INNOVATIVE CONCEPT FOR INSERT INTEGRATION IN SMC APPLICATIONS TO INCREASE PULL-OUT FORCES

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ABSTRACT

The sheet molding compound (SMC) technology offers a variety of advantages. In addition to the reproducible production of complex geometries, the direct integration of functions, such as inserts integration during the pressing process, considerably reduces the post-processing effort. In today's standard processes, the inserts are placed in the preheated press tool before the SMC material is placed. The pressure exerted by the press causes the SMC to flow around the insert and embed it in the final component.

With the embedded insert the applied load is mainly transferred from the insert to the resin-matrix rather than to the fibers. This applies in particular to the use of materials which do not exhibit any flow behavior, like nonwovens. Here, the insert is surrounded only by resin. This results in a clear optimization potential with regard to the force introduction elements.

The newly designed insert actively penetrates the material and anchors itself through a targeted forming process. In the intended paper, the newly designed insert concept will be described in more detail and a comparison will be made between today's standard inserts and the self-anchored insert concept with regard to processing and the pull-out forces when using different SMC materials.

Keywords: SMC, insert, functional integration, load introduction, composites
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1. INTRODUCTION

Fiber-reinforced plastics (FRP) have gained significant importance in the transportation industry over the last years due to their high lightweight potential. Especially in the commercial aviation, fiber composites and in particular carbon fibers play an important role. With the expected increase of passengers and thus the high demand of new aircraft, the efficiency and cost-effectiveness of manufacturing technologies for FRP as well as the ecological footprint is becoming more and more relevant. The Sheet Molding Compound (SMC) technology allows fast and low-cost manufacturing of components in a compression molding process. Recent developments in this field target the advancement of the SMC technology to open a new range of possible applications. The new recycled carbon fiber (rCF) fleece SMC technology uses recycled carbon fibers from production waste or end-of-life products which are processed to a nonwoven material and impregnated with a resin system [1]. The resulting semi-finished product can then be cured in a compression molding process. [2, 3]

One aspect in the development of FRP components is the assessment and selection of appropriate joining technologies. In this context, detachable joints offer the advantage of an efficient assembly and disassembly for maintenance or repair purposes. Metallic threaded inserts are therefore well-established and often used in conventional SMC components. However, compared to conventional SMC the newly developed SMC based on rCF fleece shows an entirely different behavior during the compression molding. As a result, conventional inserts used in SMC application have shown to be unsuitable for the use in SMC reinforced by rCF fleece (rCF-SMC). Figure 1 shows conventional inserts integrated in glass fiber-reinforced SMC (a) and rCF-SMC (b). Limited flowability of the material and thus the orientation of the fibers result in a limited strength of the insert.

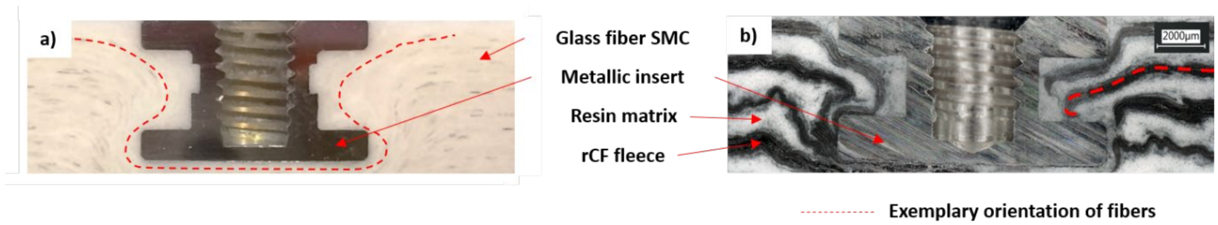


Figure 1. Cross-sectional image of conventional inserts integrated in a) glass fiber reinforced SMC and b) rCF-SMC.

In this work, a new metallic threaded insert and a concept for its integration in fleece SMC materials is introduced. Here, an interlocking of the insert and the SMC fleece is created by forming of the insert during the compression molding process. An experimental study comparing the new insert design with conventional inserts in both glass fiber-reinforced SMC and rCF fleece SMC has been performed and is presented in this paper.

1.1 Conceptual representation of the Star-Insert

When new materials are used, the new conditions usually also offer potential for optimization in combination with previously used components. This also applies to the combination of rCF-SMC and commercially available inserts described in the introduction. As Figure 1(b) illustrates, these are essentially embedded exclusively by the matrix. The fiber fleeces, which can be clearly seen, run out at the edge of the insert or are displaced and compressed horizontally during the pressing process. It can therefore be assumed that a load transmission into the component, and thus load absorption primarily via the fibers, provided by the load introduction element does not take place. The Star-Insert was designed for this purpose. During the pressing process, it anchors itself independently in the SMC nonwoven by means of a forced shaping deformation of the insert legs. The name Star-Insert is derived from the production of the insert. The blanks cut out of a metal sheet have the characteristic shape of a star (see Figure 2). After forming the insert by 90 degrees, the star-shaped serrations form the insert legs, which are anchored in the SMC material during subsequent use. Finally, a closed rivet nut is inserted into the hole in the middle.

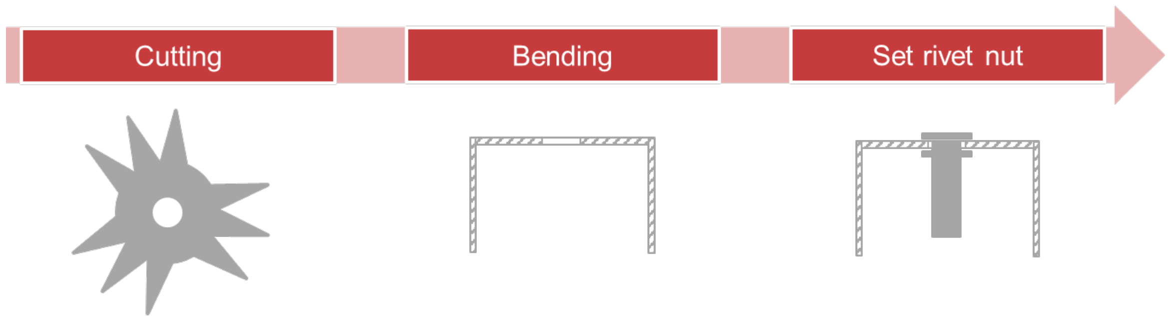


Figure 2: Manufacturing process of the Star-Insert.

The inserts can either be inserted into the SMC before pressing or integrated into the pressing process, as shown in Figure 4. To do this, the insert penetrates the SMC material with its formed serrations while the press is moving, which are bent back through 180 degrees at a certain radius by the die underneath. Depending on the tooth length, the clamping length can be influenced and thus the number of layers to be clamped can be determined. To further increase the anchoring forces, an additional disc can be integrated into the clamping area as a final layer. This allows the teeth to transfer the tensile forces introduced into the component over a larger area. Figure 3 presents the two described concepts of the new designed insert.

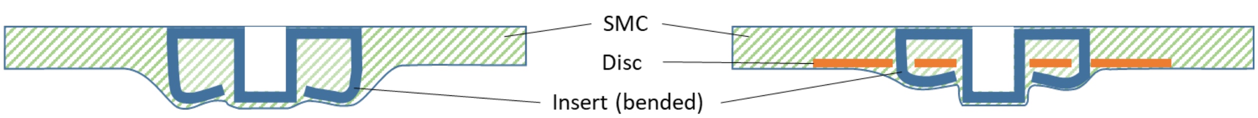


Figure 3. Integration concepts of the Star-Insert – concept 1 left, concept 2 right.

The following Figure 4 shows the insert penetration during the pressing process. In a first step, the force introduction elements are fixed on the upper tool of the press. Then the SMC stacking which was punched out at the penetration points of the rivet nut, can be inserted into the forming tool. When the upper tool is lowered, the teeth penetrate the SMC. When reaching the clamping length, the teeth are deflected and thus formed. After the pressing process, the component can be ejected.

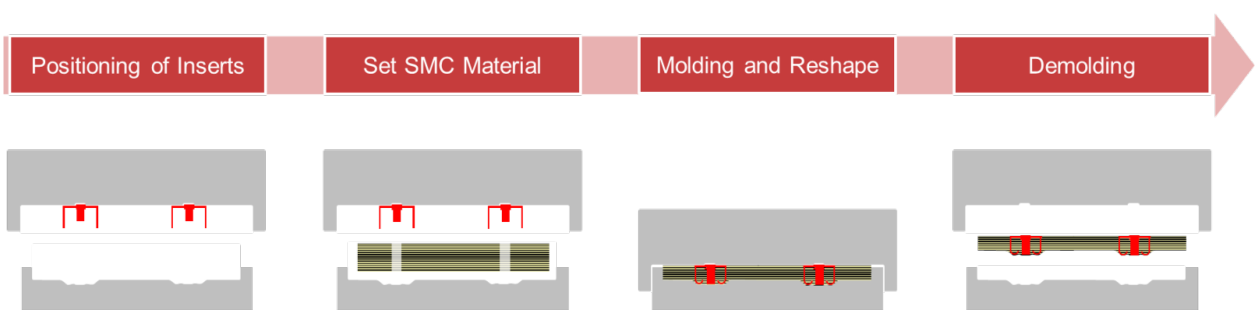


Figure 4. SMC process flow with insert integration.

2. EXPERIMENTAL INVESTIGATION

This chapter is subdivided into the description of the preparation of test specimens as well as the execution of tests. Furthermore, it is described in which way the concept deviates from the previous one in order to clarify the relevance of the innovation shown above.

2.1 Sample production

Since at the time of the test sample production, no tool adapted to the project was available which would allow an insertion during the pressing process. Therefor a standard plate tool with the cavity dimensions 120 mm x 250 mm was used. In order to press the test plates with this tool, the process chain shown in chapter 1.1 was changed and the inserts were inserted and formed in advance on a stationary press. This procedure was the same for all materials used.

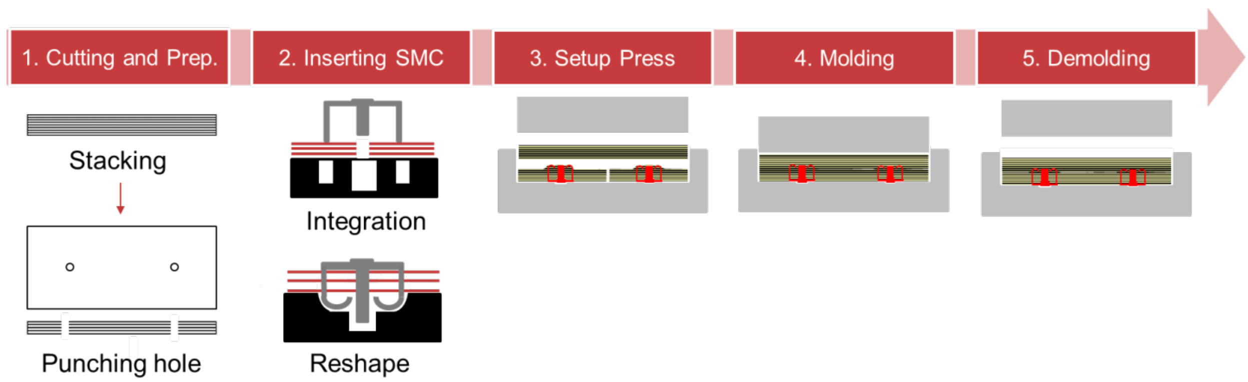


Figure 5. Process chain for producing the test samples.

Figure 5 shows the specific process for the preparation of the sample. In a first step, the clamping layers are cut to size 125 mm x 250 mm, which corresponds to half the cavity length, according to the number of clamping lengths to be used. With the plate tool used, two specimens could always be produced side by side per pressing operation. In order not to damage the upper tool, the cavity was equipped with sufficient material to completely insert the rivet nut into the plate. For this purpose, so-called cover layers were cut to size which correspond to the outer dimensions of the cavity with 120 mm x 250 mm.

Afterwards the cut clamping layers and cover layers are to be stacked separately (Figure 5/1). In the next production step, the stacked clamping layers are provided with a through hole to embed the rivet nut.

After preparing the clamping layer pack, the insert is inserted into the SMC material in the area of the through-hole using a punch and a hammer (Figure 5/2.1). The die is specially designed so that the blind rivet nut can move freely downwards and the teeth of the insert pierce the SMC layers.

To fix the insert in the SMC material, the teeth of the insert are formed in the next step (Figure 5/2.2). This is done on a stationary press, whereby the insert is pressed into a specially shaped die by means of a flat punch, up to a pressure of 2 bar. So the teeth are irreversibly deformed as intended. Due to the round shape of the die, the vertical teeth are deflected by more than 90° towards the blind rivet nut. The exact alignment of the insert in the die must be observed to avoid deformation of the teeth. In a second test variant, a disc is also inserted as the last clamping layer. This is intended to increase the extraction force once again.

The clamped layer packs can then be placed next to each other in the press and the cover layers can be applied (Figure 5/3). After aligning the components, the sample plate is pressed into their final shape at a temperature of 145 °C and a pressure of 180 bar (Figure 5/4). The curing process takes 180 s. In total this proceeding differs to the process shown in chapter 1.1, but is still representative in the direct comparison to the standard insert, which is pressed directly.

To finalize the specimens, two samples with the dimensions of 100 mm x 100 mm are cut out of each sample plate (see Figure 9).

For the investigation in this paper, two concepts and two materials were used (see chapter 1.1). Concept one is the new shaped insert itself, which is integrated. Concept two involves a disc which acts like a pressure plate. The materials are based on an unsaturated polyester matrix. V1 is a standard Polynt HUP63 with glass fibers with a length of 25 mm. V2 is an experimental SMC with the same matrix but here, a recycled carbon fiber fleece is used as reinforcement. Figure 6 gives an overview of the manufactured test panels with material and concept.

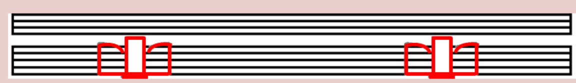
Trial	Material	Stacking
V1	- Glasfiber SMC (GSMC) - Material HUP 63 - Only Starinsert used (concept 1)	
V2	- Glasfiber SMC (GSMC) - Material HUP 63 - Starinsert + disc (concept 2)	
V3	- rCF-SMC - Only Starinsert used (concept 1)	

Figure 6. Concept and material overview.

Another advantage of the Star-Insert is the increase of the pressure area by 600 %. Looking at the compact design of the conventional insert at Figure 7, it ensures that the force is transmitted only locally into the SMC material. With an ideal reshaping of the spikes from the Star-Insert, this results in a pressure area of 75 mm^2. The area calculation is based on computer tomography (CT) data from which the dimensions of the triangular area could be determined (see Figure 8).

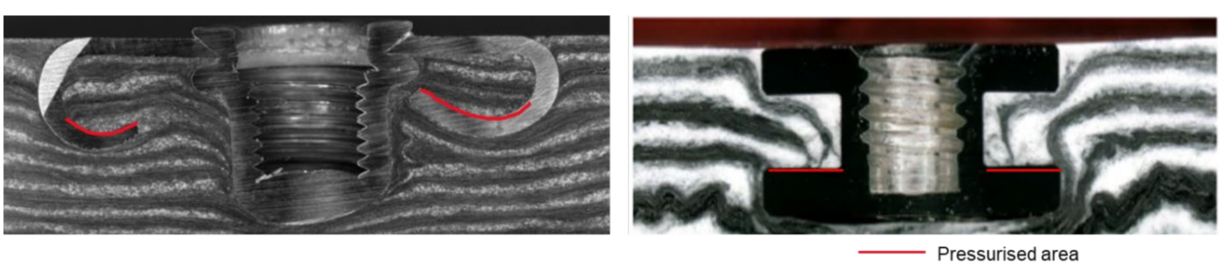


Figure 7. Sectional view of the inserted Star-Insert left and conventional insert right.

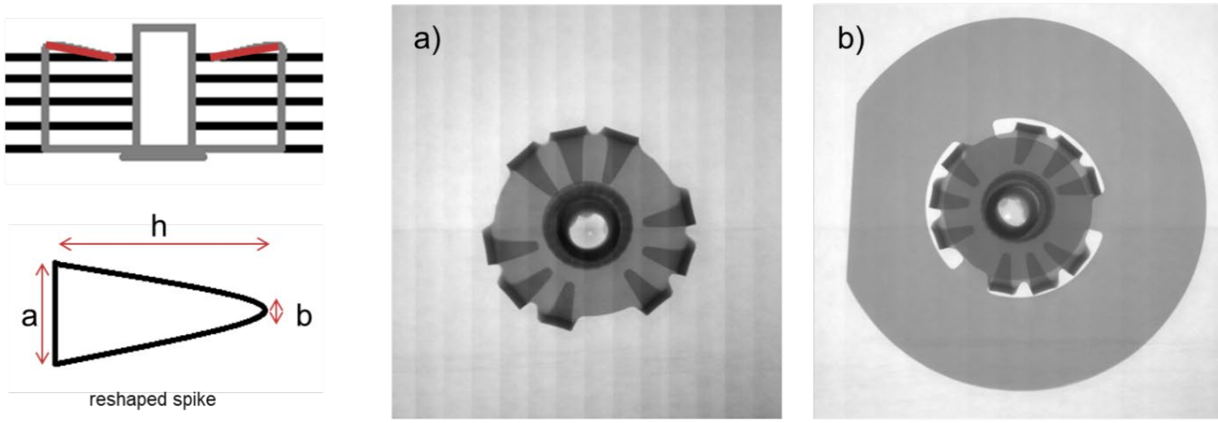


Figure 8. CT inspection of the pressed specimen; a) concept 1, b) concept 2.

2.2 Experimental procedure

For a comprehensive assessment of the new insert concept, the mechanical properties of both the conventional inserts and the newly developed inserts have been investigated. For this purpose, a uniaxial pull-out test has been performed with the above-described test specimens. Figure 9 shows a) the test setup for the pull-out test and b) the dimensions of the test specimens. The tests have been performed with the tensile testing machine Zwick Z100 from Zwick GmbH & Co.KG. The force applied is recorded using a 100 kN load cell. This is designed according to DIN EN ISO 7500-1-2016 class 0.5 for tensile loads between 200 N to 100000 N. The test speed was 2 mm/min at a preload force of 40 N and a break-off criterion at 90% of the maximum force.

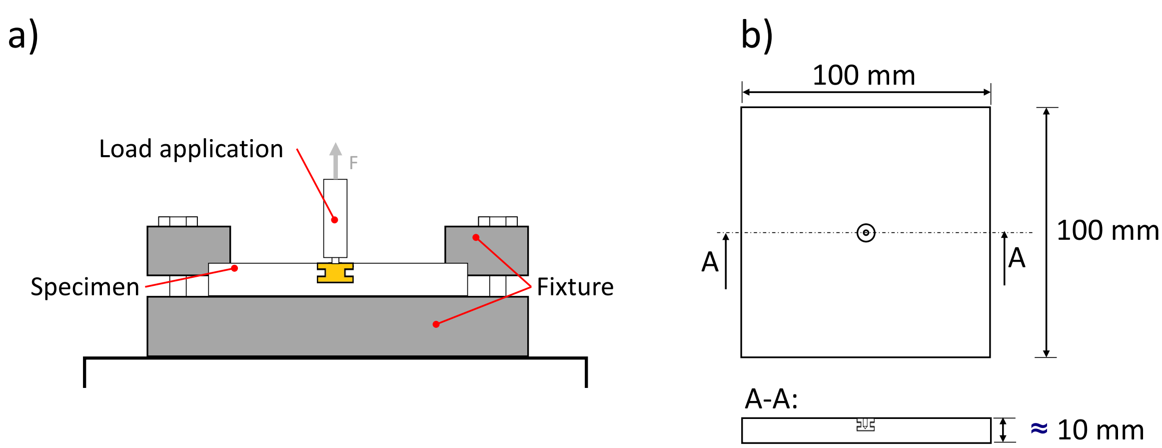


Figure 9. a) Pull-out test setup (schematic) and b) dimensions of the test specimens.

3. RESULTS ANALYSIS

A comparison between the new designed insert and the conventional insert can be made based on the results of the pull-out tests. For this purpose, the tests of the different inserts in the glass fiber reinforced SMC (GSMC) and in the rCF are considered.

3.1 Result for the GSMC

Figure 10 shows the exemplary pull out force and the displacement of the Star-Inserts out of the GSMC. Here, two test samples of the conventional insert, two test samples of the Star-Insert and two curves of concept two (with disc) are shown. The point diagram shows three main differences. It can be clearly seen that the conventional inserts (yellow) in the GSMC have a larger maximum value of 3.29 kN (Conv. Insert GSMC V1.1). After reaching this point the force curve drops steeply. Then they flatten out again before the insert fails continuously.

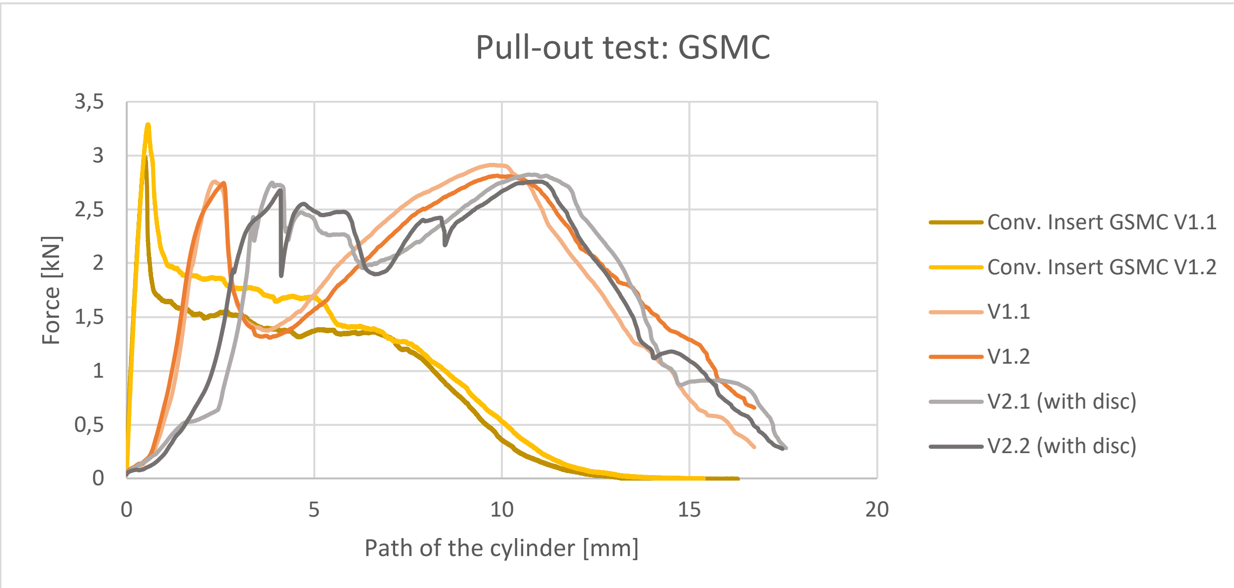


Figure 10. Result of pull-out testing of GSMC

Two peaks in V1.1 and V1.2 (orange) are clearly visible for the curve with the Star-Insert. These result from the failure behavior. The first slight increase in force results from a deformation due to the lifting of the insert head. The sheet metal bulges in the direction of pull-out. If the upper sheet cannot deform any further, the force increase becomes steeper until its first peak of 2.7 kN (V1.1). The subsequent drop in force is caused by a local material failure at the insert. At a certain point (here approx. 3.5 mm), the force absorption is extended globally by the insert due to the embedded and crimped long fibers, and a new increase in force occurs. This increase reaches at least the previous maximum or even exceeds it (here 2.9 kN (V1.1)). The subsequent drop in force is a mixture of SMC and insert failure. Continuous withdrawal causes more and more fibers to be loosened from the SMC, while the deformed teeth of the insert bend up more and more until the specimen fails completely.

The curve of V2 (grey), which consists of an inserted Star-Insert and disc, is similar to that of V1, which shows an almost equal extraction force. However, it can be clearly seen that the force loss between the two peaks is weaker than in V1. Since the disc directly ensures a large-area force distribution around the insert, there is only a slight local failure of the SMC here. The repeated drop and increase in force results from effects in the deformation of the teeth, which repeatedly wedge themselves in the material when pulled out upwards.

3.2 Result for the rCF-SMC

The tests with the rCF-SMC achieved different results compared to GSMC (see Figure 11). An average value of 2.35 kN results for the maximum force of the Star-Insert. The conventional insert, however, can only withstand an average maximum force of 1.4 kN. This corresponds to only 60 % of the Star-Insert and an increased pull-out force by 68 %.

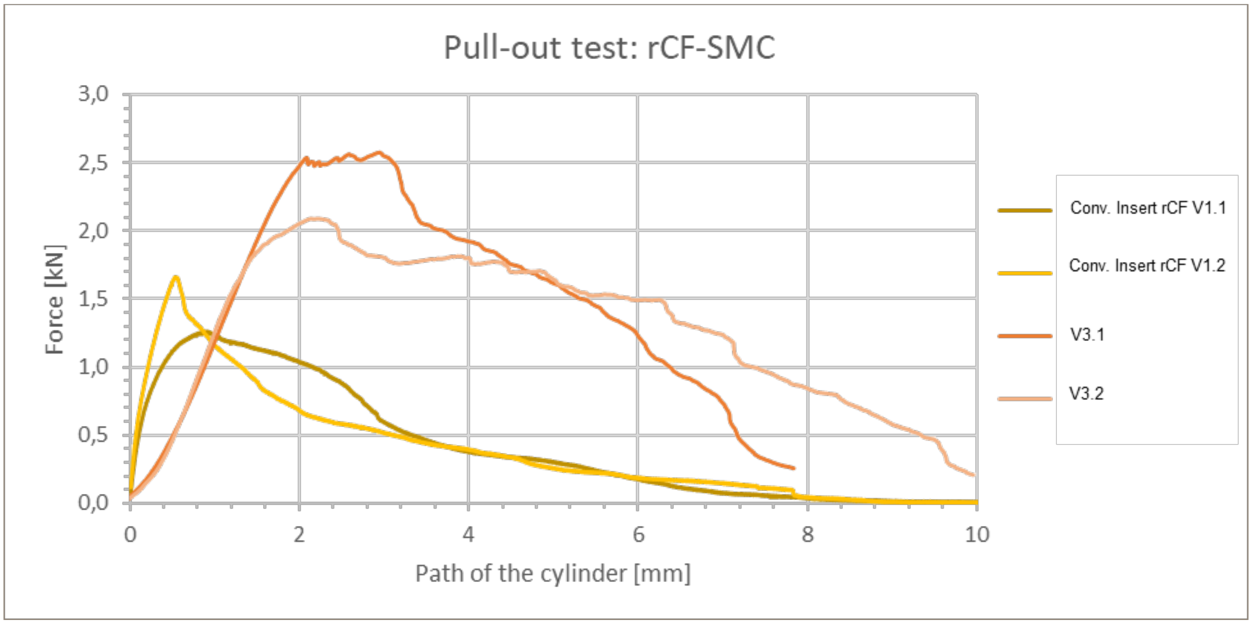


Figure 11. Result of the pull-out testing of rCF-SMC

Compared to the GSMC, here the test samples finally fail after they reached the global maximum. After reaching the global maximum, the Star-Inserts show an almost plateau formation before the extraction force drops. This is due to the form-fit connection of the two inserts. Once the firm connection between insert and the matrix material has been broken, the conventional insert is only slightly retained in the rCF-SMC material due to its geometry. The Star-Insert, on the other hand, engages the formed spikes into the fiber structure (see Figure 7) of the rCF-SMC material and thus transfers the force acting on the Star-Insert into the fiber structure. Due to the brittle behavior of rCF-SMC there is no deformation of the teeth. Failure here is primarily due to the material used.

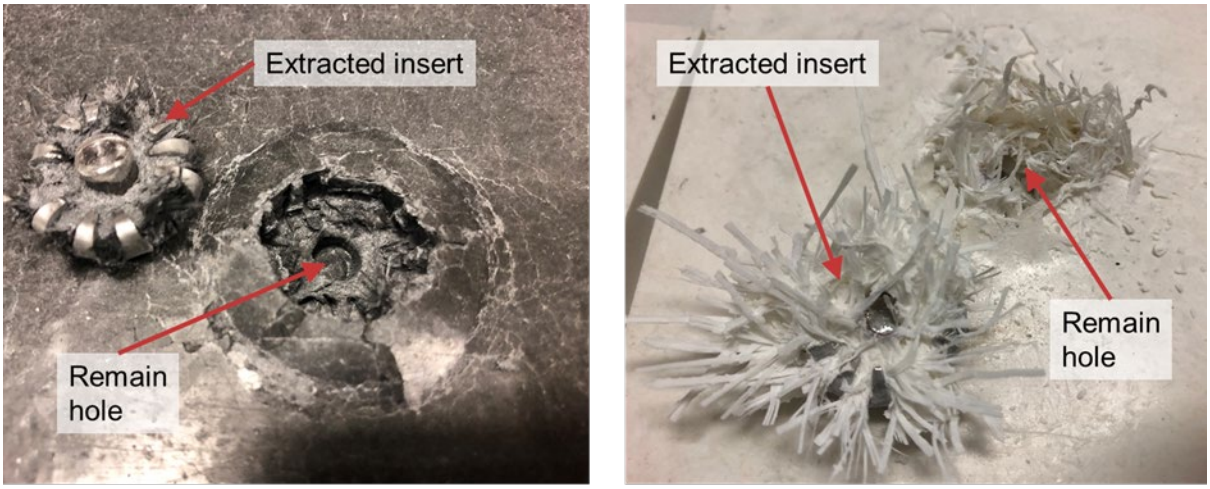


Figure 12. Concept 1: failed specimen after testing - rCF-SMC (left); GSMC (right).

Figure 11 above shows the clearly different material behavior when using the star insert. While the GSMC variant extracts a clearly recognizable fiber mesh, a clear imprint of the insert remains in the rCF-SMC, which did not allow any deformation even during the extraction test.

4. SUMMARY AND OUTLOOK

The current work deals with the development and a first feasibility analysis for the application of a new insert type for SMC. This so-called Star-Insert can be applied by using a self-anchoring principle within compression molding processes. On the one hand the processing of the Star-Insert was focused to validate the manufacturing feasibility. On the other hand, the testing of pull-out forces when using different SMC materials was performed to analyses the load introduction zone. Hence, the effect of using the new insert compared to conventional inserts could be shown by performing first investigations in combination with subsequent image as well as CT analyses.

The results of these first investigations show that the new insert concept is promising for the application of nonwoven SMC. Moreover, this field offers a wide variation of the influence parameters to be investigated in further studies. For example, geometrical parameters such as the insert diameter as well as the length or quantity of the teeth can be varied. Therefore, also the sheet thickness of the SMC fabrics can be varied which influences the overall characteristics. In addition, the combination of new inserts with other composites and appropriate production technologies should be investigated. A stud or hook can also be applied to a flat insert surfaces in a subsequent process step. All in all, a wide variety of process, material and geometric parameters has to be analyzed in future.

5. ACKNOWLEDGEMENT

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6. REFERENCES

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