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Design of 3D textile preforms as composite materials for advanced aircraft structures

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Abstract
The article comprehensively reviews the design aspects of 3D woven preforms for application in advanced aircraft structures. Owing to their structural attributes of high stiffness and strength properties composite materials have been successfully used in structural applications. 3D textile composites have been developed prompted by the requirements of reducing fabrication cost, increasing through thickness mechanical properties and improving damage tolerance. Various techniques have been developed in the production of preforms. These techniques have been reviewed. The detection of the damages in textile preform and composite have been the major focus and different techniques developed.

Key words: *3D textile preform, Aircraft structure, Damage detection, Production methods, Stitching types, Fabric deformation.*

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I. INTRODUCTION

Owing to their structural merits relating to high specific strength and stiffness, composite materials have been effectively utilized in structural applications. The two dimensional laminates constitute the first generation composite. Despite such composites being characterized by high stiffness and strength properties, their out of plane properties are poor and the fabric laying up process in more time consuming. In order to overcome the setbacks of the 2D laminates, 3D structures have been developed during the past few years. The development of 3D textile composites has been driven by the needs of reducing fabrication cost, increasing through thickness mechanical properties and improving impact damage tolerance. The development of 3D textile composites has been largely undertaken by NASA. Furthermore, the marine, construction and automotive industries have supported the development of 3D composites. 3D textile composites containing 3 dimensional performs has the following characteristics: improved stiffness and strength in the thickness direction, elimination of the inter laminar structure due to integrated structure, possibilities of near net shape design and manufacturing. 3D textile composites based on textile performs are manufactured by several processing techniques, resin infiltration and consolidation techniques. Preforms are classified into two main categories called two and three dimensional textile performs [1]. Dividing 2D and 3D are determined by the presence of reinforcing fibres laying in the through thickness direction as shown in figure 1. 3D textile performs can be divided into four major groups according to their manufacturing techniques: Braiding, Weaving, stitching and knitting [2].

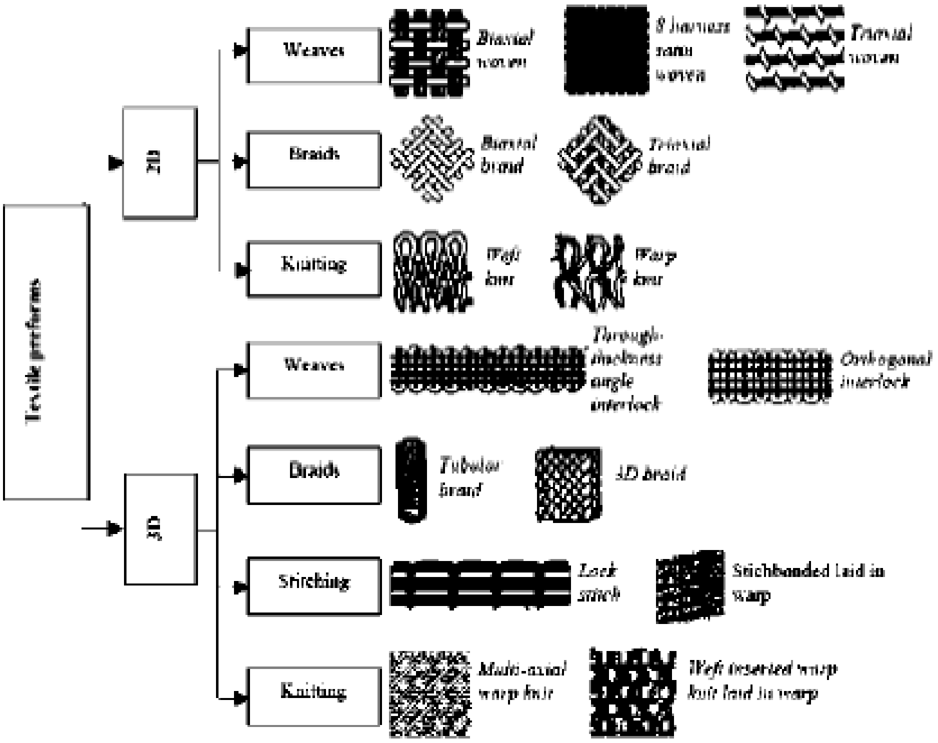

Figure 1 – Important types of textile performs [3]

In textile composite structures, failures originate from manufacturing defects or in service induced damage. Manufacturing defect can degrade the performance of the composite to a point where the composite cannot be safely used for an aircraft structure. The point at which the severity of the defect becomes safety critical depends on the application and can only be determined by structural integrity assessment. All the processes related to the production of 3D performs, fabric architects, and their specification and deformation modes have been reviewed. Textile stitched performs and their crucial challenges in order to serve this crucial technique for the future research have been discussed. Preform compaction, the effect of compaction and deformation modes on porosity and permeability have been reviewed. The structural integrity assessment of textile composite by the inspection procedures to prevent structural failures from the manufacturing damages, have also been highlighted.

Preforming methods

Weaving

As shown in figure 2, the weaving process involves insertion of nominally straight weft yarns between layers of warp. The warps lie parallel to the direction of the weaving process designated the x-axis. The weft yarns are oriented orthogonally to the warp yarns and parallel to the y-axis. Except for a little out of plane waviness, the warp and weft yarns lie purely in the x-y plane without interlacing each other similarly to a 0/90 laminate. In 3D weaving, a small proportion of in-plane yarns are woven that they bind together the multiple layers of warp and weft yarns. These yarns are termed ‘z’ binders because they are woven through the thickness of the perform, designated the z-axis. 3D woven performs can be manufactured by using the most common types of commercial looms. Jacquard looms are the most popular due to their high degrees of automation and good control of the fibre structures. The benefits of this automation in the weaving process are: reducing the manufacturing costs versus reducing the labour hours, scrap rates, process inspections, and consequently, increasing repeatability and quality control. The loom can be used to manufacture integrated net shaped performs such as blade stiffnes panels.

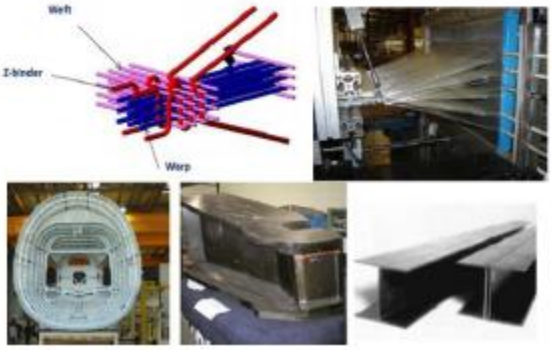

Figure 2 – 3D weaving machine and 3D woven composite applications. From left to right – Fuselage, Landing gear, 3D woven I beams [1].

Stitching

There has been considerable interest in composites produced by stitching layers of textile fabric and subsequently impregnating the perform with resin by using a liquid molding technique. The stitching process is carried out using industrial stitching machines. Stitching machines can stitch various kinds of performs with high performance yarns as stitching threads. The extent of through thickness reinforcement in stitched composites structures is between 1-5%, which is a same amount of reinforcement in 3D woven, braided and knitted composites [4,5]. The use of through thickness stitching in composite owes to the following reasons: possibility of joining composite structures to provide high through thickness strength and resistance to peel loads, decreasing the costs of component manufacture greatly by reducing RTM tooling costs, improving interlaminar fracture toughness, impact resistance and tolerance, construct 3D complex shapes by stitching several separate performs together, eliminating the need for mechanical fasteners, such as rivets, screws and bolts, and finally, reducing the weight and production cost as well. Figure 3 depicts the manufacturing stage of an aircraft composite panel stiffened by stitching process.

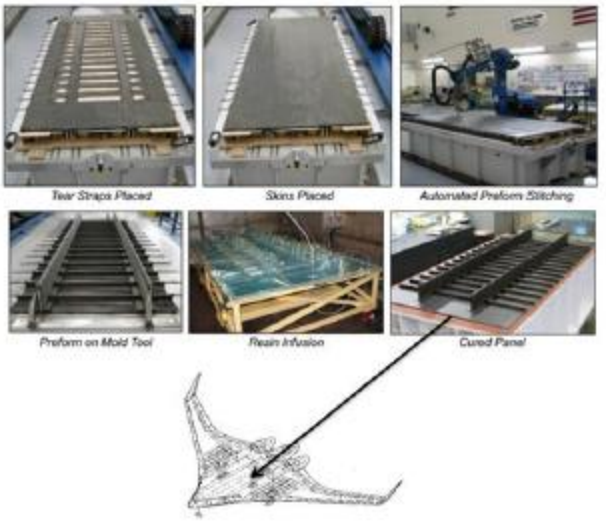

Figure 3 – Manufacturing process of stiffened stitched panel using vacuum infusion process and its location on the air craft [6].

Despite these advantages for stitched composites there are some disadvantages with the stitching process. The main one of those is a reduction in the in plane properties of the resultant composite component. As the needle penetrates into the fabric, it can cause localized in plane fibre damages and fabric distortions, which have been found to reduce the mechanical performance of the composites. Furthermore, the performance reduction is increased by the loops formed during stitching which can also crimp the fabric in the thickness direction if the tension in the stitch thread becomes high. Stitching process causes distortions in the fabric and in resin rich regions in the composite. This region mostly acts as a crack initiator which can decrease the performance of the composite.

Braiding and knitting

3D braiding process can be used for producing a near net shape preforms. This process can be applied to produce airframe spars, F-section fuselage frames, rib stiffened panels, rocket nose cones, fuselage barrels, tail shafts, and rocket engine nozzles [7]. In braiding process, several carriers move spools in the circular path such that the end of yarns is fixed on a mandrel and interlace. The main disadvantages of the 3D are slow throughput and complicated set ups.

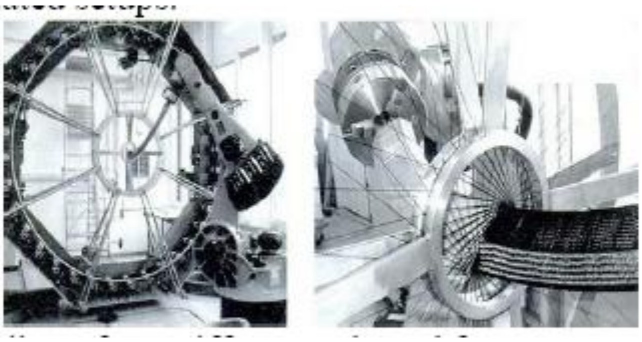

Figure 4 – Robotic braiding of a J-stiffener. [7].

Knitting process is used to the production of garments. It has received attention from the preform manufacturers for producing complex 3D structures. The knitted fibre architecture results high flexibility. However the major disadvantages of this process is that fibre breakges occur during the manufacturing of preform, particularly for carbon fibres [8-11]. Other major problem around the knitted reinforcements is the loop structure makes local stress concentrations. So their mechanical properties are generally lower than alternative techniques.

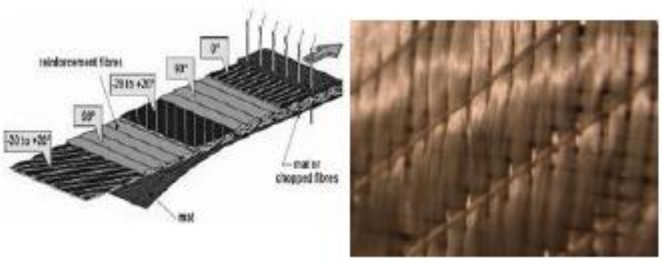

Figure 4 – Manufacture of multiaxial knitted fabric by LIBA technique and snapshot of knitted Fabric [10]

Fabric deformation modes

The use of textile fabrics in aerospace industry gives the possibility to produce complex shape components using liquid composite moulding. The textile fabric structure influences the manufacturing properties such as deformability, porosity and permeability and mechanical properties of final composite parts. The characterization of local fiber variation occurred during forming, fibre volume fraction and fibre thickness are significant parameters to describe the performance of textile fabrics. During the forming of textile fabrics the following deformation mode occur: shearing, straightening, wrinkling, stretching, interply stitching and intra ply slippage [12,13]. If the directions of applied tensile load to textile fabric do not coincide with the fibre tow orientation, fabric shear mode occurs. This deformation is subject to high friction. Figure below depicts the shearing modes occurred in transverse or parallel to fibre tow.

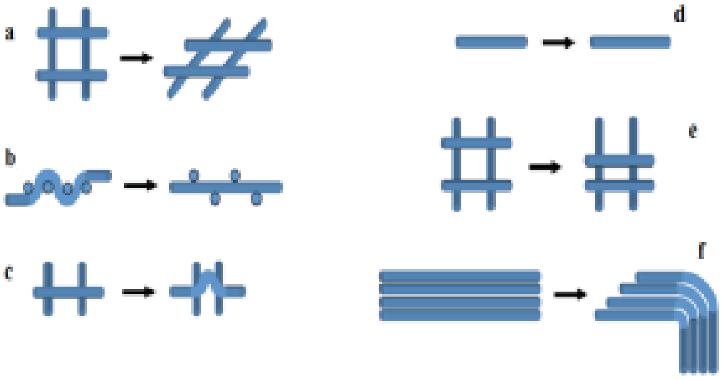

Figure 5 – Deformation modes of a textile fabric

a) Shearing ; b) Straightening ; c) wrinkling ; d) stretching ; e) intra ply slippage

Fibre straightening is accompanied with changes in fibre curvature under tensile load. Effect of fibre straightening mode is substantial for knitted fabrics. However, effect is low for other fabrics with low undulation structure. Elastic stretching of fibre has minor importance, because the reinforcement textiles used for advanced applications are composed of high elastic tensile modulus. Interply and intraply slipping of the fibre tows mostly occur at corners of the surface and sharp edges [14-17].

In addition to the deformation modes mentioned above, other effects such as bending and torsion occur, as shown in figure below. It can be because of the friction between the fibre tows and compression caused by forces normal to the axes of the fibre tows.

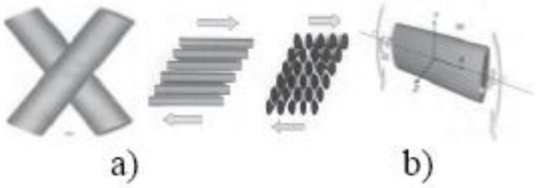

Figure 6 – a) Fibre shearing in direction of fibre tow and in transverse direction

b) Bending and twisting deformations [15]

Based on the deformaton modes demonstrated above, textile mechanics of preforms must include a description of their behavior under combined biaxial tension, shear and compression loading conditions. In order to provide a clearer understanding of the tests to be included are tensile test, shear test, compression test, bending test, and friction test. The fabric behavior under loading is also to be considered.

Textile forming

Complex shaped textile composite needs 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 behavior for forming. For instance, drapability of fabric for a nose cone or blade geometrics are the main characteristics investigated for the adaptation of the fabric on their tools.

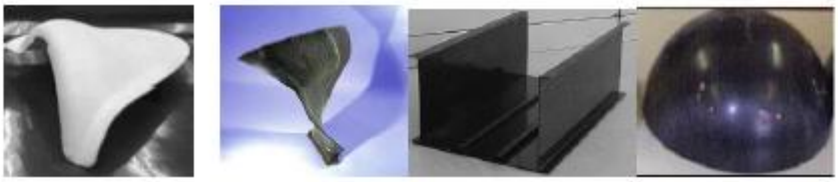

Figure 7 – Typical complex shape parts composed of textile fabric

The drapability of textile fabrics can be expressed in terms of shear deformation, local shear angle yarn slippage and wrinkling defect [18]. To be clearer, drape test fo four different types of textile fabric including a basket, plain, twill, and satin weave are depicted in figure below

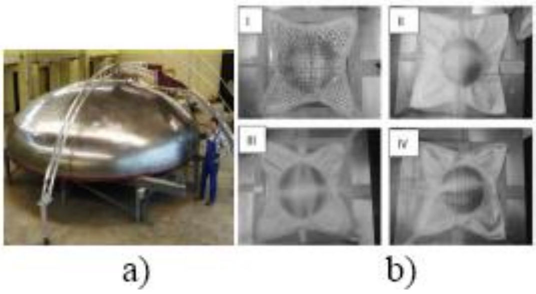

Figure 8 – a) Double curve surface used for manufacturing of bulk head pressure
b) Textile fabrics draped on hemispherical I) Basket II) Plain III) Twill IV) 5 harness satin. [18]

It is clearly seen that the plain weave exhibits high shear deformation and the worst drapeability due to high level of fiber undulation in comparison with other fabrics. It is worth to say that these local shear deformations can result in considerable local change of fiber volume fraction.

Textile composite manfacturing process

A wide range of manufacturing processes are available for the textile composite. The most commonly used process is the resin transfer molding which provides industry to manufacture net shape parts in closed tooling. The main feature in resin transfer molding is the injection of the liquid polymer through a dry perform laid in a closed mold. The impregnation quality depends on the combination of pressure at which the resin is injected, temperature, resin viscosity, mold cavity shape and perform properties. Many other techniques are derived from this manufacturing method, such as the resin infusion process in which resin flows through the mold and impregnates the fibres due to vacuum applied in the outlet. This technique allows the possibility to fabricate various composite components ranging from low to high performance, and small to large dimensions [19,20]. Highly complex structures can be produced by using vacuum resin transfer molding that reduces part count and off setting costs with the intermediate assembly stage.

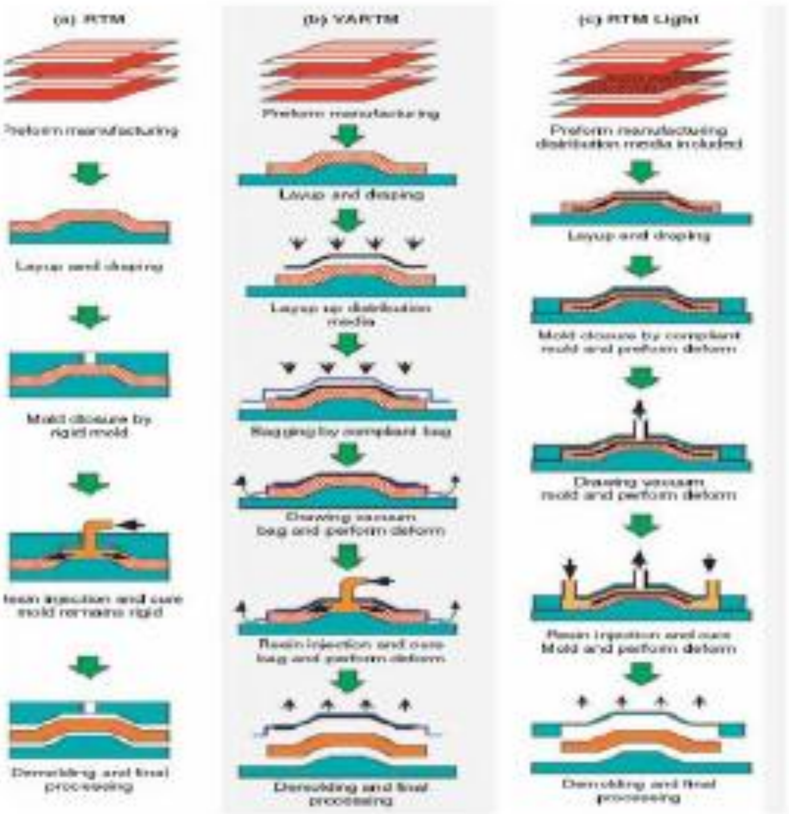

Figure 9 – Typical composite manufacturing process [19]

A number of factors influence the composite manufacturing process. These are

a) Dependency of resin flow to fabric structure
b) Effect of perform thickness on flow patterns
c) Compressibility of textile fabric
d) Dependence of permeability in textile fabric

Quality problems associated with manufacture of textile composite

The resin transfer molding processes can fabricate high performance textile composite structures. Improved resin curing process and control of relevant process parameters are significant issues to enhance product quality. If these parameters are not controlled void formation can result the reduction in the mechanical properties [21-23]. The main reasons leading to form void in resin transfer molding technique can be classified as follows:

a) Evaporation of mold
b) Resin outgassing
c) Preform permeability
d) Fibre volume
e) Race tracking

Defects in composites

Most common defects appearing in textile composite structure are as follows:

a) Delamination
b) Ply misalignment
c) Disbands
d) Voids
e) Impact damage
f) Porosity
g) Inclusions
h) Erosion
i) Matrix cracking
j) Inaccurate fibre volume fraction
k) Fibre breakage
l) Kissing bonds
m) Incorrect cure

Damages in 3D textile preforms

The most important part for manufacturing 3D textile composites is textile performs which have considerable influence on the mechanical properties of the textile composite. The various types of defects in textile performs (2D and 3D) is shown in figure below

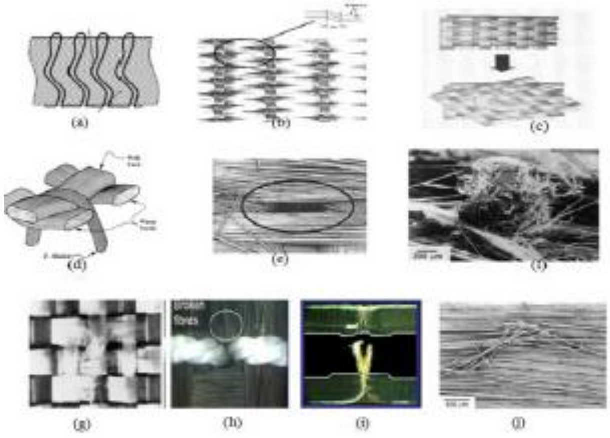

Figure - Different types of preform defects [25]

a) Misaligned through the thickness yarn
b) Misalignment of fibre bundle due to stitching
c) Textile fabric misalignment
d) Fibre crimping
e) Resin rich region

f) Fibre pullout
g) g-j) Fibre breakage

The defects are classified as follows

a) Fibre misalignment
b) Fibre crimping
c) Fibre breakage
d) Resin rich pocket
e) Compaction
f) Stitch distortions
g) Fibre pull out
h) Inclusions
i) Moisture entrapment

Non destructive testing of 3D textile perform composite

Because of advanced applications of textile composite in aircraft structure, there is high need to non destructive evaluation for these composites [24,25]. Non destructive testing process for textile composite can be divided into two parts: Inspection of perform and final composite**.** Ultrasonic and elastic waves and X ray techniques have been adopted.

II. CONCLUSION

3D textile performs and composite specifications and various types of damages in these materials have been highlighted. Furthermore, the deformation mode of textile fabrics have been discussed, and so also fabric architects. A great deal of experimental data have been published on the strength of stitched composites for various load conditions, but there is still an impediment to the acceptance of stitched textile fabrics for aerospace composite industry due to uncertainty and conflicting research results concerning their degradation and in plane properties. This is probably because of not disclosing the key parameters such as thread tension, needle size etc. Furthermore, the state of the art non destructive testing techniques developed for detecting defects in 3D performs and composite has been presented. At the moment, it can be claimed that that X-ray imaging method especially micro CT technique and C-scan ultrasonic are most useful methods to detect damages in textile perform and composite.

REFERENCES

[1]. Poe C. (1997). A review of the NASA textile composites research, T.R.N-97-1321. Washington DC.
[2]. National Aeronautics and Space Administration.
[3]. Mouritz A (1997). Review of applications for advanced three dimensional fibre textile composite,
[4]. Composite, 30(12), 1445-1461.
[5]. Horrocks, A. R., (2000). *Handbook of technical textiles*. Cambridge, England: Woodhead.
[6]. Bogdanovich, E., & Mohamed M. (2009, Nov/Dec). Three-dimensional reinforcements for composites. *Proceedings of the ICCM International Conferences on Composite Materials, Edinburgh, UK.*
[7]. Tong L., Mouritz, A. P., & Bannist, M. (2002). *3D fibre reinforced polymer composites*. London: Elsevier Science.
[8]. Weimer C., Mitschang P., & Drechsler K. (2000). Approach to net-shape preforming using textile technologies. Part I: Edges. *Composites: Part A, 31*(11), 1261-1268.
[9]. Uozumi, T., Kito, A., & Yamamoto, T. (2005). Cfrp using braided preforms/rtm process for aircraft applications. *Advanced Composite Materials, 14*(4), 365-383.
[10]. Robitaille, F., & Gauvin, R. (2014). Compaction of textile reinforcements for composites manufacturing. I: Review of experimental results. *Polymer Composites, 19*(2), 198-216. https://doi.org/10.1002/pc.10091.
[11]. Schmitt R. (2007). A method for edge detection of textile preforms using a light-section sensor for the automated manufacturing of fibre-reinforced plastics. *Proceedings Of Spie Optical Measurement Systems For Industrial Inspection V At The World Of Photonics Congress, Munich, Germany*.
[12]. Otluri, P., & Atkinson, J. (2003). Automated manufacture of composites: Handling, measurement of properties and lay-up simulations. *Composites Part A: Applied Science And Manufacturing, 34*(6), 493-501.
[13]. Potluri P., & Sagar, T. V. (2008). Compaction modelling of textile preforms for composite structures. *Composite Structures, 86*(1-3), 177-185.
[14]. Barandun, G. A. (2009). *Injection strategies for liquid composite moulding processes*. doi: https://doi.org/10.3929/ethz-a-005963299.
[15]. Clarke, S. (2018). *3D woven textiles for composite applications*. Retrieved from http://www.uammi.org/new/wp-content/uploads/2018/03/06-Steve-Clarke- TEAM-3D-Weaving-UAMMI-Slides-032018.pdf.
[16]. Ermanni P. (2009). *Textile halbzeuge*. Retreived from https://www.carbon-connected.de/ Group/ ETH.Zuerich.Institut.fuer.Mechanische. Systeme.Zentrum.fuer.Strukturtechnologien/
[17]. Schmitt R. (2007). A method for edge detection of textile preforms using a light-section sensor for the automated manufacturing of fibre-reinforced plastics. *Proceedings Of Spie Optical Measurement Systems For Industrial Inspection V At The World Of Photonics Congress, Munich, Germany*.
[18]. Grujicic M., Chittajallu, K. M., & Walsh S. (2005). Non-isothermal preform infiltration during the vacuum-assisted resin transfer molding (vartm) process. *Applied Surface Science, 245*(1-4), 51-64.
[19]. Aroush, D., Gauthier, C., Youssef, S., & Wagner D. (2006). A study of fracture of unidirectional composites using in situ high-resolution synchrotron x-ray microtomography. *Composites Science & Technology, 66*, 1348-1353.

[20]. Hearle, J. (2015). Introduction. In X. Chen, *Advances in 3D textiles*. Cambridge, England: Woodhead.

[21]. Kapadia A. (2007). Non destructive testing of composite materials. *Natural Composties Network*. KU Leuven. (2018). *Research*. Retreived from https://www.kuleuven.be/ onderzoek/

[22]. Robitaille, F., & Gauvin, R. (2014). Compaction of textile reinforcements for composites manufacturing. I: Review of experimental results. *Polymer Composites*, *19*(2), 198-216. https://doi.org/10.1002/pc.10091.

[23]. Robo-technology.com (n.d.). *Design*. Retreived from http://www.robo-technology.com/robo/de/kompetenzen/maschinenbau.

[24]. Unnþórsson R., Jonsson, M. T., & Runarsson, T. P. (2004). Ndt methods for evaluating carbon fiber composites. Retreived from https://notendur.hi.is/runson/ Project/ comptest2004_paper.pdf.

[25]. Hermanek, P., & Carmignato, S. (2017). Porosity measurement service using x-ray tomography. *Precision Engineering, 49*, 377-387.

[26]. Vernet, N., & Trochu F. (2015). In-plane and through-thickness permeability models for three dimensional Interlock fabrics. *Journal of Composite Materials*, *50*(14), 1951-69.

[27]. Abbasali S., (2019). 3d textile preforms and composites for aircraft strcutures: a review,

[28]. International Journal of Aviation, Aeronautics, and Aerospace Volume 6, issue 1, 1-39.