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Preparation of textile preform with sewing machines and bending properties of stitched woven glass fibre fabrics①

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Abstract: With the increasing demand of light structure composite in industry, carbon and glass fibres are more and more used, because of their light mass, high strength, high temperature endurance and erosion resistance. This paper focuses on the process of forming a preform. Up to the finished preform, the multilayer reinforced fabrics are subjected to the following procedures: pattern design, cutting and sewing. Considering the fabric properties, the 3-dimensional CAD software and sewing machines, which are generally used in the clothing industry, are also suitable for the processing of the reinforced fabrics. This study aims also to the changes of property arising from the sewing process. Bending stiffness and changes of thickness after sewing are studied. These properties will provide input data for CAD pattern design.

Key words: 3D reinforcement; textile preform; bending stiffness; thickness; CAD
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1 INTRODUCTION

Sewing technology is currently very often applied in the assembly of the fibre reinforcement. The pieces with different contours can be connected together to form a three-dimensional shape. It is also possible to sew the pieces together to get a large surface, which is several times larger than the width of commercially available fabrics[1]. For the multilayer reinforced fabrics, the sewing technique, which builds up stitches through each layer, is an effective way to avoid the delamination[2, 3]. The most common methods for assembly involve a lot of hand work. The high labor cost will raise the cost of end products greatly. In order to reduce the cost, the automatic process is demanded for the mass production. CNC sewing machine, Robot controlled sewing machine and some special machines are designed to achieve this requirement. Through the sewing process, the out-of-plane mechanical properties will be greatly increased[4]. It has been reported that the delamination will be reduced as the stitch density increases[5, 6]. The studies of impact damage resistance proved that the stitching increases the impact delamination energy greatly and the damage size within the grid of the stitches reduces[4, 7]. There are also many researches for the changes of in-plane properties like tension, shear and compression. Many literatures[8, 9] reported that the stitching reduces in-plane properties. Some of them found that through the stitching, the in-plane mechanical properties can be improved, degraded or remain unchanged[10]. A lot of work has been done to obtain the change of material properties. But the researches on the other properties like bending stiffness and thickness of preform are very seldom. To know the ability of draping, it is also necessary to know the changes of bending property.

2 PROCESS OF ASSEMBLING ROTOR WITH SEWING TECHNOLOGY

As an example, the following procedures demonstrate how to finish a rotor preform from carbon-PEEK fabric.

2.1 Pattern design

In this process the 2-dimensional pattern will be calculated from cubic construction. The properties of fabric deformations like shearing, bending and thickness will be considered in the calculation.

2.2 Cutting

Considering the slippage on the edge of pieces, laser cutting machine will be applied for the cutting process to get a smooth and closed edges. Only when there are thermoplastic fibers in the fabric, can the melted edge be generated[11]. Otherwise, overlap stitch is needed to protect the exact outline of the pieces.

2.3 Prefixing

Before the assembly, prefixing ensures an ex-

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act form and connecting position between two different pieces. The holding devices are designed to position and to keep an exact shape[12]. It is also helpful for the sewing process.

2.4 Sewing

There are many different traditional sewing machines, which can be used for the sewing of preform. Because of some special requirements from material, quality, forms and the mass production, some special machines like Robot controlled sewing machine and CNC sewing machines are required.

Figs. 1−3 show how these sewing machines work on different parts of rotor.

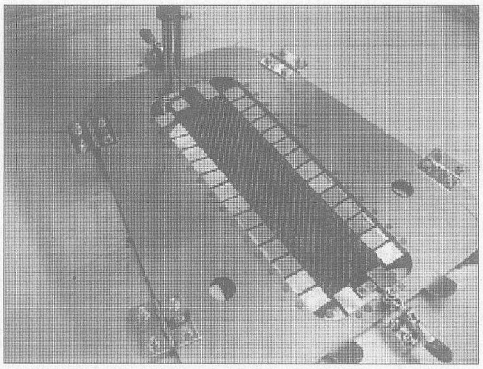

Fig. 1 KSL CNC sewing machine for blades of rotor

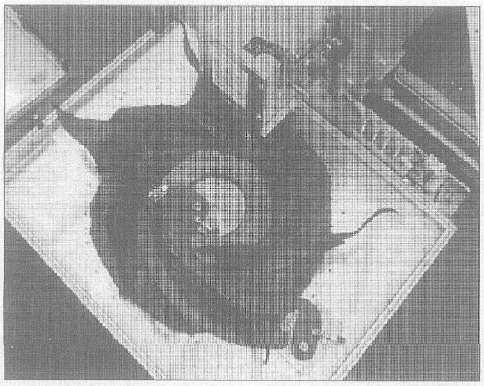

Fig. 2 KSL CNC sewing machine for connection of blades and under plate

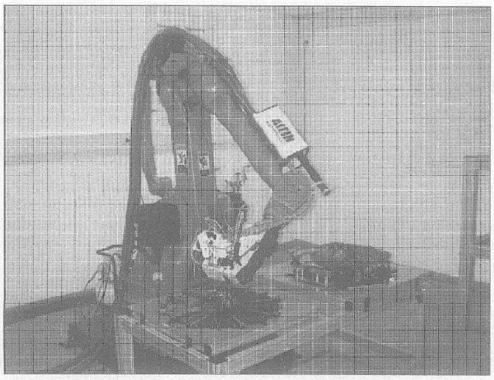

Fig. 3 ALTIN Robot controlled one side sewing machine for parts of cap and blades with cap

3 BENDING STIFFNESS AND THICKNESS OF WOVEN GLASS FABRIC

To achieve the accurate pattern form of the pieces, it is necessary to measure some properties of the material. Bending stiffness influences the deformability of the fabrics. The changes of the thickness during the sewing process affects the permeability of the preform. These factors decide the quality of the end product. The bending stiffness and the thickness of different samples with stitches and without stitches will be measured.

3.1 Bending stiffness

3.1.1 Bending stiffness of textile fabrics

Bending stiffness is a measurement of stiffness, where two equal and opposite forces are acted along parallel lines on either end of a strip of unit width bent into unit curvature in the absence of any tension. It is the resistance, with which the fabric can against a certain change of its curvature.

3.1.2 Measurement

The measurement was taken according to the DIN 53362. The device for measuring the bending length is shown in Fig. 4. The description of the specimen is listed in Table 1. The specimen will be moved in 10 s to reach the inclined surface. The bending length will be measured.

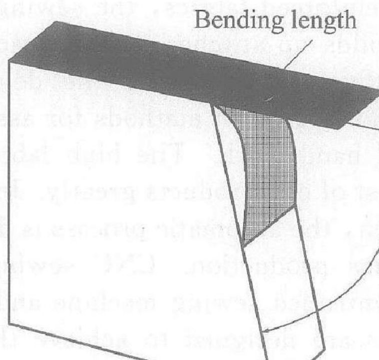

Fig. 4 Schematic map of cantilever test

Sewing properties from G_{A1}:

Sewing thread: Glass coated with Teflon;

Distance between the stitches: 10 mm;

Stitch length: 4 mm;

Stitch direction: 0°, 45°, 135°, 90° to the test direction;

Stitch type: Lock-stitch;

Needle thickness: 110 nm.

The bending stiffness will be calculated with the following equations:

$$B = F_1 \cdot \left[\frac{L_{Ü}}{2} \right]^2 \qquad (1)$$

Table 1 Description of specimen

Material	Structure	Marking	Mass per area/(g·m^{-2})	Number of tows/cm^{-1}	Yarn count (tex)	Fabric width/cm
E-glass	Satin 8	GA1	287.4	Warp 21.6 Weft 22.3	Warp 69.85 Weft 60.50	100
E-glass	Twill 2/2	GK1	397.9	Warp 5.96 Weft 6.7	Warp 339.7 Weft 271.3	100

$$G = \frac{F_l}{b} \cdot \left[\frac{L_Ü}{2}\right]^3 = m_F \cdot \left[\frac{L_Ü}{2}\right]^3 \cdot 10^{-3} \qquad (2)$$

where F_l —Linear weight force, mN/cm;

$L_Ü$ —Overhang length, cm;

b —Width of the specimen, cm;

$F_l = g_n \cdot \left[\frac{m}{l}\right]$;

m —Mass of specimen, g;

l —Length of specimen, cm;

g_n —Acceleration of fall, 9.80665 cm/s^2.

3.1.3 Evaluation

The measurement was carried out depending on the combination of filament orientations. Two layers were sewn together and tested. Fig. 5 shows the different bending stiffness 'G' resulted in the different combinations of warp and weft directions. The warp with warp (KK) has the highest bending stiffness, whereas warp with weft (KS) has the lowest.

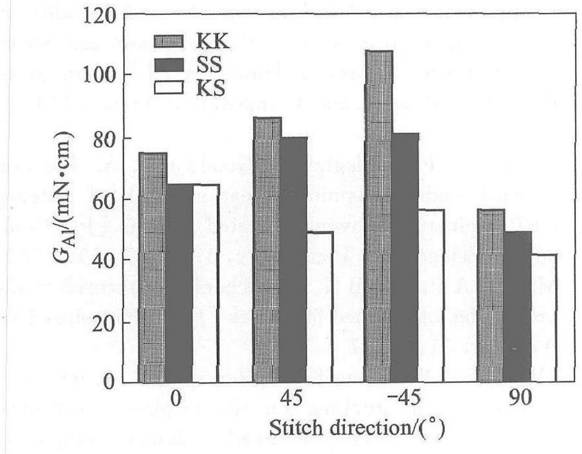

Fig. 5 Bending stiffness in dependence on filament orientations for two layer specimen

While the G_{Al} were tested with different combinations of filament directions, a series of measurements of G_{Kl} with different stitch distances were carried out. The results are shown in Fig. 6 and Fig. 7. It is not a surprise that as the stitch distances increase, the bending stiffness reduces. The more the fabric will be sewn, the tighter the specimen is. It is interesting that there is a point that the bending stiffness does not change obviously. There is almost no difference on the bending effect between 10 mm and 15 mm stitch distance. This result can be used in the sewing process to avoid too many stitches on the fabrics, but at the same time to have enough stitches to assure the firm connection between layers.

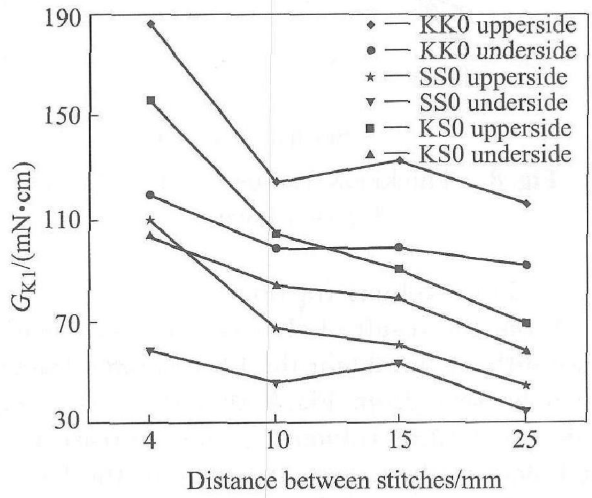

Fig. 6 Bending stiffness of 0°-stitches with different stitch distances for two layer

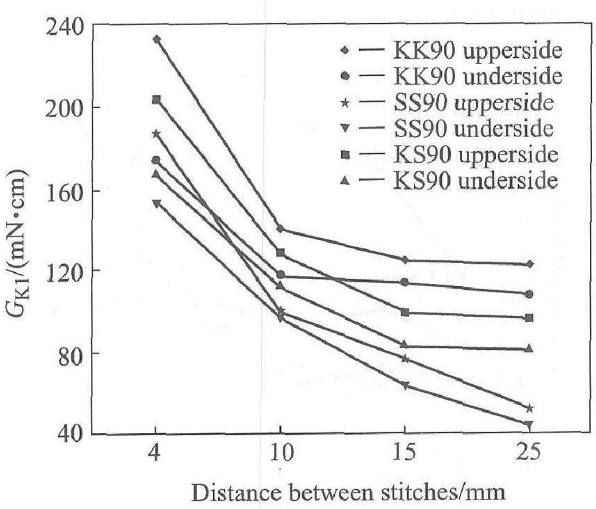

Fig. 7 Bending stiffness of 90°-stitch with different stitch distances for two layer

3.2 Thickness measurement

3.2.1 Thickness

The change of thickness will affect significantly the permeability of the fabrics. As it is shown in Fig. 8, the thickness increases as the stitch distances decrease. During the sewing process, the sewing thread will change the fibre orientation, and the fibres will move together to the center of the stitch loop. How strongly the fibres will move depends on the tension of the sewing thread. Owing to this movement, the thin fabrics will be thicker after the sewing.

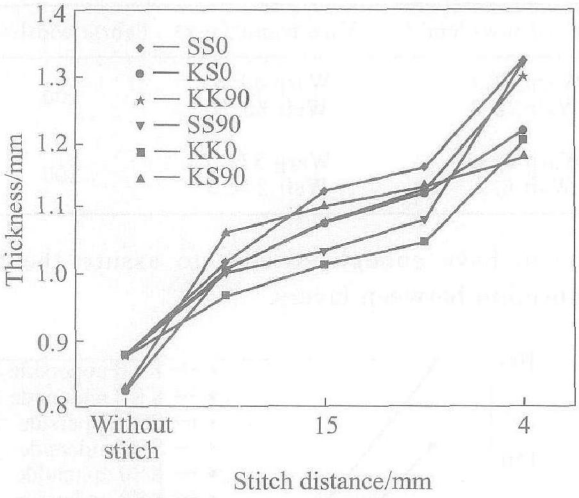

Fig. 8 Thickness versus stitch distances for two layers

3.2.2 Fibre volume fraction

From the result of thickness measurement, it is not difficult to obtain the fibre volume fraction. It can be seen from Fig. 9 that there is a slight tendency of fibre volume fraction increase as the stitch density decreases. It is due to the fact that low fabric compressibility and sewing thread tension occur during the sewing. This is likely to lead to the fibre reorientation and inaccuracies of pattern structures.

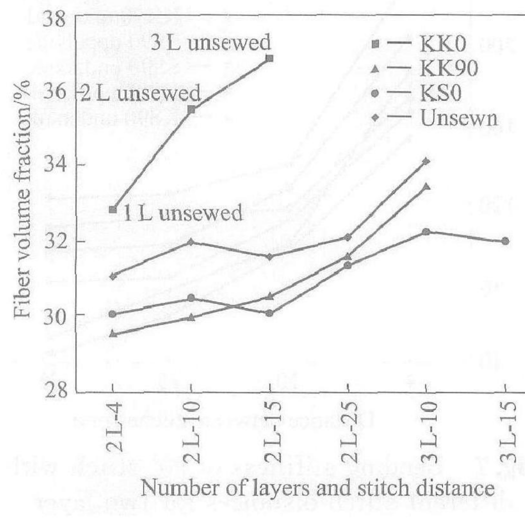

Fig. 9 Fibre volume fraction vs stitch distances for two layer

4 SUMMARY

Sewing technique is applied on the multilayer fabrics from carbon or glass fibre to reduce or avoid the delamination between two layers. To reach the requirement of the complex form and mass production, CNC and Robot sewing machines are developed for the precise and cubic forms. The properties of material like bending stiffness and thickness are measured and analyzed. The combination of filament orientation is found to have a considerable effect on the bending properties. The thickness and fibre volume fraction is related to the stitch distances.

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