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BEHAVIOR OF CATHODIC DIP PAINT COATED FIBER REINFORCED POLYMER/METAL HYBRIDS

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ABSTRACT

Increasing mechanical, economic and environmental requirements lead to multi material designs, wherein different classes of materials and manufacturing processes are merged to realize lightweight components with a high level of functional integration. Particularly in automotive industry the use of corresponding technologies will rise in the near future, as they can provide a significant contribution to weight reduction, energy conservation and therefore to the protection of natural resources. Especially the use of continuous fiber reinforced polymers (FRP) with thermoplastic matrices offers advantages for automotive components, due to its good specific characteristics and its suitability for mass production. In conjunction with isotropic materials, such as steel or aluminum, optimized lightweight structures can be produced, whose properties can be easily adapted to the given component requirements.

The present paper deals with the development of innovative hybrid laminates with low residual stresses, made of thin-walled steel sheets and glass fiber reinforced thermoplastic (GFRP) prepregs layers. Thereby the interlaminar shear strength (ILSS) was increased by an optimization of the FRP/metal-interfaces, carried out by examining the influence of several pre-operations like sanding, cleaning with organic solvents and applying primer systems. Based on these findings optimized compound samples were prepared and tested under realistic Cathodic dip paint conditions to determine the influence on the ILSS.

KEYWORDS: hybrids, composites, fiber reinforced plastics, lightweight design, metal thin sheets, ILSS, FRP

INTRODUCTION

The increasingly disparate requirements for components with respect to mechanical, economic and environmental properties require a specific combination of different material classes and manufacturing processes. Especially in automotive industry the use of such multi-material designs will rise in the near future, as these can provide a significant contribution to weight reduction, energy conservation and therefore to the protection of natural resources. Particular attention is paid to the new material composition made of fiber reinforced thermoplastics and metallic (M) components. By targeted exploitation of the excellent mechanical properties, combined with suitable capabilities for mass production, cost-effective and weight-optimized parts with high stiffness and load capacity can be provided [1-3].

An approach that follows this idea is the combination of metal and fiber reinforced plastics (FRP) in form of hybrid laminates. Such FRP/M-hybrid laminates are characterized by excellent mechanical properties at high damage tolerances. Commercial available hybrid laminates with continuous fiber reinforcement are e.g.:

- GLARE® (glass fiber reinforced thermoset/aluminum foil),
- ARALL® (aramid yarn reinforced thermoset/aluminum foil) and
- CARALL® (carbon fiber reinforced thermoset/aluminum foil).

These were developed to increase the impact resistance and damage tolerance of fuselage components. In this regard a well-known example is the successful integration of GLARE® into the Airbus A380 [4]. However, by the use of thermosetting matrices the aforementioned hybrid laminates possess the material specific disadvantages with regard to recycling, malleability and cycle times. Consequently those are not suitable for automotive mass production [5,6].

By contrast, suitable processing properties are offered by thermoplastic based hybrid laminates that are currently only available as semi-finished products without fiber reinforcement (ALUCOBOND®,

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BONDAL®, LITECOR®, …) [7,8]. Therefore the mechanical properties are severely limited. To extend the material performance of thermoplastic based hybrid laminates, the ambition of this research is the development of GFRP/M-hybrid laminates with polyamide 6 (PA6) matrix in order to ensure a suitable usability for automotive mass production.

In addition to relatively low process times, thermoplastic based FRP/M-hybrid laminates offer larger achievable degrees of deformation, favorable damping properties, a higher damage tolerance as well as excellent properties in terms of impact- and fatigue strength in comparison with thermoset based types [6,9].

MANUFACTURING OF HYBRID LAMINATES

For the preparation of thermoplastic based FRP/M-hybrid laminates, textile semifinished products are preconsolidated to continuous fiber reinforced prepregs. In the following step the prepregs and the metallic top layers are processed by a hot press under defined temperature and pressure conditions. To achieve high strength and stiffness values, strong adhesive forces between FRP and metallic components are required. So the interface has to be optimized by an appropriate surface pretreatment.

In the present study continuous glass fiber reinforced hybrid laminates were examined, whose structure is explained in table 1 more detailed.

Table 1. Structure of the investigated hybrid laminates

Metal	Steel HC260LAD+Z100
Matrix	Polyamide 6 (PA 6)
Reinforcement fibers	Glass fiber (G)
Fiber volume content	47%
Layer structure	$[HC260LAD/0_2^G]_s$
Thickness metal	2 x 1.0 mm
Thickness FRP	0.65 mm
Thickness HL	2.65 mm

The preparation of the hybrid laminates was accomplished on a Collin P/M hot press with a corresponding mold. The curve shape of the temperature and pressure during the pressing process is shown in figure 2, wherein the required consolidation time is highlighted. The manufacturing process can be divided into three stages:

- Heating and plasticizing of the thermoplastic matrix (35 bar, 285 °C, 10 min)
- Consolidation of the fiber reinforced thermoplastic (60 bar, 285 °C, 3.5 min)
- Cooling and solidifying of the thermoplastic melt (60 bar, 80 °C, 6.5 min)

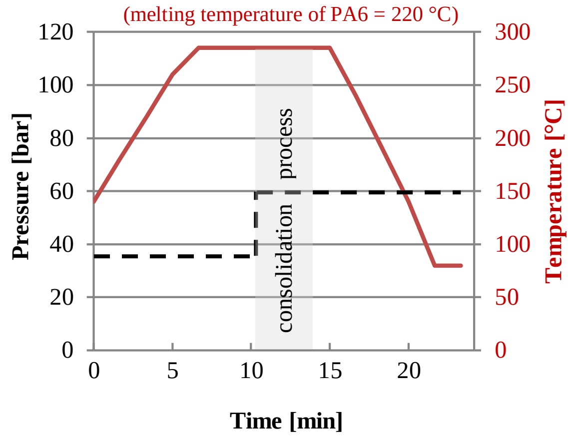

Figure 1. Temperature and pressure profile of hybrid laminate production

During the process, the high-viscose thermoplastic polymer matrix is pressed against the surface of the metallic component, so that adhesive forces between the materials can occur. At the same time the reinforcing fibers are fully impregnated and consolidated.

CATHODIC DIP-PAINT TREATMENT

Due to its excellent properties in terms of impact- and fatigue strength, achievable degrees of deformation, damping and damage tolerances, hybrid laminates are predestined for structural applications in automotive components. Therefore they usually have to pass through an intricate paint job. The average cycle time is about 15 hours [10]. In this process, the body of the vehicle goes through a chain of modules in which various coatings and protective layers are applied. One part is the cathodic dip painting (CDP) process, which is an effective way for the protection against corrosion. After several cleaning and degreasing processes a voltage of 380 V is created between the dip coating tank and the vehicle body [10]. The positively charged paint particles flow towards the negatively charged body of the vehicle due to the applied potential. With this technology a uniform paint coating is realizable even in inaccessible areas and cavities. The applied cataphoresis primer is then baked in a CDP oven at about 185 °C after a multi-stage rinsing.

Due to this intensive thermal loads, which can induce critical residual stresses, the resistance against the CDP processes represents a major requirement for the use of new materials in novel car body concepts.

To investigate the influence of the CDP process chain on the interlaminar shear strength (ILSS) of the hy-

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brid laminates, specimens in accordance with DIN EN 2377 [11] were sent to the Volkswagen AG Wolfsburg for a CDP-treatment. For the sake of contacting, the samples were provided with a borehole (diameter = 3.0 mm) to induce the voltage by a copper wire. The temperature profile of the traversed CDP process is illustrated in figure 2.

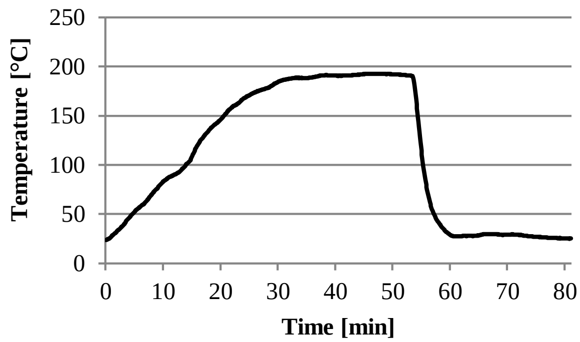

Figure 2. Temperature profile of the cathodic dip painting process

The measured temperature curve shows a slow and steady heating of the specimens. The maximum temperature of 190 °C (± 2.8 °C) was reached after about 45 minutes and maintained for a period of 17 minutes. The cooling to 29 °C (± 3.9 °C) was carried out relatively quickly, within about 6.5 minutes.

INTERLAMINAR SHEAR STRENGTH

An important parameter for the characterization of FRP/M-hybrid laminates is the ILSS, which represents the maximum shear stress at the moment of the first failure. It provides a quality feature for the assess of the adhesion between the FRP and the metal component. The determination of the apparent ILSS was carried out in accordance with DIN EN 2377 [11] that was created to determine the apparent ILSS of unidirectional glass fiber reinforced polymers. In this bending test, the bearing distance is low in relation to the thickness of the specimens, so that the specimen is loaded and broken by shear stress.

Table 2. Specification of pretreatment methods

V1	$[HC260LAD/0_2^G]_s$ + no pretreatment
V2	$[HC260LAD/0_2^G]_s$ + organic solvent
V3	$[HC260LAD/0_2^G]_s$ + sandblasting* + organic solvent
V4	$[HC260LAD/0_2^G]_s$ + bonding agent „Vestamelt“

* Parameters: 3 bar, d_K = 105 – 149 µm

To evaluate the influence of different surface treatments on the apparent ILSS of the hybrid laminates, various pretreatments were applied to the metallic components. The methods were chosen with regard to their ability for automotive mass production (table 2).

RESULTS AND DISCUSSION

The results of the testings show a significant influence of the metal surface preparation on the apparent ILSS. The best results were obtained through the use of the bonding agent with about 54 MPa in variant V4 (Figure 3). Considering V1 and V2 it is further shown that the cleaning of the metallic sheets with organic solvents is advantageous. However, the removal of the zinc layer by means of sandblasting (V3) has a negative effect on the apparent ILSS.

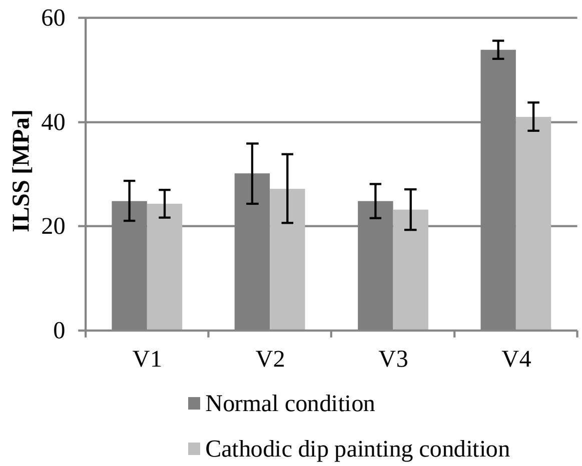

Figure 3. Apparent interlaminar shear strength of the investigated hybrid laminates; number of specimens: 5

Furthermore it can be observed that all specimens have survived the CDP conditions without apparent defects. The bending tests also confirm a cohesion of the hybrid laminates after the application and baking of the cataphoresis primer. Nevertheless, in comparison with the specimens in a normal state the apparent ILSS tends to decrease slightly after the CDP processing. As shown in figure 4 apparent defects to the laminates by the CDP can be excluded on the basis of microscopic microsection. Neither a trapping of air nor fiber or matrix damage is visible.

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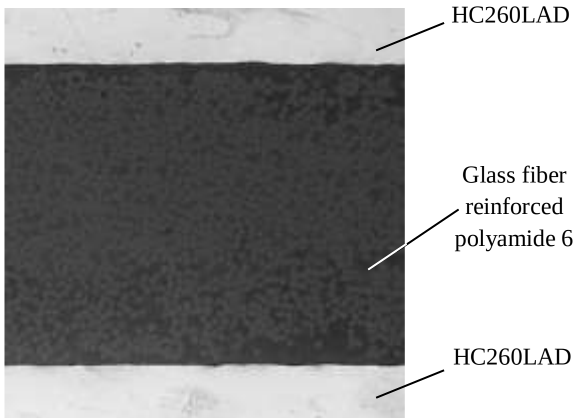

Figure 4. Sectional microscopic microsection of a hybrid laminate after the cathodic dip painting process

More likely a negative effect of the drilled hole is responsible for the decreased ILSS. Since the decrease particularly relates to the specimens of variant V4 an additional influence of the CDP on the bonding agent must be suspected. In this case further investigations are necessary.

CONCLUSION

The design principle of hybrid construction allows the manufacturing of weight-optimized structures with high stiffness and resistance that meet the increasing demands for energy-efficient production processes and components with high power density. In the automotive industry this trend is particularly strong. Especially the use of continuous fiber reinforced thermoplastics offers advantages for automotive components, due to its good specific characteristics and its suitability for mass production. In conjunction with traditional isotropic materials such as steel or aluminum heavy-duty lightweight structures can be produced, whose properties can be specifically adapted to the given component requirements.

In the present study the development of innovative hybrid laminates with low residual stresses, made of steel sheets/foils and glass fiber reinforced thermoplastics is shown. To increase the ILSS an optimization of the specific interfaces was carried out by examining the influence of several pre-operations like sandblasting, cleaning with organic solvents and applying bonding agent systems. The results show a significant influence of the surface preparation on the apparent ILSS. By applying a bonding agent on the surfaces of the metal sheets, the ILSS was increased more about the half, compared with untreated hybrid laminates.

All specimens have survived the CDP conditions without apparent defects, which was shown in microscopic microsections. Nevertheless, in comparison with the specimens in a normal state the apparent ILSS tends to decrease slightly after the CDP processing. This effect can be attributed to the drilled contact borehole and an additional influence of the CDP on the bonding agent. According to the findings further investigations on the influence are necessary. Finally it can be said that hybrid laminates represent a high potential for automotive lightweight constructions as there is only a low influence on hybrid laminates by CDP treatment. Due to investigation purposes the presented laminates were produced with relatively thick-walled metal sheets. The determined results found the basis for the manufacturing and further characterization of weight optimized hybrid laminates with thinner metallic cover layers.

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