Development of a generic geometry to test the limits of automated draping and stamp forming processes in composite manufacturing

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COVER SHEET

Title: **Development of a generic geometry to test the limits of automated draping and stamp forming processes in composite manufacturing**

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ABSTRACT

There are many process parameters that are important in automated composite manufacturing, starting with the handling of fabrics in the preforming process. Characterization of fabrics on their preforming qualities – which will be referred to as drapability in this paper – is necessary to tune the manufacturing process. The location where the fabric is held, the amount and direction of tension applied to the fabric, the order in which it is deformed, all play a major role in how much in-plane shear deformation a fabric can undergo. The inclusion of process parameters in the characterization of fabrics on drapability is therefore important. In this paper a method is developed to determine the critical shear angle of a fabric whilst including process parameters. A family of geometric shapes is derived and a testing procedure to determine the critical shear angle of a fabric using these shapes is proposed. It is discussed how the presented process can be used to tune draping and stamp forming processes in automated composite manufacturing.

1. INTRODUCTION

Automation of composite manufacturing involves the mimicking of hand manufacturing of composites, as the word manu (hand) suggests, in a replicable fashion. One step in the manufacturing process to be automated is bringing the fabric from its 2D state into the desired three-dimensional shape. Many parameters play a role in this deformation, e.g. local tension on fibers and normal pressure, and determine how much deformation the fabric can accommodate, before shear locking or wrinkling occur.

In this paper the amount of deformation a fabric can accommodate will be referred to as drapability. In-plane shear of the fabric plays an important role in drapability. There is a significant amount of literature that focuses on understanding the in-plane shear of woven fabrics [1 – 6]. Several tests have been devised to predict the critical in-plane shear angle of a woven fabric [1 – 3]. The outcome of these tests can be used to make predictions on whether a fabric can follow a given geometry, or – if not – where cuts are to be made in the fabric.

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Drapability however, as mentioned, does not depend on the critical in-plane shear angle of a fabric alone. The process parameters of the draping process play an important role and can be used to increase the amount of deformation a fabric can accommodate [4, 5]. Therefore a family of geometries is derived in this paper that can be used for a large range of manufacturing processes to characterize the drapability of a fabric. The derivation of these shapes follows from an inverse approach [6].

In section 2 a brief overview is given of methods to characterize fabrics on critical shearing angle and drapability that can be found in literature. After this a family of geometries is derived in section 3. A testing procedure for the characterization of drapability using the derived family of geometries is given in section 4. Finally, the approach and its advantages and disadvantages are discussed in section 5.

2. LITERATURE

In literature different methods can be found to characterize the deformability of woven fabrics: bias extension and biaxial extension [1,2], yarn pull-out [3] and the picture frame test [1,2].

Bias extension refers to a test where a rectangular test-specimen is cut from the fabric such that the warp and weft direction are rotated respectively +45˚ and -45˚ with respect to the longitudinal axis of the rectangle [1]. The specimen is clamped in at both ends and extended at a constant strain-rate. This is the simplest test to measure the resistance of a fabric against shearing deformation.

For biaxial extension the procedure is similar to that for bias extension, but the specimen is cross-shaped and extended in two perpendicular directions. [1] It is possible this way to investigate the effect of fiber tension on the shearing of the fabric.

Yarn pull-out can be used to predict the angle at which shear locking occurs [3]. A rectangular fabric specimen is clamped in on two sides. One or more yarns are then pulled out on the free side of the specimen.

A square fabric cut-out, aligned with the warp and weft direction of the fabric is placed in a frame for what is known as the picture frame test [1]. The frame is placed under an angle of 45˚ in a tensile testing machine and top and bottom corner of the square frame are pulled apart. This way the resistance against shearing of the fabric can be measured, assuming that the frame is frictionless.

All of the above tests can be used to make a prediction on the locking angle of the fabric, but all share the same drawback: they do not included, or only to a limited extend, manufacturing parameters. Even more so, especially for the picture frame test, the clamping of the fabric causes a distortion of the test result. This makes it more difficult to predict drapability of a fabric for an actual application. Therefore a method that is closer to the actual manufacturing process is required. One way to achieve this is the derivation shapes following an inverse approach [6].

3. METHODOLOGY

The method presented in this paper is designed such that it can be fully integrated in any automated draping process. This is possible because the method is entirely based on the geometry of the object being draped. In this section the simplest possible family of shapes will be derived.

In-plane shear of a generic fabric

A generic fabric has two directions, warp and weft, 90-degree angle (see Figure 1). It is assumed that the fibers in the fabric are infinitely stiff in longitudinal direction, but can accommodate moderate bending and that they can only hinge at the intersection of two fibers.

When a square cutout of dimension lxl such a fabric undergoes pure shear at a constant shearing angle the resulting shape will be as shown in Figure 2. The lengths of long and short diagonal of the sheared cutout become as given in equations 1 and 2 respectively.

$$q = 2l\cos\left(\frac{\pi}{4}-\frac{\gamma}{2}\right) \tag{1}$$

$$p = 2l\sin\left(\frac{\pi}{4}-\frac{\gamma}{2}\right) \tag{2}$$

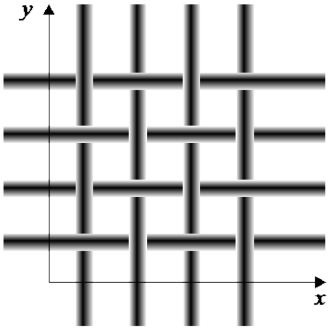

Figure 1. Generic plain weave fabric.

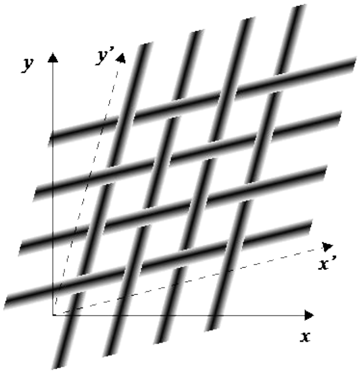

Figure 2. Pure shear of generic plain weave fabric.

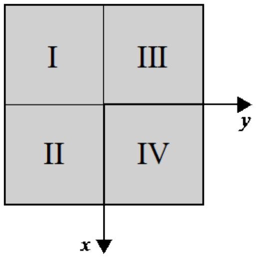

Figure 3. Square piece of fabric divided into four quadrants.

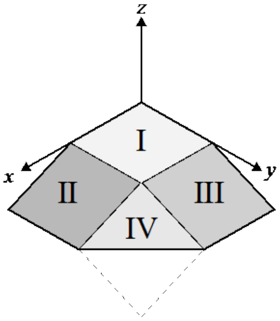

Figure 4. Square piece of fabric with deformed region IV.

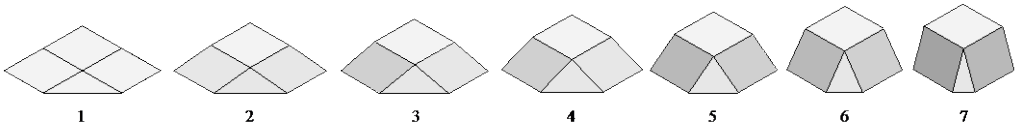

Figure 5. Example of a range of 7 blocks for different shear angles.

Four-quadrant square

A square piece of fabric is divided into four quadrants of equal size numbered I, II, III and IV (see Figure 3). Only quadrant IV is subjected to pure shear at a constant shearing angle. Out-of-plane deformation of quadrants II and III is required to accommodate the deformation of quadrant IV. One possibility is to keep quadrant four in one plane. The resulting geometry resembles a quarter pyramid (see Figure 4).

The height of the geometry and the shearing angle can be directly related to each other using equation 3.

$$h = l\sqrt{\sin(\gamma)} \tag{3}$$

A discrete range of shearing angles can be translated into a discrete range of blocks to test the drapability of a fabric, see Figure 5. The height of blocks for a range from 0 to 90° in 15° intervals are given for $l = 100$mm in table I. The family of blocks can be used to test the drapability of a fabric as will be described in the next section.

4. TESTING PROCEDURE

The proposed procedure is based on the four quadrants of the test-specimen and consists of the following steps:

1. Cutout test-specimen, aligning the borders of the cutout with the warp and weft direction of the fabric
2. Allign quadrants I, II and III on the block and fix
3. Deform quadrant IV using the draping or stamp forming process under consideration
4. Inspect the deformed quadrant IV for defects, e.g. wrinkles
5. Repeat the above for a block with for a larger shear angle until the shear angle for which defects occur after draping or stamp forming
6. Draw conclusions based on process parameters and the largest shear angle giving an acceptable result of the deformed quadrant IV

Depending on the control over the draping process step 2 and 3 of the draping procedure may be combined.

5. DISCUSSION

A method to test for the drapability of a generic fabric, i.e. the critical shear angle of a generic fabric under actual manufacturing conditions, is presented in this paper. The presented approach is based on the geometry of the fabric in its deformed state. Therefore the approach can be applied to a large range of draping and stamp forming processes and can be used to investigate the effect of process parameters on drapability. This feature sets it apart from methods described in literature to determine the critical shear angle of a fabric [1 – 3].

The results that are obtained using the described method are not absolute and depend on the amount of defects in the sheared material that are considered to be acceptable. For certain applications a light onset of wrinkling or visible variation in shearing angle may be acceptable, whereas for other applications only a homogenous shear angle without wrinkling can be accepted.

TABLE I. HEIGHT OF BLOCK AS FUNCTION OF SHEARING ANGLE

γ [°]	h [mm]
0	0
15	25.8
30	50.0
45	70.7
60	86.6
75	96.6
90	100

A drawback of the presented approach using blocks that result in a constant shearing angle for quadrant IV of the fabric is that a set of blocks with discrete variation in shear angle is required to perform the characterization of the drapability of a fabric. This also limits the accuracy of the outcome of the characterization in terms of shearing angle. The development of a geometry with a continuously increasing shearing angle is required to overcome this drawback.

It is important to validate the correctness of a testing block by draping a highly deformable fabric over it and measuring the resulting shearing angle in quadrant IV. This can be done using for instance a protractor. After validation a range of testing blocks can in turn be used to characterize a fabric on drapability as input for CAE.

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