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INFLUENCE OF HONEYCOMB CORE STABILIZATION ON COMPOSITE SANDWICH STRUCTURE GEOMETRY

Mateusz Michalski, **Wojciech Krauze**
Institute of Aviation, Center for Composite Technologies
al. Krakowska 110/114, 02-256 Warsaw
mateusz.michalski@ilot.edu.pl, wojciech.krauze@ilot.edu.pl

Abstract

Authors showed the influence of stabilization of the honeycomb core on shape of the composite sandwich test panel. Adhesive film laid on core ramps and cured with suitable cure cycle served as core stabilizer. Test panel geometry included different ramp angles (20° and 30°). To verify stabilization process a technology trial was performed. Three test panels were manufactured (3-stage, 1-stage and 1-stage with stabilized core). All test panels were manufactured in OoA process (Out of Autoclave). Panel surfaces were scanned with 3D scanner and compared with the reference CAD model. Both outer skin and inner skin were manufactured in Automated Fiber Placement Laboratory of Warsaw Institute of Aviation.

Keywords: composite, carbon fiber, sandwich structure, AFP, thermoset material

1. INTRODUCTION

1.1. Composite sandwich structures

Sandwich structures are common in the aerospace industry and have proved to be successfully implemented over the years in various commercial aircraft (1983 – Rudder in Airbus A310; wing trailing edge panels in Airbus A350; floor, landing gear door, spoilers of Airbus A380; fuselage of Falcon 2000LX) [1÷5].

Materials commonly used for skins: Composite Carbon Fiber or Glass Fiber prepregs with epoxy resin

Materials used for core:

1. foam core (PVC – Polyvinyl chloride, PMI - polymethacrylimide) [6] (Figure 1);
2. honeycomb core – aramid, aluminum alloys (Figure 2).

Figure 1. PMI foam during machining to helicopter blade core shape [Zięba M., 2016]

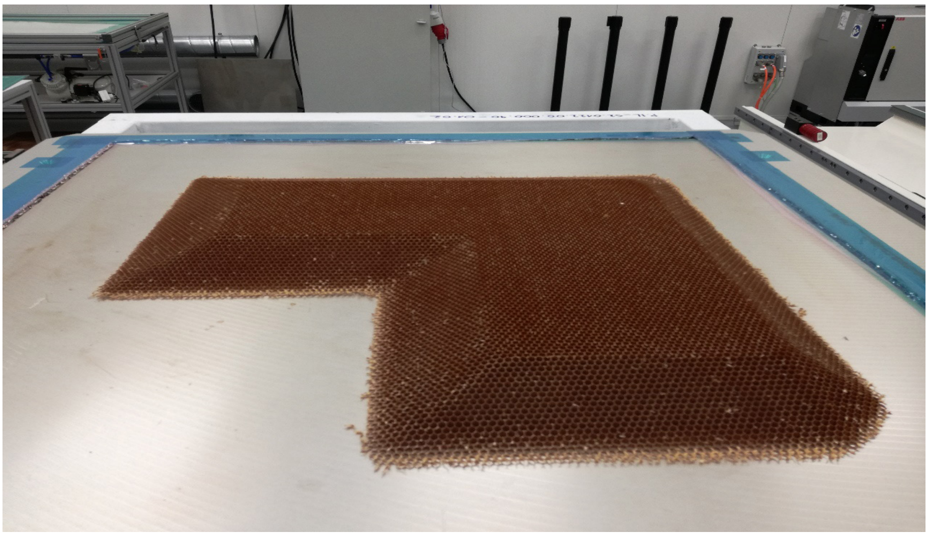

Figure 2. Aramid honeycomb core after CNC machining to required shape [Michalski, 2018]

2. MANUFACTURING METHODS OF COMPOSITE SANDWICH STRUCTURES

2.1. 1-stage process

1-stage process consists of lay-up and cure all parts of sandwich panel (uncured outer skin, layer of film adhesive, core, layer of film adhesive and uncured inner skin) in one, single step. (Figure 3).

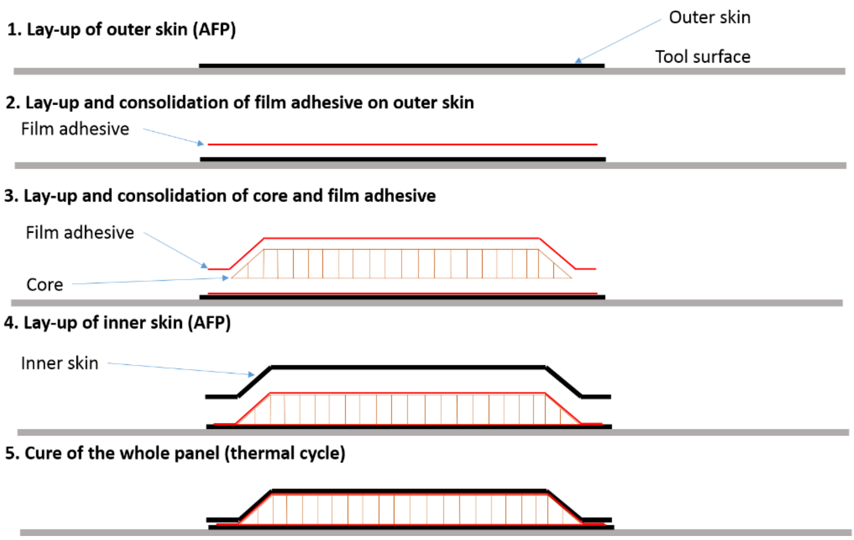

Figure 3. Scheme for 1-stage manufacturing process of composite sandwich panel

2.2. 2-stage process

2-stage process requires to undergo 2 cure cycles: (Figure 4):

1. Cure of outer skin (1st cure cycle),
2. Lay-up of film adhesive, core, film adhesive and inner skin (2nd cure cycle).

2-stage process was not used to manufacture panels described in this paper. It is more complex than 1-stage process and should be considered if 1-stage process does not provide required shape of cured panel.

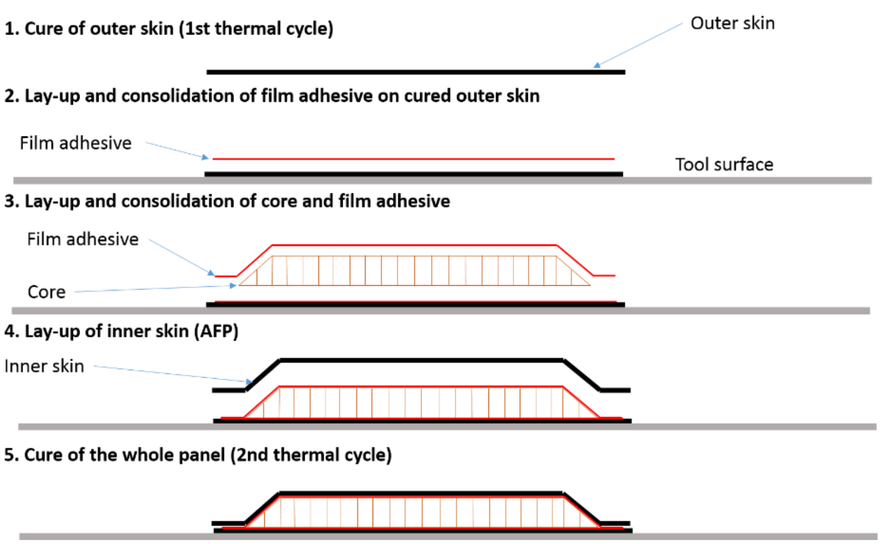

Figure 4. Scheme for 2-stage manufacturing process of composite sandwich panel

2.3. 3-stage process

3-stage process requires to undergo 3 cure cycles (Figure 5):

1. 1st stage - cure of outer skin,
2. Lay-up and cure of layer of film adhesive and core – in 2nd stage core is bonded with the cured outer skin using layer of film adhesive;
3. 3rd stage consists of lay-up and cure of panel inner skin which completes the composite sandwich panel.

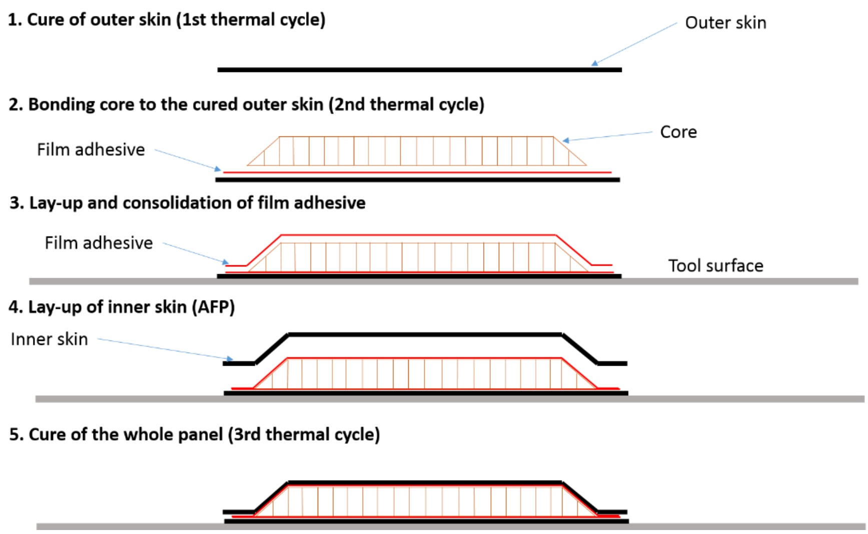

Figure 5. Scheme for 3-stage manufacturing process of composite sandwich panel

3. CORE STABILIZATION

During cure cycle of the composite sandwich panel a pressure acts on the panel due to vacuum in the vacuum bag. It causes a deformation of the core especially in the ramp area (Figure 6), because core is susceptible to deformation in directions perpendicular to its height with minimal force. Core stabilization is a process that allows the core to maintain its shape during cure cycle. It is realized by local lay-up and cure of film adhesive in additional cure cycle.

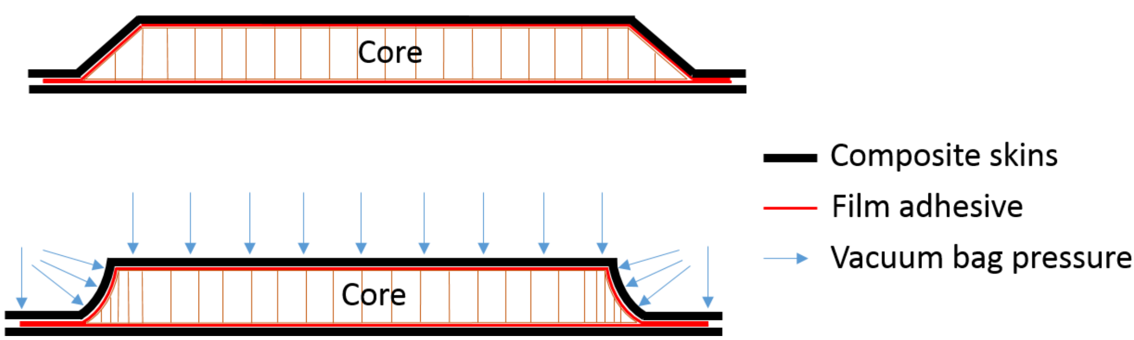

Figure 6. Deformation of core due to a pressure acting on core surface in the vacuum bag during cure cycle.

Core deformation effect does not occur in panels manufactured in 3-stage process because 2nd stage provides stabilization to the core.

Reason for using core stabilization is directly related to cost of manufacturing. 3-stage process is the most time and labor consuming process which translates to elevated production cost of each panel. Because of that one should seek different processes that reduce time and labor (in this case 1-stage process is the most cost effective). Main disadvantage of using core stabilization is the panel mass increase due to 2 additional layers of film adhesive.

4. MATERIALS USED TO MANUFACTURE COMPOSITE SANDWICH PANELS

Material used to manufacture skins of test panels is PARK E-752LT HTS45 12K in form of unidirectional prepreg slit to 0.25” (6.35 mm) wide tapes bespoke for Automated Fiber Placement machines (AFP) [7].

Core material is Nomex HRH-10 (density 45 kg/m^3 and cell size 3/16”).

Film adhesive used for both bonding core with laminate and stabilizing the core is 3M FM 309-1 of density 225 g/m^2.

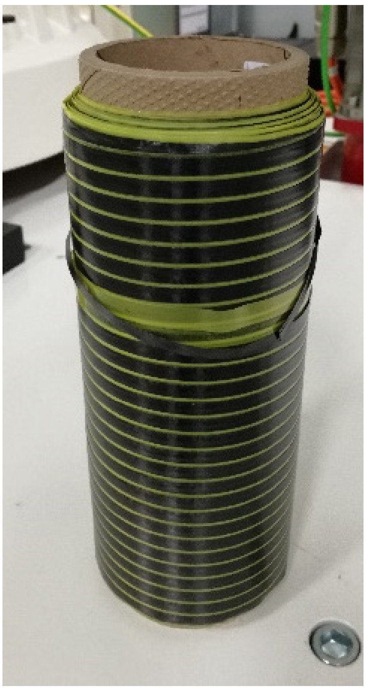

Figure 7. Bobbin of unidirectional prepreg of PARK E-752LT HTS45 12K [Krauze, 2018]

5. TECHNOLOGY TRIAL OF CORE STABILIZATION

Before stabilization of the L-shaped core a technology trial was performed on a simple, hand-shaped core panel with approximate ramp angle of 45deg. Technology trial consisted of lay-up of film adhesive on the upper and lower side of the core and cure with thermal cycle for FM 309-1 film adhesive.

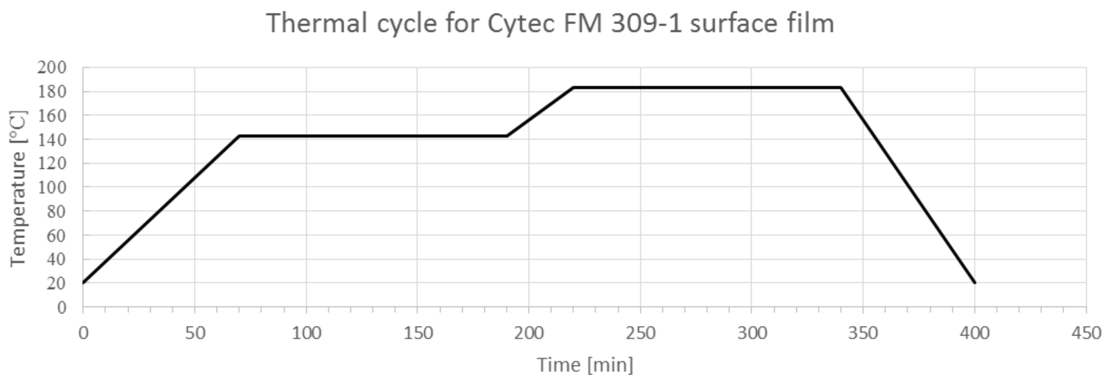

Figure 8. Cure cycle for Cytec FM 309-1 film adhesive

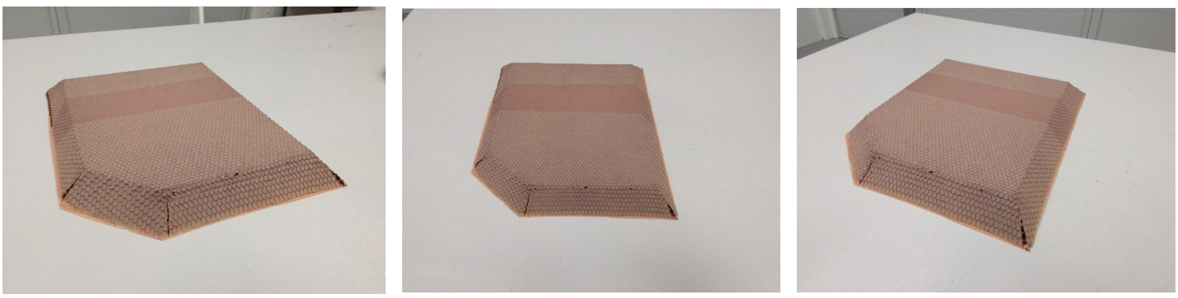

Figure 9. Technology trial of core stabilization [Michalski, 2017]

The result of the trial showed that film adhesive was evenly distributed across whole core surface and core shape remained unchanged during cure cycle. Due to positive result of the trial technology was transferred to the L-shaped panel.

In order to reduce weight of the adhesive only ramps with surplus were covered with film adhesive (Figure 10).

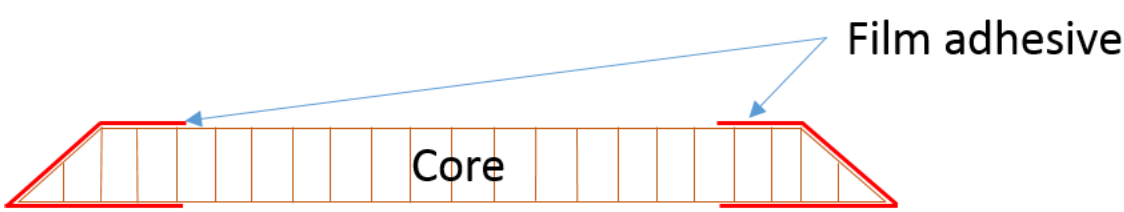

Figure 10. Scheme of film adhesive layers for core stabilization

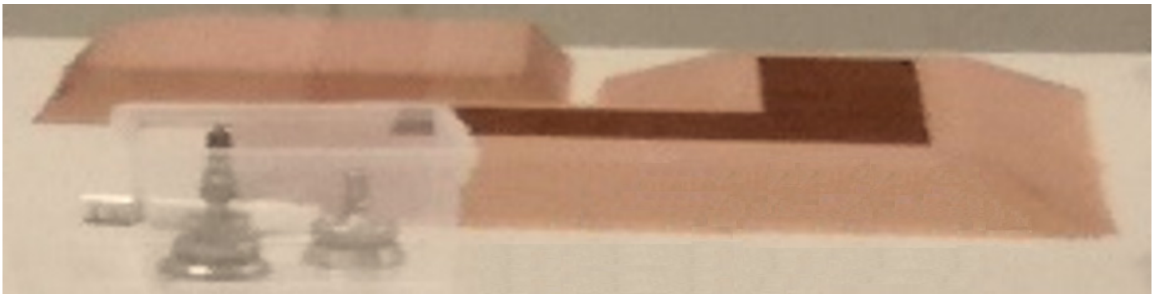

Figure 11. Stabilized core of L-shaped panel [Michalski, 2017]

6. COMPOSITE SANDWICH TEST PANELS

In order to effectively measure the effect of core stabilization on the shape of composite sandwich panel a 3D scan was performed on each manufactured panel inner skin surface. Digitized surfaces were then compared with nominal shape (CAD model). Model was prepared using Dassault Systems Catia V5 software package with CPD module used for film adhesive flat pattern creation [8]. Comparison showed how and to what extent the shape of the manufactured panels differ from the reference geometry. Comparison was performed on 3 different composite sandwich panels:

1. 1-stage composite L-shaped sandwich panel (core without stabilization);
2. 1-stage composite L-shaped sandwich panel (core with stabilization);
3. 3-stage composite sandwich panel.

Reference geometry and dimensions of the panel are shown in (Figure 12, Figure 13, Figure 14).

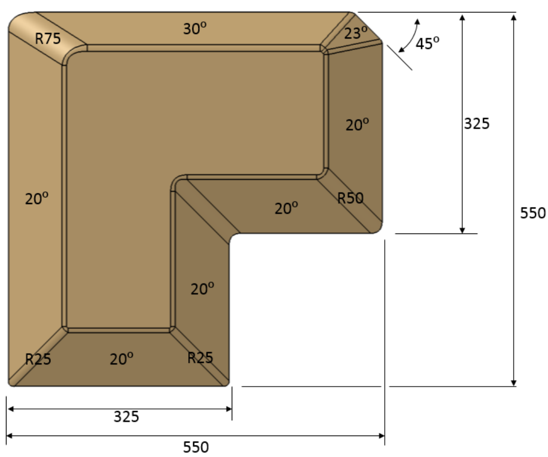

Figure 12. Dimensions of L-shaped core

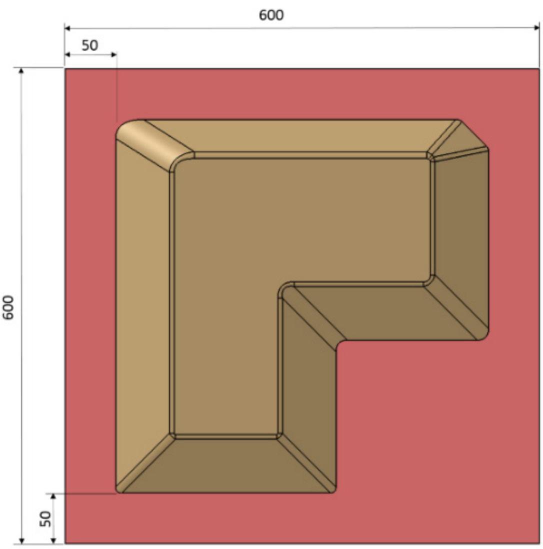

Figure 13. Laminate dimensions and core position on the laminate

Figure 14. Height of the core

During visual inspection panel manufactured in 3-stage process did not show deformation of ramps (Figure 15). On panels manufactured in 1-stage process 30° ramp deformed which can be clearly seen in (Figure 16 and Figure 17).

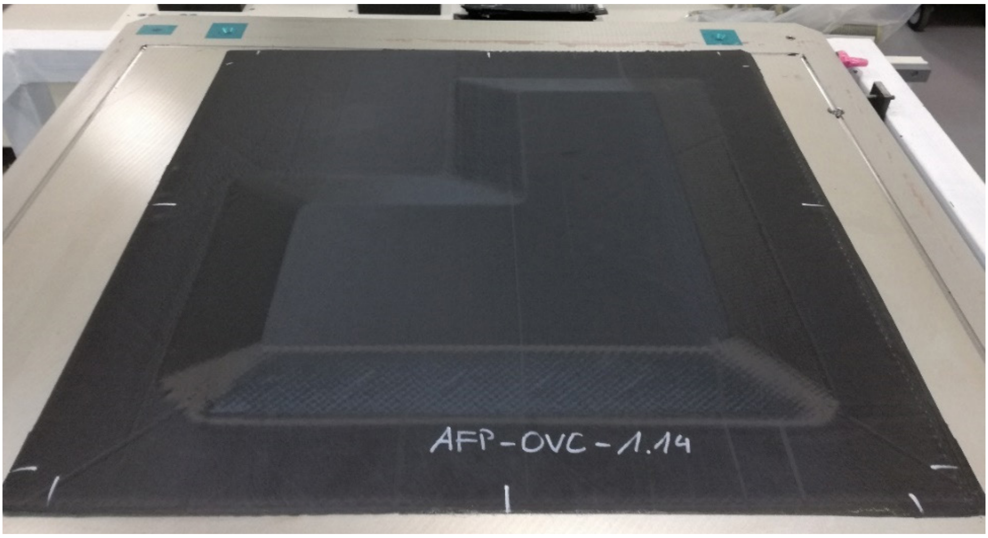

Figure 15. Cured panel manufactured in 3-stage process [Krauze, 2018]

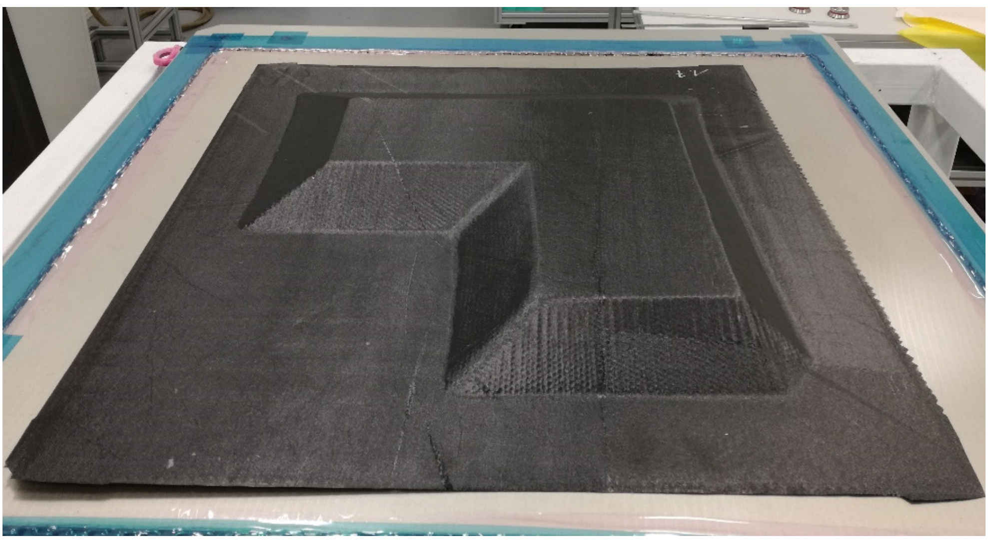

Figure 16. Cured panel manufactured in 1-stage process without core stabilization [Krauze, 2018]

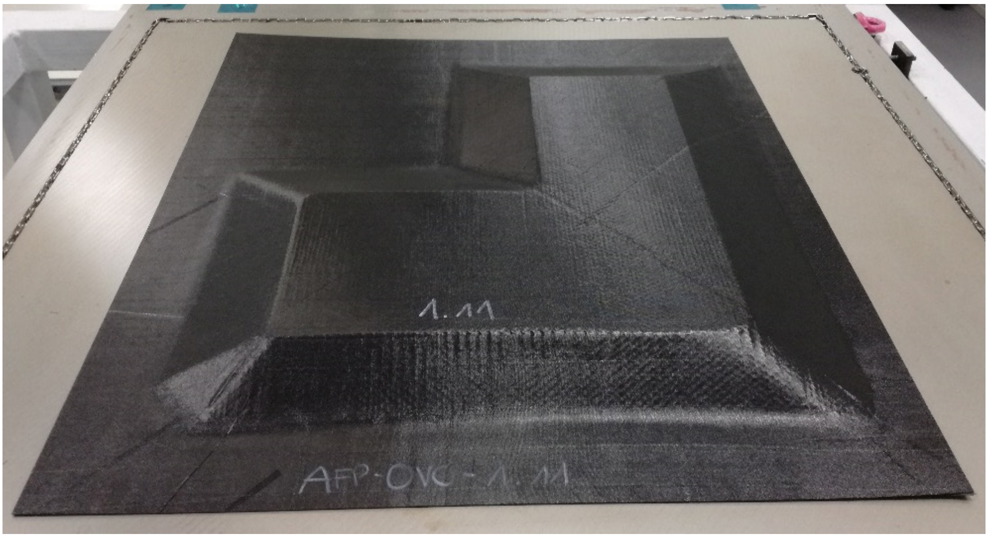

Figure 17. Cured panel manufactured in 1-stage process with core stabilization [Krauze, 2018]

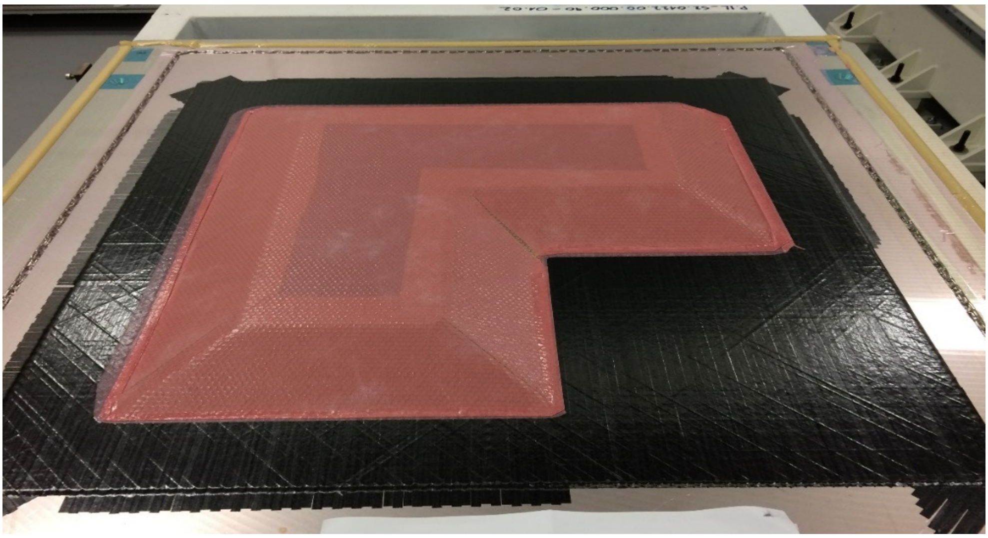

Figure 18. Stabilized core laid on the outer skin with layer of film adhesive [Krauze, 2018]

7. COMPARISON OF MANUFACTURED COMPOSITE SANDWICH PANELS

Composite panels were scanned with Creaform Handyscan 700 3D scanner and were analyzed for deformations compared to reference shape (CAD model). Additionally, a comparison between panels with and without stabilization was performed.

Analyses of 3D scans illustrate differences in shape of the measured object compared to the reference (in millimeters). Positive value indicates that the measured point of surface is outside of the reference object. Negative value indicates that the measured point of surface is inside the reference object.

It can be seen that in 1-stage panel without core stabilization whole surface of the 30° ramp is collapsed. Deformation is equal to 7÷10 mm. Sides of the ramp are less deformed with the ramp center being the most deformed area. 20° ramps are moved inside around 2mm compared to the reference geometry. (Figure 20)

In 1-stage panel with core stabilization 30° ramp deformation is significantly lower (5÷8.5 mm) compared to the panel without stabilization. 20° ramps are equally moved inside around 2 mm (Figure 21). Ramps surrounding the laminate area of the panel are moved outside compared to the reference geometry due to lay-up of additional 4 local plies on the laminate area which are not included in the CAD model (area marked with a frame).

Deformations in 3-stage panel were significantly lower compared to the 1-stage panels' geometries and were equal to around 1mm all over the inner skin surface. There was no difference in deformation of 20° and 30° ramp. Laminate area surrounding the core is elevated compared to the reference CAD geometry due to lay-up of additional frame to compensate for core nose height (Figure 19).

Direct comparison of geometry of 1-stage panels confirms that stabilization reduces 30° ramp deformation of 2÷4 mm (Figure 23). Difference in height in laminate area and adjacent ramps is a result of additional 4 plies laid in that area in panel with stabilized core (marked with a frame - Figure 21).

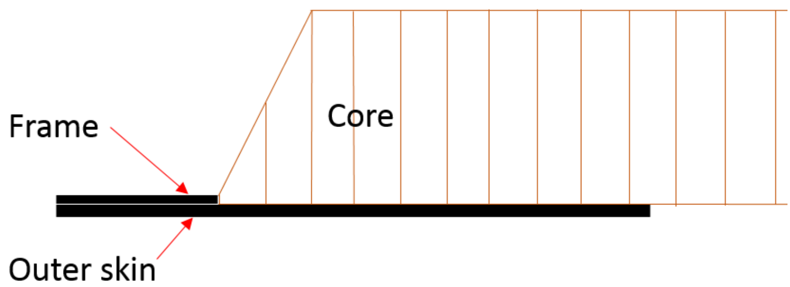

Figure 19. Frame laid to compensate for core nose height

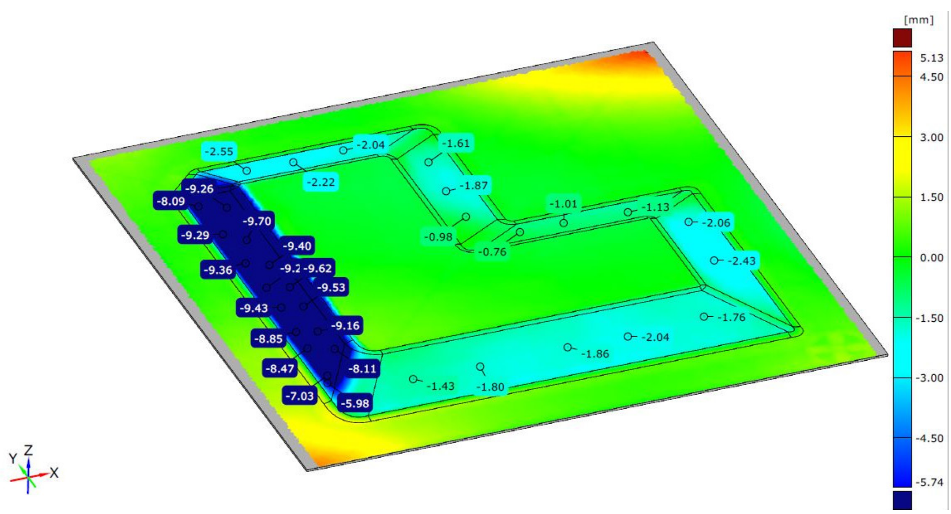

Figure 20. Comparison of inner skin shape of panel without core stabilization with CAD reference geometry

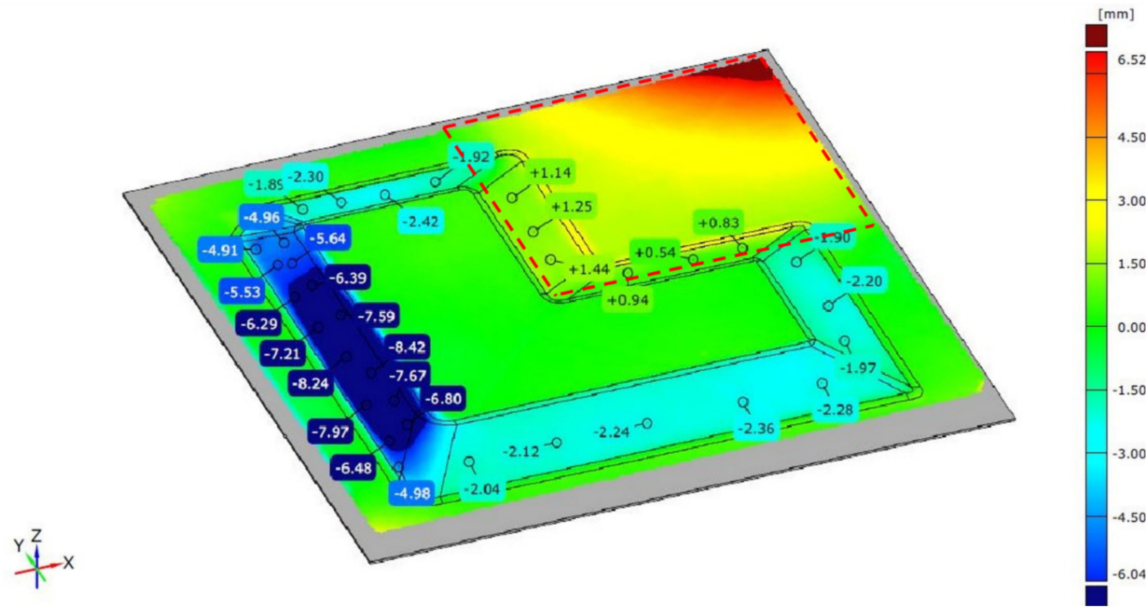

Figure 21. Comparison of inner skin shape of panel with core stabilization with CAD reference geometry

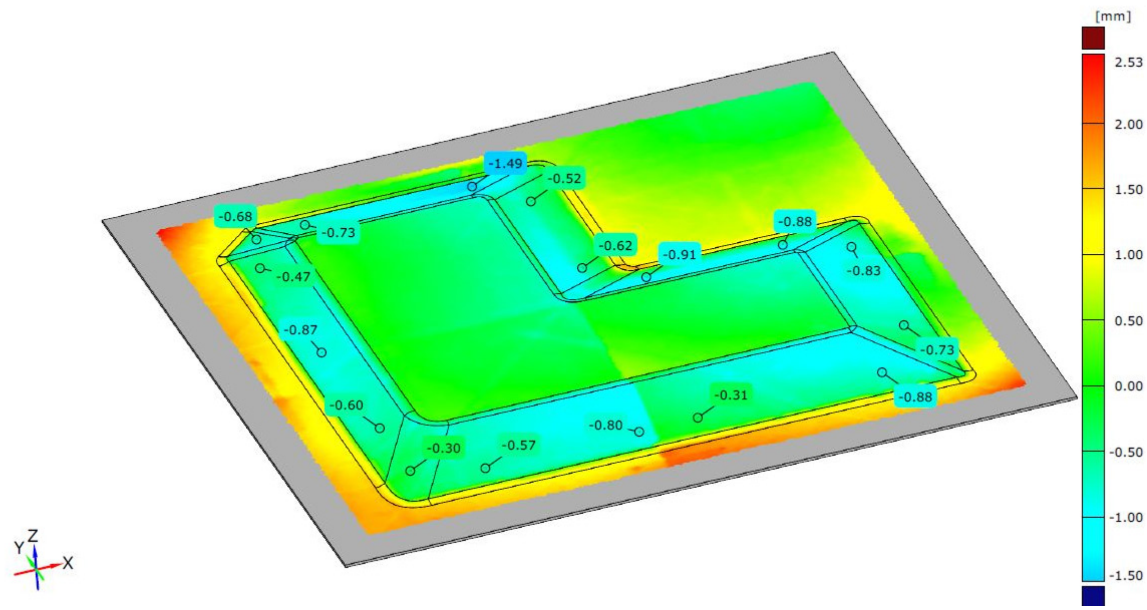

Figure 22. Comparison of inner skin shape of 3-stage panel with CAD reference geometry

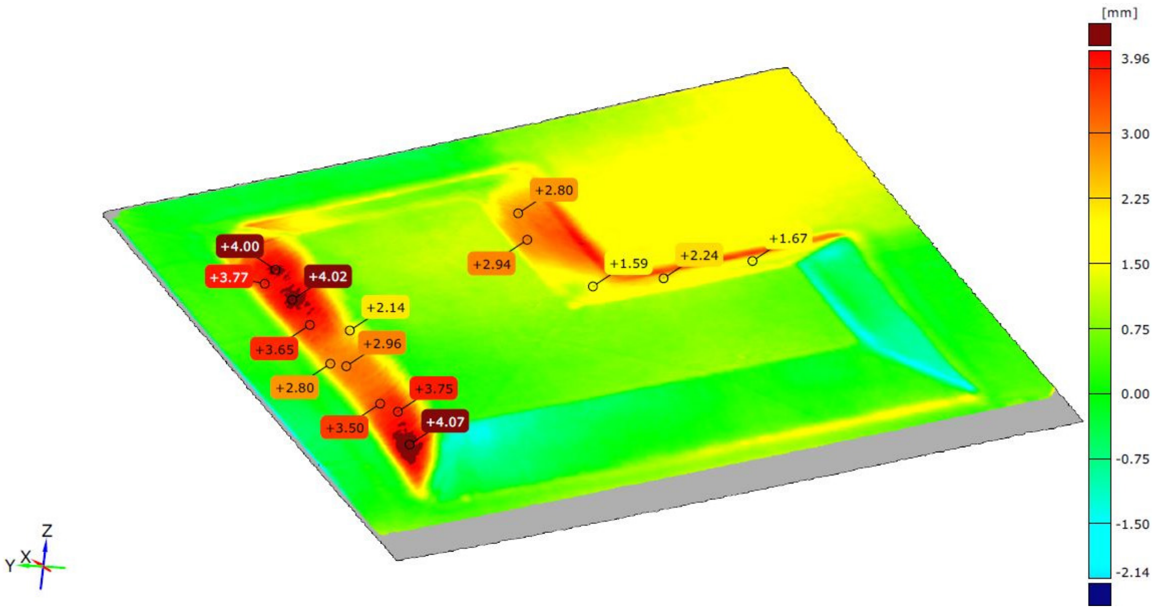

Figure 23. Comparison of inner skin shape of panel without core stabilization with panel with core stabilization

8. CONCLUSIONS

Based on performed geometry analyses of manufactured composite sandwich panels authors conclude that:

1. Core stabilization resulted in lower ramp deformations in 1-stage composite panel but it did not prevent core deformation. Difference in 30° ramp deformation between panel with stabilization and panel without stabilization was 2÷4 mm.
3. Influence of core stabilization for 20° ramp angle is negligible. Deformation of 20° ramp for both panel with stabilized core and without stabilization was identical and equal to ~2 mm compared to the reference CAD model.
4. For 30° ramp angle both panels (with and without stabilization) were severely deformed compared to the reference CAD model (5÷8.5 mm and 7÷10 mm respectively).
5. Geometry of panel manufactured in 3-stage process is the closest to the geometry of reference CAD model. Deformations are equal to around 1mm (panel is thinner than reference) all over the inner skin surface.
6. Future tests should include usage of different type and density of film adhesive which might have positive effect on preventing deformation of ramps with angles greater than 20°.
7. In case of no or very little improvement of inner skin geometry using core stabilization in 1-stage process it may be necessary to manufacture composite sandwich panel in 2-stage process.
8. For ramp angles of 20° and less it is not necessary to stabilize core in 1-stage process.
9. Surface geometry comparison using 3D scanning is very efficient (time of scan of 1 panel – 15 min) and allows to verify shape on whole surface what is a significant improvement over traditional metrological methods where measurements are typically performed locally on previously defined control points.

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WPŁYW STABILIZACJI WYPEŁNIACZA KOMÓRKOWEGO NA KSZTAŁT KOMPOZYTOWEJ STRUKTURY PRZEKŁADKOWEJ

Streszczenie

W artykule przedstawiono wpływ stabilizacji wypełniacza komórkowego na kształt utwardzonej części kompozytowej w postaci przekładkowego panelu testowego o różnych kątach pochylenia ramp (20° oraz 30°). Jako stabilizator wypełniacza posłużył klej błonkowy położony na rampach wypełniacza i następnie utwardzony w odpowiednim cyklu termicznym. Po przeprowadzeniu pozytywnej próby technologicznej stabilizacji wypełniacza zostały wykonane 3 panele w różnych technologiach (1 oraz 3 etapowym). Panel ze stabilizowanym wypełniaczem został utwardzony w procesie 1 etapowym. Wszystkie panele wytworzone zostały w procesie bez użycia autoklawu (OOA – Out of Autoclave). Porównaniu metodą skanowania 3D została poddana powierzchnia wynikowa paneli po utwardzeniu. Jako referencję do porównania został przyjęty model CAD panelu. Zarówno warstwa zewnętrzna jak i wewnętrzna zostały ułożone w Laboratorium Zrobotyzowanego Układania Taśm Kompozytowych Instytutu Lotnictwa za pomocą robota AFP (Automated Fiber Placement).

<u>Słowa kluczowe</u>: kompozyt, włókno węglowe, struktura przekładkowa, AFP, materiał termo-utwardzalny