平面织物成型研究

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摘 要: 综述了平面织物成型过程, 详细讨论了贴膜成型原理, 分析了平面织物在成型过程中所有可能出现的空隙、重叠、起拱、起皱、单层厚度不匀、层间滑移以及面内过度剪切等等不正常情况. 介绍了平面织物成型的铺覆建模方法, 举例说明了在二维增强织物成型设计中插入省的重要作用. 此外, 提出了几种适用的评价平面织物可成型性的方法. 研究发现, 平面织物的面内剪切性能对于平面织物的三维曲面成型至关重要, 许多成型过程中出现的不正常情况均是由于面内过度剪切造成的.

关键词: 成型; 平面增强织物; 铺覆及剪切性能
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Forming of sheet textile reinforcements

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Abstract: This paper reviews the sheet forming processes (in which the diaphragm forming process is discussed particularly in detail), analyzes all the possible anomalous events (such as gaps, overlaps, buckling, wrinkles, ply thickness variation, interlaminar slip as well as excessive intraply shearing) that may occur during forming. And it presents the mapping modeling methodology and illustrates the substantial importance of dart inserting in 2D textile reinforcement design. In addition, some practical means for assessing the conformability of sheet textile reinforcements are put forward. The analysis suggests that the property of shearing of a sheet cloth plays most important role when conforming to a 3D surface. Furthermore, the anomalous events, or in other words, the defects, are just due to the excessive shearing deformation.

Keywords: forming; sheet textile reinforcements; mapping and shearing property

1 Introduction

Composites, especially the textile— reinforced materials, have received increasing interest and attention over the past two decades. In place of aluminum and duralumin, advanced composite materials have been increasingly used in the field of aircraft and other vehicle industries[1]. Although there are so many 3D textile preforms[2] (such as 3D braiding, 3D weaving, orthogonal nonwovens, winding, hand lay up, etc.), their production costs are usually too high and shapes as well as sizes of these kinds of preforms are also limited to machines and manufacturing technology. On the contrary, the 3D preforms produced by sheet forming process present a great potential in vast applications due to low production cost, easy handling, large range of optional sheet forms as well as uniform mechanical properties.

The dominant sheet forming processes for thermoplastic composite materials can be classified as rubber pad forming, matched-metal die forming, hydroforming, vacuum forming and diaphragm forming[3,13,16], of which the diaphragm forming is shown to be one of the more promising fabrication routes for complex— curvature structures, as shown in Fig. 1. Fig. 2 is an example of diaphragm— formed product.

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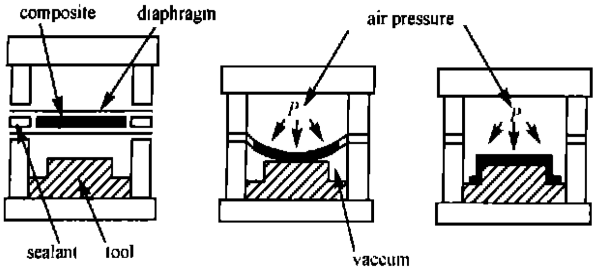


Fig. 1　Diaphragm forming process[2]

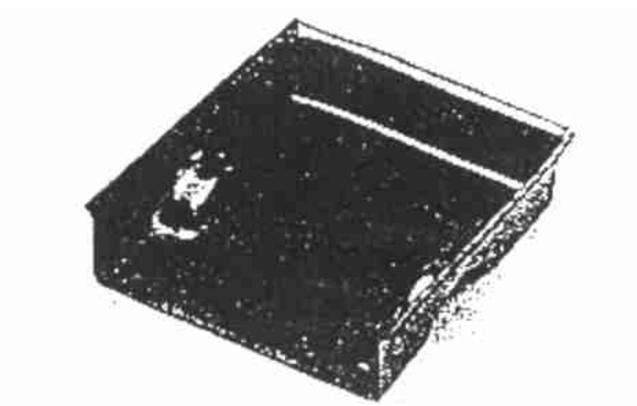


Fig. 2　Diaphragm formed 8— ply quasi-isotropic [0° / $+45^{\circ}$ / -45° / 90°] $_s$ trailer shape[4]

It can be seen from Fig. 1 that complex deformations may occur during sheet forming. The primary deformation mechanisms[4] are illustrated in Fig. 3. Theoretical approaches to model the sheet forming process must take these factors into account.

As far as the conforming or fitting of 2D cloth to 3D curved surface is concerned, many authors[5~8, 11~12, 14~15, 17~19] have been carrying out much research work, all of which are limited to plain—weave fabrics. Except Mack and Taylor, who gave an analytical solution in modeling of fitting process, numerical mapping method is particularly esteemed.

2　Anomalous events that may occur during sheet-forming

During sheet forming process, the sheet reinforcement will transform from its original plane state to a 3D curved state. Many deformations (especially shearing deformation) must take place in this process, otherwise an acceptable fitting is impossible to be obtained. But on the other hand, many anomalous events may also occur during this process. The possible unfavorable events are listed below:

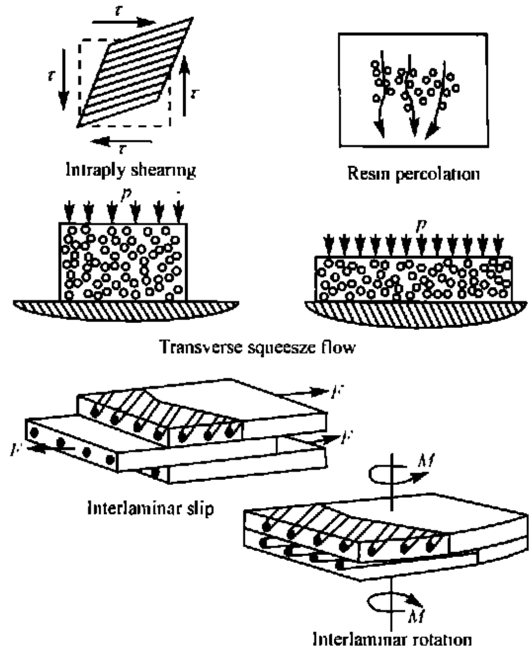


Fig. 3　Laminate deformation mechanisms[4]

Longitudinal fiber flow; Transverse fiber flow; Excessive intraply shearing; Interlaminar slip; Resin percolation; Interlaminar debonding or rotation; Fiber waviness changes; Buckling (Fig. 4); Wrinkles (Fig. 5); Ply thickness variation (Fig. 6).

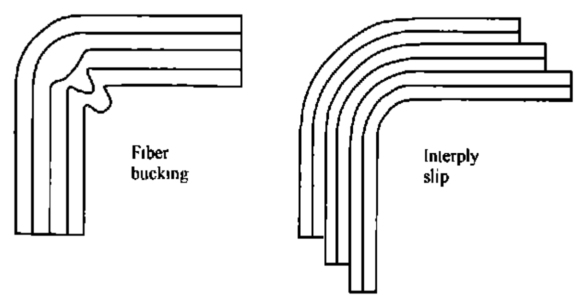
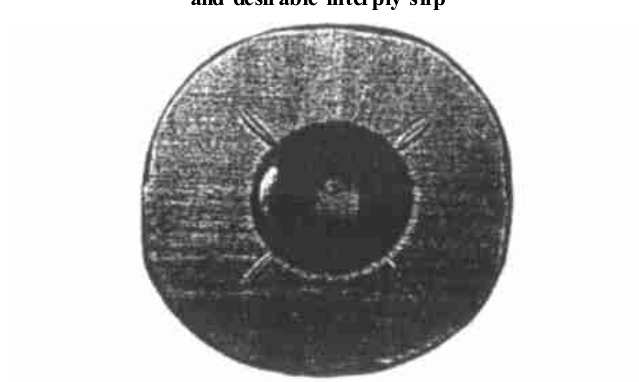


Fig. 4　Laminate bend showing undesirable buckling and desirable interply slip[2]



(The laminate is [0° / 90°] $_{4s}$ and the central section is a shallow segment of a sphere. The wrinkles form at 45° to the fiber direction.)

Fig. 5　Diaphragm— formed part with laminate wrinkles[2]

During the forming process, the intraply shear deformation will result in a surface area reduction of the ply, as shown in Fig. 6. Under the assumption of unchanged fiber volume fraction in the deformed ply, the ply thickness t of each deformed layer can then be obtained: $t = \dfrac{t_0}{\sin\ \theta}$

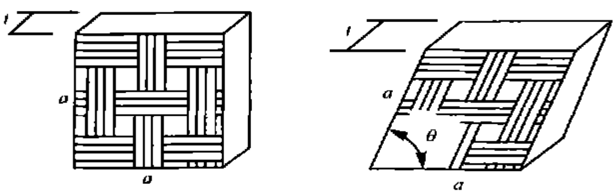


Fig. 6　Area reduction and ply thickness increase due to shear deformation[10]

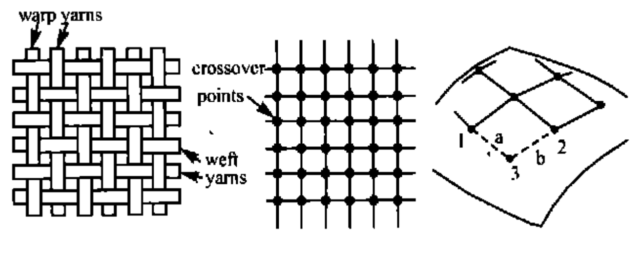
3　Modeling-A mapping method

At present, there are two popular schemes to model the sheet forming process: one is mapping, the other is continuum mechanical model. The former views forming as a process of geometric transformation: the initially flat sheet of composite is mapped onto the curved, three—dimensional surface of the tool, and the intermediate stages during forming are not considered. In contrast, the mechanical approach views forming as a process of gradual shape change; which considers all of the intermediate stages as the composite laminate deforms from its initial shape to the final one. This means that mechanical approach is much richer in detail than mapping calculations, and also more complicated[2]. In addition, the mapping approach gives a clean, well—defined mathematical problem that can be solved accurately by analytical or numerical solutions[5]. Therefore, researchers particularly esteem the mapping scheme.

Here, the concrete mapping process is demonstrated, which is based on the research[9] of Masaki Aono and his co-workers. There are three basic assumptions concerning the mapping model, as listed below:

(1) The cloth consists of vertical and horizontal inextensible threads; (2) There is no slippage at a crossing of a vertical thread (warp) and a horizontal thread (weft) when the cloth is deformed; (3) A thread segment between adjacent crossings is straight.

According to these three assumptions, the pain weave cloth can be regarded as a pin—jointed net system, as shown in Fig. 7.



(a)　Plain weave fabric　(b)　Mesh system　(c)　Pin-jointed system

Fig. 7　Illustration of a pin— jointed system[9, 10]

Then, the cloth can be represented by a two-dimensional rectangular array of fixed links, the warp and the weft, which are connected at pin points that represent the crossover points in the weave. The location of each point on the surface of the part can be calculated point by point using three conditions[10].

◆The distance between the point calculated and the previous point in the weft direction of the fabric is equal to the given yarn spacing.

◆The distance between the point calculated and the previous point in the warp direction of the fabric is equal to the given yarn spacing.

◆The point coordinates must satisfy the surface equation.

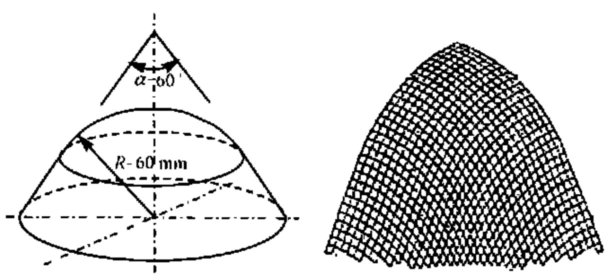
From Fig. 7(c), pin-joint 3 can be generated by pin—joints 1 and 2, and a and b are the yarn spacing in the warp and weft directions of the fabric. Accordingly, coordinates of point 3 can be obtained by solving the following equations, where x_i, y_i and z_i are the points′ coordinates and F is the surface equation.

$$(x_3 - x_1)^2 + (y_3 - y_1)^2 + (z_3 - z_1)^2 = a^2$$
$$(x_3 - x_2)^2 + (y_3 - y_2)^2 + (z_3 - z_2)^2 = b^2$$
$$F(x_3, y_3, z_3) = 0$$

In Fig. 8, an example[10] of simulation result using the above mapping model is given.

4　Removal of anomalous events — dart insertion method

As mentioned in Part 2 of this paper, there are so many anomalous events, in other words—defects, that may be produced during sheet forming process. Some of them, not very serious, may be acceptable as far as the final composite part is concerned. Others (such as visible buckling or wrinkles), however, must be removed or avoided either in the 2D cloth design stage or in forming process. It can be noted that the shearing deformation plays the most important role as far as both of the conformability of the flat reinforcement and defects that may occur are concerned. Most of the serious defects are related to excessive shearing deformation, especially for wrinkles and buckling. Since it is basically impossible to make the flat fabric " shear free" (This means that the fabric can be sheared to any degree as needed. As far as a plain weave cloth is concerned, this implies that the angle between the central lines of warps and wefts can freely vary from 0° to 180°), anomalous events must occur when the flat cloth undergoes an excessive shearing deformation. That is to say, to a great degree, the anomalous events are unavoidable. Then how to remove the defects produced in sheet forming will bear great practical significance.



(a) Mold geometry used for experimental verification[10]　　(b) Simulation results

Fig. 8 An example of simulation using pin— jointed system model[10]

Masaki Aono and his co—workers made a great contribution[9] in this respect. They developed a software that incorporates the dart insertion approach in it to tackle the anomalous events caused by excessive shearing deformation.

The inserted darts are classified into two types—stitched darts and trimmed darts, as shown in Fig. 9. With stitched darts, excessive materials are removed and the edges are stitched to produce a darting edge. With trimmed darts, excessive materials are simply removed without stitching. There are two types of trimmed darts-linear cut and polygonal cut.

Dart insertion process is illustrated in Fig. 10. First, the mapping process is made according to the model demonstrated above. Then find out the anomalous regions where darts may be inserted. Last, follow the steps listed in Fig. 10 to insert darts.

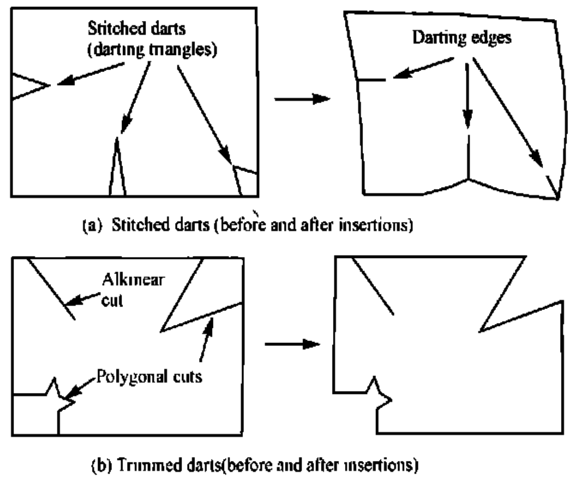
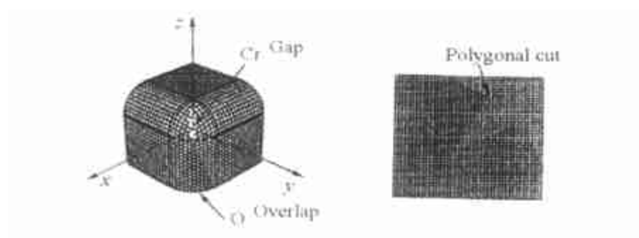
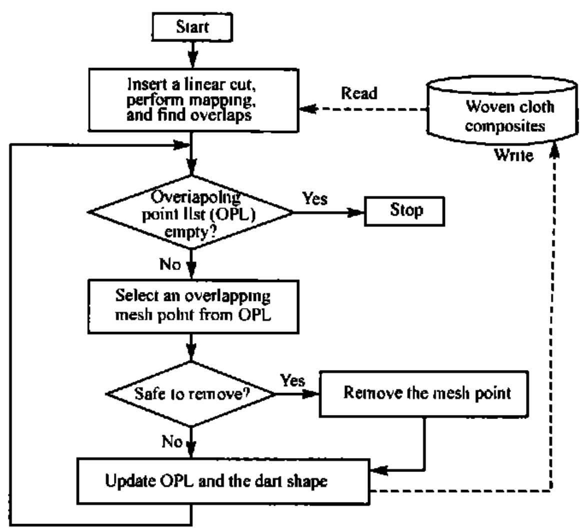


Fig. 9 Illustration of types of darts[9]



(a) mapping results-overlaps are found　　(b) try to insert polygonal cut



(c) Illustration of dart insertion

Fig. 10 Steps of dart insertion[9]

In Fig. 11, two examples of dart insertion are given.

5 Assessment of the conformability of sheet textile reinforcements

Since the sheet forming is one of the most important composite forming processes, it is necessary to develop a set of parameters as well as experimental methods to assess the conformablity of sheet textile reinforcements, in which the composite designers should take great interests. Currently, these kind of parameters and experimental methods are still unavailable or have not formally come into being.

Mack and Tayler published a paper[5] about " fitting " in 1956, which should be the earliest literature concerning the conformability of plain weave fabric. As shown in Fig. 12, their experimental results are illustrated. It can be seen that remarkable shearing deformation occurs between the two yarn systems.

Actually, the following three aspects, at least, can be employed when considering the conformability of a sheet textile reinforcement:

1) Study the shearing properties of a flat fabric. Fabric is quite different from paper, which can form curved surfaces with double curvatures; on the contrary, paper can not. This kind of deformability of fabrics mainly concerns the shearing deformation. Therefore, the shearing properties can be used to assess the conformability of a fabric. For example, the initial shearing modulus, energy of shearing deformation as well as the shear recovery rate can be obtained from the shearing hysteresis curve of a fabric, and these parameters can be taken as assessing criteria. Fig. 13 shows an example of shearing hysteresis curve of a woven fabric, which is obtained by Kawabata's Evaluation System.

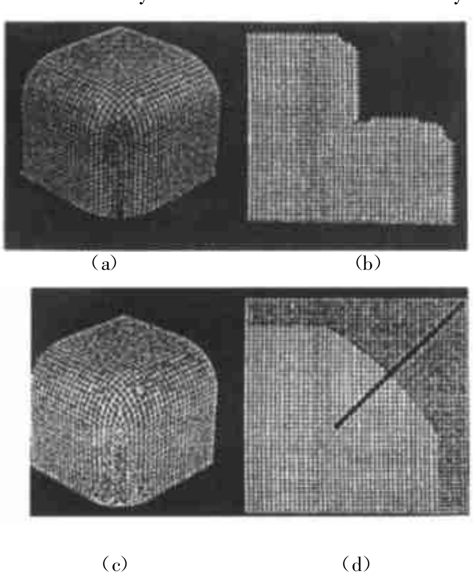


Fig. 11　Examples of dart insertion[9]

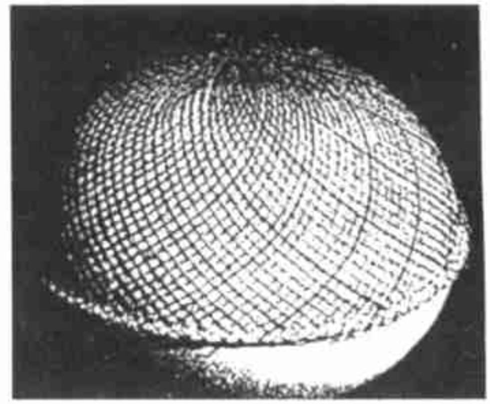


Fig. 12　'Leno' net fitted to a sphere[5]

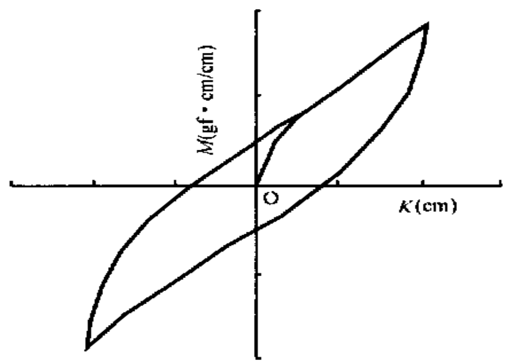


Fig. 13　An example of shearing hysteresis curve of a woven fabric

2) Study the drape properties of flat fabrics. Drape properties can be used to describe the conformability of a fabric from a more comprehensive sense. Actually, draping and forming are very much alike from each other, and draping process itself is just' as same as ' forming process by nature, in which only the gravity of the fabric is involved, but without external forces (such as air pressure in diaphragm forming, as shown in Fig. 1). Generally, the better of the drape of a flat fabric, the better of its conformability.

3) Apply the experiment of semi-sphere pressing. This method, developed by the authors of this paper, turned out to be workable(Fig. 14). And Fig. 15 shows the outline of the deformed fabric (a multiaxial warp knitted fabric with 4 glass inserting yarn systems).

This experiment is much close to the real forming process. Not only the anomalous events (buckling or wrinkles, as shown in Fig. 15) can be observed directly, but also a pressing curve can be obtained from the computer that is attached to Instron 4466. As shown in Fig. 16, an example of pressing curve is illustrated.

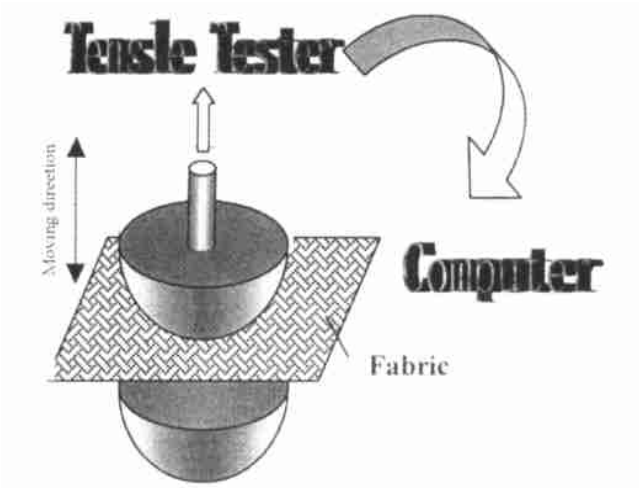


Fig. 14 Illustration of experimental device of semi-sphere pressing

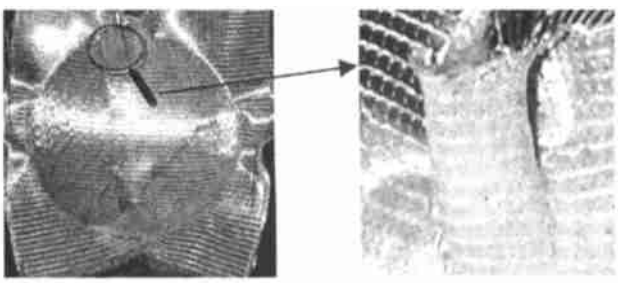


Fig. 15 The deformed fabric

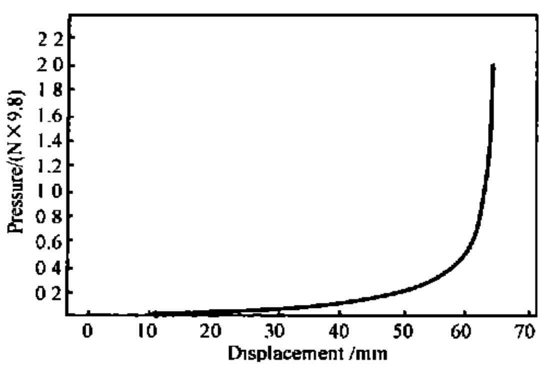


Fig. 16 An example of pressing curve from semi-sphere pressing experiment

The initial pressing modulus and pressing energy can be read off from the above curve directly. The smaller these values, the better the conformability of a flat fabric.

6 Summary

This paper presents an outline of the forming of sheet textile reinforcements, in which the diaphragm forming process is particularly described in detail. As far as modeling of sheet forming is concerned, there are two popular approaches, one is mapping, the other is continuum mechanical method. They are not completely competitive, but complementary[2]. The present paper prefers the mapping method due to its unique advantages as mentioned in Part 3. All anomalous events that may occur during sheet forming process are also presented. Dart insertion in 2D cloth is a feasible method to tackle some of the anomalous events (especially for wrinkles and overlaps), even though this may be at the cost of some mechanical properties of the final composite part.

With the spreading of application fields of textile composites, study of the forming of sheet textile reinforcements will deserve more and more attention as well as more and more practical significance. Currently, the research work is still in its preliminary stage, and the methodology and theory have not been well developed. Besides, the experimental approaches, to a great degree, are also not available. Common sense about the assessment of the conformability of a flat fabric has not been reached. In the near future, all the issues mentioned above should be solved. The mapping method will deserve more attention due to its cleanness, simpleness as well as directness. The three assessing aspects as mentioned in part 5 will lay a foundation for the subsequent research work.

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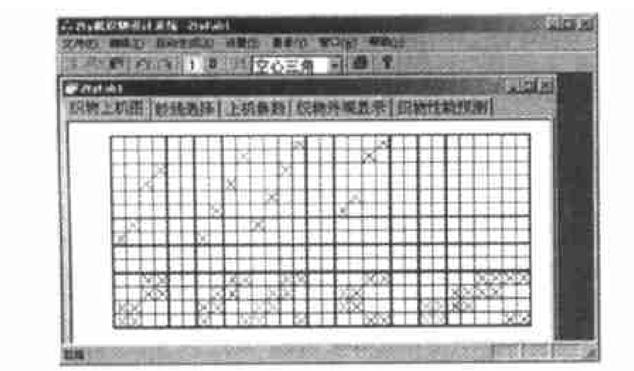

图 3　在机织物设计系统中集成上机图设计服务器软件

件编辑. 而图 3 则表示该服务器软件可作为一个模块无缝集成到一个机织物设计软件系统中.

4　结束语

将上机图对象通过嵌入或链接(OLE)到容器程序中, 仅仅是 ActiveX 服务器的最基本功能. 更进一步的是, 如果再加上自动化功能或者编制成COM 组件, 提供自动化接口, 将上机图对象公开和暴露给其他应用程序, 使得上机图内部各种信息能够传送出去, 其它程序(自动化控制器程序)就可以更方便地在程序一级重用或加以控制[3]. 感兴趣的机织物设计软件开发商通过授权后, 就可以象搭积木一样将该服务器程序集成为他们软件的一部分直接使用, 无需再做类似的重复性工作, 从而实现软件的重用, 提高了软件的开发效率[4]. 因此, 选择 COM 组件开发各个软件模块, 应该是纺织品 CAD 软件系统开发的方向.

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