Influences of the Sewing Process on the Compaction Behavior of Fibrous Preforms

Ogale, A.[1], Floeck, M.[1], Stadtfeld, H. C.[1], Mitschang, P.[1] and Bickerton, S.[2]

[1] *Institut fuer Verbundwerkstoffe GmbH, Erwin-Schroedinger-Strasse 58, 67663 Kaiserslautern, Germany: amol.ogale@ivw.uni-kl.de*

[2] *Center for Advanced Composites Materials, University of Auckland, Private Bag 92019, Auckland, New Zealand: s.bickerton@auckland.ac.nz*

SUMMARY: The compression behavior of textile fabrics and the preforms made from them significantly influences the subsequent process steps, i.e. liquid composite molding (LCM). These influences can range from a mere advantage in handling of assembled preforms to local changes of fiber volume content (F_v) with their respective change in local permeability. The phenomenon of preform structural compaction depends on the geometry of the particular preform, i.e. fabric type, fabric geometry, tailored reinforcements, preforming procedures, parameters, etc. Out-of-plane compaction of fibrous preforms can result in possible in-plane extensions. While a stack of fabric layers is able to extend within its in-plane directions, a debulked preform utilizing appropriate sewing patterns is limited in this respect. This paper presents preliminary results of studies performed at Auckland and Kaiserslautern concerning preform compaction behavior of stitched and unstitched fibrous reinforcements. Initial investigations are presented into the effect of preform assembly sewing techniques on the compaction behavior of these structure.

KEYWORDS: Preform, compaction, fiber reinforced polymer composite, sewing, liquid composite molding

INTRODUCTION

In the LCM processes, particularly, resin transfer molding (RTM), preform placement and its near net shape is of primary importance [i]. Composite manufacturing by means of RTM is a widespread technology and has high scope to develop in order to obtain high quality products. The interrelation between the manufactured preform and final fiber reinforced plastic (FRP) characteristics is linked by means of the RTM process. Since preforms are the latest sub- product before the LCM process, they need to be manufactured considering all the RTM related aspects: mold placement, compaction behavior, probable hindrances for resin transfer, etc. Preforms can be manufactured in various ways according to their end applications. Tailored reinforcements or sewn multi-textile-preforms have remarkable advantages in terms of their near-net-shape and ready-to-impregnate features. Sewn assembly can hold two or more layers of mono- or multi-structural reinforcing materials. Different sub-preforms can be sewn with varied pre-compaction level according to the tooling need.

Preform pre-compaction during stitching and compaction during the RTM process influence the preform permeability. Compaction behavior of sewn preform is influenced by the sewing thread tension, stitching pattern, and presser-foot pressure (compression of reinforcing material during stitching) [i].
Many researchers have made attempts to examine compaction of fibrous lay-up [ii,iii,iv]. Grimsley et. al. explained the compaction behavior of stitched multi-axial non-crimp fabric (NCF) material in dry and wet condition during vacuum assisted resin transfer molding (VARTM) [iv]. The time-dependent tooling forces acting on the unstitched preforms during the RTM process are also of great importance relating to preform properties and injection technique [v].
Some studies regarding compaction behavior of differently stitched NCFs have been found in the literature and the influence of stitch density is explained [vi]. Influence of garment based sewing technology on the preform compaction was not well exploited before; therefore, it is a topic of discussion within the scope of this paper. In the current work, influence of sewing thread tension and stitch density on the preform compaction behavior is examined. The relationship between applied compaction stress and corresponding fiber volume content has been evaluated.

EXPERIMENTATION

Preform Manufacturing

Preforms were manufactured according to a set design of experiment, so that the influence of sewing parameters is clearly visible. Three different types of textile fabric systems made up of glass fibers were used for the experimentation: plain woven fabric (821 g/m^2), biaxial NCF, (1200 g/m^2) and triaxial NCF (1200 g/m^2). The sewing thread used was a standard polyester thread from Amann & Söhne GmbH & Co.KG. (No. 50). An automatic sewing machine (from KSL Keilmann Sondermaschinenbau GmbH) was used for preform stitching and the stitching speed was 1,000 stitches/min. The applied thread tension for preform manufacturing was set to two extreme levels. Low needle thread tension was 68 cN, corresponding bobbin thread tension was 144 cN, high needle thread tension was 500 cN, and the corresponding bobbin thread tension was 250 cN. Two different stitch densities were achieved by using different stitch patterns. Stitching patterns were designed using CAD software and fed to the sewing machine. Table 1 shows the experimental design.

Table 1: Design of experiment: preform panel manufacturing

Fabric Type		Stitch pattern			
		5 mm x 5 mm (13.33 stitches/cm^2)		20 mm x 20 mm (3.33 stitches/cm^2)	
		Low thread tension (300 cN)	High thread tension (500 cN)	Low thread tension (300 cN)	High thread tension (500 cN)
Plain woven		X	X	X	X
Non-crimp fabric	Biaxial	X	x	X	X
	Triaxial	X	x	X	X

Sewn preforms were then punched to the exact size of the testing rig (180 x 220 mm). To investigate the reproducibility and homogeneity of the recorded data, three specimens were stitched for every set of preforming variables.

Testing

Preforms were tested for dry compaction behavior in terms of stress required to compress the particular stitched lay-up and corresponding reduction in the thickness. An Instron testing machine was used at constant speed mode. First the specimen was loosely inserted between the two parallel plates of the test rig, as the test proceeded; the plates were driven together at a constant speed compressing the lay-up. The Instron records the applied load and corresponding preform thickness. The thickness data can then be converted into fiber volume content, thus it is possible to plot a graph of F_v obtained against the applied load on the lay-up. All of the stitched preforms were tested and compared with the results of unstitched fabric lay-up.

RESULTS AND DISCUSSION

Time Dependent Compaction

Preforms were tested for dry compaction behavior in terms of stress needed to compress the particular stitched and unstitched lay-up to obtain required fiber volume content. The results of progressive preform compaction were classified according to the stages of fiber volume content (from 55 to 65% fiber volume content). Fig. 2a shows the time dependent compaction behavior of biaxial NCF, triaxial NCF, and woven fabric. Fig. 2b shows a plot of compaction stress vs. change in the preform thickness. The triaxial fabric preform has high initial thickness thus it starts compacting earlier than the other types of preforms and needs high compaction stress to achieve the required preform thickness.

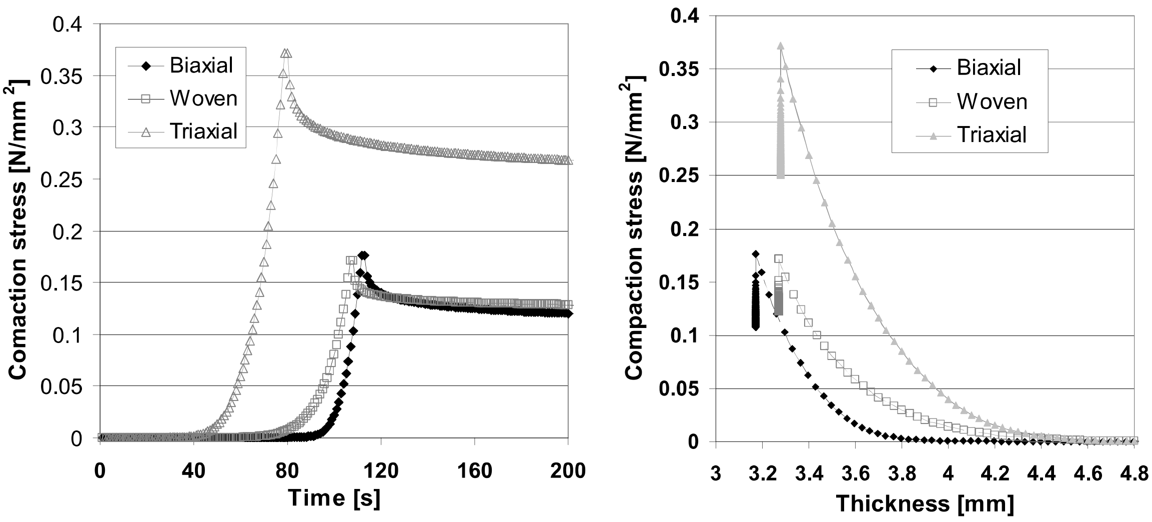

Fig. 2: Compaction behavior of 20 x 20 stitched preforms for achieving 60% fiber volume a) Plot of compaction stress vs. time b) Plot of compaction stress vs. preform thickness

On the other hand, biaxial fabric has less preform thickness so the required compaction stress is also lower than the triaxial fabric lay-up. Because of the wavy structure of woven fabric, the lay-up thickness is higher compared to the well oriented biaxial fabric, thus more compaction stress is needed to achieve 65% fiber volume.

Fiber Volume Content a Function of Compaction Stress

A plot of the peak applied compaction stress required to achieve corresponding fiber volume content is shown in Fig. 3. The maximum stress required to compact a preform was 38 KN (in case of preform with 5 x 5 stitching pattern and high thread tension). Thread tension applied during the preforming is a vital parameter in case of preforms stitched with a high stitch density. In the category of stitched preforms, a 20 x 20 stitched preform requires the smallest compaction stress to achieve the required fiber volume content. Preforms stitched with low stitch density are not affected by the applied thread tension. The same trend was observed for triaxial and woven fabrics but with the different intensities.

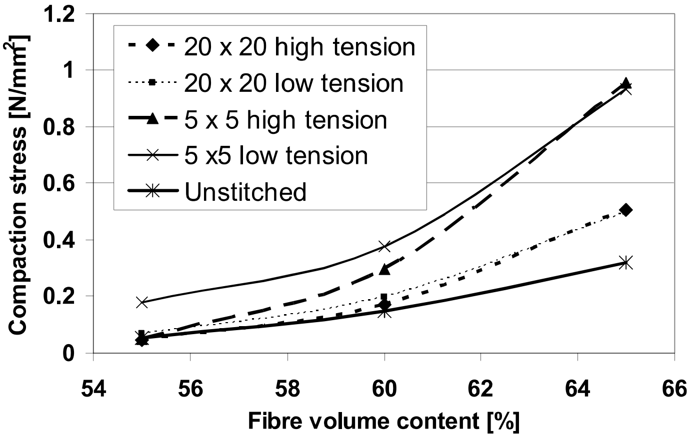

Fig. 3: Compaction behavior of biaxial NCF lay-up

Fig. 4 shows the combined data of compaction stress required for all the various stitched preforms and unstitched lay-ups. In general, achieving high F_v %, stitched preforms require more compaction stress than the unstitched lay-ups. On the contrary in the case of stitched preforms with low stitch density, the initial compaction stress needed was lower compared to the unstitched preform.

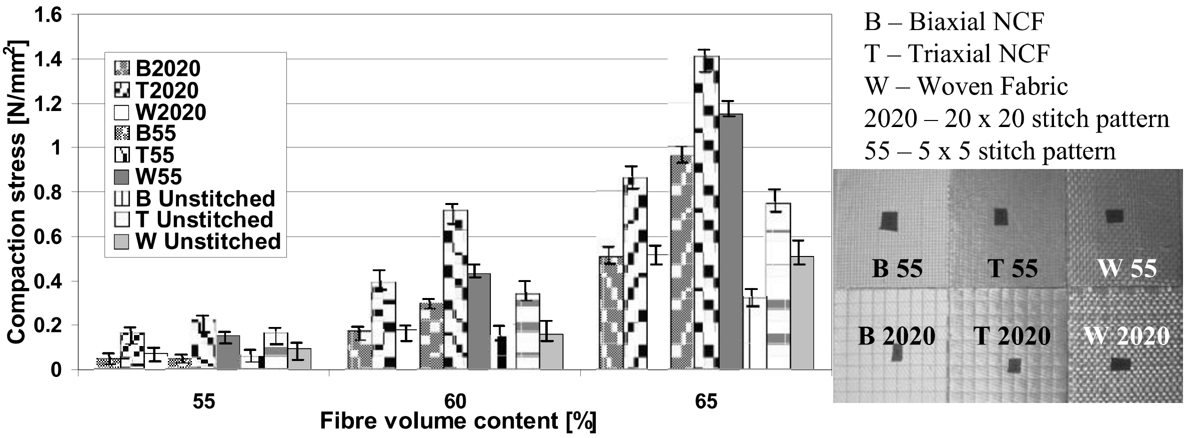

Fig. 4: Steps of F_V % with respect to compaction stress for different textile preforms

The preforms stitched with the high stitch density are blocked to further free movement of reinforcing fibers, thus the phenomenon of fibrous compaction [iii] is more complex. Therefore, this type of preform requires higher compaction stress to achieve the desired preform thickness. Preforms stitched with the low stitch density allow further rearrangement of the reinforcing structure which facilitates easier fibrous compaction. Therefore, up to a certain level, these require low compaction stress to compress the complete structure compared to the preforms with densely stitched preforms, and unstitched fabric lay-up. As the preform compaction proceeds, the reinforced fibers may get repositioned which causes the linear deformation of a preform. Due to the stitches, fiber reorientation becomes difficult and it does not allow the linear deformation of a stitched structure. Thus, the higher compaction stress is required to obtain desired preform thickness. Only in the case of unstitched lay-up, unhindered linear deformation is allowed. This phenomenon keeps the lay-up compacted and causes easy deformation of the lay-up, thus it requires less compaction stress to reach the required preform thickness.

CONCLUSION

According to the basic textile structure, sewn preforms show different compaction behavior than the unstitched lay-up. The lay-up structure and sewing parameters influence the final preform fiber volume content, thus for particular preform application it is possible to use specified sewing variables. Intensity of applied thread tension and stitch density are the parameters of preform engineering and can be optimized for different sub-preforms. Sewing operation supports the pre-compaction of fibrous lay-up to a certain extent of fiber volume content. Pre-compacted preforms with high stitch density can be suitable in the process stage of net shape preforming which again reduce the tool loading time.

REFERENCES

[i] P. Mitschang, A. Ogale, J. Schlimbach, F. Weyrauch, C. Weimer, "Preform Technology: a Necessary Requirement for Quality Controlled LCM-Processes", Polymers & Polymer Composites Vol. 11, No. 8, Pages 605-622 (2003).

[ii] B. Chen and T.-W. Chou, "Compaction of woven fabric preforms in liquid composite molding process: Nesting and multiplayer deformation", *Compos Science and Technology, Volume 60*, Pages 2223-2231 (2000).

[iii] B. Chen, A. H.-D. Cheng, and T. -W. Chou, "A nonlinear compaction model for fibrous preforms", *Composites Part A: Applied Science and Manufacturing, Volume 32,* Pages 701-707 (2001).

[iv] B. W. Grimsley, P. Hubert, X. Song, R. J. Cano, A. C. Loos and R. B. Pipes, "Flow and compaction during the vacuum assisted resin transfer molding process". Internet address: http://techreports.larc.nasa.gov/ltrs/PDF/2001/mtg/NASA-2001-33sampe-bwg2.pdf

[v] S. Bickerton, H.C. Stadtfeld, and P. Mitschang, "Modelling tooling forces generated during the resin transfer molding process", *Proc. 24th International SAMPE Europe conference*, Paris, April 1-3, Pages 693-701 (2003).

[vi] S. V. Lomov, E. B. Belov, T. Bischoff, S. B. Ghosh, T. Truong Chi, and I. Verpoest, "Carbon composites based on multiaxial multiply stitched preforms. Part 1. geometry of the preform", *Composites Part A: Applied Science and Manufacturing, Volume 33,* Pages 1171-1183 (2002).