Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 44 (2016) 310 – 315

www.elsevier.com/locate/procedia

6th CIRP Conference on Assembly Technologies and Systems (CATS)

A new approach on integrating joining inserts for composite sandwich structures with foam cores

J. Schwennen*, V. Sessner, J. Fleischer

wbk Institute of Production Science, Karlsruhe Institute of Technology (KIT), Kaiserstr. 12, 76131 Karlsruhe, Germany

* Corresponding author. Tel.: +49 721 608-41674; fax: +49 721 608-45005. *E-mail address:* jan.schwennen@kit.edu

Abstract

Due to their high potential in lightweight designs composite sandwich structures with foam cores are gaining in importance in the automotive industry. To carry localized loads, sandwich structures require load introduction elements. In current solutions applied in the aerospace industry the inserts are embedded after the sandwich panels have been manufactured. This is very time consuming and therefore too expensive for automotive industry. In this paper, two new approaches are investigated experimentally, where the inserts get integrated during the preforming process or during the foam core manufacturing. With these manufacturing methods the performance and failure behavior of various insert geometries and different foam core densities will be determined by static pull out tests.

Peer-review under responsibility of the organizing committee of the 6th CIRP Conference on Assembly Technologies and Systems (CATS)

Keywords: joining; insert; composite; sandwich; RTM

1. Introduction

Increasing demands for lower CO_2 emissions and fuel consumption in the automotive industry require new lightweight structures. Therefore designs from the aerospace sector are gaining importance for high volume productions of automotive components. Fiber-reinforced plastics (frp) offer great stiffness and strength to weight ratios thus have an outstanding potential for lightweight design. Used in sandwich structures with light core materials and facesheets made of frp, these characteristics can be applied even more effectively. By adding only little weight due to the additional core the structure becomes a lot more rigid for bending, thus less material is needed and lighter parts can be designed. Common core materials are honeycomb structures or polymeric foams. Honeycomb cores are already widely spread in the aerospace industry due to their high specific mechanical properties. They can outperform foam cores in terms of stiffness to weight ratios [1, 2]. However this advantage is balanced out by higher costs [3], making foam cores more suitable for applications in the automotive industry. A further advantage of foam cores is that complex 3D core geometries can be easily manufactured by filling an appendant tool with foam. They also provide good insulation characteristics [4], and show great energy absorption capabilities [5].

In order to join sandwich panels and carry local loads subjected to the surface, the structure needs reinforcements in the form of so-called inserts to prevent premature failure. Their task is to introduce the loads widespread and avoid stress concentrations [6]. So far many investigations on inserts in different sandwich structures have been carried out. The inserts are commonly classified as partial when the core is only partly substituted by the insert, and through the thickness, when the complete thickness of the core is substituted by additional potting material or the insert itself. Nguyen at al. [1] examined the failure behavior of cylindrical through the thickness inserts in foam core sandwich structures. Several failure modes were observed showing different peaks in the load displacement curves. The most

Peer-review under responsibility of the organizing committee of the 6th CIRP Conference on Assembly Technologies and Systems (CATS)
doi:10.1016/j.procir.2016.02.121

critical failure mode was identified as shear cracking in the foam core and was also predicted with a finite element analysis. Shipsha et al. [7] showed that the failure loads of partial and through the thickness inserts can be increased by optimizing the geometry of the insert which reduces stress concentrations. Nevertheless it is still hard to predict which geometry is generally the best and how the inserts will behave, due to the large variety of examined insert geometries, sandwich materials and dimensions of the structures. Consequently, experimental investigations still need to be carried out to examine the failure behavior and load bearing capacities for specific part dimensions, insert types and material properties.

To increase the use of frp sandwich structures in the automotive industry, also new manufacturing chains will have to be developed, which will enable cheaper components in high volume productions. In the aerospace industry it is common to integrate the insets after the sandwich manufacturing in an additional production step [8]. However, for the automotive industry this is too time-consuming and expensive. Great potential for frp manufacturing in the automotive industry is seen in resin transfer molding (RTM) and especially high pressure resin transfer molding, because of its suitability for automated manufacturing of parts with high quality surfaces [9]. Consequently in this paper a new manufacturing approach for frp sandwich structures with embedded inserts has been investigated. Furthermore the failure behavior of various insert geometries, manufactured with these methods, will be examined.

2. Integration of inserts into sandwich structures

Under the new approach for manufacturing composite foam sandwich structures with embedded inserts, using the resin transfer molding process, the reinforcements will be integrated before the sandwich is manufactured. Accordingly, rework after the resin injection is reduced. In order to do so, two different methods have been used. Figure 1 shows the production chain for sandwich manufacturing using the RTM process. The important steps are foaming of the core, stacking the fiber textiles onto the core, resin injection in the RTM mold and potential rework after demolding the finished sandwich structure. Inserts can be

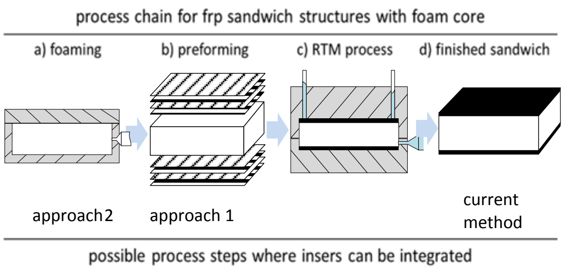

Figure 1: Process chain for fiber reinforced sandwich structures. Inserts can be integrated during different steps of the manufacturing process

integrated into the structure on various steps of the process chain, having specific advantages and disadvantages.

The current most frequently used method is to embed the inserts after the sandwich manufacture has been completed. This results in additional process steps which leads to higher costs. A hole has to be drilled in the sandwich structure, then the insert is placed in the hole and the surrounding is filled with potting material. Additional cure time is needed for the potting material. Also the facesheets have to be damaged locally which lowers the failure loads.

A new approach is to embed the inserts during the preform process (approach 1). Thus, no additional machining after the RTM process is necessary and no extra cure time is needed, as the resin of the RTM process can be used as potting material. In addition, the fiber continuity can be maintained by placing the fibers around the bolt of the insert. This leads to an increased maximum pull out force of the inserts as described in [10]. However with this method only simple insert geometries can be embedded without performing complex and time consuming machining to the core. Welding studs on thin metal plates which can be seen in Figure 4 were chosen for this method because they can be easily embedded in the structure by placing them on top of the core or putting them through clearance holes. Cones are used to slide the fiber textiles around the bolts during preforming and seal the inserts during the RTM process, preventing the resin to flow into the threat. Further methods to seal inner and outer threaded bolts during the resin injection were also tested by Ballier et al. [11].

In order to further reduce the process scope for high volume productions the second new approach is to foam the inserts into the core during the foam manufacture (approach 2). To do so the inserts are placed in the foaming tool. With this method both simple and complex insert geometries can be easily embedded into the core and no machining to the core or additional potting material is needed. Ideally the inserts are already sealed for the RTM process, when placed in the foaming tool and have cones to easily push the fiber textiles over the insert bolts for automated preforming. The only rework step after the RTM process is to remove the sealing from the insert. Thus the process time for the insert integration with this method compared to the insert integration after the sandwich manufacture can be reduced by several process steps, what saves time and therefore money.

3. Setup for experimental investigations

The new manufacturing approaches are now applied to fabricate sandwich structures with different insert geometries. Then quasi-static pull-out tests will be performed with the specimens.

Figure 2 shows the dimensions of the specimens with the embedded inserts. The sandwich plate has a 20 mm thick foam core and the facesheets are 2.7 mm thick. The structures will be manufactured by resin transfer molding. The used epoxy resin system is from Sika® (Biresin®

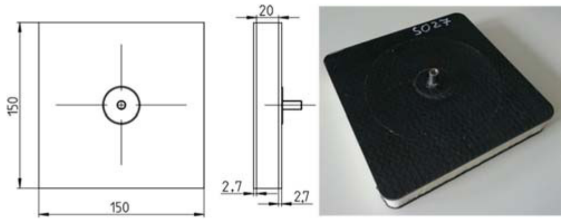

Figure 2: dimensions of the specimen

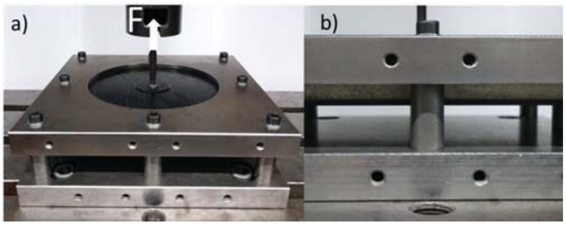

Figure 3: a) the insert will be pulled out through a hole in the upper plate; b) specimen are not clamped in the test device

CR170/Ch150-3). Specimens with facesheets made from 6 and 8 layers of Panex 35 unidirectional carbon fibers with a fabric weight of 309 g/m² were tested. This leads to a facesheet fiber volume content of 38% or 51%. The preforming was done manually. The plies had a stacking sequence of 0°/90°. Both face laminates are built symmetrically. During preforming the insert bolt will be pushed through the plies using a cone. In this way the fiber continuity is maintained. After the RTM process the only rework step on the insert is to remove the cone which sealed the inner thread.

Pull-out tests will be performed on a quasi-static material testing machine which records the load displacement curves. Figure 3 shows the experimental setup. The specimens are not clamped between the upper and bottom plate of the test device as it can be seen in Figure 3b. Through a hole in the upper plate with a diameter of 125 mm the inserts will be pulled out.

4. Pull out tests on flat metal sheet inserts

Three different insert types were tested. They are shown in Figure 4. They consist of a 1 mm thick base plate with a diameter of 30 mm with M6 welding studs. All inserts are

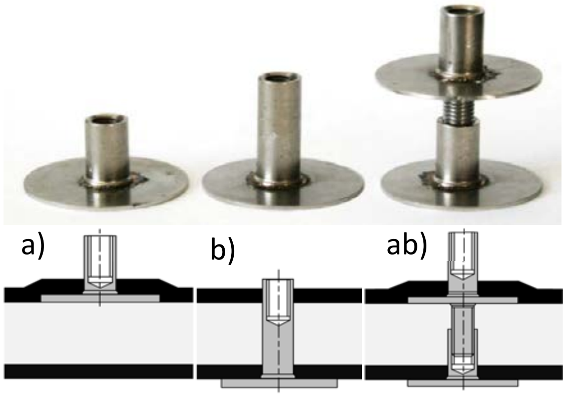

Figure 4: Three insert geometries for pull out tests. Metal sheets have a diameter of 30 mm and a thickness of 1 mm. a) above, b) below, ab) above and below

made of stainless steel (1.4301) to avoid contact corrosion. All specimens were manufactured by embedding the inserts after the foaming process but before the RTM process (approach 1, see Figure 1). The core is made of Rohacell ® 110 IG-F foam. For the insert type b and the type ab a hole was drilled in the core before preforming. The inserts are designed to withstand pull-out forces, accordingly the metal plates are placed below the carbon fibers. Each test series consists of 3 specimens of the same insert type. For these series each facesheet of the sandwich structure consists of 6 layers of unidirectional carbon fiber fabric with a $[0/90/0]_s$ setup.

4.1. Results and discussion

The experimental investigations of the pull out tests are presented in the following. The failure behavior of the specimens and the tensile forces were examined.

4.1.1. Failure behavior

Figure 5 shows exemplary load displacement curves for each insert type. The inserts show different failure behavior for each type and also have different maximum strengths. The curve for the inserts that are connected to the upper facesheet (insert a) consists of two parts (Figure 5a). This was caused by the testing machine which stops the pull out test automatically if the maximumload decreased by more

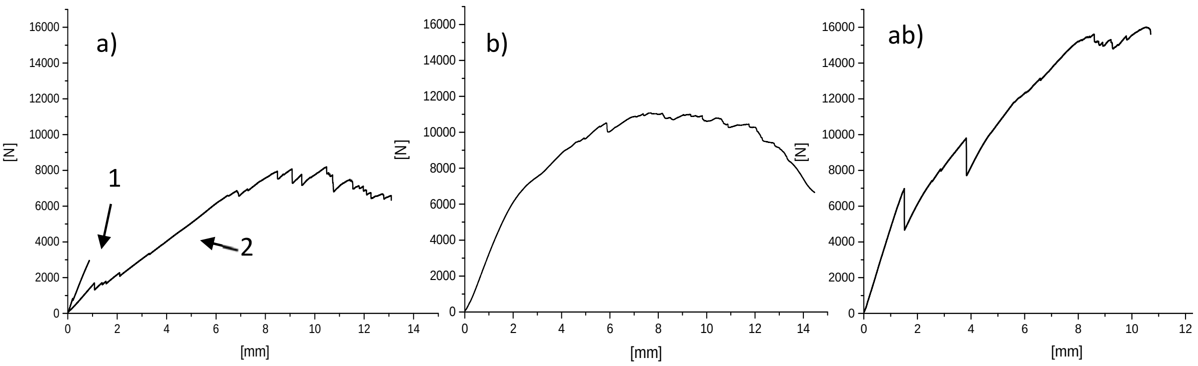

Figure 5: Exemplary load displacement curves for the three different inserts. a) above, b) below, ab) above and below

than 40%. After a linear rise the curve (1) is intermitted as the load dropped abruptly for more than 40%, so that the experiment was automatically aborted. The reason for the peak in the load displacement curve is that the base plate of the insert and parts of the top facesheet debonded from the core since at this point no failure of the laminate could be detected from the outside. After that, the specimens were tested again with the same experimental setup, which leads to the second curve (2). Now the curve shows a lower rigidity, as parts of the upper facesheet have already debonded from the core, the tensile force however further increases. As a consequence the debonding of core and facesheet continues until first fibers start to break in the area around the bolt. After that, delamination and fiber cracking leads to a complete failure of the upper facesheet, as shown in Figure 6a. On the lower face however no defects can be detected. The described behavior occurred on all three specimens of this type.

The failure behavior of the inserts that are connected to the lower face of the sandwich structure (insert b) is shown in Figure 5b and Figure 6b. The load displacement curve shows no characteristic peak in the beginning. After a linear rise the curve shows a degressive behavior. This is caused by plastic deformation of the insert base plate (see Figure 6b) and deformation of the core due to high compression force in the area of the insert base plate. On the upper side of the sandwich structure no defects in the laminate could be found, only the bolt of the insert was pulled out further due to the deformation of its base plate.

The load displacement curve for the insert connected to both sides of the sandwich (insert ab) first shows a linear segment and then two peaks (Figure 5ab). Two failure modes are assumed to cause these peaks. One is the debonding of the core and upper facesheet. The other is shear failure in the foam core material, since cracks could be observed in the core material after manually removing the upper face after the tensile test. One of these cracks can be seen in Figure 6ab. However it is uncertain which of these two failure modes occurred first. Two of three specimens of this insert type showed this behavior, whereas the third one only had the first peak in its load displacement curve.

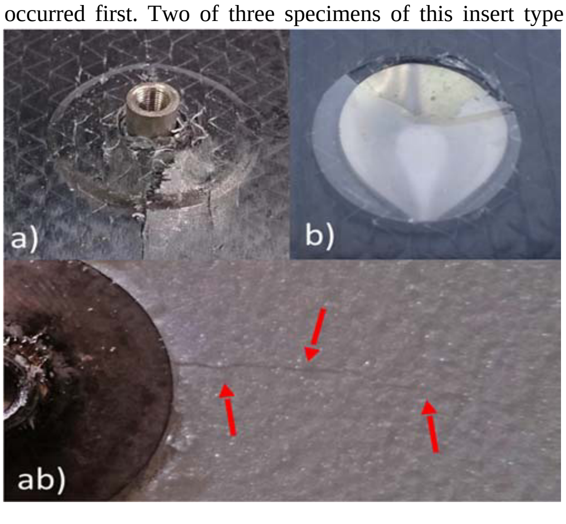

Figure 6: Pictures of the failed specimen: a) above; b) below; ab) above and below insert, cracks in the core going out from the insert can be seen, after manually removing the upper facesheet for insert ab.

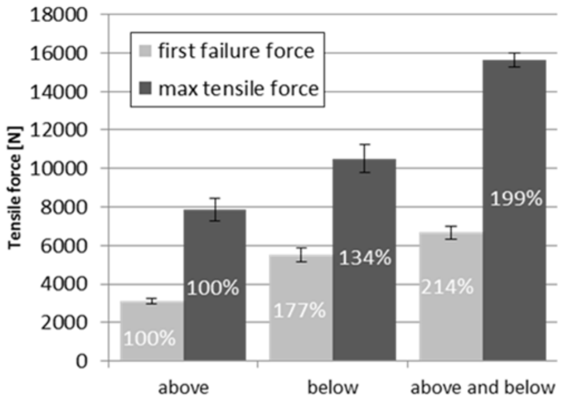

Figure 7: Force of first failure and maximum tensile force for above, below, above and below embedded inserts. Percentages show the improvement compared to the above inserts.

4.1.2. Tensile force

For technical applications two forces are important. The force when either plastic deformation or a first failure occurs which marks the allowable operating load under normal conditions and the maximum load capacity which can be seen as a safety reserve for crashes. Those two loads are shown in Figure 7 for the tested specimens. The first failure force for insert a and insert ab is marked by the first peak in the load displacement curve. For insert b it is marked by the start of degressive behavior in the load displacement curve.

For each insert type the values for the maximum strength are at least twice as high as the ones for the first failure. Both loads can be significantly increased by insert b and insert ab. Debonding of the top facesheet and the core seems to be the most critical failure mode, leading to low first failure forces for insert a. This can barely be influenced by the insert geometry, as it mostly depends on the strength of the bonding between the core and facesheet. Whereas the geometry of insert b and insert ab can be improved by a thicker base plate on the lower sandwich side. This will prevent early plastic deformation of the metal sheet and therefore reduce stress concentrations around the insert bolt.

5. Pull out tests on foamed in metal sheet Inserts with different foam densities

For the second experimental investigations three different foam densities, that possess the same type of insert, were tested in pull out tests. For manufacturing the specimens approach 2 (see Figure 1) is taken. The tested insert geometry is shown in Figure 8. The M6 flange nut is foamed into the core during the foam manufacturing process. To increase the load introduction area, a round metal washer with a thickness of 2 mm and a diameter of 30 mm is put between the top facesheet and the flange nut during the preforming process. Both metal parts are made of stainless steel (1.4301). In

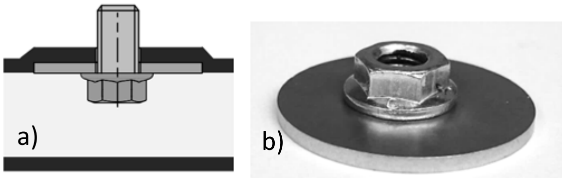

Figure 8: Insert geometry with foamed in M6 flange nut and 2mm thick metal plate with a 30 mm diameter above.

comparison to the experimental investigations in paragraph 4 the thickness of the metal plate was doubled in order to reduce plastic deformation of the insert which leads to lower maximum tensile strengths. Also the facesheets consist of 8 plies of carbon fiber fabric leading to a higher fiber volume content. The layers were stacked in $[0/90/0/90]_s$ orientation. For the RTM process a threaded rod is screwed into the flange nut to prevent the resin from flowing into the nut. The top of the rod was slid through the plies of carbon fiber during preforming to maintain the fiber continuity. The rod and the inner threat were sealed with silicone, so that after the RTM process the only rework needed, is to unscrew the threaded bolt. The core material consists of polyurethane foam with three different densities of 200g/l, 300g/l or 400g/l. For each density 5 specimens were tested.

5.1. Results and discussion

The experimental investigations of the pull out tests are presented in the following. The failure behavior of the specimens and the tensile forces are examined. Also the rigidity of the specimen is evaluated.

5.1.1. Failure behavior

One exemplary load displacement curve for each foam density is shown in Figure 10. The three curves show a very similar behavior. After a linear segment the first peak again marks the debonding of the core material and the top sheet in the area around the insert. This behavior occurred on all tested specimens. For this test series the pull out test was not aborted automatically after the first peak, because the limit of tensile force decline was set to a higher value (compare with Figure 5a). After that, the force further increased, followed by a second linear segment. During this part of the

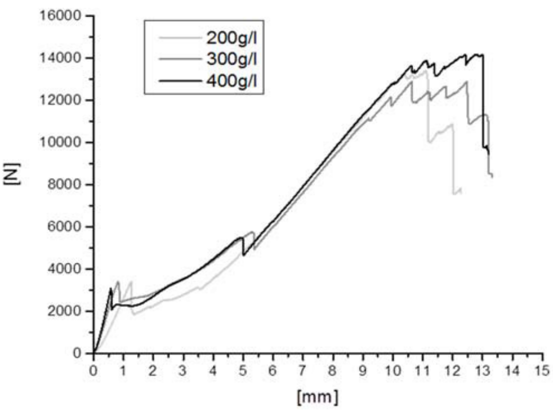

Figure 10: exemplary load displacement curves for each foam density with the insert geometry shown in Figure 8

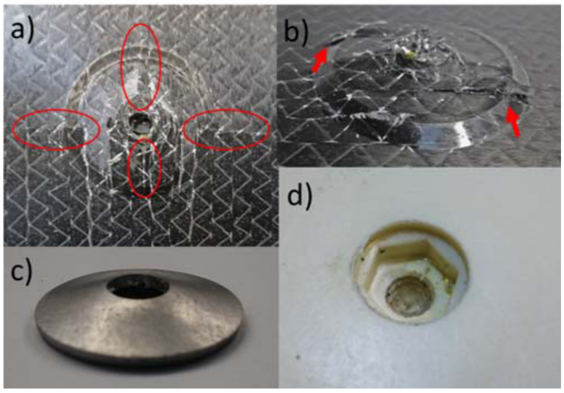

Figure 9: exemplary pictures of the failed specimens. a) crosswise cracks going out from the insert bolt; b) delamination and fiber cracking going out from the outer area of the metal plate; c) plastic deformation of the metal plate after the pull out test; d) hole in the foam core where the flange nut was foamed in

pull out test most areas of the top facesheet have already debonded from the core. For some specimens the core even separated completely from the top facesheet and fell off, so that only the top face was responsible for the mechanical behavior after that. All specimens showed the same failure behavior on the top sheet. First the fibers around the bolt started to crack, then delamination on the outer area of the metal plate occurred (Figure 9b), followed by crosswise placed cracks starting from insert bolt (Figure 9a). Also the metal plate of the insert was deformed plastically (Figure 9c), but not as much as the 1 mm thick metal sheets from paragraph 4 though.

After the pull out tests the separated cores were examined. Barely no failure on the foam could be seen in the area where the flange nut was embedded (Figure 9d). This means that the bonding between the insert and the core was not strong enough to transfer shear loads into the core. This is caused by the manufacturing process where the flange nut was foamed into the core without the use of additional potting material. In the future this can be improved by using insert geometries with an undercut to transfer loads positively into the core material. This will prevent early debonding of the top facesheet and the core. Also the inserts can be connected to the lower facesheet to increase the load bearing capacity.

5.1.2. Tensile force and rigidity

Figure 11 shows the tensile forces for the first failure and the maximum load capacity for this series. For all specimens the maximum tensile force is more than three times as high as the first peak when the core and the top facesheet detached. This is similar behavior as to that seen in Figure 7 for insert a. However, no significant difference in tensile forces can be detected for the tested foam densities, since the standard deviations for each force are overlapping.

Also the rigidity of the specimen is calculated from the slope of the load displacement curves by using the difference quotient. But only the first linear part of the curve, before the

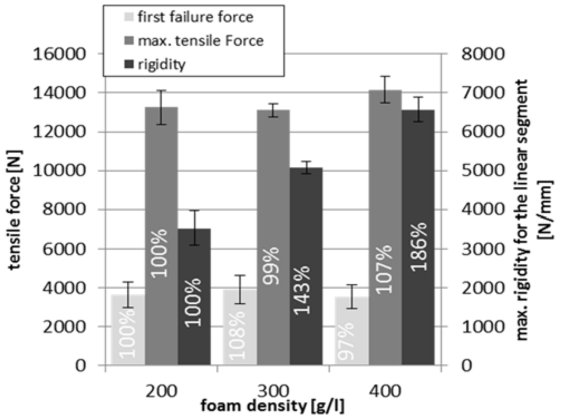

Figure 11: Force of first failure and maximum tensile force (primary y-axes). Rigidity of the first linear segment of the load displacement curves (secondary y-axes) for the three different foam densities with the insert geometry shown in Figure 8

core debonds from the facesheet, is examined (compare Figure 10). After that mainly the top facesheet influences the mechanical behavior. As it can be seen in Figure 11 the rigidity of the specimen shows higher values for higher foam densities. This behavior is plausible because when the core itself has a higher tensile- and shear-modulus, the whole sandwich structure becomes more rigid. It is shown that with higher foam densities the sandwich structure also responds more rigid when the loads are applied locally in the form of an insert. The rigidity of the specimen was increased by 43% and 86% with an increase in foam density from 200g/l to 300g/l and 400g/l.

6. Conclusion

Two new approaches to embed inserts into sandwich structures with foam cores, manufactured by RTM, were presented in this paper. In the first approach the inserts were embedded during the preforming process, in the second one the inserts were foamed directly into the core material during the foam manufacturing process. Both methods reduce process steps and rework after the RTM process and no extra time for the potting material to cure is needed. Consequently process time is reduced and costs for high volume productions can be lowered.

Specimens for experimental quasi static pull out tests with different insert types were manufactured, using these two methods. Inserts with flat metal sheets were used to introduce the loads. It was shown that the inserts behave very differently in pull out tests by connecting them to the top, the bottom or both facesheets. The highest tensile forces were achieved with inserts that were connected to both faces. It was also shown that the force where first parts of the sandwich structure began to fail are a lot lower than the maximum tensile force. Therefore the load introduction has room for improvement. Pull out tests on specimens with inserts which were foamed into the core, using different foam densities, showed no difference for the tensile forces. The analyzed failure behavior showed that the loads could not be transferred into the core material sufficiently before the top facesheet had debonded from the foam core. This can be improved by insert geometries which can transfer loads into the core material positively or inserts which are also connected to the lower facesheet. However with higher foam densities the stiffness of the sandwich structure had increased.

For future investigations other insert geometries will be tested to improve the mechanical properties on pull out forces, and the results will be compared to inserts integrated after the sandwich manufacture.

Acknowledgement

At this point, we wish to extend out special gratitude to the Federal Ministry of Education and Research (BMBF) which has funded the presented work under Grant No. 03X3041S.

SPONSORED BY THE

Federal Ministry
of Education
and Research

References

[1] Nguyen K, Park Y, Kweon J, Choi J. Failure behaviour of foam-based sandwich joints under pull-out testing. Composite Structures 2012;94(2):617–24.
[2] Herbeck L, Kleineberg M, Schöppinger C. foam cores in RTM structures: manufacturing aid or high-performance sandwich. In: Go for the best through Advanced Materials & Processes, p. 515–525.
[3] Friedrich HE. Leichtbau in der Fahrzeugtechnik. Wiesbaden: Imprint: Springer Vieweg; 2013.
[4] Dallner C, Sandler J, Hillebrecht M, Reul W. Faserverbundkonzept für ein Cabrio-Dachmodul. ATZproduktion 2012;5(3):178–83.
[5] Eckstein L, Seidel K, Ickert L, Bastian R. CFK-Motorhaube in Integralbauweise. ATZ Automobiltech Z 2013;115(3):198–203.
[6] Byoung JK, Dai GL. Characteristics of joining inserts for composite sandwich panels. Composite Structures 2008;86(1–3):55–60.
[7] Shipsha A, Soderlund J, Zenkert D. Shape Optimisation of an Internal Metal Doubler for Load Introduction in Sandwich Structures. Sandwich Construction 4: Fourth International Conference on Sandwich Construction. 1998:839–51.
[8] Raghu N, Battley M, Southward T. Strength Variability of Inserts in Sandwich Panels. Journal of Sandwich Structures and Materials 2009;11(6):501–17.
[9] ATZ-Fachtagung Werkstoffe im Automobilbau. ATZ Automobiltech Z 2011;113(7-8):526–7.
[10] Gebhardt J, Fleischer J. Experimental Investigation and Performance Enhancement of Inserts in Composite Parts. Procedia 5CIRP6 2014;23(0):7–12.
[11] Ballier F, Schwennen J, Berkmann J, Fleischer J. The Hybrid RTM Process Chain: Automated Insertion of Load Introducing Elements during Subpreform Assembling. AMM 2015;794:312–9.