ATTACHMENT STRATEGIES FOR BAYPREG® F-SANDWICH COMPOSITES

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Abstract

New automotive applications of sandwich composites require the development and characterization of reliable attachment techniques needed for the creation of functional structures. Baypreg® F is Bayer's proprietary name for the two-component polyurethane material that bonds and holds the composite structure together, which is normally made of a honeycomb-type paper core sandwiched between glass fiber mats. In this paper, we present testing results to compare different attachment strategies applicable to this type of sandwich composites. As joints are a potential source of stress concentration and weight increase, their performance should be as good as if not better than the underlying composite. We compare the performance of adhesive bonds, embedded inserts and mechanical fasteners and discuss their advantages and disadvantages. Furthermore, we discuss characterization of attachment techniques for computer simulations and outline plans for further development and testing.

The need for attachments in sandwich composites

The development of attachment or joining techniques is critical for the success of many automotive composite applications. This is especially true when dealing with sandwich composites like those made with two-component polyurethane skins. This technology is currently used in the automotive market for parts with relatively large surface areas such as sliding sun-roofs, spare tire covers and load floors. Despite its practical success, questions remain about the comparative performance, assembly method and computer modeling of different attachment techniques. While working on a specific automotive load floor application, we developed a test matrix to compare the performance of adhesive bonds, embedded inserts and mechanical fasteners to help answer some of these questions.

To manufacture this family of sandwich composites, a honeycomb-type core is placed between natural or glass fiber mats and impregnated on both sides with polyurethane. The low viscosity of the two-component polyurethane mixture ensures that the fibers are thoroughly wetted. The outer layers are then placed in a pre-heated mold, together with the lightweight core layer consisting of rigid foam or a honeycomb-type structure made of paper, plastic or aluminum, and pressed into their final shape at an elevated temperature (60 to 120 °C) and pressure (6 to 8 bar). Under these conditions, the polyurethane cures rapidly, firmly joining all the elements of the composite structure. If a blowing agent is added to the polyurethane, it will additionally penetrate the cells of the honeycomb, enhancing the bonding of the composite. The thickness and shape of the structure can vary according to the mold shape, which allows for attachment areas to be prepared for better locating and bonding.

Attachment methods

Joining and attachments have been identified as critical areas of research and development in composites for the automotive industry. According to the Centro Ricerche Fiat [a], the availability of high performance polymer-based blends make adhesives one of the most widely accepted and promising joining methods for composites. Adhesives allow the possibility of tailoring properties to design requirements and can have other advantages such as high fatigue and corrosion resistance, sealing characteristics, reduced stress concentration, larger styling possibilities and the capacity to absorb wider tolerances. On the other hand, adhesives can have disadvantages such as the need for careful handling, surface preparation, long curing time and sometimes high temperature curing.

Some of the traditional mechanical fastening methods used in the automotive industry for joining metallic components, such as rivets, may not always be appropriate for sandwich composites. In our case, the main concerns with rivets are stress concentration due to the presence of holes, lack of plasticity of the top skin and the potential for water intrusion in the paper core. On the other hand, we do not see delamination, differences in thermal expansion or corrosion as limiting factors for the use of rivets in sandwich composites made with this two-component polyurethane skins. Regarding the risk of delamination, we have observed a very intimate bonding between the composite layers, such that we expect the paper core to fail before the outer layers peel off. On the positive side, rivets require very little surface preparation, are simple and easy to install and can allow for disassembly, as shown in the next sections.

The use of embedded inserts is our third potential attachment technique. In this case, we introduce a metallic insert during the manufacturing process of the composite which can be later used for connecting a third component. The method could be viewed as an "online-adhesive" technique in which the polyurethane and/or glass mat are used to join the metallic insert to the composite. However, as we introduce a foreign object in the sandwich structure, the risk of delamination becomes a concern. This method has the advantage of eliminating secondary operations, although it requires careful preparation of the sandwich package prior to manufacturing resulting in longer cycle times. A disadvantage of the method is a more limited tolerance flexibility when compare to adhesives or rivets.

Test setup and specimen preparation

As the driving force behind this attachment study is the development of a functional sandwich composite load floor structure, we focused our efforts on developing a test setup that closely reflects the loading conditions of the actual application. Based on the dimensions of the load floor, we decided to work with 25.4mm thick composite samples cut into 101.6mm squares, made with honeycomb-type paper core and glass mat with a density of 900 g/m^2. The inserts used for the adhesive and rivet testing were made of 3.4mm thick carbon-steel sheet cut into 40mm squares with a M8x1.25 thread female stud welded on the center. The holding fixture of the samples overlapped 12.7mm on all four edges of the samples, while the insert was pulled at 0.5mm/s until failure or separation occurred.

In addition to the two-component epoxy adhesive tests, we experimented with three types of readily available mechanical fasteners:

- 5 and 6mm diameter carbon-steel threaded inserts,
- 4mm diameter dome-head aluminum rivets,
- 4.8mm diameter dome-head split-tail aluminum fasteners.

For the dome-head rivets and fasteners, we used the same metallic inserts described above, placing a rivet in each corner of the insert (figure 1, top right corner). However, the threaded inserts were tested individually as shown in figure 2. For this reason, we make a projection of the total holding force of the metallic insert by multiplying the force generated by one insert times four, as shown in the results section below. Otherwise, the installation of the rivets and inserts, and the size of the holes on the composite were made according to the specifications of the fastener manufacturer.

The embedded inserts were made in a similar manner as that used for adhesives and rivets, with the exception that the blind threaded stud is facing the core of the composite sandwich (figure 3). We used a dome shaped stud to prevent contamination and minimize damage to the core. It is important to note that we placed the insert on the surface of the sandwich package and not below the glass mat.

Test matrix and experimental results

Tables I and II show the test matrices, maximum force values and strength of the adhesively bonded, embedded and riveted inserts. To determine the strength, we divide the maximum force by the surface area of the 40mm square metallic insert. For the adhesive test results, we establish a qualitative measure of the bonding by assigning a number according the type of failure:

- Adhesive failure = 1, i.e., adhesive remained on the composite skin, detached from the metal,
- Cohesive failure = 2, i.e., adhesive remained on metal insert, no fibers were pulled,
- Cohesive failure with fibers pulled = 3, i.e., adhesive in metal and fibers pulled from skin.

On table I we note that the maximum force and strength is obtained for those inserts showing a cohesive failure with fibers pulled (failure type 3). In addition, we conducted experiments to determine the "inherent strength" of the sandwich composite in tension. For this experiment, we adhesively attached 101.6mm square composite samples to rigid plates. As expected, the paper core pulled apart before the adhesive failed or delamination occurred. This results in an average pull-out inherent strength of 1,075 kPa. Figure 4 shows a graphical summary of all results obtained with a reference to the sandwich composite inherent strength. This figure compares the best adhesive test results (failure type 3) and the best embedded insert test results, with the average strength for the dome-head rivets and the average projected strength of the threaded inserts.

Discussion of results

Results indicate a number of potential alternatives for attachments to this type of sandwich composites. Using the calculated inherent strength of the paper core as a reference, we observe that only the embedded inserts and the dome head rivets perform below expectations. In the case of embedded inserts, we could improve the bonding performance by allowing polyurethane to flow through holes in the metallic insert to interlock with the rest of the structure. Another alternative would be to embed the insert below the glass mat, although this may complicate the package preparation procedure.

Adhesive bonding remains an attractive joining method for sandwich composites. In addition to the advantages we already mentioned, polyurethane adhesives are generally chemically compatible with the outer skin of the composite. A major factor in adhesive performance is the preparation of the surface. For some applications, the use of coated metallic components that need to be attached to composites may become a challenge to resolve. Once the appropriate surface preparation procedure and adhesive formulation are found, adhesives are expected to perform very satisfactorily.

In our study we were also pleasantly surprised with the performance of the split-tail fastener and the threaded inserts. Results indicate that if a wide enough area is used for the flange of the fastener, the maximum clamping force can be significant compared to adhesive bonding. Furthermore, it is conceivable that other fastener designs could be adapted for this particular application, making them even more attractive.

Conclusions and future work

In this paper, we have presented experimental test results to evaluate the performance of different attachment techniques for polyurethane-skin sandwich composites with a focus on application development. Based on experimentation with attachments, modeling and actual part testing, we have been able to produce market-competitive composite structures for automotive applications. However, we recognize the need for further investigation in the development and optimization of attachment techniques for sandwich composites.

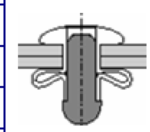
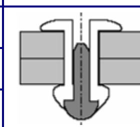
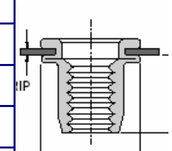
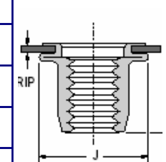
Further development of sandwich composites in automotive applications will require the introduction and refinement of testing protocols, computer simulation techniques, and engineering design methodologies for both composites and their attachments. Finite element modeling of attachments may require specialized testing to couple experimental data with simplified modeling techniques based on special connector elements. Other alternatives may include the use of submodeling techniques to migrate from the overall composite structure to the localized attachment region. In addition to static testing, the development of new automotive composites products and their attachments requires further work to evaluate failure, crashworthiness, repeated loading, creep and the effect of environmental conditions. Our focus is to develop this capability and understanding progressively as we pursue market opportunities.

Table I: Test matrix, maximum force and strength for adhesively bonded and embedded inserts.

Test specimen	Attachment method	Maximum Force (N)	Strength (KPa)	Failure Type §
1	adhesive	755.5	472.2	1.8
2	adhesive	1441.5	900.9	1.5
3	adhesive	1825.2	1140.8	2.0
4	adhesive	640.2	400.1	1.5
5	adhesive	1792.4	1120.2	1.1
6	adhesive	2217.7	1386.0	2.9
7	adhesive	1123.2	702.0	2.0
8	adhesive	1845.6	1153.5	2.1
9	adhesive	2358.9	1474.3	3.0
10	adhesive	1829.7	1143.6	2.1
11	embedded	1071.3	669.5	-
12	embedded	985.1	615.7	-

§ Adhesive failure = 1, i.e., adhesive remained on the composite skin, detached from the metal.
Cohesive failure = 2, i.e., adhesive remained on metal insert, no fibers were pulled
Cohesive failure with fibers pulled = 3, i.e., adhesive in metal and fibers pulled from composite skin

Table II: Test matrix, maximum force and strength for rivets and threaded inserts.

Test specimen	Fastener type	Diameter (mm)	Maximum Force (N)	Maximum Projected Force (N) §	Strength (KPa)	Graphic
13	Split-tail	4.8	2518.2	-	1574	
14	Split-tail	4.8	1873.4	-	1171	
15	Split-tail	4.8	2756.9	-	1723	
16	Split-tail	4.8	2670.7	-	1669	
17	Split-tail	4.8	2122.1	-	1326	
18	Dome-head	4	1474.4	-	922	
19	Dome-head	4	1765.3	-	1103	
20	Dome-head	4	1758.5	-	1099	
21	Threaded	5	940.1	3760.4	2350	
22	Threaded	5	823.5	3294.1	2059	
23	Threaded	5	803.1	3212.5	2008	
24	Threaded	5	843.3	3373.1	2108	
25	Threaded	5	770.4	3081.7	1926	
26	Threaded	6	971.2	3884.8	2428	
27	Threaded	6	771.1	3084.3	1928	
28	Threaded	6	820.6	3282.4	2052	
29	Threaded	6	710.2	2840.7	1775	
30	Threaded	6	839.1	3356.3	2098	

§ *For threaded inserts the maximum projected force is equal to the maximum force multiplied by 4*

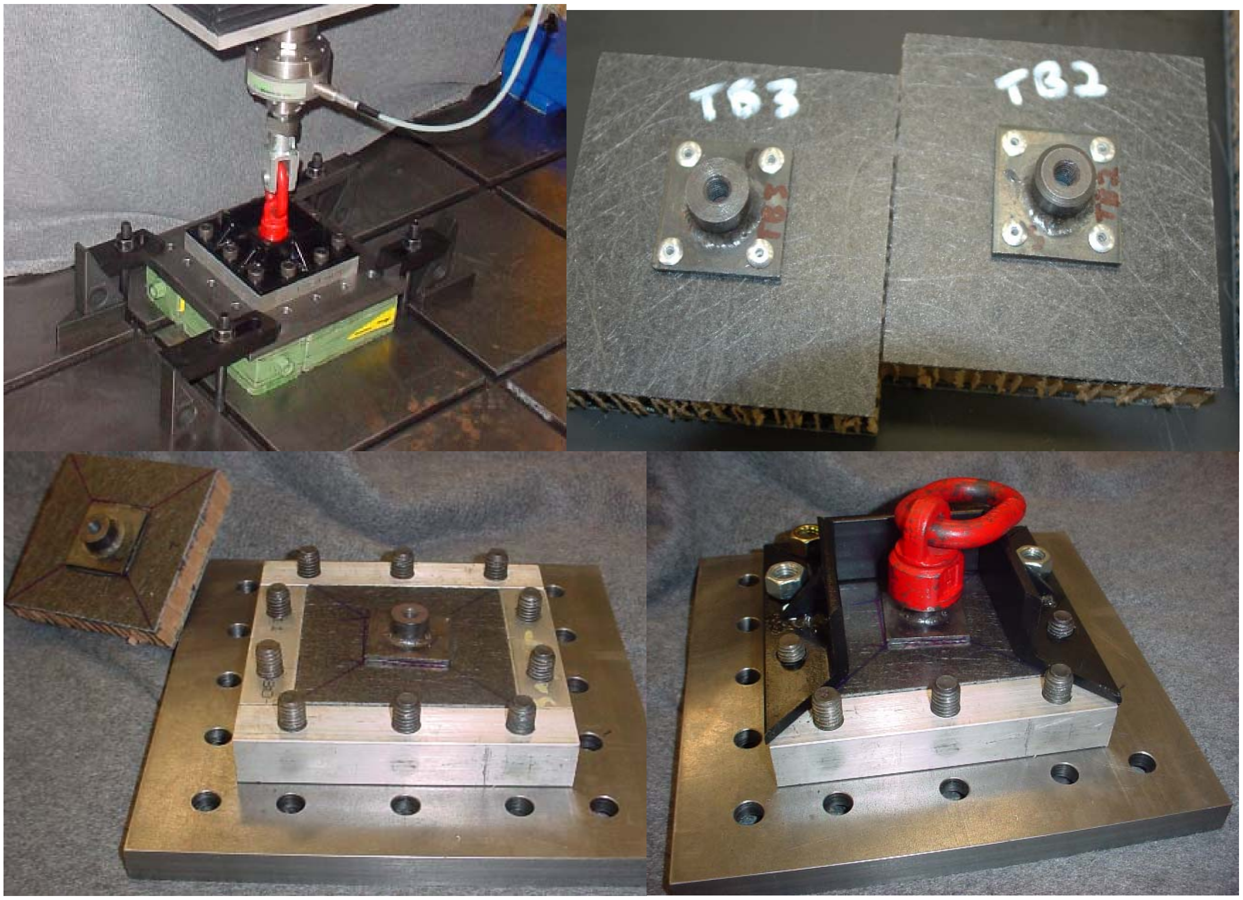


Figure 1: From left top corner, clockwise: pull out test setup, specimen with riveted metallic insert, holding fixture with adhesively bonded specimens, fixture with edge angles to hold specimen.

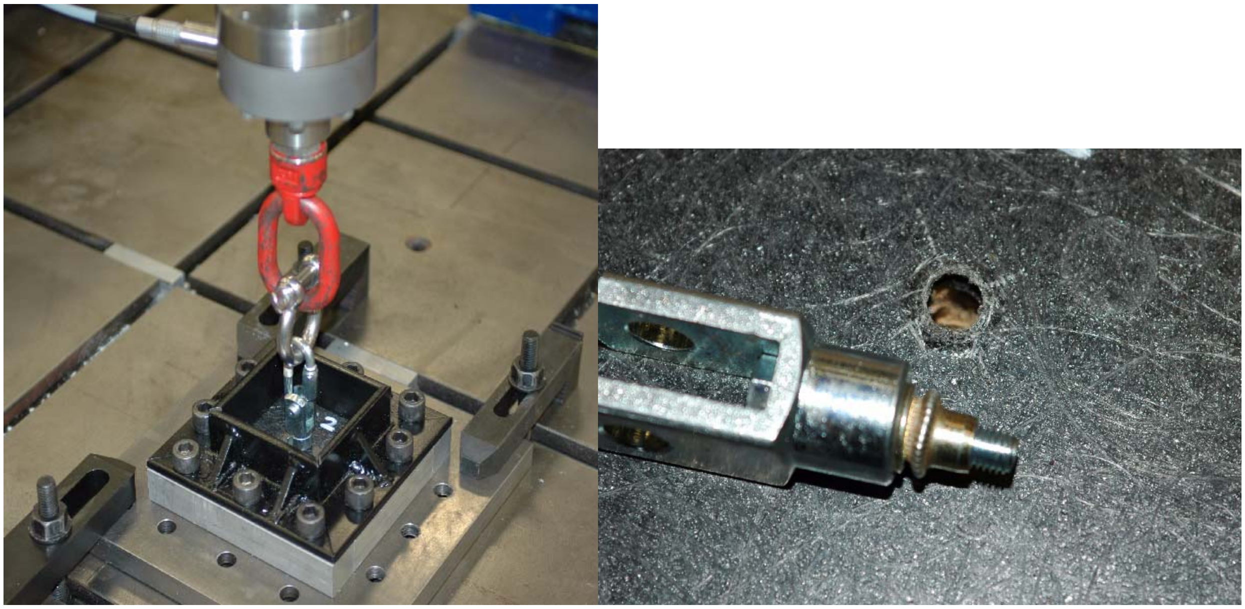
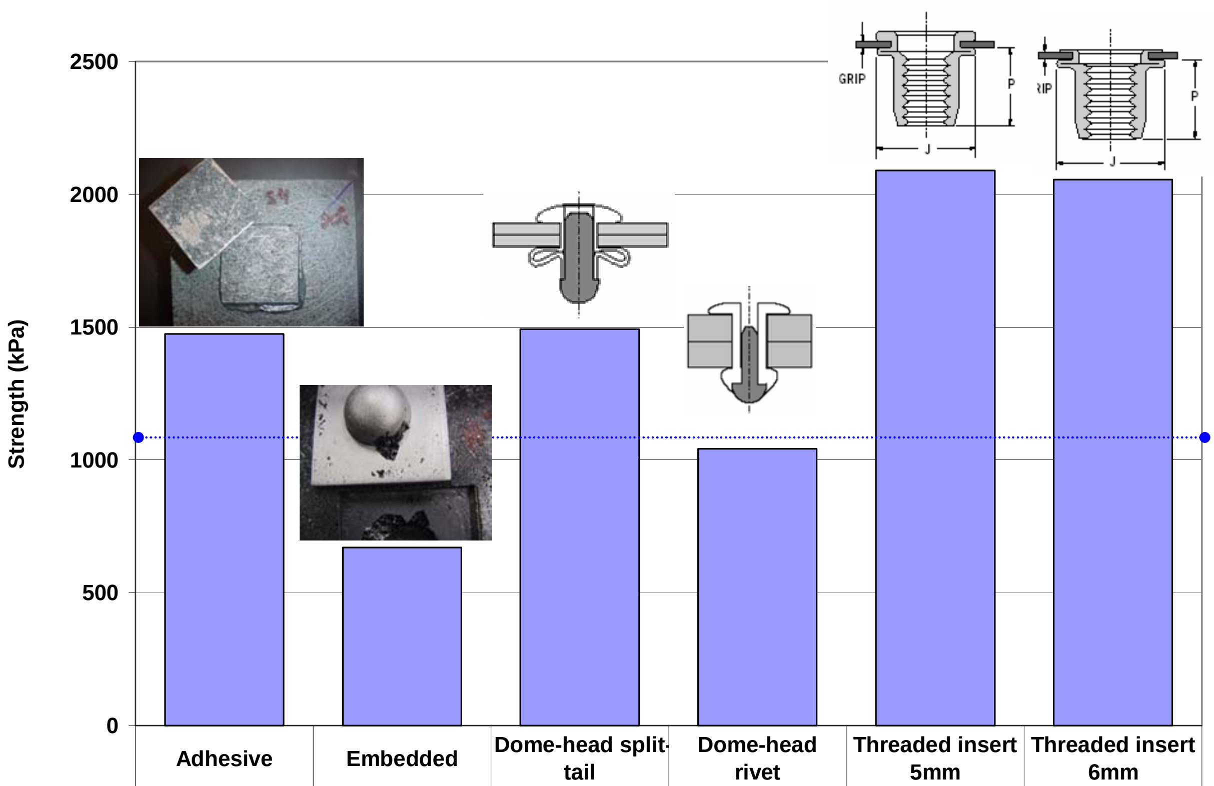


Figure 2: Threaded inserts were tested individually, as shown.

Figure 3: Embedded inserts geometry and placing.



	Adhesive	Embedded	Dome-head split-tail	Dome-head rivet	Threaded insert 5mm	Threaded insert 6mm
Strength (kPa)	1474	670	1493	1041	2090	2056

Figure 4: Strength of the different attachment methods. The composite sandwich inherent strength of 1,075 kPa is indicated by the dotted line.

Acknowledgements

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[a] Centro Ricerche Fiat, *The Research Requirements of Transport Sectors to Facilitate an Increased Usage of Composite Materials. Part II: Composite Material Research Requirements of the Automotive Industry*, (2004).