Effect of Untreated and Alkaline-Cleaned Surfaces on the Joint Strength of Plastic-Metal-Hybrids

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Abstract: Plastic-metal-hybrids are becoming more widely used for their high lightweight construction potential. In the field of hybrid composites, research has been developing rapidly for many years. The structural strength is a priority in research, so that measures of mechanical grouting of the metal insert surface lead to better traction results. Another benefit would be an impermeable joint zone. Therefore, the joint strength had been tested before and after alkaline-cleansing. The present paper proves the effects of alkaline-cleaned and untreated, laser-textured metal surfaces on the joint strength of plastic-metal-hybrids. The assessment showed a significant effect of the cleansing on the failure mechanism. In addition, the joint strength of all hybrid specimens was determined up to 15 MPa. The results of the examination also show a joint strength above the strength of the selected polymer material.

Keywords: Alkaline-cleansing, hybrid injection molding, joint strength, laser-texture, plastic-metal-hybrid.

1. Introduction

Hybridisation of plastic-metal-joints has become a substantial factor of lightweight construction. The combination of various materials from different material groups often focuses on an increase of structural strength [1]. To gain added value of the components not only by considering the joint strength, the present paper explores the function fulfillment of impermeability in material transition zones [2]. Therefore, it considers the pretreatment of the hybrid plastic-metal transition zone with alkaline-cleansing and its effect on the joint strength, based on the demonstration of correlation between increasing joint strength and an improved impermeability [3], [4].

To open up new fields of application, beneath the required structural strength, impermeability of material transitions has to be considered. Within a cleansing approach using a special system of Henkel®, Bonderite C-AK 1563 as alkaline cleanser and Henkel Bonderite C-AD 5003 as surfactant additive as well as an untreated reference the wetting behavior has been initially examined by a contact angle analysis. The applied aluminous metal inserts are laser-structured in the material transition zone (overlap area), to ensure a higher traction in the following injection molding process [5]. The injection-molded joint strength samples are made of three different plastics types based on PA6.6 and PPA including 35 % glass fibers and are analyzed and assessed with regard to the joint strength.

2. Material

2.1. Polymer Materials

Table 1. Selected Polymer Materials

#	Type Description	Matrix	Glass Fiber Content
A	DuPont Zytel HTN 54 G35 HSLR BK031 [6]	PPA[a]	35 %
B	Albis PA66 A 2035/507 GF35 EF [7]	PA6.6	35 %
C	DuPont Zytel 70 G35 HSLX BK357 [8]	PA6.6	35 %

[a] Copolyamide based on epsilon-caprolactam, hexamethylediamine and terephtalic acid; examined by Differential Scanning Calorimetry method (DSC)

2.2. Semi-finished Metal Inserts

The metal inserts are made of pressure die-casting plates of an aluminium-silicon-alloy (AlSi9Cu3(Fe)). The semi-finished products were cut by water jet from larger plates and were roughly cleaned from cutting aids and other contamination with acetone-soaked wipes. After the cutting process, no further cooling lubricants were applied on the metal inserts as it would be after CNC-machining. Subsequently, a lasertexture with a structure depth of 450 µm and a structure width of 12.5 mm was applied onto the surface by Trumpf Lasertechnik with an ablation rate of 2.3 cm^2/s by a TruMicro 7060 Laser (850 W, 5-100 kHz). The design of the metal inserts is based on DIN 1465 [9] with an overlap area of 12.5 mm by 25 mm.

3. Methods

3.1. Cleansing

The cleansing process of all alkaline-cleaned specimens was carried out with the cleansing agent Bonderite C-AK 1563 [10] and the wetting agent Bonderite C-AD 5003 [11]. The products are based on polyacrylates and phospates and are especially suitable for the treatment of galvanized steel and aluminium. The metal inserts were treated with the cleansing agents for 6 min and were used in an injection molding process (sample manufacturing) thereafter. Untreated specimens after the laser-texture-process were used as a reference.

3.2. Contact Angle Analysis

The evaluation of the cleansing treatment was done by a contact angle analysis (OCA25, DataPhysics), with water as a test liquid as illustrated in Fig. 1 and 2. The applied drop of the test liquid interacts with the surface tension of the substrate and spreads with a specific contact angle. The characteristic angle allows to draw conclusions concerning the wetting behavior of the investigated surface, i.e. hydrophilic surfaces could be wetted better with test liquids and result in a lower contact angle of the surface. Fig. 1 shows the analysis of an exemplary uncleaned specimen.

Fig. 2. illustrates the analysis of an exemplary alkaline-cleaned specimen with a lower contact angle. This means a more hydrophilic surface and thereby a better wetting behavior in relation to the analyzed uncleaned specimen in Fig. 1.

An advantageous wetting behavior of surfaces is substantial for the application of fluids as plasticized polyamides or adhesion promoters. Table 2 shows the difference between the results of untreated and alkaline-treated aluminium surfaces. The contact angle decreases by 54.4 % from 76.8° to 35.0° by alkaline-cleansing.

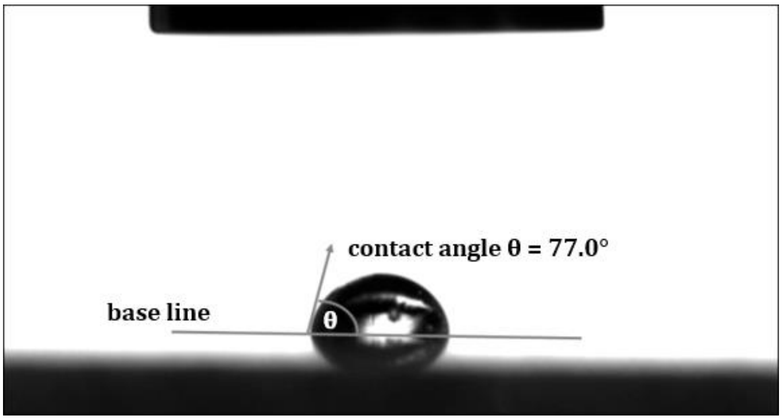

Fig. 1. Contact angle analysis of an exemplary uncleaned specimen, test liquid: water, contact angle: 77.0°.

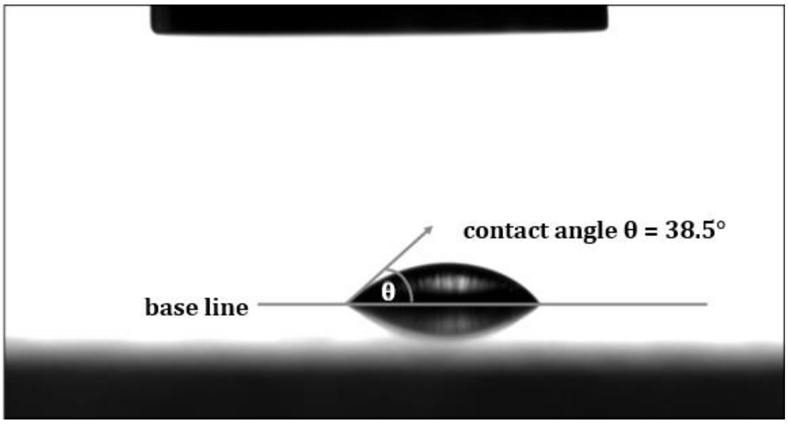

Fig. 2. Contact angle analysis of an exemplary alkaline-cleaned specimen, test liquid: water, contact angle: 38.5°.

Table 2. Contact Angle of Alkaline-Cleaned and Untreated Specimens

Parameter	Untreated Specimen	Alkaline-Cleaned Specimen
Contact Angle	76.8 °	35.0 °
Standard Deviation	2.9 °	2.5 °

3.3. Injection Molding Process

Specimens were produced in an injection molding process (injection molding machine Engel Victory 120 Spec). For manufacturing, no further release agents were used. The substantial parameters for the process, plasticizing unit temperature and mold temperature, are shown in Table 3 below.

Table 3. Parameters of Injection Molding Processes

Material	Plastification Unit Temperature (nozzle)	Mold Temperature
A	320 °C	110 °C
B	280 °C	95 °C
C	295 °C	100 °C

3.4. Joint Strength Test

The joint strength testing in accordance to DIN 1465 was performed on a Z100 test station (Zwick/Roell, 100 kN). All specimens were conditioned for 12 hours in a convection oven at 70° C. The testing speed was 50 mm / min.

4. Results and Discussion

4.1. Comparison of the Joint Strength Depending on the Chosen Plastic Material and the Effect of Alkaline-Cleansing

Fig. 3 illustrates the joint strength of six tested specimens of each variant with results between 11.3 MPa and 14.3 MPa (with mean values and variance). Transferable loads of the joint zone before cleaning were (not significantly) increased in two of three tested polymer materials. The joint strength of Material A decreases (not significantly) with cleansing and is in the range of standard deviation as shown in the figure. A significantly lower scattering of the results was detected in 2 of 3 variants. The main cause for this effect is supposed to be found in the inhomogeneity of the glassfiber distribution of the polymer.

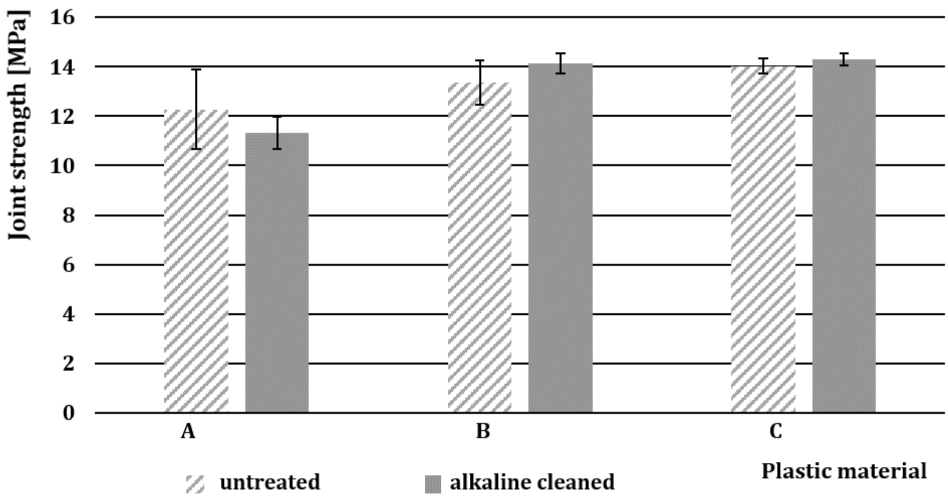

Fig. 3. Comparison of joint strengths before and after cleaning; illustrated with mean value and variance.

4.2. Joint Strength Analysis

In Fig. 3 the filtered data show in (a) that the scattering was primarily affected by the selected type of polymer material. This may be induced by an inhomogenous allocation of the fibers within the polymer during the injection molding process. The allocation of fibers depends on the specific flow characteristics of the polymer material and is therefore a specific material property.

The filtered data illustrates the fiber reinforced plastic materials' maximum strength. Fig. 4 a shows the joint strength of hybrid specimens with DuPont's PPA varying between 7.01 MPa and 15.06 MPa. Hybrid specimens with Albis' PA6.6 vary between 11.09 MPa to 15.75 MPa and specimens with DuPont's PA6.6 range from 13.26 MPa to 15.07 MPa. However, there is no significant effect of the alkaline-cleansing on the scattering, as shown in (b).

However, the charts show the significant increase of cohesive failures of all plastics (Fig. 4 b and c). The potential weakness of the joint zone shifts by alkaline-cleansing on to weaknesses within the polymer material. In this case the sample will break with adhesive failure. An increase of the glass fiber content in the matrix may lead to further increases of the joint strength.

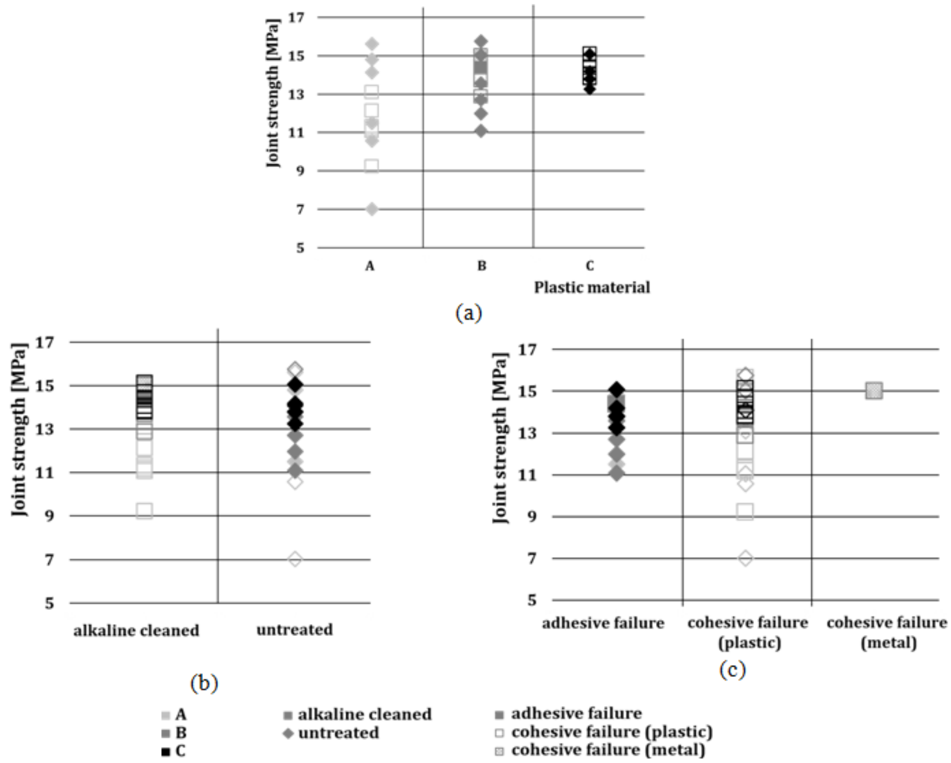

Fig. 4. Joint strength, filtered data by plastic material (a), alkaline-cleaned and untreated specimens (b) and filtered data by failure mechanism (c).

5. Conclusion

As a part of this investigation, the joint strength specimens were tested for three different polymer materials (A [9], B [10], C [11]) and an alkaline-cleansing surface treatment compared to an untreated reference. In the following assessment of the joint strength, the results showed a joint strength of all specimens up to 15 MPa. In addition to that the assessment also indicates a significant influence of the cleansing on the failure mechanism.

Although all alkaline-cleaned and untreated specimens were located in the same range of joint strength, the filtered data illustrates the impact of cleansing in detail. The joint strength of alkaline-cleaned specimens is estimated to be above the polymer materials strength. In addition to a moderate total increase of structural strength inside the range of the scattering, the assessment especially of the filtered data is highly relevant with respect to the impermeability of joint zones: The adhesive and cohesive failure mechanisms are recommended to be valued as an exclusive indicator of the specimen failure after alkaline-cleansing, which assumes a joint strength beyond the detected values.

A testing with higher fiber contents is recommended as well as further investigations, such as compression tests. In addition to that further tests are recommended to ensure a statistical coverage. Pursuing investigations concerning the influence of chemically aggressive media storage and climate conditions will be done to reinforce the hypothesis mentioned in the beginning and to show the correlation between structural strength and impermeability of hybrid transition zones. The relatively high effort of the cleansing, compared to other conventional methods, shall be estimated in dependence of the particular procedure.

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