Lightweight Construction of a Multipurpose Vehicle Cabin

The structural bonding technology has proved itself as a real alternative to welding in the body shell stage. Walter Mauser GmbH and Henkel demonstrate in a common project, that a cabin frame, mainly joined by an adhesive, can withstand extreme loads in combination with a significant reduction of mass.

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In the past welding has been the traditional way to build up driver's cabs for various non-automotive vehicles. However, this technique is limited in metal thickness, as thin walled structures are difficult to weld due to effects like warping or complete fusion.
In the automotive industry, where lightweight construction and fuel consumption play a key role in the early design stages, structural bonding applications on the car body have been launched area-wide since the nineties. This technique allows the joining of metal sheets with wall thicknesses in the range of 0.7 mm without losing any strength. In addition, an improved stiffness and fatigue performance of the glued joint can be obtained compared to the equivalent welded connection. Due to these obvious advantages, structural bonding applications have become a very attractive alternative for a broad variety of different industry sectors.

Challenge: Reducing the cabin weight without compromising safety

Walter Mauser GmbH, a manufacturer of cabs for special vehicles and construction machines of all kinds, is a family company located in Lower Austria that has grown from a one-man business into a global player. The reputation of this sought-after specialty OEM has traveled far and wide. Around 92 percent of the 15,000 cabs manufactured every year – in 147 different models – are exported. As some of their customers request a significant reduction of mass to increase operating distances, lightweight construction is getting more and more important for them.
Within in a project with a customer producing electric-driven multipurpose vehicle, Mauser were faced with reducing the weight of the cabin by half, without compromising safety. These two requirements challenged them with a problem they had never before.
Mauser's approach consisted of the substitution of the standard steel used for the frame structure by a high-strength steel. Through this, they could easily reduce the material thickness of all sheets and tubes from 2 mm to 1 mm and retained the same material strength. As a long-term solution Mauser thinks using aluminium instead of steel which will additionally reduce weight by a factor of three.
The resulting challenge for them was the selection of an appropriate joining technology. So far they have used welding for all permanent steel connections. This would result in excessive rework. Especially warping effects would cause a lot of reworking to reshape the framework.

Introducing structural bonding

The cooperation with Henkel opened Mauser the opportunity to introduce bonding as a solution. Henkel has a longtime experience in structural bonding applications, which enables them to integrate the technology in a production process and support the design of the parts to be joined.
First Henkel selected an adhesive from their broad portfolio, based on the requirements and production conditions. For this, intensive preliminary aging and strength tests were carried out in the Henkel laboratories by using substrate samples provided by Mauser. To substitute a welded joint by bonding, a high-strength product is necessary to guarantee the same performance. Since the adhesive shall be applied in the body shell stage, the product must adhere to an oily substrate and absorb a moderate amount of oil.
Henkel's one component heat-curing structural adhesive Teroson EP 5089 meets these requirements and has proved its outstanding performance in the automotive industry for years at big OEMs. The epoxy-based product is cured in an oven process and results, when completely cured, in tensile shear strengths above 25 N/mm². Due to its high viscosity it is wash off-resistant, which becomes important when the structure runs through dipping bathes.
At the Mauser production site the metal sheets achieve substrate temperatures up to 200 °C in the e-coat oven process for 40 minutes, which is sufficient to completely cure the product. The thermal load in the downstream powder paint oven process has no significant influence on the physical performance of the adhesive. As one

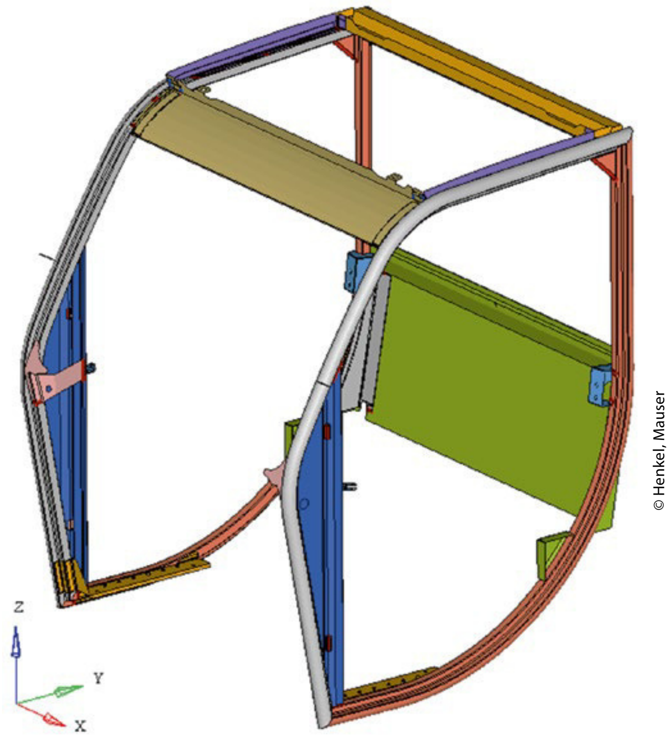

Figure 1 > CAD model of the cabin frame

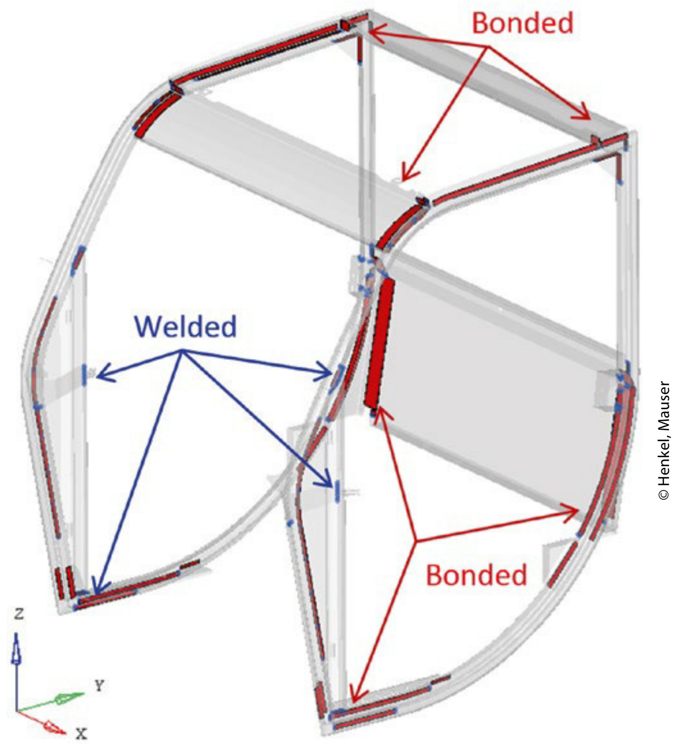

Figure 2 > Redesigned areas of the CAD model

component heat-curing adhesives have no initial strength, a mechanical fixation of the joint like riveting or spot welding is required. Here Mauser used stitch welding to connect the metal parts.

Changes of the cabin frame

The design changes of the cabin frame to prepare the structure for bonding were conducted in a close interchange between the two partners. Mauser's construction engineers redesigned the CAD model *(figure 1)* based on guidelines provided by Henkel.
Further adaptions and recommendations were done by Henkel's technical customer service engineering team by involving various experts from the company. Especially joining direction, mechanical loads on the connections and accessibility for the stitch welding tool were key parameters for the redesign.
The considered load directions conformed to the conditions of the Roll Over Protective Structure (ROPS) test which is a standardized method to check the driver`s safety in case of rollover. For dimensioning of the glue flanges, well-known and established values of the automotive industry were applied. This means e.g. an overlap of the parts to be joined of at least 16 mm which is suitable for a fixation technique. *Figure 2* shows the changes in the redesigned bonding-appropriate structure. All areas highlighted in red correspond to glued joints while some connections will still be welded (colored in blue).

Building up of the cabin structure

To support the assembly of the frame, engineers from Henkel's technical customer service traveled to Mauser's production site in Austria. Within one day the cabin structure was built up step by step. First the flanges were cleaned to guarantee an adequate adhesion *(figure 3)*. In doing so tabs soaked with Henkel's Teroson VR 20 – a solvent-based universal cleaner- were used. Usually cleaning becomes necessary if a contaminated surface exists. This includes dust or non-tested oils, as Teroson EP 5089 is able to absorb proved oils up to an amount of 3 g/m².
The adhesive provided in 300 ml cartridges was applied manually by a heated hand-gun *(figure 4)*. Heating up the adhesive is necessary to reduce the product's viscosity during the application. In the next step the parts were successively joined and each fixed by stitch welding whereby two points were sufficient in most cases.
Afterwards the cabin frame passed the regular production line – dipping bathes for cleaning and e-coat lacquer application as well as the e-coat oven itself. The adhesive cured completely within in the process which results in a solid and strong frame.

Prediction of load cases

Parallel to the assembly and real life test of the cabin, a Finite Element (FE) model of the structure was created. This enabled the prediction of load cases by applying the simulation technique on the one hand and gave Mauser the chance of further design changes in a validated model on the other hand. Based on the updated CAD data Henkel's expert team created a very detailed model of the cabin. As an established tool for complex investigations like the ROPS test, the nonlinear Finite element software LS-Dyna

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Figure 3 > Cleaning of the flanges

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Figure 4 > Teroson EP 5089 application by a heated hand-gun

was used. The steel was modeled by shell elements and the adhesive by solid elements. For both materials an elastic-plastic non-linear material model approach was used. In the adhesive material model, the failure at a defined plastic strain was given to point out fracturing of the glued joints, whilst no failure criterion was defined in the steel material model. The mechanical loads for the model were extracted from the guidelines of the ROPS test. These constraints, summarized in *table 1*, are either defined by maximum deformation force or deformation energy. In this case the absolute values of forces and energies are scaled based on the mass M_{ref} of the entire cabin. Like in the real life test, the loads were applied successively on the frame, whereby deformations of former steps were the start conditions for the subsequent ones. *Figure 5* shows the ROPS setup with a fixed cabin and the transmission of force of load case 1 via a hydraulic cylinder.

	Load case		**Load value**
1	Back side right, load direction from the back to the front		Deformation energy: $E = 1.4 * M_{ref}$ E= 1.4 * 900= 1260 J
2	Back side, load direction from the top to the bottom		Deformation force: $F = 20 * M_{ref}$ F= 20 * 900= 18000 N
3	Front side left, load direction from the front to the back		Deformation energy: $E = 1.4 * M_{ref}$ E= 1.4 * 900= 1260 J
4	Side, load direction from the left to the right		Deformation energy: $E = 1.75 * M_{ref}$ E= 1.75 * 900= 1575 J
5	Front side, load direction from the top to the bottom		Deformation force: $F = 20 * M_{ref}$ F= 20 * 900= 18000 N

Table 1 > Load cases of the ROPS test

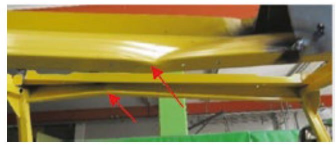
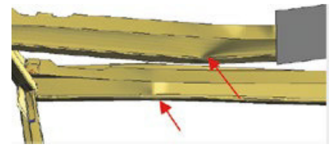
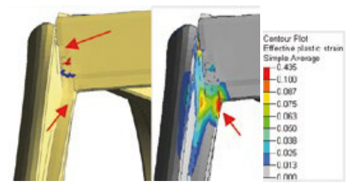
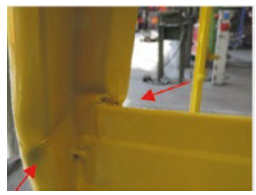
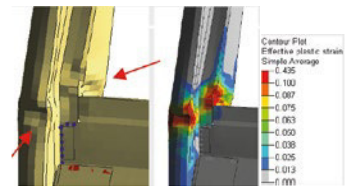
#	Description	Test	Simulation
1	Good conformance of front and back roof frame		
2	Mode of failure in the upper left corner is validated in the simulation (crack is represented by a high stress level as the failure criterion is not defined)		
3	Good conformance at left back transversal frame		

Table 2 > Comparison of test and simulation results

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Figure 5 > Load case 1 of ROPS test

Comparison of real life test and simulation results

The real life ROPS test was conducted by a certified testing institute and the bonded frame passed it successfully. Here it was verified that the driver's safety, represented by a zone around the seat, was not affected by the deformed cabin.

The FE simulation showed a good correlation to the real test. The deflections and deformations of the frame in the FE simulation were represented precisely by the real test (*Table 2*). As there was no failure criterion defined in the steel material model, the high plastic strain concentration in the FEA at certain positions can be used as an indicator to predict the material failure of the steel frame.

Conclusions

The close cooperation of the two partners was in the end the key for the project's success. All essential advantages of the bonding technology could be revealed, but also how thoroughly the customer's process had to be analyzed. The selection of an appropriate adhesive, the preparation of the parts to be joined as well as the production conditions, had to be evaluated individually. In addition, designing parts by involving recent simulation tools will continue to grow, especially in the case of adhesive applications. The present project has shown that the simulation technique can substitute complex tests and by that reduce costs. Once a validated model is created, design changes can be integrated with relatively low effort and tested on the computer instead of in real life. //

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