ASSEMBLY COMPOSITE SANDWICH STRUCTURES WITH SEWING TECHNIQUES

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Abstract
Fibre reinforced composites are increasingly used for load bearing components. Most of fibre reinforced composites are built up of many plies and among these plies there are no any strengthening fibres. The lack of strengthening fibres leads to delamination when such a composite is impacted. These delaminations spread quickly over the whole laminate and result in catastrophic breakage of composite. Furthermore, delamination causes a great reduction of life time of a composite. As an effective way to avoid delamination, stitching becomes widely used because of the improved through-the-thickness mechanical properties.
In this paper sewing techniques for manufacturing composite sandwich structures are introduced. Woven fabrics made of glass and polypropylene filaments are layered and stitched together to form a space structure. Besides manufacturing process, mechanical properties of stitched glass/polypropylene woven composites are also investigated. Stitching effects on tensile strength and lap-joint strength of fibre reinforced thermoplastic polymer composite are studied. Sewing threads made of different fibre materials and stitch row orientations are evaluated. The fracture mechanisms are also discussed. Our results indicate that the stitching by glass sewing threads does not decrease the tensile strength of composite. Furthermore, the study of lap-joint strength shows that lap-joint structure has obvious influence on the lap-joint strength.

Key words: stitching, composite, sandwich structure, tensile strength, impact properties

1. Introduction

Thermoplastic hybrid structures are used to develop and test making-up processes (CAD, cutting, piling, assembly) for the manufacture of textile spacer preforms.
Making-up techniques allow the fabrication of large-size spacer preforms and complex component designs. In the first project phase mainly flat spacer preforms were developed and manufactured. Since the assembly procedure for textile spacer preforms definitely had a novelty value, it was protected by patent. Programs for CNC-controlled sewing machines have been developed and sewing techniques have been tested with the aim to integrate inserts.
To continue this research (interconnection phase), it is necessary to develop and test curved spacer preforms, manufactured on the basis of making-up processes, taking account of process safety, quality assurance and reproducibility. These curved spacer preforms have strengthening trusses and webs, force introduction zones and sensory properties.
The essential steps are listed below:

- shape- and load-oriented pattern generation of various textile semifinished products from the industry and other subprojects
- design and construction of tools for staple holders for the manufacture of these singly curved spacer preforms
- stiffness-enhancing trusses and webs and force introduction zones thanks to inserts
- integration of functionalised hybrid yarns with sensory during the making-up process
- introduction of sensor networks focussing on contacting on the basis of making-up processes and CAD design of the sensor network geometry.

Drawing upon the results and findings of the fabrication of singly curved spacer preforms, the conceptual development of doubly curved spacer preforms is begun. This task makes high demands on the making-up process of manufacturing.

2. Manufacturing of spacer preforms

It is the aim to manufacture spacer preforms with rectangular and triangular cross sections. To reduce proneness to delamination, stiffening z seams are introduced in the individual layer staples in prefabrication and subassembly processes. The sewability of these packs of layers has been experimentally tested to determine optimum sewing parameters, such as needle size, shape of the needle tip, type of sewing thread, fineness of the sewing thread.

For manufacturing spacer preforms of the same wall thickness and with rectangular section, we employ the principle of sewing the structure seam by seam. Four packs of layers A, B, C and D are necessary for this purpose (Fig. 1). Manufacturing starts on the left at seam 1 and is finished at seam 57 (for a spacer preform width of 900 mm). Chambers are formed by gathering layers B and C in folds and folding away the layer (A or D) that is not needed in the process.

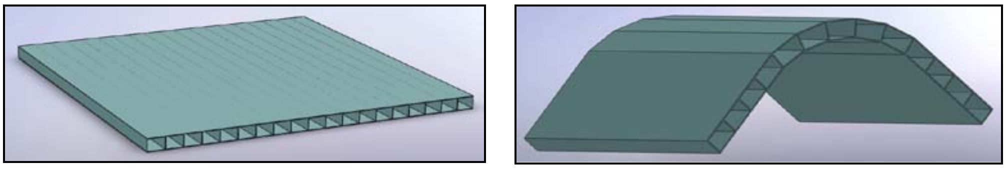

Figure 1. Schematic view of a flat (left) and a curved (right) spacer preform (uniform wall thickness)

Fig. 2 shows a spacer preform with uniform wall thickness. Each of the layer packs A, B, C, D, consists of two layers of a GF-PP multilayer knitted structure (*MLG*). Each chamber has a width of 45 mm and a height of 30 mm.

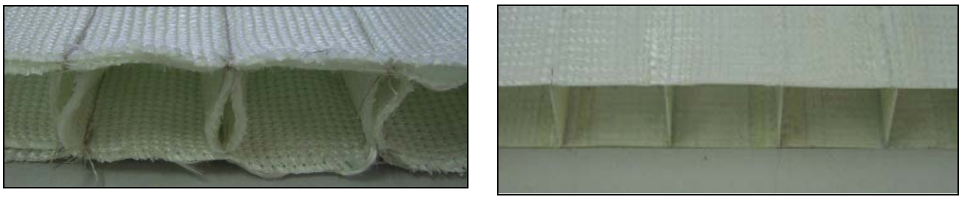

Figure 2. Spacer preform with uniform wall thickness and rectangular cross section made of multilayer knitted structure, textile (left) and composite (right)

A new type of fixing device has been designed and built to manufacture spacer preforms with triangular sections. The CNC x-y sewing machine KL 102 is the only machine that is used to assemble this type of preforms. Here again, the structure is sewn seam by seam. First, the bottom pack and the central pack of layers are sewn together while the top pack is folded back from the sewing process. Reproducible sewing requires additional fixing elements. Subsequently, the lower pack of layers is folded back and a sewing process is started in which the central pack and the top pack of layers are sewn together. This approach is continued until the spacer preform is finished.

3. Experimental

3.1 Tensile properties

The first set of experiments investigates tensile strengths and modulus of unstitched and stitched composites. Except of sewing thread GF/PP, as shown in Fig. 3, the stitching does not greatly change either tensile strength or modulus.

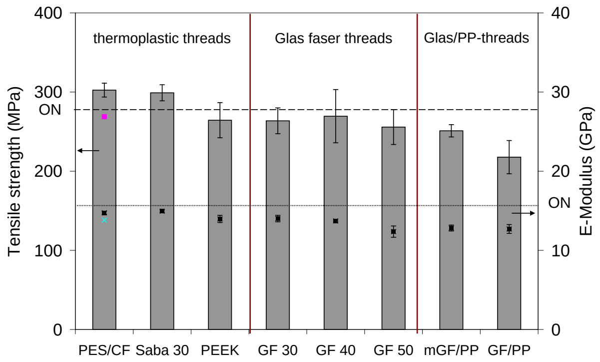

Figure 3. Effect of sewing threads on tensile strength and modulus of unstitched specimens and 0° stitched specimens, ON for unstitched specimen in dot line. Error bars represent standard deviations

It is supposed that the decrease in tensile strength of specimens with GF/PP sewing thread arises from severe distortion around the stitches caused by its thick sewing thread (647 tex) which leads to a degradation of the laminate integrity. Generally, stitching has some drawbacks on the tensile strength like stress concentration at the stitch point, fibre misalignment, crimping of fibres, and fibre breakage arising from needle perforation. Therefore, the general degradations of in-plane strength were caused by stitching as reported by most of the literature [1, 2, 3]. Nevertheless, most sewing threads do not reduce the tensile strength in this study, which is inconsistent with the reported cases. We believe that fibre breakage caused from stitching can be neglected in this work, since the stitching was performed on dry preforms. During tensile loading, various cracks (fiber/matrix interfacial debonding, delaminations, etc.) occur between plies and filament bundles of woven composite. Stitching in thickness direction inhibits these cracks, particularly delamination and crack propagation. Therefore, it retains the tensile strength. It is also believed that an increase in the fibre volume fraction resulting from additional sewing threads slightly increases the strength of a stitched composite [4]. These advantages compensate the reduction of strength. As a whole effect, stitching does not decrease the tensile strength of glass/PP woven composite.

3.2 Impact toughness

The impact toughness values of unstitched and stitched composites at different stitch row directions and temperatures are tested. Most stitched specimens have higher impact toughness than the unstitched ones (ON). The unstitched specimens show better impact properties at higher temperature than those at lower temperature. Apart from specimens with PBO and PES/CF sewing threads, most specimens with sewing threads show much higher values of impact toughness at 0° stitch row direction, particularly at low temperatures. Only a marginal effect was found at 90° stitch row direction for different temperatures.

3.2.1 Effect of stitching

Typical force-deflection curves from an unstitched specimen and a stitched specimen with PBO thread tested at room temperature (20°C) are compared in Fig 4.

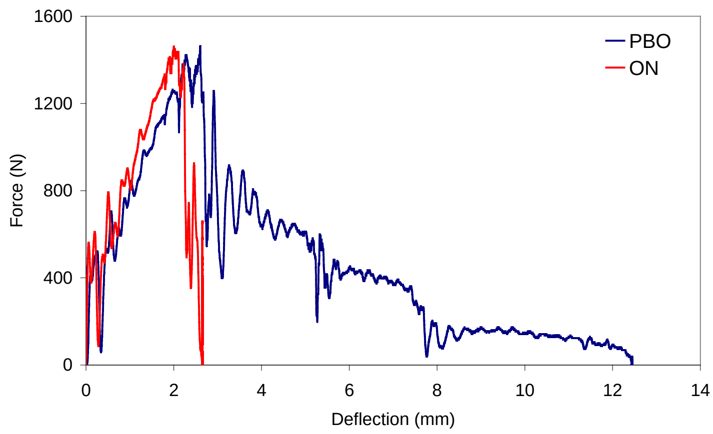

Figure 4. Force-deflection curves of an unstitched specimen (ON) and a stitched specimen (PBO) including PBO sewing thread at room temperature (20°C)

The traces of both unstitched (ON) and stitched specimen (PBO) show almost the same linear increase in force to the peak force (F_m) where some damage is initiated. After damage initiation, there is a sharp dropping off in force of the unstitched specimen. This implies that little energy was absorbed in the damage propagation process. However, the trace of stitched specimen shows a dropping off in several stages after the specimen reaches F_m. Hence, the gradual dropping off leads to a much higher deflection value associated with much more energy absorption. Therefore, in this case the total energy absorption of the stitched sample is more than twice higher than that of specimen without stitching.

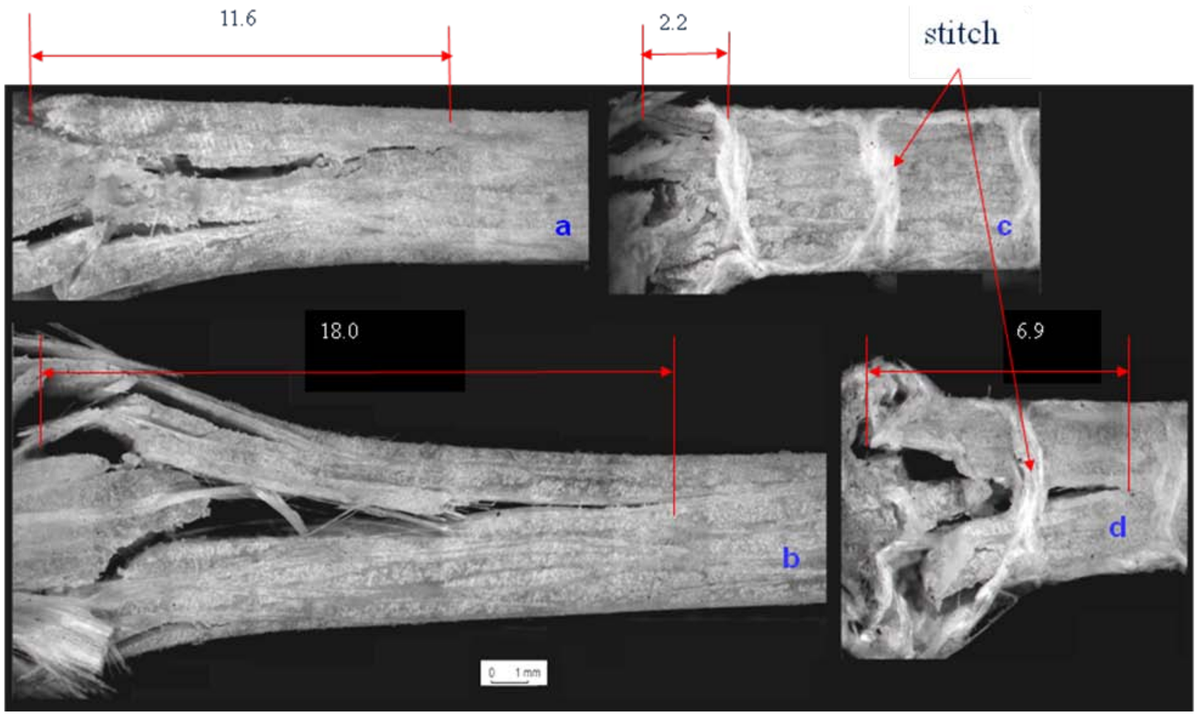

Figure 5. Light microscope photos of specimens after impact tests: (a) +20°C, unstitched, (b) –20°C, unstitched, (c) +20°C, stitched specimen with sewing thread GF 40, (d) –20°C, stitched specimen with sewing thread GF 50

Long delamination cracks of specimens without stitching can be clearly seen in both Fig. 5a and b. For the stitched cases, the crack stops at one stitch or gets through this stitch but stops at the next one (Fig. 5c, d). In this way, they exhibit much smaller Delamination. The stitching in the thickness direction inhibits the propagation of delamination and tends to reduce the delamination size and change failure mode [5]. Under impact loading, the crack grows between the plies until it is arrested by the nearest stitch. The stitching threads carry most of the load at the crack tip, the so-called 'bridging effect'. It is well known that a large crack resulting from delamination leads to a huge shortening of lifetime of structure service. Once the damage due to impact is reduced by stitching, the residual properties should be relatively improved [5]. Overall, stitching restricts the propagation of delamination and resulting in improved impact properties.

4. Conclusion

Sewing technology enables the manufacturing of spacer performs with a great variety of geometries. The application of drapable textile performs permits the development of flat and curved spacer performs. The manufacturing by sewing requires a CAD-supported determination of seam contour. The elongated located orientation of reinforcing yarns results in composites with excellent mechanical properties.

5. References

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