Multiweave – A prototype weaving machine for multiaxial technical fabrics

Mário Lima
Department of Mechanical Engineering, University of Minho, 4800-058 Guimarães, Portugal
Raul Fangueiro
Department of Textile Engineering, University of Minho, 4800-058 Guimarães, Portugal
António Costa
P & Maia Lda, Piscia, Creixomil, Guimarães, Portugal
Christien Rosiepen
Institut für Textiltechnik der RWTH Aachen, Aachen, Germany
and
Válter Rocha
Agilus Institute of Innovation in Information Technologies, Matosinhos, Portugal

Received 7 May 2008; accepted 25 June 2008

This paper reports the study on a multiaxial 2D interlaced woven structure able to provide specified strengths in four different directions and the development of its manufacturing process. This structure is obtained by the insertion of interlaced bias yarns at approximately 45° between the weft and the warp. Using the principle of the insertion and interlacement of yarns in bias directions, a multiaxial weaving system has been designed which comprises the warp feeding, bias yarns feeding and criss-cross insertion, shedding, incorporating one heddle, weft feeding and insertion, beating-up mechanism, incorporating the reed, fabric taking-up and winding mechanisms. The designing of the system includes the use of conventional weaving elements with completely new mechanisms or the modification of existing ones. The multiweave prototype developed in this work is used to produce different types of directionally oriented structures using various types of fibres (HT polyester, aramid, carbon and glass) and yarn counts. The important characteristics of this new fabric structure is the criss-crossing between all four sets of yarns which increases the capability for supporting more severe mechanical loads without failure, i.e. without delaminating. The strength-weight ratio is expected to increase, which can be very advantageous for applications in the areas like composites for the aircraft and car industries as well as in marine textiles for boat and ship building, which are the products subjected to severe stressing conditions.

Keywords: Composites, Multiaxial weaving, Multiweave, Technical textiles

1 Introduction

One of the most important characteristics of technical textiles is the possibility of providing specified strength in multiple directions. This necessitated the development of multiaxial and tetraxial fabrics. The use and impact of the multiaxial fabric may be found in two different types of products, namely (i) technical textiles, such as composites for car and aircraft industry, conveyor belts, inflatable boats, sails, boat hulls, air inflated houses, geotextiles, wall coverings, sport devices, tarpaulins, tents, grinding and lapping disks and for many other applications on products that still use traditional technology of gluing together several layers of fabrics, differently oriented; and (ii) garments, designed to be tear resistant with an original texture, easily conformable and dimensionally stable. They can be used for different articles, such as military and protective clothing. Although the application on conventional clothing looks considerably out of the way, the possible applications on tennis and other sports shoes and some sportswear need to be further explored.

Several efforts to produce multiaxial interlaced fabrics have been made in the past. Many European patents have described the tetraxial1–3 and multiaxial4–5 structures and machines for their production. These patents propose different solutions for the problem of bias yarns feeding and criss-crossing, but none has proved to be sufficiently good for the construction of
a reliable commercial multiaxial weaving machine. Following the earlier work, a new multiaxial woven structure and the respective manufacturing process have been developed. This kind of fabric is designed to boost the reinforcement in bias directions by the insertion of interlaced yarns between the weft and the warp.

2 Materials and Methods

2.1 Materials

Fabric samples of different fibres were prepared using the multiweave prototype. The fabric details are given in Table 1 and the respective samples are shown in Fig. 1, where the high regularity of the fabrics can be observed.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Warp</th>
<th>Bias</th>
<th>Weft</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PES 1100/2 dtex</td>
<td>PES 1100/2 dtex</td>
<td>Aramid 2200 dtex</td>
</tr>
<tr>
<td>2</td>
<td>PES 1100/4 dtex</td>
<td>PES 1100/4 dtex</td>
<td>PES 1100/4 dtex</td>
</tr>
<tr>
<td>3</td>
<td>PES 1100/2 dtex</td>
<td>PES 1100/2 dtex</td>
<td>Carbon 800 tex</td>
</tr>
</tbody>
</table>

2.2 Methodology

2.2.1 Model

A multiaxial woven fabric can be obtained by interlacing 4 sets of yarns, the warps (blue), the wefts (green) and other two sets of bias yarns at +45° and -45° (red) as shown in Fig. 2.

2.2.2 Prototype

The main specifications for the design of the limited scale multiweave development prototype were established according to the available technical capabilities. The resulting multiweave machine, whose assembly design is shown in Fig. 3 (a), comprises the elements, such as bias yarns feeding system, mechanism for the criss-cross insertion of the bias yarns, warping system, shedding system incorporating the heddle, weft insertion system, beating-up mechanism incorporating the reed, and fabric taking-up system. The details of the fabric formation area are shown in Fig. 3(b), where the shed, the weft insertion needle and the special reed at the beating position are shown.

2.2.3 Working Principle

The bias yarns are inserted from the bias beams through a tension compensation device with a step-wise movement in two very close parallel layers in opposite directions by means of an appropriate mechanism. The heddle and the reed are in their lower and backward positions, out of the plane of the bias yarns, allowing their free criss-crossing. The heddle rises forming the shed and the warps interlace with the bias. The shed is formed between the warp and the two very close parallel layers of the bias yarns. A first (false) beating takes place to clear the shed; this is found necessary due to the reason that when the warp yarns are raised by the heddle, they are partially held up by the criss-crossing effect of the bias, preventing from obtaining a clear shed. The weft yarn is then inserted, interlaced with the warps and the bias yarns as shown in Fig. 4; a second (real) beating operation takes place which compacts the fabric at the same
time when the heddle moves down to its rest position closing the shed and holding the weft. The taking-up mechanism advances one step and the fabric is wound-up.

During the development process, all synchronization has been achieved mechanically to help getting a working prototype faster. Therefore, all movements are mechanically driven from a main shaft with the help of cam and intermittent mechanisms. With all the mechanical systems sufficiently developed, the required torque in the main shaft could be measured. Consequently the most important decisions, such as choosing the driving motor and the frequency inverter, were made. The control system is based on an ARM MCU microcontroller board with embedded software designed to control the motor, detect emergency stops using sensors and interface with users. The main functionalities of the control system include broken weft, warp, bias yarns detection; strained weft detection; and speed regulation. The main user interface options include total fabric produced, fabric produced since the machine was turned on or the last counter reset, average speed (mm/s) since the machine was turned on since the last counter reset, motor’s main shaft speed in rpm, number of emergency stops, total emergency’s down-time and programming a certain amount of fabric production.

2.2.4 Testing
As there are no standards available for multiaxial fabric testing, a new procedure needs to be developed in order to test the mechanical properties of the multiweave fabrics. Therefore, conventional strip and grab tensile tests were carried out.

3 Results and Discussion
Figure 5 shows the typical tensile behaviour for 1100/2 HT polyester multiweave fabric (sample No. 2). This multiweave sample shows a quite anisotropic behaviour once the mechanical parameters vary according to the tested direction. As expected, due to the double weft insertion, the sample gives
higher tensile strength in the weft direction. Grab tests or force-elongation tests for multiweave sample comprise the following observations: (i) weft, bias and warp yarns show a similar behaviour, which is typical for a woven structure, (ii) differences in the graphs are mainly due to the “double weft” or the different materials used, and (iii) the weft always seems to be less crimped than the warp or bias.

Figure 6 compares the tensile behaviour in the weft direction for different materials, such as carbon, aramid (Kevlar®) and polyester. As expected, the carbon exhibits the higher tensile strength, followed by aramid and then polyester. On the other hand, polyester exhibits the higher elongation, while aramid the lower one.

To keep the multiaxial structure fixed and to produce a first multiaxial composite, a multiweave fabric has been laminated in a polyester resin. It is observed that when both fabric and resin are made of the same material, the fabric structure does not change. Figure 7 compares the tensile behaviour of laminated and non-laminated multiweave 1100/2 HT polyester fabric. As it can be observed that the maximum applicable force is approximately ten times higher for the laminated sample than that for the non-laminated one. While the resin can only compensate shear stress, tensile stress is compensated by the fabric structure.

4 Conclusions
The multiweave concept was embodied in a development prototype which proved its feasibility. The design of newly developed multiaxial weaving system is concerned with the characteristics of the fabric structure, where there is criss-crossing between all sets of yarns, which increases the capability for supporting more severe mechanical loads without failure, i.e. without delaminating. Simultaneously, the strength-weight ratio is expected to increase, which can be very advantageous for applications, such as in the aircraft and car industries. Other important application areas are marine textiles, such as composites for boat and ship building, which are the products having severe stressing conditions. The main result is the multiweave prototype which is being used to produce different types of directionally oriented structures, using various types of fibres (HT polyester, aramid, carbon and glass) and yarn counts.

The present limited scale development prototype is observed as a learning tool from which much know-how be acquired. Some mechanisms and details need reviewing and optimisation. However, some aspects need to be identified, e.g. while moving to a larger fabric width (500 mm or 1000 mm), extra problems will be raised by the extra complexity of the bias yarns feeding system and the fabric being produced presents a structure which is not yet very dense, mainly due to the limitations imposed by the relatively high bias pitch, hence more research and development is required to find out the appropriate solutions.

**Industrial Importance:** This study is expected to be exploited by the technical textiles sector, mainly in textile reinforced composites for high technological applications, replacing with advantages the existing techniques of using several layers of fabrics, differently oriented, to achieve a higher isotropic behaviour.

**Acknowledgement**
The authors are grateful to the European Commission, VI Framework Programme for funding project Multiweave COOP-CT-2003-1-508125. They
are also thankful to all the partners of the consortium for their efforts during the development of multiweave project.

References