EMBEDDED ATTACHMENTS FOR PU-BASED SANDWICH COMPOSITES

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Abstract

Attachments are critical for the performance of sandwich composites in automotive components. In this paper, we continue our investigation on attachments techniques [a] and focus on a procedure to embed and test attachments for polyurethane (PU) based sandwich composites. In developing reliable attachment techniques and methods for evaluation and design, we open new application possibilities for this family of composites in the automotive market. Embedded attachments are particularly suited for PU-based sandwich composites, as the two-component polyurethane mixture allows intimate interlocking of the different sandwich “ingredients”. We discuss the performance of different attachment designs and configurations for applications where extra functionality can be added to this type of structures.

PU-based sandwich composites and the need for attachments

For decades, the automotive industry has been supporting the development of alternative fuels, lightweight designs and innovative materials and composites which are now ready for commercialization. Because of their weight and strength characteristics, sandwich composites already provide functionality and performance in some interior automotive components. As sandwich composites continue to migrate from high performance and cost applications, there is a need for cost-effective manufacturing, assembly and attachment technology. In this paper, we look into attachments techniques for polyurethane-based sandwich composites. In particular, we focus our attention on embedded attachments and compare their performance to adhesive and other forms of mechanical bonding.

PU-based sandwich composites offer distinct advantages compared to other sandwich composites based on epoxy resins or heat-bonded thermoplastics. As apposed these systems, the polyurethane resin is an integral part of the composite which can be shaped in one step and perform as a functional and decorative reinforcement, skin/core interface and more importantly as the “glue” that bonds all the sandwich “ingredients” together. Polyurethane’s ease of handling allows us to embed inserts which can serve as viable attachments for functional automotive components.

To manufacture this family of sandwich composites, we place a “packet” with a honeycomb-type core between natural or glass fiber mats impregnated on both sides with polyurethane. The viscosity of the PU-resin mixture is comparable to that of motor oil, making the impregnation and handling extremely easy compared to epoxy resins. We can add additional components, devices and attachments as initial ingredients of the package as per requirements of the application. 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).

We use a family of PU-resins provided by Bayer MaterialScience under the name Baypreg®. The polyol-isocynate mixture can be formulated to cure at different temperatures, extending or reducing the gel and de-molding time as needed. Once the package is placed on the mold 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.

Embedded attachments

Many commercial adhesives used in industrial and consumer applications are based on polyurethane resins. Therefore, it is not surprising that we use embedded inserts as an “online adhesion” process, where the PU-resin is used for bonding one more ingredient of the sandwich composite system. However, as we introduce a foreign object in the sandwich structure, the risk of delamination becomes a concern. This attachment method has the advantage of eliminating secondary operations, although it requires careful preparation of the sandwich package prior to manufacturing which could result in longer cycle times. As the inserts can be located relying on the mold design or prefabricated frames, the location of the attachments can be controlled precisely. This provides good tolerances but limits the possibility of in-place modifications, as adhesives do.

Compared to other attachment methods embedded attachments provide higher function integration potential, as complex multi-material inserts or assemblies could be designed and manufactured. From a mechanical point of view, we compare the performance of embedded attachments with other joining methods such as adhesives, rivets and threaded inserts. These attachments are all applied in secondary operations to one side of the sandwich structure and provide advantages and disadvantages as discussed by Osio and Lidner [a].

Test setup and specimen preparation

As the driving force behind this attachment study is the development of an automotive sandwich composite load floor structure, we focused our efforts on developing a test setup that closely reflects the loading conditions of the actual load floor application. Based on the dimensions of the load floor, we decided to work with 25.4mm thick composite samples cut into 152.4mm squares, made with honeycomb-type paper core and glass mat with a density of 900 g/m^2. 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 (figure 1).

The inserts used for the study are manufactured by the company Rotaloc Int’l, Inc, which specializes in fastening systems in which the adhesive flows into the perforated plates thereby producing a lock against rotation. We experimented with four types of readily available carbon steel 6mm thread fasteners:

- Circular and rectangular base plate inserts (also known as B and T plates),
- Hex nut and collar-type threads (named F1 and F2).

The embedded inserts were placed with the collar or thread facing towards the core with a stud screwed in place to prevent the resin from blocking the threads. The inserts were placed below the glass mat reinforcement next to the honeycomb paper core. Samples were weighted to assure that the amount of resin was comparable in all samples (figure 1).

Test matrix and experimental results

Table I shows the test matrix, maximum force values and strength of the embedded inserts. To determine the strength, we divide the maximum force by the surface area of the B and T type metallic inserts. On this table, we note that maximum force is achieved for the B-type bases, although the strength is higher for T-type bases. All B-type inserts initiate a delamination process as the bonding strength is reduced despite the holes through which the resin can flow. The failure in T-type inserts is localized and does not propagate throughout the skin/core interface. In all cases inserts were permanently deformed after the pull test, indicating that the strength of the skin is comparable to that of the inserts themselves.

We also 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 3 shows a graphical summary of all results obtained in this and previous studies [a] with a reference to the sandwich composite inherent strength. This figure compares the best adhesive test results, the average strength for the dome-head rivets and the average projected strength of the threaded inserts against the different types of embedded inserts discussed here.

Discussion of results

This study is a continuation of previous work on attachment techniques for PU-based sandwich composites. Results indicate that embedded inserts offers pull-out forces which are comparable with other secondary bonding operations such as adhesives and rivets. Using the calculated inherent strength of the paper core as a reference, we observe that the B-type inserts produce pull out force which is marginally acceptable. The strength provided by the smaller T-type inserts is higher and does not cause delamination. It seems that the key for good embedded insert design is to balance the advantages of a larger base area with the potential for delamination. On the other hand, the length of the thread does not seem to play a significant role in the strength of the attachment.

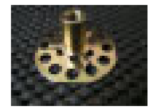
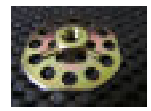
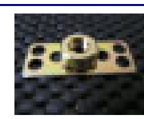
We could continue improve the design and layout of embedded attachment according to the loading conditions of the specific application. In particular, we note that the strength and reinforcement features of the base need to be considered as design factors. Further improvement can be achieved by connecting embedded attachments and modifying the locations and amount of perforations for the resin to flow.

Conclusions and future work

In this paper, we have presented additional experimental test results to evaluate the performance of embedded attachment for polyurethane-skin sandwich composites and compared them to previous attachment methods. Our focus is applications development driven, but at the same time we look for fundamental understanding of the main issues governing the effective performance of attachments. Embedded attachments are a feasible alternative once a design has been finalized and fitted with the rest of the components of the assembly. Further improvements could be achieved by locally reinforcing embedded attachments with extra mat and resin around critical areas. Furthermore, a much larger “insert” can be considered making the structure more of a metal-sandwich composite hybrid.

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. We also foresee the need to model the manufacturing process along with embedded attachments, as a necessary step for reliable computer models. 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.

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

Sample No.	Thread type	Plate Type	Maximum Force (N)	Strength (kPa)	Graphic
920921	collar	B38	1022.4	899.5	
920925	collar	B38	1129.9	994.2	
920920	nut	B38	1327.7	1168.3	
920924	nut	B38	1479.3	1301.6	
920923	collar	T38	1254.9	2198.7	
920927	collar	T38	916.8	1606.3	
920922	nut	T38	1069.3	1873.6	
920926	nut	T38	840.0	1471.8	

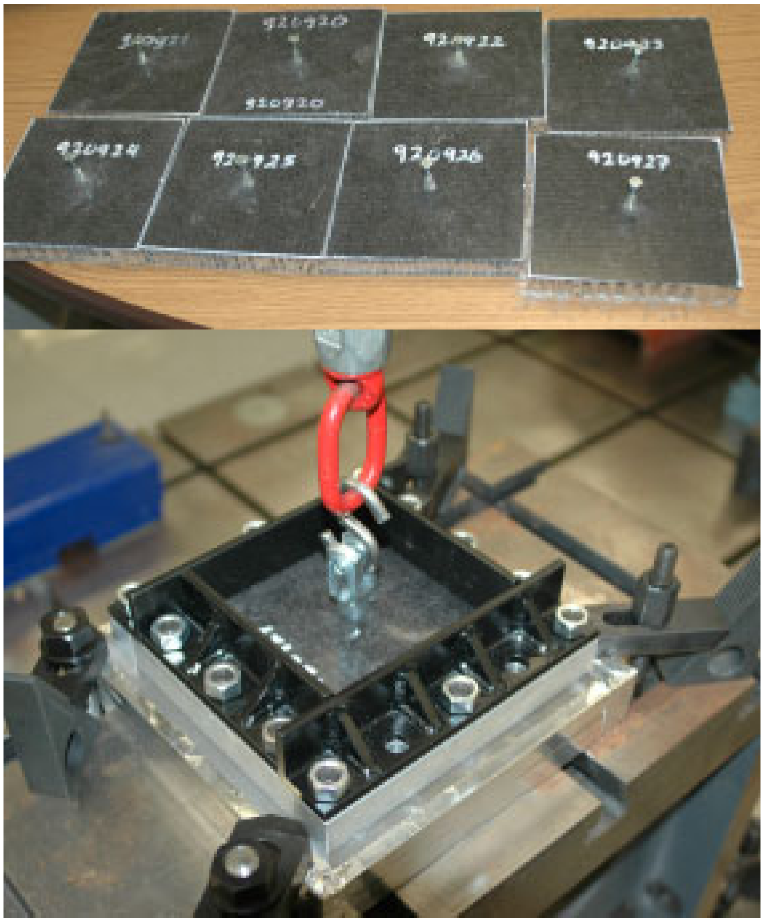


Figure 1: Samples with embedded inserts, holding fixture with pull test setup.

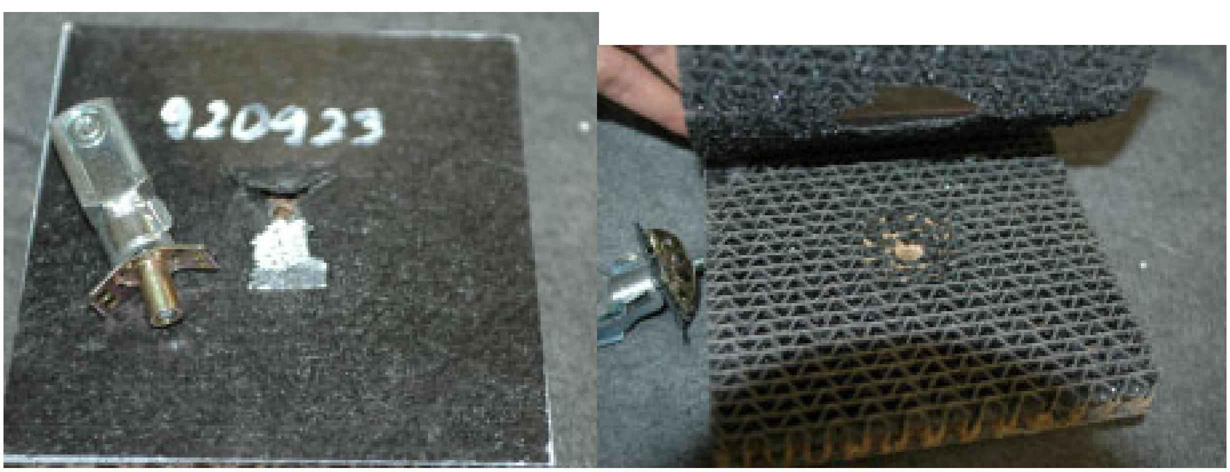


Figure 2: T38 and B38 base inserts shows local and delamination failures modes, respectively.

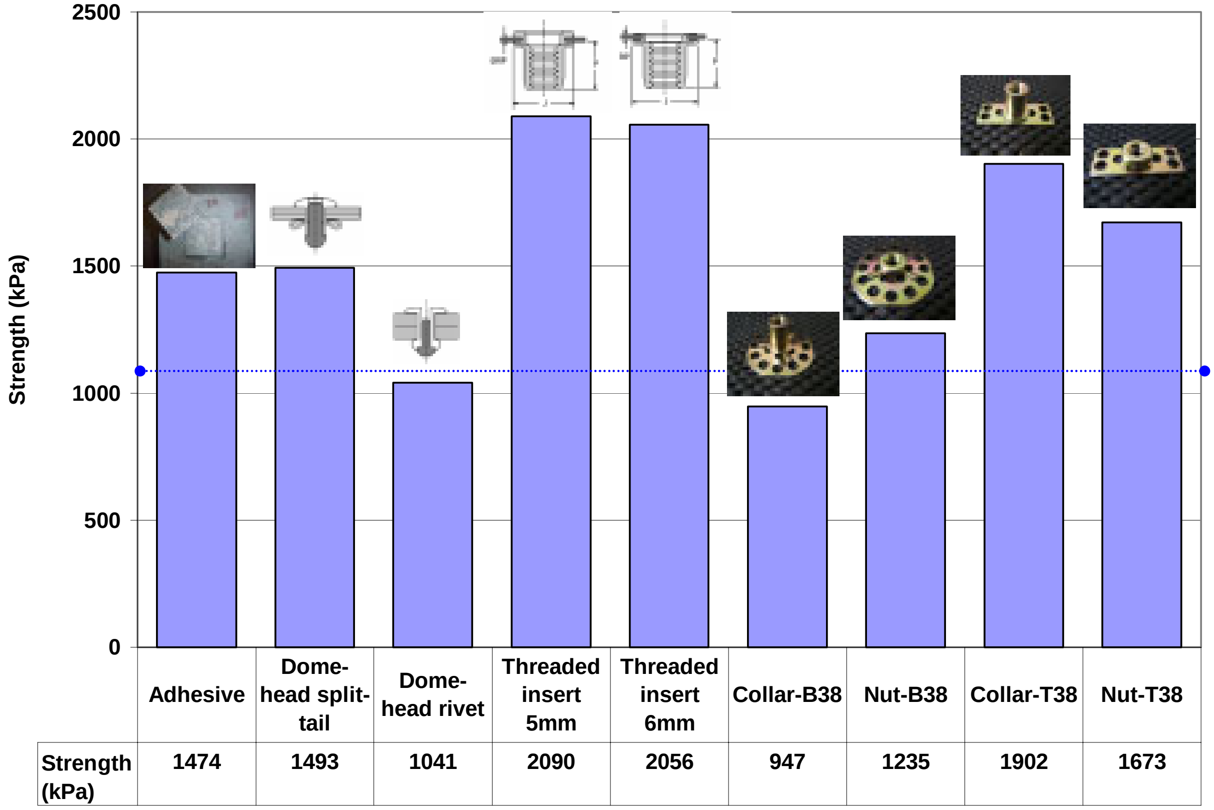


Figure 3: Strength of the different attachment methods. The composite sandwich inherent strength of 1,075 kPa is indicated by the dotted line.

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[a], I.G. Osio and G. Lindner "*Attachment Strategies for Baypreg F-Sandwich Composites.*" 2004 SPE ACCE, (2004).