Adhesive Films for High-Strength Metal-Plastic Lightweight Components

Metal-plastic hybrid structures play an important role in lightweight vehicle design. For affordable and efficient manufacturing of hybrid structural components, Nolax has developed adhesive films with which dissimilar materials such as plastic and metal can be firmly bonded without pre-treatment and in one production step.

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The key elements of lightweight design are a significant contribution to CO_2 savings, sustainability, and resource efficiency. Since reducing the weight to be transported requires less energy for propulsion, the role of efficient metal-plastic hybrid construction has become increasingly important [1] [2] [3] [4] [5] [6] [7] [8].

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Figure 1 > Nolax has developed adhesive films for structural hybrid lightweight parts, which combine weight reduction with improved performance and efficient production process.

Dissimilar materials such as metals and plastics can be joined in various ways. Adhesive bonds offer advantages compared to mechanical joining methods in terms of force and load distribution. Thermoplastic adhesive films from Nolax are specially developed for this, with dissimilar materials such as metals and various plastics joined together in one simple connection step (*Figure 1*). The adhesive bond distributes tension evenly over the entire component. Thus, the component can absorb and transmit higher forces, or hold existing loads for a longer period.

Film technology as a bridge between materials

It is often the case that the materials to be joined are incompatible. The plastic doesn't adhere easily to the metal side of the hybrid component. The solution developed by Nolax works without time-consuming pre-treatment of the metal surface using primers, micro structuring, plasma treatment or a combination of these methods. The metal only needs a clean surface for attaching the adhesive film and requires no special preparation. That means that metals like aluminum, bare or galvanized steel or stainless steel can be directly coated with an adhesive film. To be able to join the materials, however, the adhesive film must have the right chemical composition, which requires the appropriate expertise and know-how.

Dissimilar materials such as metals and plastics, which often also have a strongly opposed polarity, need different chemical connections. The most common material combinations for structural automotive applications include aluminum or steel and filled polypropylene (PP) or polyamide (PA66, PA6). Nolax has developed thermoplastic adhesive films for these applications. Multilayer films are most commonly used here. The two outer layers of the adhesive film each consist of different chemical compositions, matched to the connecting substrates. Even recycled plastics or bio-based plastics can be used with such adhesive films.

Production of metal-plastic hybrid components

The production of light and durable metal-plastic hybrid components using adhesive films essentially consists of three steps: coating the metal surface with the adhesive film, forming the coated metal sheet, and injection molding of the plastic component to the coated metal part.

Coating of the metal surface with the adhesive film

The coating of a flat metal sheet can be done in batches to individual sheets of metal, pre-punched components or continuously on a metal coil. For this purpose, laminating systems such as the flatbed laminating system or double-belt calender shown in *Figure 2* are suitable. Other coating processes such as transfer or roll calenders can also be considered depending on the material substrate. A combination of a roller calender and a flatbed laminator often delivers optimal results.

Shaping of the coated sheet metal

The adhesive films are tough and elastic. They can be processed with the most common forming processes (*Figure 3*), and even high aspect ratios in deep-drawing processes can be reproduced well without damaging the coating.

Injection molding of the plastic component to the coated metal part

The coated and formed metal parts are placed in the injection molding tool. The plastic is directly injected onto the coating, which activates the thermoplastic adhesive film. After opening the injection molding tool, the finished component can be removed (*Figure 4*).
Metal inserts that have already been formed can also be coated with the adhesive film before the injection molding process. To do this, steps 1 and 2 are simply reversed in the process described above. The application process changes only slightly. The flexible adhesive film can be coated onto the heated metal surface with a suitable apparatus, for example a stamp adapted to the shaped metal part (*Figure 5*). The plastic is then back-injected, extruded or compression molded.
Another advantage of this application technique is that a partial coating of the metal insert is possible. The adhesive film is only applied to the areas where it is needed and where the plastic component will then be placed. Areas without plastic remain uncoated. After the application of the adhesive film, the injection molding process takes place in exactly the same way as in the production via a flat sheet metal coating.
Currently a number of institutions and companies have also taken on the topic of hybrid structures made of metal and plastic and their lightweight design potential. As well as injection molding as a shaping process for plastics, other methods can be considered and used, such as the extrusion or compression molding of organo sheets. The basic principle is also retained here: the organo sheet is pressed onto the coated surface while warm, the adhesive film is activated by the heat input and the bond between the organo sheet, and the semi-finished metal product is established. This in turn creates a hybrid metal-plastic component that is light, stiff, strong, and functional.

Feasibility – tests, results, demonstrator

Nolax has provided proof of feasibility in numerous tests, both in its own laboratory and in cooperation with research institutes and companies from the automotive industry. These partners include institutes at the University of Paderborn and the University of Erlangen, the Automotive Center Südwestfalen, the Open Hybrid Lab Factory and the Technical University of Braunschweig.
Lap shear tests on single overlapped test specimens according to DIN EN 1465 showed that strengths of over 12 MPa can be achieved with the combination of steel or aluminum with PA6 (*Figure 6*). The multi-layer adhesive film A22.5011 from Nolax was used as the adhesion promoter, and the pull-off speed on the universal testing machine was 5 mm/min.
The strength has been established on galvanized steel and on aluminum, measured both initially and after 50 days of storage in the climate change test according to the Volkswagen test specification PV 1200. Values of over 14 MPa were obtained on an additionally phosphated surface (centre columns in *Figure 6*). The consistently high strength immediately after production and after severe exposure to climate change test shows the robustness of the connection.
The transferability of the data to real-world components is shown using principle components, so-called demonstrators. Various tests and simulations have been carried out for this purpose. An Erlangen beam, i.e. a U-profile made of metal reinforced on the

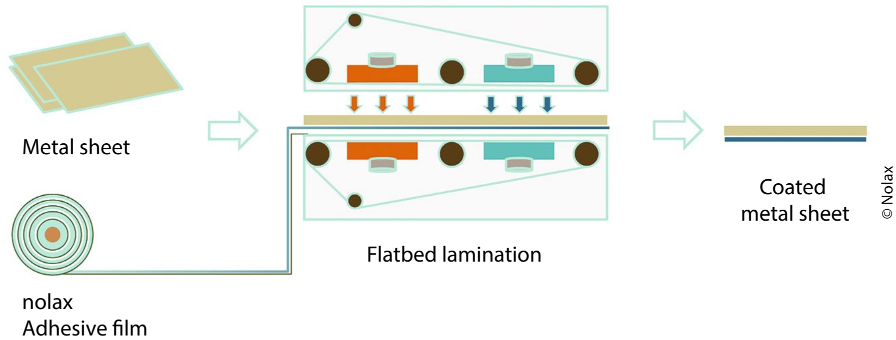


Figure 2 > Application of adhesive films on metal sheets

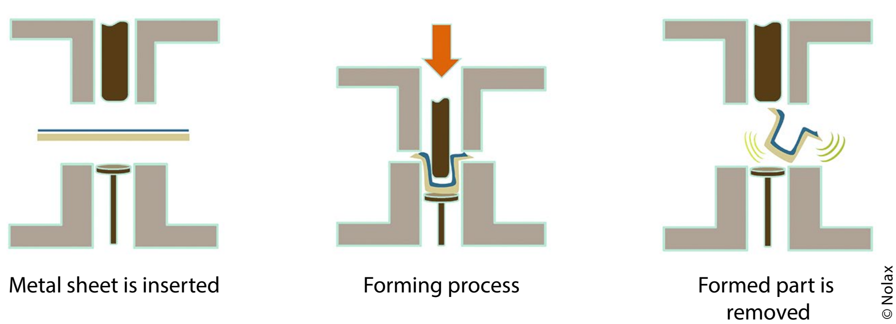


Figure 3 > The coated adhesive films do not tear during the metal forming process.

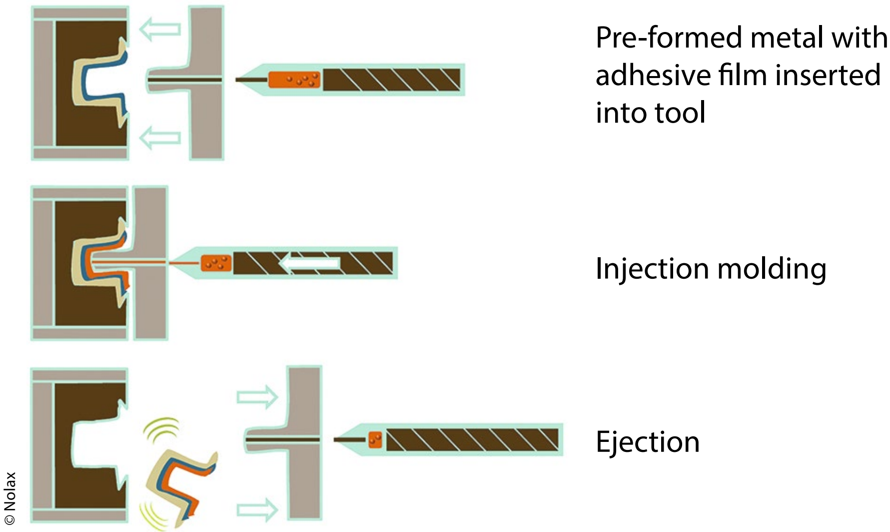


Figure 4 > In injection molding, the hybrid component is produced in a single step.

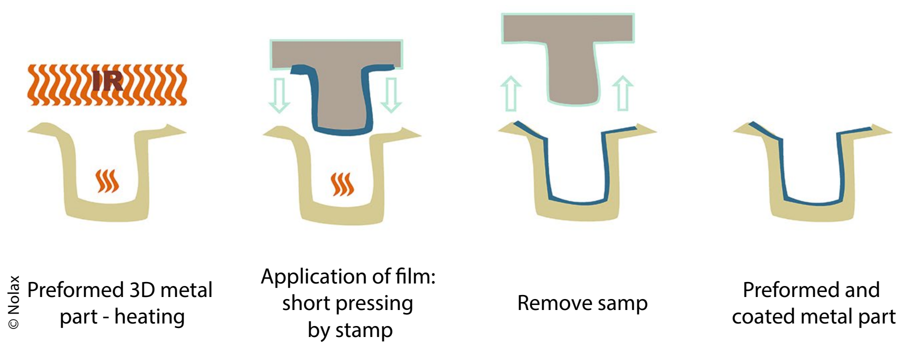


Figure 5 > 3D application process of adhesive film onto a preformed semi-finished metal part

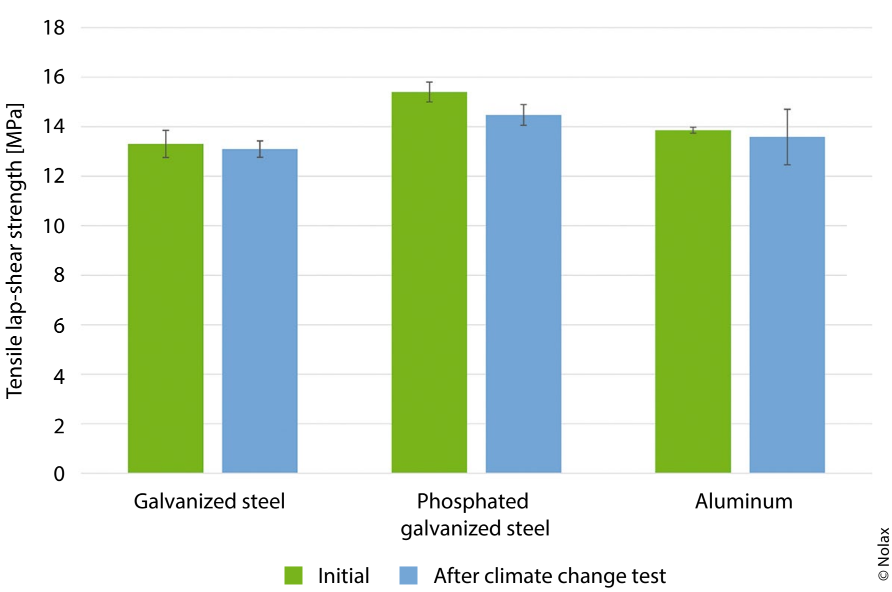


Figure 6 > Tensile lap-shear strength determined on hybrid test specimens made of aluminum or steel and an injection-molded plastic (PA6-GF30)

inside with plastic ribs, served as the component of choice (*Figure 7*).

Torsion tests on this component showed that the torsional rigidity was four times higher than that of a component with purely mechanical connectivity, using injection points and undercuts on the underside of the component. The potential for energy absorption also increased by half of the original value (*Figure 8*).

Dreessen [9] also showed that the component withstands dynamic loads much longer with the help of the adhesive film: more than 60 % more load cycles could be transferred compared to a component connected with a positive fit via undercuts. In practice, this means that integrally connected components can have a longer service life or can be designed to be lighter.

A Nolax-commissioned study at Neue Materialien Fürth (NMF) revealed that with alternative three-dimensional coating, with the right tools, the same high performance is achieved as the reference. This consists of a full flat sheet coating with Nolax adhesive film A22.5011. The above-mentioned carrier from Erlangen served as a demonstrator. For the internal coating of the already formed sheet steel, NMF built a stamp that could apply the adhesive film to a U-profile previously heated to 250 °C.

After the 3D application of the adhesive film, the PA6-GF30 plastic was injected. This hybrid component was tested for torsional strength. In the quasi-static torsion test, the specimen is firmly clamped on one side while the opposite side is slowly twisted to 90° at 1.5°/s. The torsion angle torque curve is recorded during the test. Torsional rigidity, torsional moment and work expended are characteristic values that can be derived from the test.

Figure 9 shows that the reference achieved the same values as a sample produced using the 3D coating process after subsequent forming of the coated sheet and the injection molding process with PA6. Thus, high-performance, and durable metal-plastic hybrid structures can be manufactured with the desired and necessary lightweight potential, regardless of the sequence of the coating and forming process of the metal part.

Transfer to real components

The performance of the hybrid design, which was determined using test specimens and principle components, is transferable to real components. Applications are conceivable both in the interior and exterior of vehicles, wherever load-bearing metal structures can be replaced by lightweight hybrid structures. Among other things carriers, rocker panels, structures in hoods and doors, front ends and, since the current and future development towards electromobility, structures for battery housings are possible areas of application.

Scientific work on performance of metal-plastic hybrid structures

The work cited below as an example shows that the data generated minimizes complex and expensive trial and error tests and that the components in a hybrid structure can be designed very precisely in advance using simulation. This is important with regard to an economically interesting component design.
The in-depth scientific work by Dreessen [9] should be mentioned as an example. A well-founded scientific treatise on the performance of metal-plastic hybrid structures was created in close cooperation with Sitech Sitztechnik, a Volkswagen subsidiary at the time, and the scientific support provided by the Institute of Machine Tools and Production Technology (IWF) at the Technische Universität Braunschweig. In particular, the transferability of the data from the structure simulation to the real component was an essential part of the work. A very good agreement was found. The hybrid component, the center section of a car rear seat, has passed the safety-relevant load case "frontal impact with protection against cargo" based on ECE R17.
This shows a possible technology transfer to series production. The hybrid component shown could be manufactured at no additional cost compared to a steel component, but with a weight reduction of over 30 % (*Figure 10*), which approximately corresponds to the weight of a magnesium construction. Fundamental to the high standard of performance is the even distribution of force in the bonding zone.

Simulation for a load-based component design

An important aspect in addition to the technical and economic feasibility is the simulation of the components and their properties. In his work, Dreessen [9] referred to a previous simulation to dimension the component appropriately for the load. In the paper, the findings from the simulation were verified in a real test: the data from the simulation correlate very well with the observed component behavior.

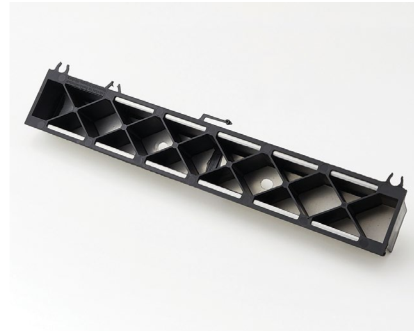
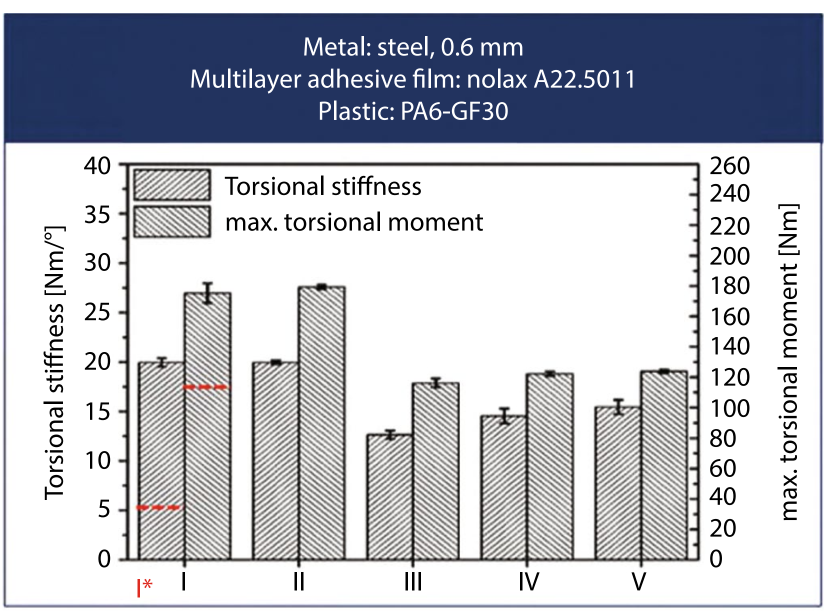


Figure 7 > Erlangen beam principle component: metal U-profile, internally equipped with adhesive film, reinforced with injection-molded plastic ribs (black). (Metal: AlMg3, 0.6 mm; multilayer adhesive film: Nolax A22.5011; plastic: PA6-GF30)

Grubenmann [10] used measurements on test specimens in a sandwich structure in a finite element analysis (FEA) to generate the virtual component characteristics and forming properties, which corresponded very well to the experimental results. The sandwich structure consisted of two aluminum cover layers and a PA6 organo sheet core, which were connected using the appropriate Nolax adhesive film A22.5011. Grubenmann was able to show a significant potential for lightweight design if a component consists of a hybrid structure instead of full metal.



I - Initial test; PA6 dry without adhesion promoter, just form fit*

I - initial test; PA6 dry

II - after e-coat simulation (30 min, 200 °C)

III - PA6 conditioned (according to EN ISO 1110)

IV - after climate change test (50 days) PA6 conditioned (according to EN ISO 1110)

V – after salt spray test (according to DIN EN ISO 9227:2012), PA6 conditioned (according to EN ISO 1110)

Figure 8 > Results on Erlangen beam with 0.6 mm steel sheet; the red dashed lines (I*) correspond to the values without adhesive film, just form fit due to undercuts, injection through holes in the underside of the part (PA6 dry = freshly injected, unconditioned)

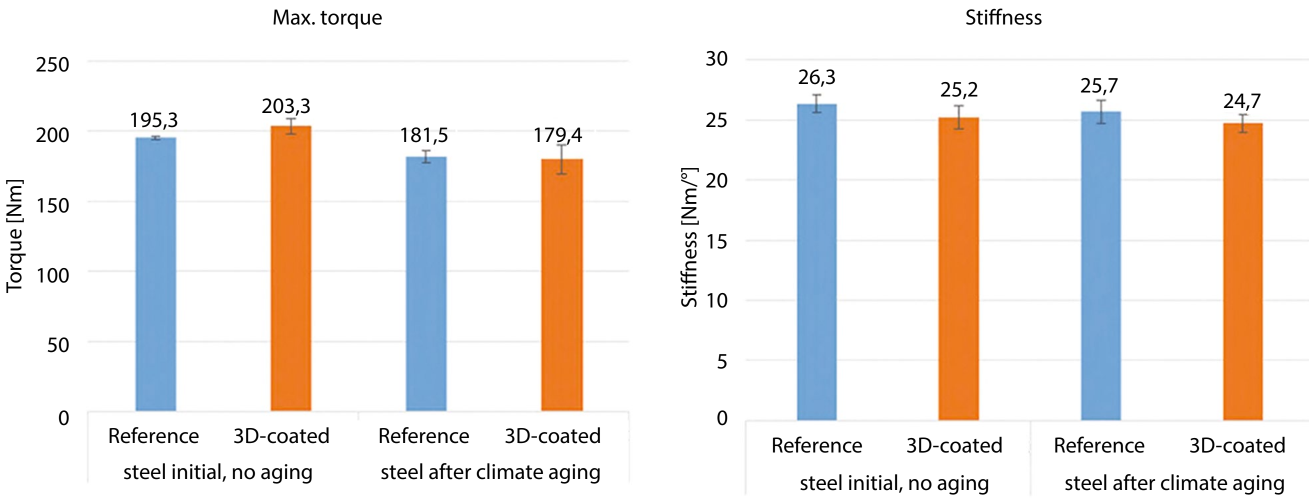


Figure 9 > Result 3D coating of the Erlangen beam with 1 mm steel

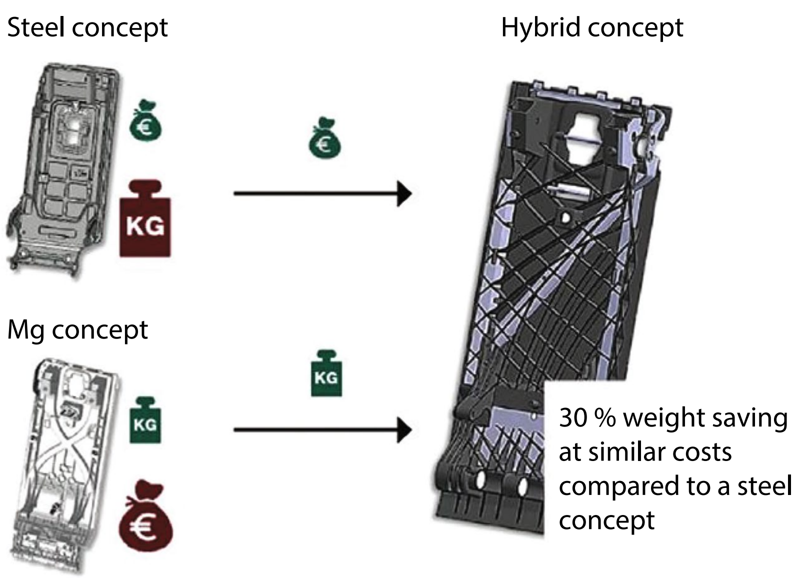


Figure 10 > Construction of a car seat in a metal-plastic hybrid design

Normalized for the thickness and density of the components, the result was a specific energy absorption that was only 20 % lower for the hybrid structure than for the construction made of high-strength steel. The designed hybrid component was 60 % lighter than the steel part. Normalized to 100 % of the performance, there is still great potential for lightweight design.

Conclusions

In summary, it can be stated that the bonding solutions for metals and plastics using the adhesive films presented by Nolax have proven their practical suitability and are ready for series use.

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