FORMABILITY OF WEFT-KNITTED FABRICS ON A HEMISPHERE

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Abstract:

In this paper, the formability of weft-knitted fabrics produced with glass filaments on an electronic flat knitting machine is experimentally investigated. A simple method used for the analysis of formability is proposed. Cutting patterns for different structures are given and the variation trends of the areas and fiber volume fractions are analyzed. The results show that due to their loop structures weft-knitted structures can easily be deformed to fit a hemisphere surface without the formation of wrinkling.

Key words:

weft knitting, formability, composite, deformation, hemisphere, glass fiber.

1. Introduction

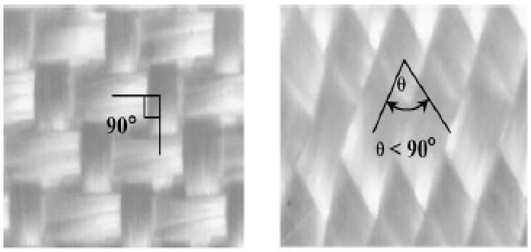
Weft-knitted fabrics have received much attention in recent years in the composite field due to their excellent formability. Formability is the ability of a planar textile structure to be directly deformed to fit a three-dimensional surface without the formation of wrinkling, kinks or tears. Formability is also known as drapability. It is an important characteristic of textile performance in the manufacturing of three-dimensional composite components. By properly using formability, the cutting of planar textile fabrics to fit three-dimensional shapes could be eliminated in the manufacturing process. This not only increases the productivity of composite fabrication, but also enhances the mechanical properties of composite parts because the integrity of the reinforcement is maintained.

Many investigations into the formability of textile structures for composite reinforcement have been carried out. However, most of these investigations are concentrated on woven and biaxial knitted fabrics [1-6]. Only a few investigative works concern weft-knitted fabrics [7-9]. Taking into account the increasing applications of weft-knitted fabrics in the manufacturing of shell composites with complicated shapes, it is becoming ever more important to achieve a better understanding of their formability.

In this paper, the formability of the weft-knitted fabrics fabricated using glass filaments is investigated. An experimental method is proposed for the analysis of their formability. The cutting patterns for the different structures are given and the variation trends of the areas and fiber volume fractions are analyzed.

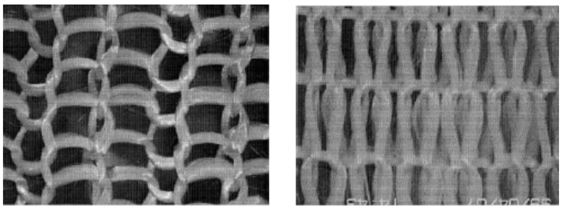
2. The structural deformation feature of weft-knitted fabrics and method used for formability analysis

Formability refers to the deformation of a planar textile structure to fit a given three-dimensional surface. However, deformation modes necessary to obtain required shapes are totally different between woven and weft-knitted fabrics. According to previous studies [1-6], shear deformation is the main deformation mode for woven and biaxial knitted fabrics in the forming process. As shown in Figure 1, shear angle θ between the warp and weft yarns is the only parameter used to describe the deformation ability of a woven or a biaxial knitted fabric. When the required θ exceeds the allowed limit of the fabric structure, wrinkles will occur. Biaxial knitted fabrics normally have better formability than woven fabrics because they allow for a larger change θ [6]. Nevertheless, the formability through shear deformation mode is very limited. In contrast to woven and biaxial knitted fabrics, stretching deformation is the primary mode of deformation for weft-knitted fabrics in the forming process. As shown in Figure 2, a weft-knitted fabric is easy to deform in both the warp and weft directions due to its pure loop structure. Compared to shear deformation, stretching deformation will provide weft-knitted fabrics better formability than woven and biaxial knitted fabrics.



(a) (b)

Figure1. Shear deformation of a woven fabric; (a) un-deformed, (b) deformed.



(a) (b)

Figure 2. Stretching deformations of weft-knitted fabrics; (a) course stretching, (b) wale stretching.

There is no doubt that analyzing how a planar knitted fabric is deformed to fit a three-dimensional surface is a very complicated process. Owing to loop shape deformation and yarn transferring, theoretical analysis and simulation of formability is much more difficult in the case of the weft-knitted fabrics than in the case of the woven and biaxial knitted fabrics. In this paper an experimental method is proposed in order to simplify the analysis. The method proposed is very similar with that used by S. Savci [8]. Its primary principle consists in splitting a planar preform into small units and analyzing the dimension and area variations of each unit during the fitting process. The detailed procedure involved in the method can be divided into the following steps:

Step 1: Drawing grids. Respectively drawing parallel lines along the wale and course directions on a planar fabric. After drawing, the planar fabric is divided into identical small grids. The side length of each grid depends on the precision requirement of the analysis. The smaller the side length, the higher the precision. In this paper, the side length selected was 1cm.

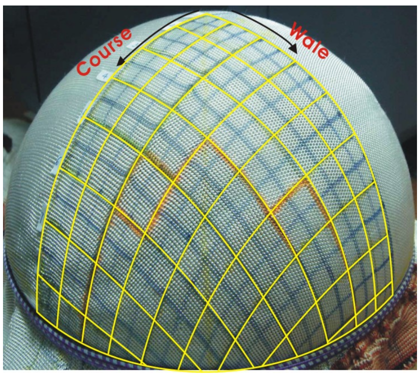


Figure 3. Method used to analyze a planar knitted fabric to be fit on a hemisphere surface.

Step 2: Making the plan fabric fit a 3D surface. In this paper, a semispherical surface was used. In order to make the analysis consistent for all fabrics and to avoid unnecessary deformations, the fitting process was carried out according to the following steps: (a) marking a point on the top of the hemisphere as a reference point; (b) making the center point of the fabric stick to the reference point of the hemisphere; (c) smoothing down the fabric gently by hand along the hemisphere surface; (d) putting on a circle elastic string and letting it slide along the fabric surface until it arrives to the equatorial line of the sphere; (e) underlining using a marker pen along the equatorial line for signing a trail of the outline.

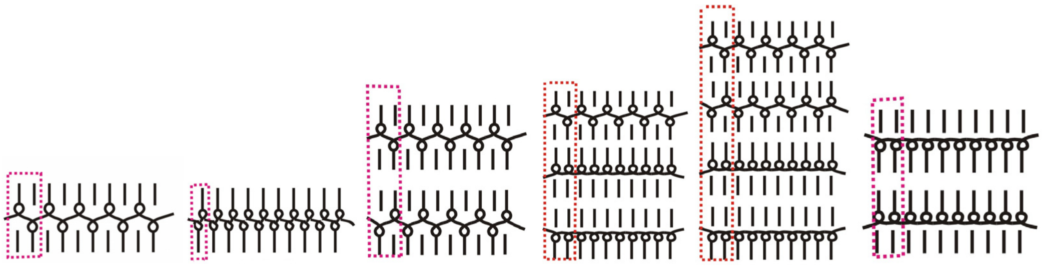
Step 3: Analyzing the dimension variation and shape change of each grid. In this way further information about the variations of the area and the fiber volume fraction for each grid can be obtained.

The fitting of a weft-knitted fabric on a semispherical surface is demonstrated in Figure 3, in which the drawing lines on the fabric clearly show the deformation of each grid. Since the hemisphere shape is symmetrical, only 1/4 of the hemisphere area is necessary to be studied. The following work will use this method to analyze the formability of the different knitted structures.

3. Formability analysis

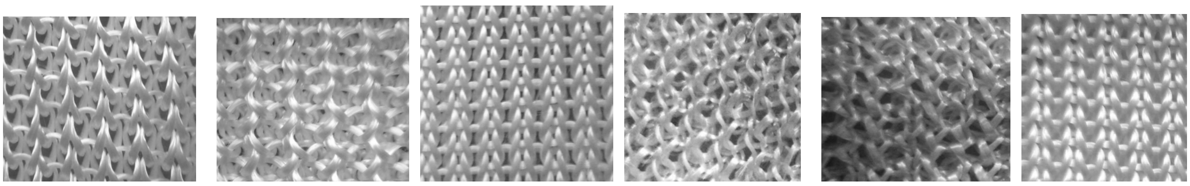
3.1 Knitted structures used for the analysis

Six weft-knitted structures, as shown in Figure 4, were selected for analysis of their formability. They were all knitted on an electronic flat knitting machine with glass filaments under the same knitting conditions. Figure 5 and Table 1 respectively show the fabrics knitted and some of their structural specifications.



(a) (b) (c) (d) (e) (f)

Figure 4. Knitted structures used;
(a) 1×1 rib, (b) Full rib, (c) Interlock, (d) Milano, (e) Double Milano, (f) Double layer jersey.



(a) (b) (c) (d) (e) (f)

Figure 5. Photographs of the fabrics knitted;
(a) 1×1 rib, (b) Full rib, (c) Interlock, (d) Milano, (e) Double Milano, (f) Double layer jersey.

Table 1. Structural specifications of the fabrics knitted.

Fabric Structure	Thickness, mm	Area density, g/m^2	Loop length in a repeating unit, mm	Wale density, courses/cm	Course density, wales/cm	Fiber volume fraction, %
1×1 rib	2.3	616.4	13.50	5.5	5.0	10.56
Full rib	2.32	672.7	13.20	5.2	4.0	11.42
Interlock	2.16	716.0	25.65	8.2	7.0	13.08
Milano	2.29	653.8	46.85	10.4	9.2	11.24
Double Milano	2.15	842.3	44.05	9.6	7.2	15.41
Double layer jersey	1.34	851.3	22.30	7.4	10.6	25.01

3.2 Determination of the cutting patterns

One of the objectives in analysis of the formability of a textile performance is to determine its cutting pattern when it is deformed to fit a three dimensional surface. Depending on the textile structure, the cutting pattern must be different even if the surface to be fit is the same. Using the method presented above, the cutting pattern for each structure to fit a 1/4 hemispherical surface can be easily determined from the outline drawn along the equatorial line of the hemisphere, as shown in Figure 6. As the structure was deformed after fitting it on the hemisphere, the area within the outline must be different from its original un-deformed area. However, the number of the grids within the outline is the same. By counting the same number on the un-deformed fabric and by marking the corresponding positions respectively along each drawing line, the cutting pattern can be obtained.

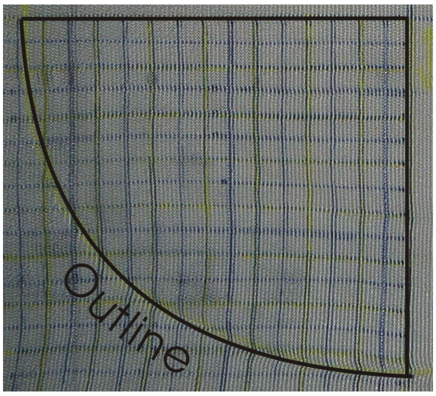


Figure 6. Outline obtained along the equatorial line of the hemisphere.

Figure 7 shows the cutting patterns obtained for six analyzed structures to fit a 1/4 hemisphere surface. It can be seen that the cutting patterns are different for each structure, even if the hemisphere surface to be fit is the same. This difference originates from different stretching abilities of the structures. Normally, the structure most easily stretched has a smaller cutting pattern. For the same structure, the lengths to be cut along the wale and course directions are also different because the stretching abilities are different in these two directions. In order to show the extent of deformation, the cutting pattern area (S_o) of each structure was compared with that of the 1/4 hemisphere surface (S_d) to be fit. As shown in Figure 8, the area change ratio (S_o/S_d) can be used to describe the formability of different weft-knitted fabrics. The lower the ratio S_o/S_d, the better the formability, because the structure with a lower S_o/S_d ratio is more easily deformed to fit a required shape. In observing Figure 8, it can be seen that the 1x1 rib structure has lowest ratio S_o/S_d among the six structures analyzed. This means that the 1x1 rib has very high deformability. Consequently, it has very good formability for producing composite parts with three dimensional shapes.

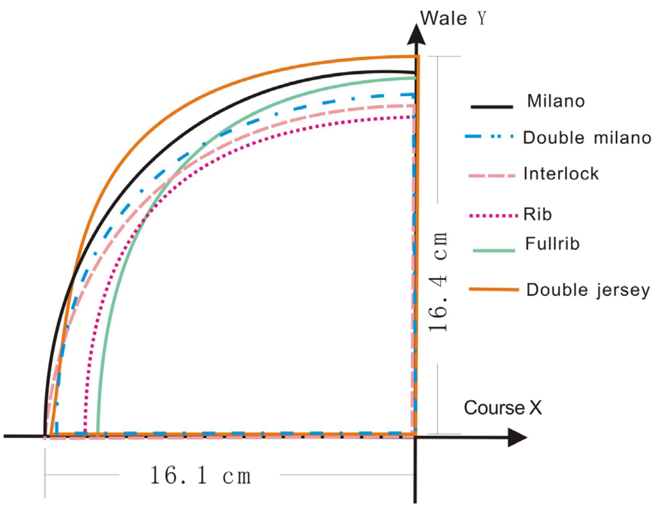


Figure 7. Cutting pattern for different structures.

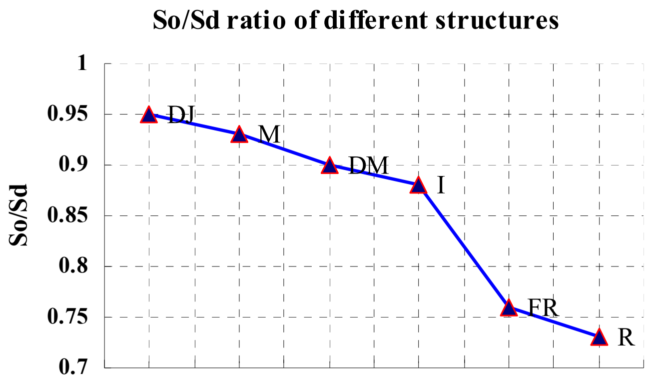


Figure 8. Area changing ratio of different structures;
DJ – double layer jersey, M – Milano, DM – double Milano, I – interlock, FR – full rib, R – 1x1 rib.

It is necessary to point out that although the deformability of the structures analyzed is different, they all fit the hemisphere surface very well without the formation of wrinkling. This again confirms the good formability of the weft-knitted structure because of its stretching deformation feature.

3.3 Determination of the variation trends of the fiber volume fractions

After a planar fabric is deformed to fit a required three dimensional surface, its fiber volume fraction V_f must be changed. Because V_f directly affects the mechanical properties of the composites, the information about its variation trends along the surface to be fit is very important during the composite design. For this reason, determination of the variation trends of V_f is also a part of the formability analysis.

The variation of V_f originates from the area change of the fabric. In order to determine the variation trends of V_f along the surface to be fit, it is necessary first to know the area change trends. As shown in Fig. 3, the area change trends can be obtained by calculating the area change of each grid. It is necessary to point out that because of the spherical shape, the surface of each grid after deformation is not planar, its four sides are not rectilinear as well. However, inasmuch the area of the grid is very small, it can be considered as a planar quadrangle after fitting on a sphere surface. As shown in Figure 9, the lengths of four sides A, B, C, D and angles θ_1 and θ_2 for each deformed grid can be obtained by direct measurement when the fabric is fit on the sphere surface. Thus, the area S for each grid can be easily calculated according to the following relation:

$$S = 0.5*(A*C*\sin\theta_1+B*D*\sin\theta_2)$$

In Figure 9, the area of the un-deformed grid was selected as 2cm x 2cm, i.e., 4 cm^2.

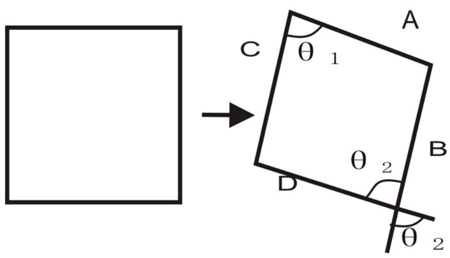


Figure 9. Deformation of a grid unit.

As an example, the area variation trends of the interlock structure are presented. As shown in Figure10, the same line represents the area variation trend along the course direction, while different lines represent the area variation trends along the wale direction. In Figure 10, courses 1 to 7 are defined as positions of the grids along the course direction, while rows 1 to 7 are defined as positions of the grids along the wale directions. Observing Fig. 10, it can be determined that:

(1) The areas of all grids are bigger than their un-deformed ones. This means that all parts of the fabric are stretched when it is fit on the hemisphere surface;

(2) The area variations of the grids along the warp direction have very obvious decreasing trends. However, the area variations of the grids along course direction are not as obvious as along the warp direction.

(3) The areas of the grids close to the equator line are smaller than these of the grid close to the top part of the hemisphere. This means that the fabric is more stretched on the top part of the hemisphere.

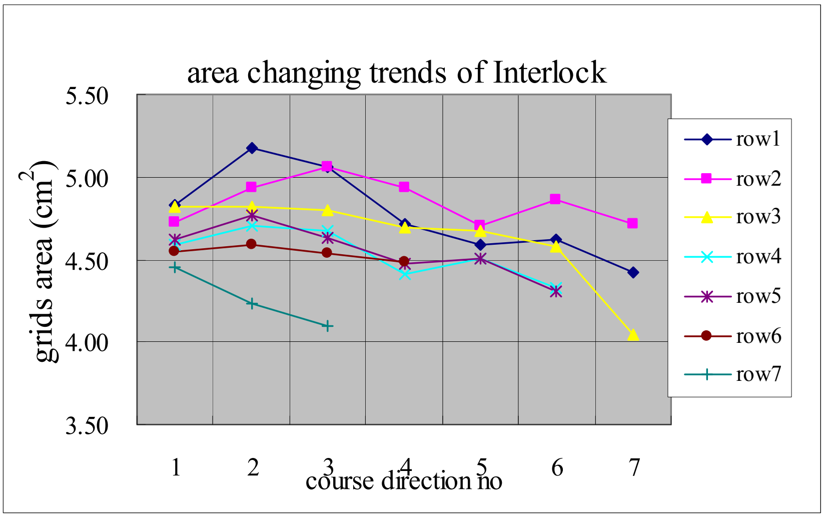


Figure10. Area variation trends of the Interlock structure.

Once the area variation trends are known, the variation trends of V_f can easily be determined. As shown in Figure 11, the variation trends of V_f are opposite to those of the areas. It is necessary to be point out that because of the stretching deformation, the V_f of the fabric decrease after fitting on the hemisphere surface. In addtion, the fiber volume fractions are no longer constant for all parts of the fabric. As the variation of V_f will considerably affect the mechanical properties of the composite parts, analyzing the variation trends of V_f can help us to determine the weak areas, where the decrease of V_f surpasses the allowed limit, and take necessary measures to avoid this during the manufacturing of composites.

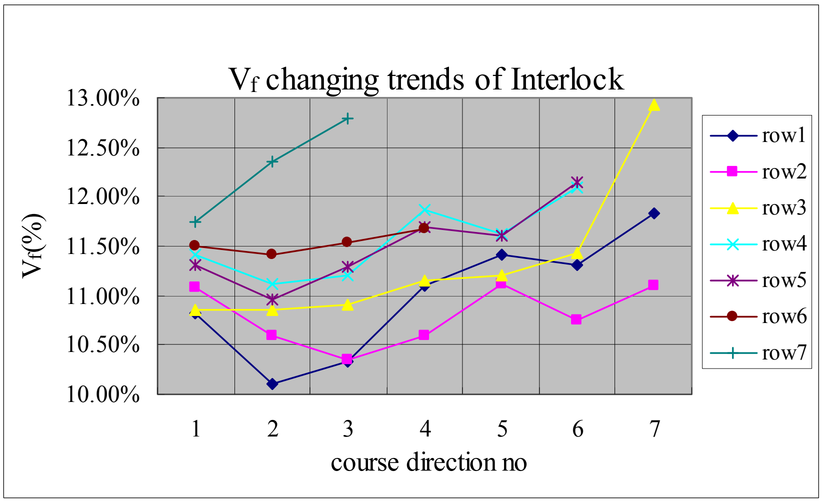


Figure 11. Variation trends of the fiber volume fraction for Interlock structure.

5. Conclusion

A method used to evaluate the formability of glass fiber weft-knitted fabrics has been presented in this paper. The cutting patterns and variation of the areas and volume fractions were analyzed. According to the results presented, the following conclusions can be drawn:

(1) The method proposed to evaluate the formability of glass fiber weft-knitted fabrics is simple but efficient. By using this method, the cutting patterns and variation trends of the area and fiber volume fraction can easily be determined.

(2) The cutting patterns depend on the knitted structures. The more easily a structure is stretched, the better its formability. Although the stretching abilities are different for the six structures analyzed, they all fit well on a hemisphere surface. The excellent formability of the weft-knitted structure is thus confirmed.

(3) The fiber volume fraction V_f is variable along all the hemisphere surface. The variations of V_f and grid areas close to the top part of the hemisphere are bigger than those close to the equator line.

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