat cushions made of warp knitted spacer fabrics can offer good mechanical support and physical comfort to the driver's body. These fabrics are stronger than polyurethane foams, can be used for longer periods of time and can even be reused with new seats covers. Therefore, these fabrics used for seats are easier to recycle than polyurethane foam ones.

New Weaving Technology

Typical spacer weaves (so-called pile weaves) are constructed of woven outer layers, which are connected by additional pile yarns. Due to the composition of the aforementioned yarns, they provide the end composite with sufficient stability and compression. However, the mechanical properties of the fabric depend directly on the properties of the pile yarns, which have a limited bending stiffness. Pile weaves cannot be used for complexly shaped and/or highly strained FRPs. Woven spacer fabrics are constructed of woven outer layers and

woven cross links instead of pile yarns. Spacer fabrics can be applied in multiple fields, such as the air and space industry, automotive industry, and the transportation branch in the form of wall elements, floor panels, inner coverings, and insulation as components in structural, efficient, and lightweight FRPs. Material properties (such as the amount of the material, the type of fiber, and the fabric geometry) and process properties (such as the number of warp beams and the weft, as well as the warp density) must be optimally combined to achieve a FRP that meets the demands of the end component (i.e., tensile strength, compressive strength, and flexural stiffness). Innovative weaving technology enables, in one process step, the production of near-net spacer fabrics with excellent mechanical properties [45,46]. Ready-made, knitting, and gluing technologies can be used as an alternative method to the manufacture of spacer fabrics [47,48]. Yet, woven spacer fabrics have several advantages: elimination of the ready-made process, full utilization of the high-performance fiber substance, strengthening in the z-direction without crimp, structural variety, and productivity (e.g., for 416 tex hybrid yarn, an E7 flat knitting machine has a thread density of 81 yarns per 10 cm, compared to a weaving machine with 200 yards per 10 cm and per layer).

Investigations have been carried out on the developed spacer fabrics constructed of GF/PP hybrid yarn for lightweight engineering applications. Multi-layer woven fabrics with weft of varying densities have been produced and tested for mechanical properties to increase the strength of spacer fabrics. The results of the studies show that through the production of three-layer fabrics (without yarn crimping), a reduction of yarn damage is achieved, as compared to fabrics with yarn crimping [49]. The measured values prove that the mechanical properties of the composites (such as tensile strength, flexural stiffness, and compression properties) are improved by a reduction in yarn damage and the non-crimped layers of the fabric structures. Composites made with crimped yarns show better impact properties compared to composites from three-layer fabrics. These contribute an important contingent to the further development of FRPs for demanding and high-performance applications. Woven spacer fabrics offer a high productivity and the greatest flexibility in adapting their material structure to the applied loads. Thus, they are pre-destined for lightweight engineering designs demanding complex structures and a multi-material design with an optimized material mix.

Flat Knitted Spacer Fabrics for Light Weight Composite Applications

It is foreseen that composites produced from 3D multi-layer spacer fabrics can have end uses that relate to the replacement of conventional panel structures that are being used for aircraft, transport vehicles, marine applications and infrastructures, lift cabins, and ballistic protection for buildings and combat vehicles, etc. But, for development of these innovative 3D spacer fabrics, modern electronic flat-knitting machines appear to be the best solution, since they are capable of manufacturing 3D complex-shaped engineering structures. Unique technical features that allow rapid and complex production include individual needle selection capability, the presence of holding down sinkers, presser-foots, racking, transfer, adapted feeding devices combined with a computer-aided design (CAD) system, and modern programming installations. Furthermore, the flexibility of the knitting process in combination with the possibility of integration of reinforcement yarns into fabric structures is capturing the attention of many researchers [50-52]. Moreover, knitted performs exhibit greater drape-ability and higher impact resistance in composites as compared to the commonly used textile structures (e.g., braiding, weaving,

unidirectional techniques). In previous work, we reported the analysis and the manufacturing of 3D spacer fabrics on the basis of surface and connecting layers, the development of 3D spacer fabrics possessing only the weft inlays and the development of multi-layered 3D spacer fabrics. The research work documented in this direction includes the basic production principles of some flat-knitted spacer fabrics without reinforcements and the theoretical presentation of knitted sandwich spacer fabrics. Nevertheless, the further developments of flat-knitted multi-layered 3D spacer fabrics including an increased number of reinforcement layers into all individual fabrics are essential for high mechanical performance in complex-shaped lightweight composite applications. The sensor networks realized into 3D spacer fabric structures by means of integrating the functional yarns during the single-step manufacturing of the multi-layered 3D spacer fabrics would be the break-through advancement in fully automated manufacturing of function-integrated textile performs and such sensor networks could be used to monitor the structural perfection of end products. However, fibers, because of their anisotropic mechanical properties and lower chemical and environmental resistances, cannot be used alone in structural engineering applications. They are, therefore, embedded in matrix materials to form fibrous composites. Fabrication of textile composites depends on the chemical nature of the matrix materials, which are generally thermoset and thermoplastic polymers. Thermoplastic composites are comprised of at least one reinforcement material and a thermoplastic polymer as matrix [53]. There are potentially a number of advantages for these composites as compared to thermoset composites. Owing to their high fracture toughness, easy recycling, elongation, short processing time, various forming possibilities, weld-ability, low cost, and resistance to medias and corrosion, they appear to be more promising for some industrial applications [54]. Conversely, thermoplastic composite manufacturing routes are two-stage processes: firstly, a precursor material is formed using high-performance fibers and thermoplastic polymers, and, finally, the component is formed into the final product by applying high pressure and temperature. Nevertheless, the commingled hybrid yarns consisting of homogeneously mixed reinforcement and matrix filaments are soft, flexible, drapeable, and are available at low cost, which makes them a forerunner for thermoplastic composite applications.

The reinforcement component of the hybrid yarn is generally high-performance fibers, such as glass, carbon, and aramid fibers. Glass fibers are used extensively due to low material cost and higher mechanical properties. The thermoplastic matrix is used to fix the reinforcement components in a defined order for better bearing of applied forces to ensure good adhesion between the fibers and matrix material and to develop low-cost products, especially for the automobile industries [55]. The use of glass filaments (GFs) and polypropylene (PP) filaments in hybrid yarn in a volume combination of 52% and 48%, respectively, is reported to optimize the mechanical properties of textile reinforced thermoplastic composites. Based on these parameters, the commingled hybrid yarn composed of GFs and PP filaments is preferred for the development of 3D spacer fabrics. One goal of the research program 'Textile-reinforced composite components for function-integrating multimaterial design in complex lightweight applications' by the German Research Foundation (SFB 639) at the Technische Universität Dresden, is to develop multilayered 3D spacer fabrics as complex-shaped textile preforms by using the flat-knitting technique in combination with hybrid yarns for high-performance thermoplastic composite applications. In order to achieve this objective, multi-layer reinforced 3D spacer fabrics curved in different angles (in the warp direction) were produced using exemplar GF-PP filament hybrid yarns

following the recently developed flat-knitting techniques. With these new manufacturing techniques, reinforcement yarns were integrated up to four layers (two warp and two weft yarns aligned as a multi-layer structure) as biaxial inlays into all surface and connecting layers of spacer fabrics. Functional yarns were also integrated successfully into spacer fabric structures in a single processing step using the innovative integration concept in order to create sensor networks for structural health monitoring of end products.

Innovative 3D spacer fabrics consisting of individual surface and connecting layers including also the single axis curvatures to the wale direction were manufactured successfully using GF-PP filament hybrid yarns by the innovative flat-knitting technologies. In order to increase the wall thickness to improve the mechanical performance of the composites, up to four reinforcement layers of the reinforcement yarns were integrated into all surface and connecting layers. With the purpose of monitoring the structural health of end products, the flat-knitting technology was developed further for the creation of sensor networks by means of innovative integration of functional yarns into 3D spacer fabric structures during the manufacturing of the multi-layered 3D spacer fabrics. The easy integration of a wide spectrum of materials into multi-layered knit structures proves the extreme flexibilities of the latest technologies developed in this research. These could be a breakthrough advancement in fully automated manufacturing of function-integrated textile performs where such seamless integration of functional yarns into the fabric structures is executed simultaneously, together with forming the multi-layered 3D spacer fabrics. Beyond the promising application trend in the area of lightweight composite structures, the novel 3D spacer fabrics produced with innovative flat-knitting technologies (by cost-effective single-stage manufacturing) can also potentially be used in different fields, for example, in textile-reinforced concretes, architectural designs, energy sectors, protective textiles, industrial textiles, and geo-textiles.

Conclusion

The structure and properties of knit spacer fabrics can be tailored to suit required end use applications. It has been found that air and water permeability of knit spacer fabrics are much better than that of wound dressings due to their structure. Findings have revealed that compression resistance as well as compression resilience of some weft knitted spacer fabrics are better than those of wound dressings. Due to the presence of spacer yarn warp knit spacer fabrics differ in compression properties from normal fabrics. They exhibit very good linear elastic compressibility during the first stage of compression which renders them suitable for seats. Warp Knit spacer fabrics with suitable compression characteristic can be used in car seats. Moreover, they are better at reducing peak pressure than polyurethane foam. A reinforced spacer fabric made of individual surface layers and joined with connecting layers shows improved mechanical properties for lightweight applications, such as textile based sandwich preforms. The development of flat-knitted multi-layered innovative three-dimensional (3D) spacer fabrics from hybrid yarns consisting of glass and polypropylene filaments have been reported. Moreover, for structural health monitoring of composites, sensor networks could be created into a 3D spacer fabric structure in a single processing step through innovative integration of functional yarns. The two-dimensional (2D) woven fabrics used for the outer layers of 3D spacer fabrics were produced from GF/PP hybrid yarns with different yarn alignments and weft densities. Furthermore, the implemented hybrid yarns and the 2D composites constructed of multi-layer fabrics were tested for mechanical properties. The processing of the GF/PP

hybrid yarn, as well as the geometry of the woven fabrics, is proven to strongly influence the mechanical properties of the end composites. Multi-layer fabrics can be used for manufacturing woven 3D spacer fabrics with minimal yarn damage and high mechanical properties. A reinforced spacer fabric made of individual surface layers and joined with connecting layers shows improved mechanical properties for lightweight applications, such as textile based sandwich preforms. The development of flat-knitted multi-layered innovative three-dimensional (3D) spacer fabrics from hybrid yarns consisting of glass and polypropylene filaments have been reported. Moreover, for structural health monitoring of composites, sensor networks could be created into a 3D spacer fabric structure in a single processing step through innovative integration of functional yarns.

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