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Characteristics of Tufted Preforms Subjected to Different Mechanical Loading for Aerospace Applications

The structure of tufted preform affects the processing properties such as porosity, permeability and mechanical properties of the final aerospace composite part. In this paper, the behavior of tufted preforms was examined under different loading conditions. The preform is experienced tensile, draping and compression test and its characteristics were examined. It was found that the tufted preform could offer higher tensile loading in comparison with untufted preform, while there was no significant difference in the extension between the two types of preforms. Draping involved the drawing of a fabric over a hole placed in a drape fixture without wrinkling. Due to high drapability and low forming energy, tufted structures could be selected as textile reinforcement for production of the complex shape specimens. The same compression behaviour was observed for both tufted and untufted preforms. Finally, the mechanical and microscopic characterization was carried out for recognizing the formability of tufted preforms to produce complex shaped textile composites.

Keywords: *Tufted preforms, deformation modes, tufting structure.*

1. INTRODUCTION

The use of textile fabrics in aerospace industry gives the possibility to produce complex shapes components using liquid composite moulding [1, 2]. The textile fabric structure influence the manufacturing properties such as deformability, porosity and permeability and mechanical properties of final composite parts [3, 4]. The characterisation of local fiber variation occurred during forming, fiber volume fraction and fiber thickness are significant parameters to describe the performance of textile fabrics [5]. During the forming of textile fabrics, the following deformation modes occur: shearing, straightening, wrinkling, stretching, inter ply slipping and intera-ply slippage [6-8]. If the directions of applied tensile load to textile fabric do not coincide with the fibre tow orientation, fabric shear mode occurs [9, 10]. Complex shaped textile composite needs the formation of textile fabric in tools before resin injection. The draping of textile fabrics on double curved surfaces has received much attention both in 2D and 3D textile structure for description of the textile behaviour for forming [11]. For instance, drapability of fabric for a nose cone or blade geometries are the main charac–teristics that have been investigated for the adaptation of fabric on their tools [12]. Characterisation of the textile fabric based on shear stiffness and drapability is needed for accurate prediction of the fabric forming for 3D- complex shaped composite structure.

To apply the composite material in particular honeycomb composites for helicopters, it is necessary to investigate aeroelastic properties of blades [13]. This aeroelastic testing can be used to determine the natural frequency modes and its damping. For this type of composites, the verification of structural accuracy and structural integrity is vital task such that the damaping properties is highly dependent on layup designing pro–cess [14]. A key difficulty in designing honeycomb com–posite structures for aerospace application is how to predict damage initiation and damage evolution. Based on the experimental results, the use of laminated textile composites in helicopter blades can improve the damage growth in fatigue test and meet standards for aerospace applications. Furthermore the damage tolerance of textile composite for helicopter blades can be improved by correct layup design. One of the important parameters for designing the composite material for aerospace applications is to investigate the influence of preload on the impact response and damage development [15]. Based on the experimental results, preloading of curved composites have an influence on the impact damage and damage growth. Preloading of composite is experiencing an impact that will increase the impact strength of the material and decrease the amount of damage in composite. A slight decrease in damage area may be seen at low impact energies since the preloading prevent out-of-plane deflection and delemantion damage.

Toward using of honeycomb composite for aero–space applications, it is crucial to improve the repair techniques to restore the structural integrity and stren–gth of the composite parts. 3D random fiber composite materials can be used to repair damaged honeycomb composites cores [16]. Based on the simulation results done by finite element technique, it is observed that 3D

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random fiber can be a significant candidate to repair the damaged honeycomb composites. In fact this materials can improve the mechanical properties of honeycomb composite experiencing the bending loads.

Since damage tolerance certification needs expen– sive testing, finite element technique can be used to investigate the consequence of changing of textile com– posite layup, textile architecture and damage growth. The micromechanical models simulated by FEM tech– niques can be used to obtain the effective properties in particular effective fiber tow properties at the micron scale and investigate the failure process arising from delamination, shear crack, fiber rupture and fiber mic– robuckling. Mostly, a representative of a volume element is used for modelling of textile composites at the micron scale. Challenges for modelling textile composites include dealing with large macroscopic gradients, transient loads, mesh generation [17].

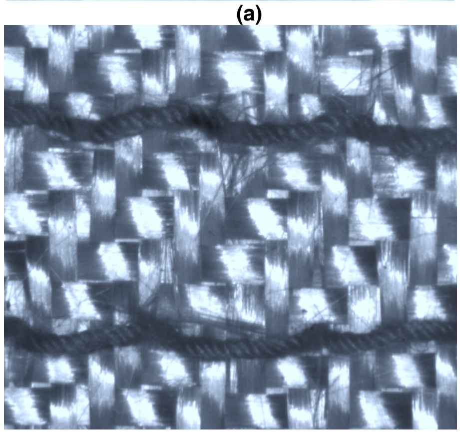
UD fabric has low drapability and shear stiffness due to lack of undulation [18, 19]. Knitted preforms have high conformability, however lower in shear stiffness due to curved fibers. 3D woven has high stability and shear stiffness due to reinforcing fiber through thickness direction. Braided fiber in compared with other fabrics has low shear resistance, but relatively high drapability. It can be concluded that braided preforms are more suitable for varying cross-sectional shapes such as cones and nozzles [20, 21]. The deformation modes occurred in tufted preforms are considerably significant to the forming process of textile preforms and their performance evaluation for advanced aerospace applications. This paper concentrates on dif– ferent tests to investigate the mechanical properties of tufted preforms and the effect of tufting on the preform formability. The preform was experienced tensile loading in different directions, draping and compression tests. Compression and drap curves were investigated based on behaviour of preforms under loading. Finally, the formed preforms were characterized based on microscopic images.

2. EXPERIMENTAL MATERIAL AND EQUIPMENT

The preforms were composed of eleven layers of twill woven glass fabrics with a quasi-isotropic lay-up. The woven fabrics have the areal weight of 305 g/m2. These fabrics were tufted with a twisted 240 Tex polyester thread using a KUKA 6-axis robot head equipped with a commercial tufting head. The tufting rows were oriented at 0° in the direction of woven fabrics, with a tufting spacing of 4 mm and pitch of 4 mm. Figure 1 is the sketch of the tufted preforms, which presents a tufted structure with polyester thread. In such a preform, the thread was in almost perpendicular way to woven fabrics surfaces to construct a stable tufted preform.

Tensile test of preform specimens was experi– mentally carried out by an MTS testing machine with a load cell capacity of 100 KN. The tensile tests were carried out on preform specimens cut in parallel and perpendicular of tufting direction. The sample size for the tensile tests was 44 mm × 130 mm, and the test speed was 100 mm/min for all preform samples. Figure 2 illustrates the tensile test set-up for textile fabrics loaded in perpendicular to tufting direction. At each end of the specimen, a length of 30 mm was clamped into the hydraulic grippers. To decrease the stress concen– tration in the clamping sections, thin aluminium sheets were bonded on the ends of each preform specimen. Each transverse (90°) tufted specimen included 16 lines of tufting within the length, yielding on average three stitches within the gauge section, and each longitudinal (0°) tufted specimen included 5 lines of tufting within the width.

(a)



(b)

Figure 1. Architectures of tufted preform in front (a) and back face (b).

Figure 2. In-plan tensile test setup.

For drapability testing, a hemispherical plunger in the diameter of 32 mm with a 150 N load cell was mounted on the Instron machine to study the formability of tufted preforms. Figure 3 displays the drape test set-up consisting of a hemispherical plunger, preform hol– der and flat tufted preform. The fixture consisted of two plates, each having a hole around 90 mm at its center. Two specimens were cut from the tufted preform and two specimens cut from untufted preform for compa–rison purposes. Each preform sample size was 140 mm by 140 mm. The sample was mounted between plate I and II shown in the Figure 3, and four screws were tighten with equal force using a torque wrench such a way that the sample could move freely during forming. The hemispherical plunger was moved down at a velocity of 5 mm/min. The touch point of a plunger and preform was set as first position. The stop position of plunger was at 20mm from the first position. Preform was slowly deformed by the plunger and the load and displacement between these two points were recorded and integration of drape loading and plunger displa–cement were defined as forming energy.

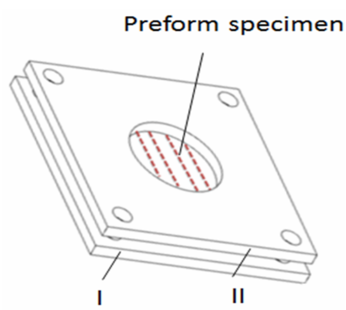


Figure 3. Experimental setup for drapability testing.

Figure 4 represents a schematic illustration of the compression test carried out by an MTS machine. The compression test set-up consisted of upper circular punch moved down and compressed the tufted preform at a constant rate. When the compressive force reached the prescribed limit, the punch reversed the movement automatically. The force and displacement were recorded during the test process. The speed rate of punch movement was 1 mm/min. The upper limit of the load was set at 20 KN. The thickness at which the compressive load reached 20 KN has been used as the final thickness and a typical load/deflection response curve for compression testing was recorded for analysis purposes.

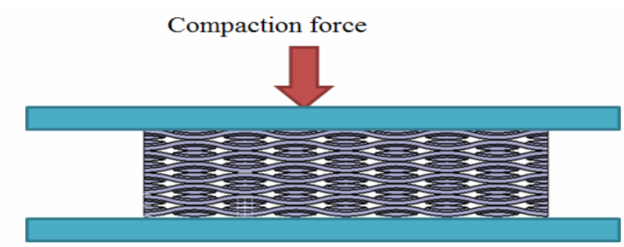


Figure 4. Compression test setup of tufted preform.

3. RESULTS AND DISCUSSION

The tensile behaviour of the tufted preforms is shown in Fig. 5. Several tests were performed to establish typical material response and sufficient repeatability. The iden–tical characteristics were observed for the tufted preforms. Note, the scattering that appeared in tensile tests could be related to the rapture of preforms from the weakest and damaged point that occurred during tufting needle penetration.

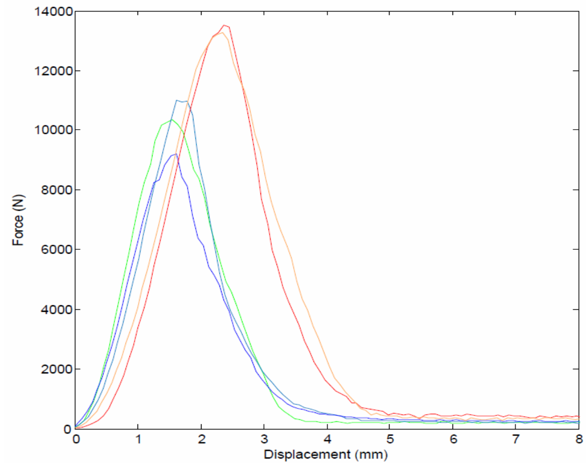


Figure 5. Load Vs Displacement for tufted perform.

Mostly, the highest values of loading at the same strain were observed for preforms with tufting compa–red to the preforms without tufting reinforcement as shown in Figure 6.

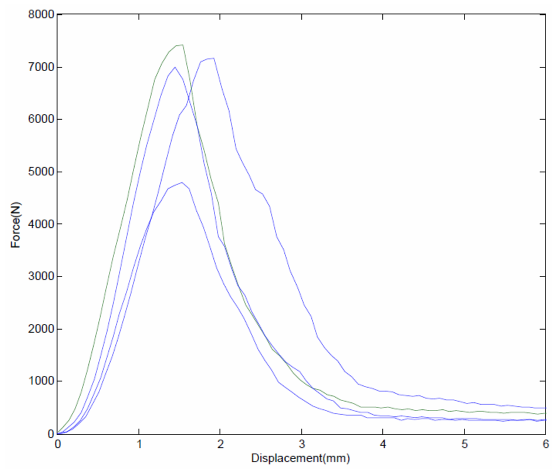


Figure 6. Curve of tensile loading of untufted perform.

According to the tensile energy defined by the area under the load-deflection curve, it can be said that the lower value of tensile energy for untufting indicates that the preform will form simply and its deformation will be better than preforms with tufting reinforcements.

Typical load/deflection curves of drapability test when the displacement reached a level of 22mm are shown in Figure 7. When the displacement of a puncher increased, the slope of the load/deflection curve incre–ased significantly, indicating a change in the deforma–tion mode. The maximum vertical displacement of the plunger along the z-axis for the plunger was set at 22 mm, but tufted preform could undergo a further displa–cement without breaking in the middle of the preform.

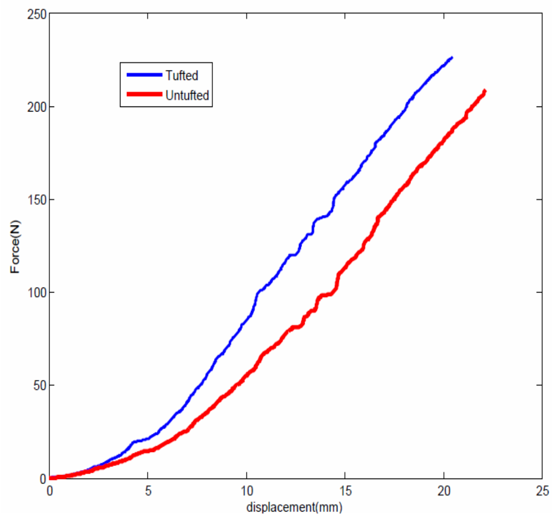


Figure 7. Load vs. deflection curve of tufted and untufted performs.

Figure 8 depicts a pressure-thickness curve of tufted fabrics. It is observed that deformation curves of both fabrics are identical and nearly each curve consists of three parts: two linear parts and an exponential part. Linear parts could be related to preform compactions because of the decrease of porosity and gaps among the filaments and fiber bundles, whereas the exponential part may be related to fibers bending, nesting and fibers cross-section deformation.

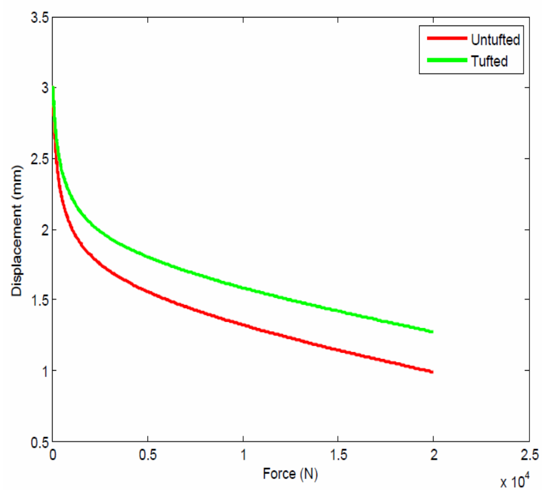
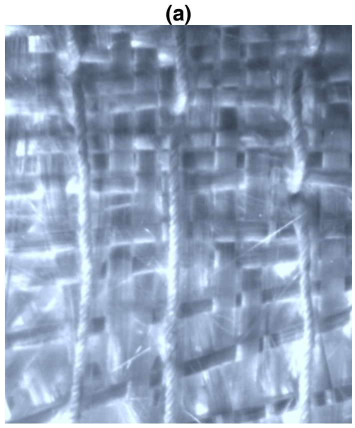


Figure 8. Load vs. displacement of compression test of performs.

The study of mechanical properties of fabrics during tension, drape and compression test displayed that for–mability parameters of a stacked woven fabric can be changed by performing tufting process. The most signi–ficant influence on the deformed fabric was stability and load–deformation response represented in details in previous chapters. Based on our observation, uniaxial test of tufted preform caused a reduced tow undulation in the loading direction and an increased tow undulation in the transverse direction, while the tufting thread stimu–latingly initiated to separate from the preform. As shown in Figure 9, two different zones could be pointed out in tensile test. In zone I, the warp and weft yarns have clamped at one end and low deformation was observed in this zone. In zone II located in the middle of the preform, the fibre bundles orientations alter until the fibre axes coincide with the directions of applied load or until maximum shear angle of fiber is achieved. Locking angles of fiber in all preforms were in the range between 15° and 40° depending on the tufting orientation.

(a)



(b)

Figure 9. Tufted preforms subjected to tensile loading a) longitudinal tufted b) transverse tufted.

During drapability testing, it was seen that tufted preform can tolerate higher deformations, which is in agreement with the conclusions of the uniaxial tensile tests. Tufted fabrics did not show any significant wrinkle onset on their surface when they were deformed, except few localized misaligned fabrics. In-plane misalignment and rotation of the fibre bundles appeared as major deformation modes during draping which could result in a difficulty referring to high fiber buckling in a composite subject to compressive loads.

Compression load applied to preforms resulted an increase in fibre volume fractions by tow flattening and decrease in tow crimp. All preforms were compressed by one type of plunger. It was revealed that the energy absorption was high in the tufted perform.

4. CONCLUSION

Experimental characterization including in-plane tensile test, transverse compression test and drapability test of tufted preforms have been conducted. The analysis of tufting effect upon fabrics deformation behaviour has shown that preform with tufting will require higher values of load to obtain the same value of elongation compared to untufted specimens. The load-extension curves of preform reveal that, generally, a loading curve could be divided into four specific regions. Draping involved the drawing of a fabric over a hole placed in drape fixture without wrinkling. Due to high drapability and low forming energy, tufted structures could be selected as textile reinforcement for production of the complex shape specimens. The same compression beha– viour and slight difference in compression energy were observed for both tufted and untufted preforms. Microscopic examination at different magnifications was utilized to investigate the intrinsic damage in a preform before and after loading and provided valuable basis to characterize the preform during forming process.

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КАРАКТЕРИСТИКЕ ТАФТОВАНИХ ПРЕДФОРМИ ИЗЛОЖЕНИХ РАЗЛИЧИТИМ МЕХАНИЧКИМ ОПТЕРЕЋЕЊИМА ЗА ПРИМЕНУ У ВАЗДУХОПЛОВСТВУ

А. Сабоктакин, Т. Ву-Кан, В. Бутун, П. Пантјукхов

Структура тафтованих предформи има утицаја на карактеристике обраде композита, као што су порозност, пропустљивост и механичка својства финалног дела за примену у ваздухопловној индустрији. Испитује се понашање тафтованих предформи у условима различитих оптерећења. Извршено је испитивање предформе на истезање, драпирање и сабијање и истражене су карактеристике сваког поступка. Доказана је већа издржљивост тафтоване предформе на оптерећење истезањем у

поређењу са нетафтованом предформом, али није нађена сигнификантна разлика код истезања између две врсте предформи. Код драпирања је извршено затезање тканине преко отвора стављене у справу за драпирање без набора. Због велике способности драпирања и мале енергије потребне за формирање, тафтоване структуре би се могле изабрати као текстилно ојачање за производњу узорака сложених облика. При сабијању је нађено исто понашање код тафтованих и нетафтованих предформи. Најзад, механичка и микроскопска карактеризација је изведена у циљу утврђивања формабилности тафто–ваних предформи да би се могле користити за производњу текстилних композита сложених облика.