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JOINING INVESTIGATIONS OF POLYMER-METAL-HYBRIDS FOR PERMANANTLY NON-LEAKING APPLICATIONS

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Abstract

The demand for light-weight construction and economic efficiency has led to the development of light-weight construction strategies, i.e., multi-material design, in many areas of industry. Here, the property profiles of the composite partners are utilized synergetically. Plastic-metal hybrid composites possess a large amount of potential in this regard owing to the weight reduction that can be achieved in the composite and the simultaneous enhancement of the mechanical properties.

Hybrid components have already proven their potential in large structural components for the bodies of cars, and are already employed in series.

A particular difficulty arises in the case of applications where sealing is required between the composite materials. Achieving a firmly bonded connection between the differing materials is a tough challenge, especially since exposure to different temperatures and media can alter the composite properties significantly. This was examined and evaluated in expansive test series.

Introduction

Hybrid structural components found in car bodies are plastic-metal composites that mainly take on a supporting role. The plastic functions as a stiffening element in form of ribbed structures. These hybrid elements are already widely employed in series in automotive construction, and can be found in front end modules, erection beams, hybrid doors, tailgate modules, roof frames, and brake pedals. These components are manufactured in an injection molding process in which a pre-formed metal sheet is positioned in the injection molding tool, and is then encased in plastic.

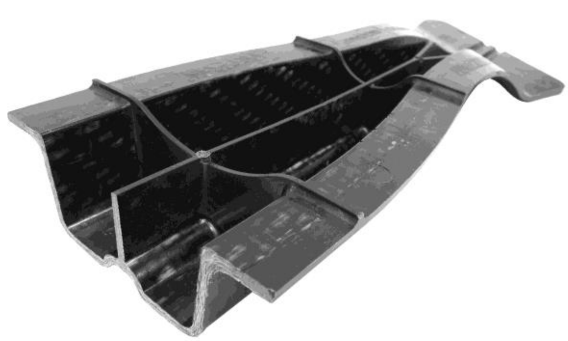

Figure 1: Hybrid structural component for the automotive industry

In contrast to applications employed in the car body, materials or material composites incorporated in the powertrain must meet additional requirements. Possible parts in a hybrid construction are oil filter housings, oil pans or gear cases. Realistically, they must be able to withstand temperatures ranging from -30 °C to +150 °C. Hybrid components must maintain their mechanical stability when subject to changes in temperature in this range. They must be equally resistant to various strongly corrosive motor oils and transmission fluids that contain additives and water. Moreover, they must be resistant against static and cyclically dynamic mechanical loads. On whole, they must ensure an ongoing performance and remain sealed when subject to a combined load consisting of all named types of loading.

In literature, several sources can be found that deal with the substitution of metal on the inside of the motor (suction pipes, tension and slide rails, cylinder head cover hood, oil filter modules) with according plastics. [3-5] The last elements that fulfill the complex requirement profile, and which are already employed in series productions are transmission fluid and motor oil pans. However, oil pans cannot be referred to as hybrid elements except for a few mounting points.

Based on the complex types of loads that components in the powertrain are subject to, the requirement profile and the correlating factors for the application of plastic-metal hybrid composites can be broken down as follows:

1. Temperature Resistance: This factor is mainly dependent on the physical properties of the selected materials. Moreover, the adhesion between the components, which is achieved with an intermediate layer in this case, affects the temperature resistance of the entire component. In the case of plastic-metal hybrids, special attention must be paid to the varying heat expansion coefficients of the materials. Last but not least, the temperature resistance is also dependent on the level of external thermic voltage load the component is exposed to.

2. Media Resistance of the Component: This factor is also dependent on the physical properties of the employed materials (whole material and intermediate layers) that come into contact with corrosive substances. In addition, it is important to make sure the materials possess sufficient resistance to forming cracks when subject to media. Due to the altered physical properties that result from influencing media, the mechanical properties can worsen, which often promotes crack propagation and defects in the sealing.

3. Mechanical Voltage Loads: The required stiffness of the component also depends on the geometry and positioning of the inlay. Additionally, the mechanical voltage loads must be regarded in connection with the thermic voltage load. Selecting the materials and coordinating them with one another in order to combine them successfully in the part is of vital importance.

4. The sealing of the entire component results from the selection of suitable materials, the susceptibility of the materials to form cracks, as well the adhesion in the bonding area. Moreover, the varying heat expansion coefficients can already lead to a separation of the composite in the production phase. [6]

The four most important challenges faced in this case can be extracted from the requirements for a plastic-metal composite. They encompass the stiffness of the component, interface adhesion, compensation of the heat expansion coefficient, and the development of cracks. According to the tribological specifications, the stiffness of the component is to be preserved on whole. This especially applies for component areas in the sealing surface, since deformation would immediately result in a leak in the marginal area.

In plastic-metal hybrids, there is a division between the functions listed in the requirements for the component. In general, a large portion of the active mechanical forces are absorbed by the metal structures, while the plastic component is responsible for sealing the flat areas in this application. Due to the strongly varying levels of heat expansion that both components display and the enhanced requirement profile, adhesion created between the metal and the thermoplast by means of injection molding is not sufficient as a long-term solution. Therefore, it is necessary to incorporate an intermediate layer in the sealing surface, which is meant to prevent leaking caused by the components separating from one another when they are subject to high loads. When designing the hybrid component, all material influences and interdependencies must be taken into account. To be precise, this encompasses the properties of the matrix material of the plastic component, those of the intermediate layer (adhesive sealing system), and the properties and surface characteristics of the metal components. [7]

Objectives

The aim of this study is to investigate chemical resistance and tightness of metal-plastic hybrids. For that practice-relevant materials should be used. Also the test conditions are oriented to the planned application in the vehicle.

First, the thermoplasts that were of practical relevance were selected, and were exposed to media commonly used in the powertrain when they were run through the aging cycles. Plastics and intermediate layer materials for the experiments, that met the requirements of the powertrain, were selected. For this purpose, the samples were also aged in media in order to determine which thermoplastics were suitable for these means. The bonding agent systems were selected based on the information provided by the manufacturer. Then, specially designed joining geometry samples were produced in an injection molding process. Their mechanical composite properties were tested after having been aged in different media. Moreover, the penetration of the media into the marginal layer was tested using contrast agents. An additionally injection molded specimen type was used to test the sealing of the composite after aging. Finally, an innovative injection molding method for the manufacture of hybrid components sealed against media will be presented.

Experimental

In order to determine the selected materials‘ resistance to media, tensile test samples were produced according to DIN EN ISO 527-2 (Figure 2) and Charpy samples with a notch on one side in accordance with DIN EN ISO 179/leA (Figure 3) using injection molding. The samples were aged in three media used in practice while being exposed to selected temperatures. Afterwards, they underwent mechanical testing.

Figure 2: Tensile test sample designated for the mechanical examination of the basic material properties

Figure 3: Charpy sample designated for the mechanical examination of the basic material properties

The materials that passed the testing were employed in the manufacture of simple hybrid samples (Figure 4). The samples were 20 mm wide, and 4 mm thick in the outer areas. They displayed an ellipse-shaped joining zone

(Figure 5). Once the metal inlays were coated with the selected bonding agent systems, the samples were manufactured using injection molding. The vertical injection molding machine KM 80-220 CV, which is produced by Krauss Maffei and has a clamping force of 800 kN, was employed. The vertical design simplifies the handling of the inlays tremendously.

Figure 4: Sample designated for the mechanical examination of the adhesive properties

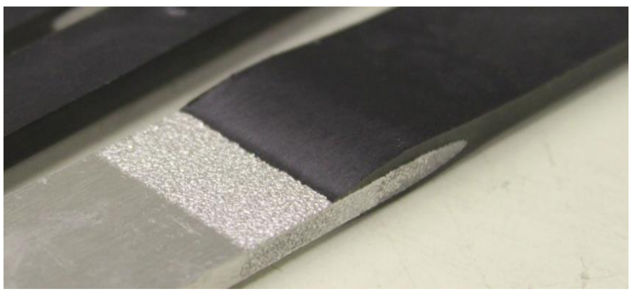

Figure 5: Seam geometry designated for the mechanical examination of the adhesive properties

The mechanical examination of the adhesive properties was also carried out after the samples had been subject to stresses induced by various media and temperatures. The penetration of the media into the marginal layer was detected using a black light, and was analyzed using a gray scale analysis.

Specially designed hybrid samples were produced to examine the sealing of the plastic-metal composites (Figure 6). These samples clearly showed the division of functions between the metal and the plastic components. The sample was 318 mm long, 270 mm wide, and 6 mm thick. Ellipse-shaped joining zones were also planned for this composite. The samples were also coated in metal, manufactured by means of an injection molding process, and exposed to various media and temperatures prior to testing.

Figure 6: Hybrid samples that were similar to models used in practice, and were designated for the examination of the sealing of the composite

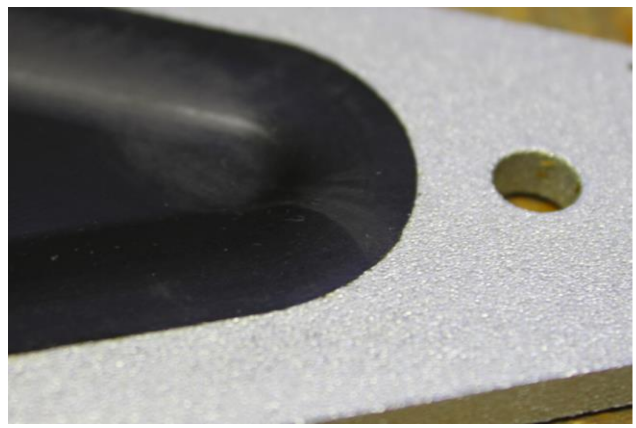

Figure 7: Close-up image of the hybrid samples

The testing unit used to determine the sealing of the composite was used to measure the flow of air that made it through the seal when constant pressure was applied. Moreover, which areas may not have been sealed correctly was tested by means of flooding the bonded area with water. Figure 8 shows the testing unit.

Figure 8: Testing unit for the measurement of the flow of a leak and for the identification of unsealed areas

Results and Discussion

The results are presented in relation to reference values. The specific values cannot be named because of a confidentiality agreement with an industrial project partner.

The basic material tests were carried out with three technical polymers that are relevant in practice: one polyamide type, one polyphenylene sulfide type, and one polyphthalamide type. After having been aged in three types of lubricant at 150°C for 21 days, the changes in the tensile strengths shown in Figure 9. Figure 10 shows the notched impact strengths of the materials after aging.

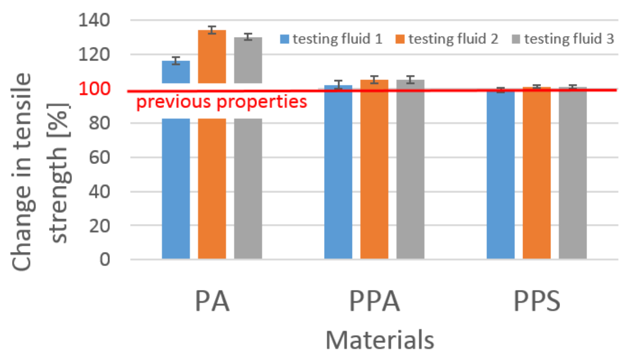

Figure 9: Alteration of the tensile strengths of the basic materials after aging tests

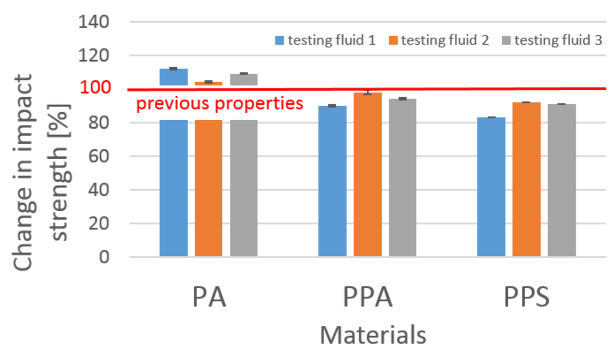

Figure 10: Alteration of the notched impact strengths of the basic materials after aging tests

By aging tests, there were no significant reductions in tensile strength. But the lubricant conditionings often contributed the increasing of values after the storage period of 21 days. The impact stress of polyamide also shows higher values, the values for the other plastics decrease. By comparison fluid 1 can be classified as the most aggressive one.

The evaluation of the following tensile tests performed on simple hybrid samples (Figure 4) clearly revealed the differences between the bonding agent systems. The results of the proven polyamide are summarized in Figure 11, in relation to the samples with the highest tension force values.

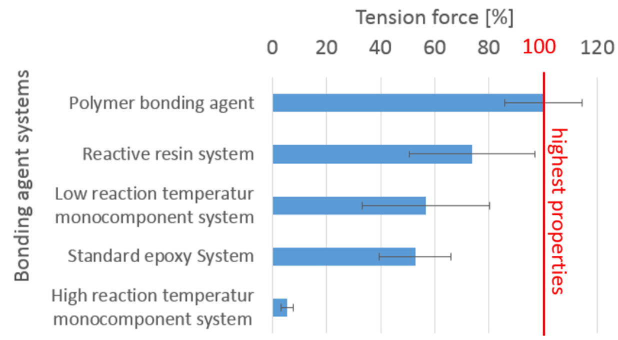

Figure 11: The adhesive properties of the polyamide aluminum simple hybrid samples after a short period of aging

The intermediate layer systems differed strongly in regards to their adhesive properties. After 4 days of aging, there were partly only low bond strengths remaining. This can be attributed to the bonding agent layer of the polymer having been molded on after it was finished reacting. Therefore, actual adhesion never took place. The temperature fluctuations contributed to dissolving the existing, firmly bonded connections further.

Figure 12 depicts the results of the gray scale analysis in summary. The graph refers to the polyamide that contains five intermediate layer systems that display the highest composite strengths. A gray scale value of zero corresponds to no penetration and is the best case.

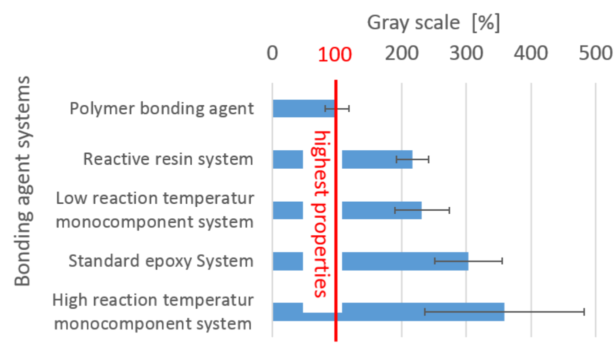

Figure 12: Results of the gray scale analysis after a short aging period in media

We observed that the test medium already penetrated the marginal layers four days into the aging cycle. This was additionally promoted by the temperature-induced expansion.

The sealing tests performed on the samples similar to models used in practice (see Figure 6) displayed leaks in several cases. The evaluation of the four most promising samples of polyamide and aluminum is shown in Figure 13. The air flow, which escaped through the marginal area, was measured.

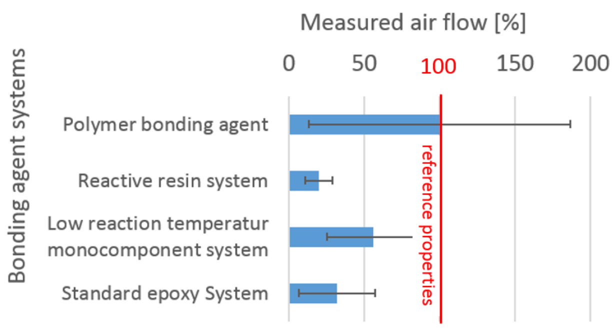

Figure 13: Results of the measurements of the sealing tests performed on the specially designed samples.

Leakage be seen practically at every hybrid sample. This must be justified by the high stresses in temperature changes. Adhesion can locally not overcome the tensions by different thermal expansion coefficients.

The previously described difficulties that arise in the connection after a temperature change and when the material is subject to stress induced by media can also become apparent in form of incomplete sealing.

Conclusions

The experiments showed that the selection of a suitable plastic is of great importance for hybrid applications that are subject to stresses caused by temperature and media. The reasons for this are the resistance and the processability of the material, which are both needed to achieve a firmly bonded connection. Modifications of the polymer, i.e., release agents, can significantly influence the adhesive behavior.
Strong bonds were found in several combinations consisting of a polymer and a bonding agent system. This bond, however, was weakened by arising tensions when the temperature changes. In general, it is important to note that applying a bonding agent layer that is finished reacting will lead to low composite properties, like those found in adhesive bonds. For this reason, the potential of elastic intermediate layers with an equalizing effect will be examined in future experiments on hybrid bonds with specific sealing requirements.

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