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Effect of the Geometries on the Fabric's Formability

R. Azzouz[1,a], S. Allaoui[1,b]

[1]ITheMM (EA 7548), University of Reims Champagne-Ardenne, France

[a]rym.azzouz@univ-reims.fr and [b]samir.allaoui@univ-reims.fr

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Abstract. The composite materials are high on demand in various applications, because of the wide range of properties that they offer. For that, they need to adapt into complex shapes to serve as a functional part. So, the forming process must be mastered and studied to benefit from what composites offer. The most used manufacturing process for composite materials is the resin transfer molding (RTM), which requires a preforming of the dry fabric into the desired shape. During the pre-forming process,yarns' networks orientation changes and different defects can be generated due to a variety of factors that have a role in their appearance, such as the process settings, type of reinforcement, the characteristics of the shapes' geometry. This study concentrates on the effect of the geometries' characteristics on the appearance of the different defects and the induced shear on the fabric. Different geometries have been selected based on a benchmark of the shapes studied in the literature [2,4,5]. The pre-forming was conducted on 3 types of dry fabrics. Woven and non-woven fabrics have been intentionally selected as fabrics with completely different structures (type of material, weaves, balance…) to observe the change in the fabric's behavior and the induced effects, in terms of profile, location and amplitude.

Introduction

The forming process for composite materials has been a challenge, as composites are known for their highly heterogeneous properties, with multiple variabilities, such as the type of material, their structures, the process type and parameters. For the pre-forming, all previous variables should be studied and understood as they play an important role in dictating the fabric behavior and the defects. Many studies[1,8,9] have investigated the effect of the factors on the profile of the defects and suggested solutions to avoid their appearance [6,7].

One of the major factors that influence the outcome of the pre-forming is the geometry type. The structural parts come in many shapes and different dimensions: the edges' radii, the inclination, the curvatures… The more complex and extreme details of the geometries are, the more defects are to appear. While studying the fabric behavior and the defects, authors selected a variation of basic geometries. They used shapes like the hemisphere[5] and the double dome[4] both inspired by the metals forming studies. Others used different types like the prism, cube, tetrahedron, [2] cone [3]... The diversity in reference geometries chosen by the authors brings to light the interest each one delivers and the reason behind choosing one and not the others in terms of the behavior and defects. However, the comparison between the results of the different studies seems complex since they were carried out under different conditions (geometry, experimental parameters, blank holder geometries, …) on different reinforcements.

The objective of this study is to investigate the effect of the geometry with a geometries benchmark which will be used for the shaping of the same reinforcements. From the geometries studied previously in the literature, a variation has been selected. The pre-forming was conducted with 3 distinct types of fabrics (material and structures) under similar conditions for all the shapes, in order to highlight the role the geometry plays in the fabric's behavior and defect manifestation. The aim is to compare fabric behavior and defects triggered by each of the geometries.

I- Experimental Process

1- Punch geometries:

Five different geometries have been selected based on two criteria: the shape frequency used and the behaviors that the geometry dictated on the fabric. The first two geometries are the hemisphere with a diameter of 100 mm (Fig. 1-a) and the double dome of 80 mm diameters, distanced by 80 mm (Fig. 1-b). The three other selected shapes are more severe in terms of the induced deformation on the fabric: the cube, the tetrahedron and the prism. They share a common point which is a triple point at the intersection of three plane surfaces, but at a different position in a reference to the punch.

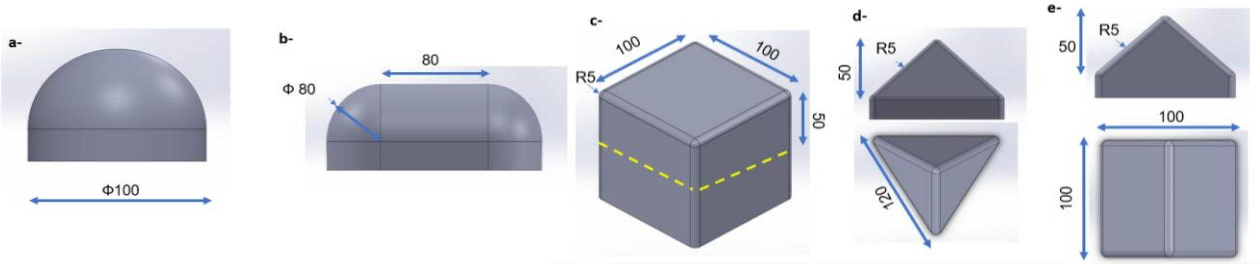
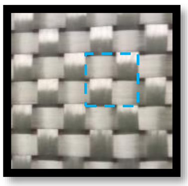
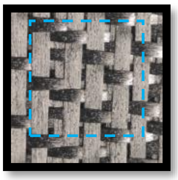


Figure 1: Punch geometries and dimensions (mm): a- Hemisphere, b- Double dome, c-Cube, d-Tetrahedron, e-Prism

2- Material and instruments:

Three different types of dry fabric have been used in this study. The first is a glass fiber taffeta with a unit cell surface of 8×8 mm and a thickness of 0.55 mm. The second is a carbon fiber interlock with a unit cell of 20×15 mm and a thickness of 0.62 mm and the last one is an NCF (Non-Crimp Fabric) with a unit cell of 5×9 mm. An initial pressure of 0.025 Bar, defined by preliminary tests, is applied to the fabric all along the geometries' perimeters by blank holders arranged over the entire contour of the open die. the speed of the punch used is 30 mm/min and the depth is 50 mm.

Table 1: The fabrics used for the preforming

Taffetas	InterlockG1151	NCF (Non-Grip Fabric)
		

Results and Discussion

1- Shearing

After conducting the pre-forming, the measurements of the shearing angles were taken for all fabrics with the 5 geometries. According to the depth of the preform two or three different levels of depth were selected and the angles in each level were measured. Going from the top to the bottom level we have: α1, α2 and α3. For each level, the measurements were concentrated on the zones where the shear was at its highest. It is observed that the obtained measurements with not have much dispersion (an average of 1° with a maximum of 3°) over the zones considered for the five geometries (table 2, table 3). In the double dome and the hemisphere (Table 2), the shearing has increased going from the top (α1) to the bottom (α3) of the preform. This is due to the fact that the excess reinforcement is greater in these areas and must therefore shear strongly to fit the geometries. The location of the high shear zones on the perimeter of the two geometries is consistent with what is found in the literature.

The angles were at their highest for the taffetas with 40°, then lower for the NCF, and the lowest for the interlock.

Table 2: The shear angles measured for the hemisphere and double dome geometries

	Hemisphere			Double dome		
	Taf	**Inter**	**NCF**	**Taf**	**Inter**	**NCF**
$\alpha 1(°)$	16±1	13±1	20.5±0.5	25±2	21±1	23±1
$\alpha 2(°)$	23±2	21±1	23±1	33±2	28±2	29±1
$\alpha 3(°)$	39±1	31±2	32±1	41±2	36±2	40±1

The triple points geometries shearing angles are also measured at different depth levels, 2 levels for the cube and the tetrahedron and three levels for the prism (Table 3). The minimum shear angles have been measured on the tetrahedron geometry while the maximum shear angles were measured on the cubic geometry at its corner's edges, reaching the measuring angle of 65° for the taffetas and 71° for the NCF. The shear values are approximately the same (between 65 and 71) for the three reinforcements which suggest that the shear at this zone is mainly driven by the geometry. In fact, this shear was generated by the sudden severe change in the geometry leading to an excess fabric at the geometry corners edges, creating a high shear that led the fabric to adapt this severe geometry.

Two levels have been measured for the tetrahedron preform, we observed three distinctive areas where the shearing was noticeable for most of the fabrics: Zone A, B and C (Fig.2) for the tetrahedral shape. For the taffetas the highest shearing was observed at the location (C) reaching 33°, as for the interlock it was observed at the zone (A) with 30°, also at the A zone the NCF shearing reached 47° at the higher depth level at $\alpha 1$.

Table 3: The shear angles measured for the cube, tetrahedron and prism geometries

	Cube			Prism		
	Taf	**Inter**	**NCF**	**Taf**	**Inter**	**NCF**
$\alpha 1$ (°)	61±1	60±2	68±1	32±2	34±1	32±1
$\alpha 2$ (°)	65±1	68±3	71±1	36±1	36±1	34.5±0.5
$\alpha 3(°)$				43±1	38±1	37±1

A	Taf	Inter	NCF
$\alpha 1(°)$	22±1	26±1	47±1
$\alpha 2(°)$	29±1	30±1	35±2

B	Taf	Inter	NCF
$\alpha 1(°)$	18±2	19.5±0.5	0±3
$\alpha 2(°)$	25±1	23±0	0±5

C	Taf	Inter	NCF
$\alpha 1(°)$	23±1	20.5±0.5	0±4
$\alpha 2(°)$	33±1	25±2	0±5

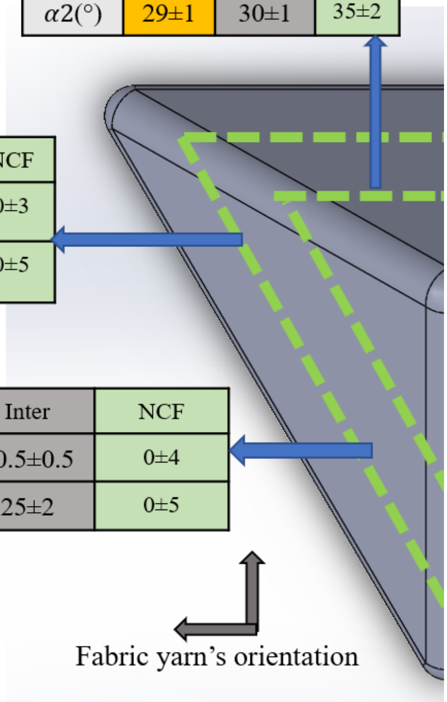


Figure 2: The shear behavior on the tetrahahedron

2- Defects

During the forming process, different defects have appeared. Depending on the fabric type and the geometry, the defects had different locations and magnitudes. In this study, 2 types of defects had been observed.

a- Slippage

The slippage is a local defect where a yarn is shifted in a transversal direction from its initial position, which creates a local curve and void and disturbs the mesoarchitecture of the fabric. This defect was measured and characterized according to the parameters illustrated in table 4. First, the unit cells (UC) subjected to the maximum change were located and the increase in their dimensions is calculated and expressed in % according to the initial unit cell dimensions. The maximal value (UC max %) reached by this parameter is presented in table 4. Two other parameters were calculated according to the expansion and change of the unit cell dimensions). The first parameter, defined as "the average UC defected per location", represents the average number of the unit cells damages that were counted for each defected zone. The second parameter, defined as the "average density per location", which is the density decease (fibers depletion) by the percentage in all the defects repeated in different areas. The slippage creates a zone with low density, where there are fewer yarns, and another with high density where the yarns have slipped. Lower density generates local weaknesses in terms of the mechanical properties contrary to the increase in the density, which is desirable. Based on that, the density decrease percentages are measured, because it creates local weaknesses in terms of the mechanical properties.

Finally, the repeatability of these defects is measured by the number of the locations which is the fourth parameter.

With the hemisphere, the slippage was located at the bottom following the direction of the fiber. The sliding manifested in two hemispherical locations for the double dome, with a similar magnitude and surface damage to the hemisphere. The hemisphere and double dome preform are those who exhibit the less defects and severity (less loss of yarn density, UC dimensions variation and number of defects)

For the triple point's pre-forms, the slippage manifested at the triple point of the tetrahedral shape, creating a gap. The top is where the tension subjected by the yarns is at its highest, resulting in this defect. The cube's slippage was concentrated at the triple point. It is where the geometry is severe, spotted on eight locations (two sides of each of the four corners), which is the maximum number of locations measured for all the preforms. On the other hand, the preform displays the lowest number of damaged cells (table 4).

For the prism, the slippage also was on the two triple points, mainly on the vertical faces in the middle as a projection of the top corner (Fig.2). The prism is the preform where the criticality of the slippage defect is the most pronounced reaching a loss of fiber density around 47% and an increase of the UC dimensions of 353%.

Table 4: The Slippage defect of the woven glass fabric (taffetas)

	UC max (%)	Average UCs defected per location	Average Density per location %	Number of defect locations
Hemisphere	162	6.5	-23.07	4
Double-Dome	153	6.45	-22.48	2
Tetrahedra	154.6	4.64	-35.34	4
Cube	164.04	4.17	-37	8
Prism	353.12	18.89	-47.06	2

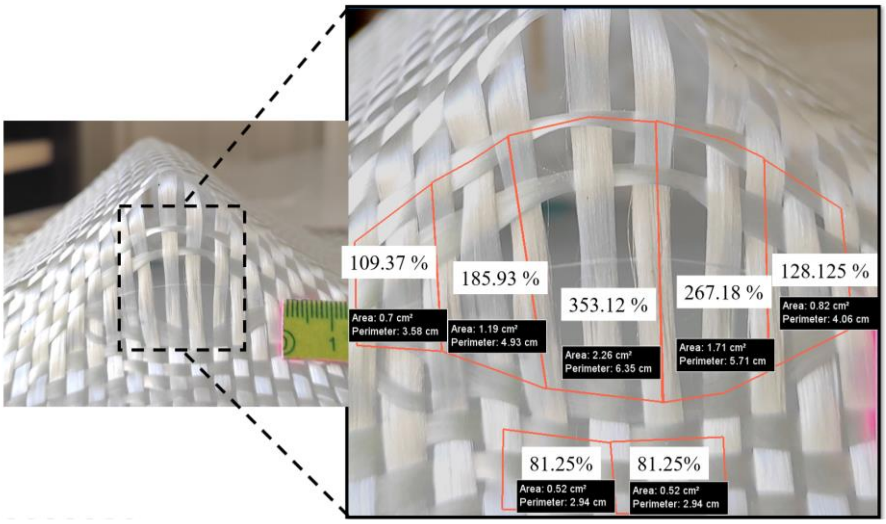


Figure 2: Slippage of the prism preform of the perpendicular plane

b- Buckling:

The buckling is an out-of-plane deformation at the scale of the yarn structure. When the yarn undergoes compression in the same direction as the yarn's fibers, it bends in a curved shape. As an out-of-plane defect, the outcome will alter the thickness of the fabric leading to a change in the mechanical properties. The buckling was observed in all five geometries and for the three types of fabrics. To compare the results, the surface affected by this defect is measured (Fig.3).

In the hemisphere and the double dome preforms, buckles appear at the base of the preforms while they appeared on the vertical planes for the prism. The buckling appeared in a form of a band. It is the projection of the triple point radius. In this zone, the in-plane curvature separating the two shearing zones created the bending and thus the local compression of the yarns that leads to buckling. The prism preforms are also subjected to buckling on the inclined planes closer to the edges.

The buckling in the tetrahedron preforms appeared in four locations: three of them followed the curvature in the yarn's direction until reaching the bottom plus, on the edge where it falls parallel to the yarns. Each vertical edge of the cube had a buckling from both sides because the yarns pass from a no-shearing to a high shearing zone, so an in-plane curvature appeared.

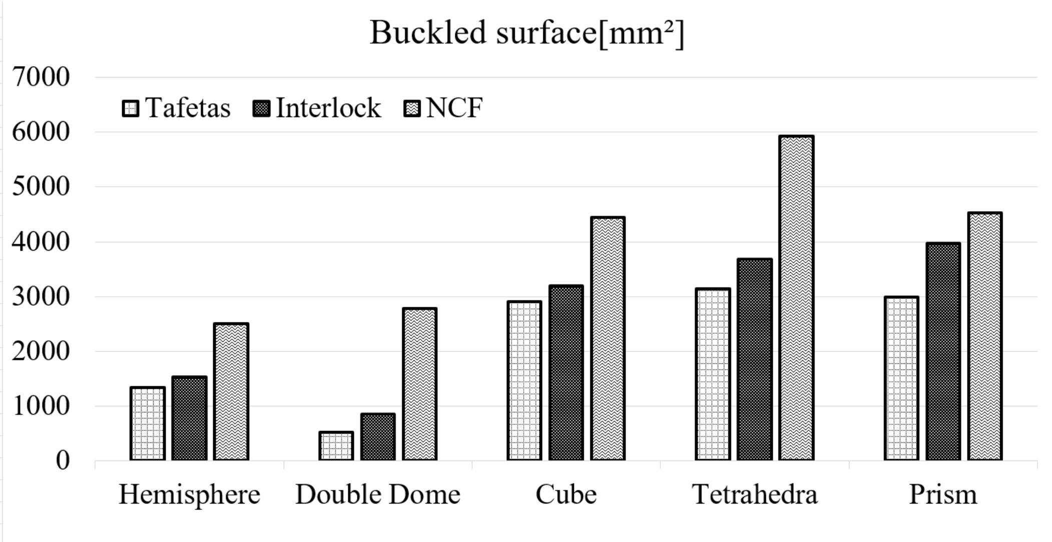


Figure 3: Buckled surface [mm²] of the tested fabrics with the different geometries

Since the pre-forming experiments were conducted under the same settings, it is considered that the defect profile differences are mainly a result of the fabric type and structure. In the first observation, the NCF surface was affected in a way higher than the rest in most cases. The NCF structure does not have separate yarns, but two layers of fibers positioned at 90° in the same direction that are stitched to maintain the structure. The buckling of the interlock and the taffetas were close in terms of the surface affected but always higher with the interlock. With the taffetas, many buckled areas had slippage. During the preforming, at a low depth, the in-plane tensile bends the yarns in a curved form, which creates the buckling. Increasing the depth demands more excess length, so higher tensile and the slippage, resulting in the disappearance of the buckles. The two faults are concurrent and are generated by the same conditions. The appearance of one of them to the detriment of the other depends on the cohesion of the reinforcement. This explains the taffetas having always the lowest buckled areas.

Conclusion

The aim of this study is to highlight the effect of the geometry on the behavior of the fabric and the defect appearance during the preforming , thus the quality of the preform. For this, geometries with unique structures have been chosen. The comparison was built on the shearing behavior and the mesoscopic defects, in our case the slippage and the buckling.

The shearing results showed that the highest angles were found at the triple point at the corners of the cube, reaching between 65° and 71° for the three types of fabrics. In this location, the shearing angle surpassed the locking angle, so wrinkling is expected. But the because of the effect of the blank holders, no wrinkles were detected. The three triple point geometries displayed a completely different shearing result. So, the geometry details and their position regarding the reinforcement had a major effect on the shearing behavior and thus the appearance of the defect.

The prism has shown a significantly higher slippage. It lost almost half of its fibers density in two locations. Comes next in order, the cube preform where the slippage was spotted at eight locations with lesser average surface and density damage. The three triple points geometries were subjected to more severe slippage than the hemisphere and the double dome, the prism being the most critical geometry. A similar pattern was observed with the buckling surface where the prism, tetrahedra and cube had the most affected surface compared to the hemisphere and the double dome.
The variation of the shearing and defects between the different geometries, even with the same preforming conditions, shows that the effect of the geometry is significant. And by understanding the effect of each geometry detail, and the fabric's response behavior. It is important to study and investigate to predict the formability limit of the different fabrics.

Acknowledgments

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