Processing relationships of hybrid polymer-metal composites in the injection moulding process

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1 Abstract

This paper describes the production of polymer-metal-hybrids with different manufacturing parameters during the injection moulding process and their influence on the shear strength. The joining between a polyamide 12 and an aluminium sheet is investigated with variable melting temperatures of the polymer, holding pressure or rather mould temperature of the injection mould. In spite of the variability of the parameters, all process employments established a connection between the parts. It was also shown, that the melting temperature correlates with the shear strength, but the shear strength values are significantly lower than stated in the literature. Finally, the successful joining of the materials to a hybrid demonstrate that such a connection method has the potential to insert in different application fields.

2 Introduction

Scientists have been researching for new engineering materials with high mechanical properties and low manufacturing effort for a long time [1]. For the manufacturing of a polymer-metal-hybrid (PMH) there are different technologies like injection over-moulding PMH, metal over-moulding PMH, adhesively-bonded polymer-metal hybrid structures and direct-adhesion polymer-metal-hybrid technology. All these production technologies have more than one production-step [2].
The advantage of combining metal and plastic parts is to reduce the total weight [3] and to generate desired properties which cannot be realised with a single bulk material. Manufacturing of a hybrid composite structure often is a two-stage process. The first step is the manufacturing of single parts and the second step is the in-mould or post-mould assembly of two or more parts. Correspondingly, a two-step process is labour-intensive and time-consuming in contrast to a one step process [4].
In this work, the realization of the connection between metal and polymer parts in a one step by using the injection moulding process is analysed. To define the technical process limits, different materials are produced in several test series, while varying the parameters melting temperature, holding pressure and mould temperature. To evaluate the influence of the manufacturing parameters, samples of the hybrid are analysed with optical methods and the shear edge test. Shear strength is determined from this test, which allows to draw conclusions on the quality of adhesion to be reached.

3 Experimentation

3.1 Materials

In the context of the investigations presented here, the polymer PA12 Grilamid TR60 was used. The material has an amorphous structure and is heat resistant. For the combination between polymer and metal in the injection moulding process, an aluminium EN AW-1050A was used and coated with adhesive technicoll 9110 which is activated by higher temperatures.

Table 1: Characteristics of the polymer PA12 Grilamid TR60

Polymer	Glass transition temperature /°C	Absorption of moisture /%	Density /kg/m³	Young's modulus /MPa
PA 12 Grilamid TR60	300-320	2,0	1060	2200

3.2 Processing parameters

During the manufacturing of the hybrids, various process parameters were applied. The parameters melting temperature, holding pressure and mould temperature were modified gradually. The grades of the parameters were the maximum, minimum and the mean value of the processing area, summarized in Table 2.

Table 2: Processing parameters of the samples PA12 Grilamid TR60

Sample	Melting temperature /°C	Mould temperature /°C	Holding pressure /bar
A1	290	60	300
A2	290	100	300
A3	290	60	650
A4	290	100	650
A5	290	80	475
A6	350	60	475
A7	350	100	475
A8	350	80	300
A9	350	80	650
A10	350	80	475
A11	320	60	300
A12	320	100	300
A13	320	60	650
A14	320	100	650
A15	320	80	475

3.3 Test methods

Figure 1a) shows the tool that was used for the manufacturing of the hybrids. The cutting plate was placed on the aluminium and filled with polymer during the injection moulding process. Samples of

the hybrid were taken 60 mm (near) and 150 mm (distant) away from injection point to investigate changing adhesion. The samples were extracted with the measurement of 12,5 mm x 25 mm.
The shear strength between the material parts is investigated by using the shear edge test [5]. The testing device and a test sample is demonstrated in Figure 1b). To hold the test sample in position it is inserted between two support plates and the upper and lower frame displace the different parts of the hybrid during the test. As a result, a force-displacement-curve can be recorded. The testing device is installed in the tension testing machine (Inspekt table blue), the force is measured by a load cell with 5 kN and the testing speed is set to 1 mm / min. With the geometry parameters of the test samples the shear strength can be determined [6]. For the optical analysis a macroscope (Leica Wild M 420), a light microscope (Leica DMRE) and a scanning electron microscope (Zeiss) were used. For the microscope analyses the samples were embedded in a cold cast resin, treated with 4000 µm grade sandpaper and polished with an OPS disc. The samples for the REM-analyses were coated with gold and an EDX-analysis was performed to take a closer look at the interface.

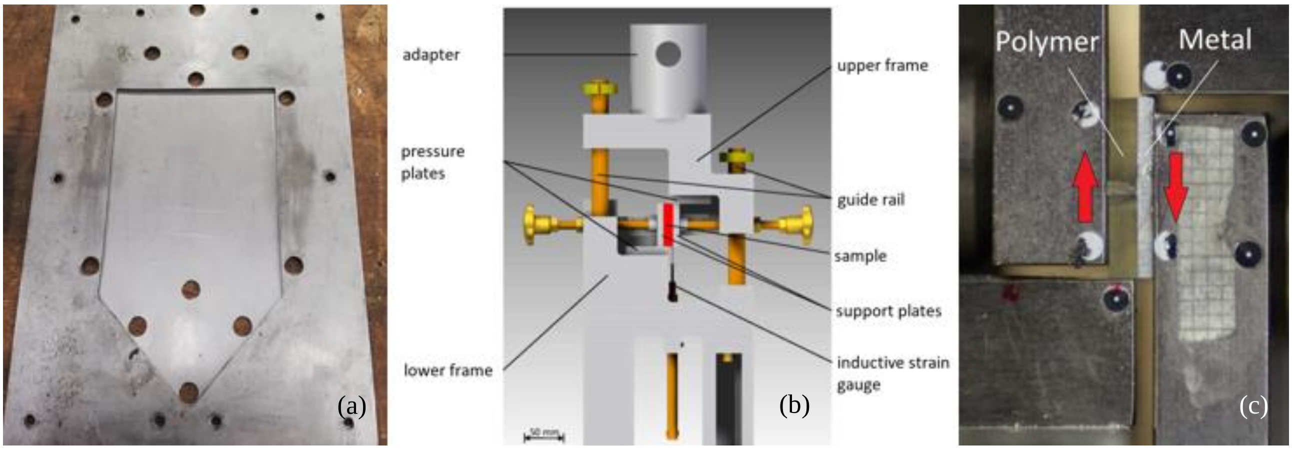

Figure 1: (a) Insertion tool [7], (b) testing advice of the shear strength test [5] and (c) a mounted test sample.

4 Results

4.1 Influence of manufacturing parameters on interface properties

After the shear edge test, the resulting shear strengths are dependent on the manufacturing parameters melting temperature, holding pressure and mould temperature. In Figure 2 shear strength values over the samples are indicated. Sample A14 has the highest shear strength and was manufacturing by applying the highest melting temperature, holding pressure and mould temperature. With increasing melting temperature above the other parameters, the shear strength of the last tested samples (A10-A15) increase. With the series of experiments, the shear strength along the flow path of the polymer melting was investigate and samples near and further away from the sprue were taken from the hybrid. The adhesion between polymer and metal changes between the area near and distant from the sprue. Figure 2 presents the average values of the hybrid samples. Figure 3 shows the force-displacement-curve of different samples with the same manufacturing parameters. During the shear edge test, the samples show two fracture forms, ductile and brittle, respectively.

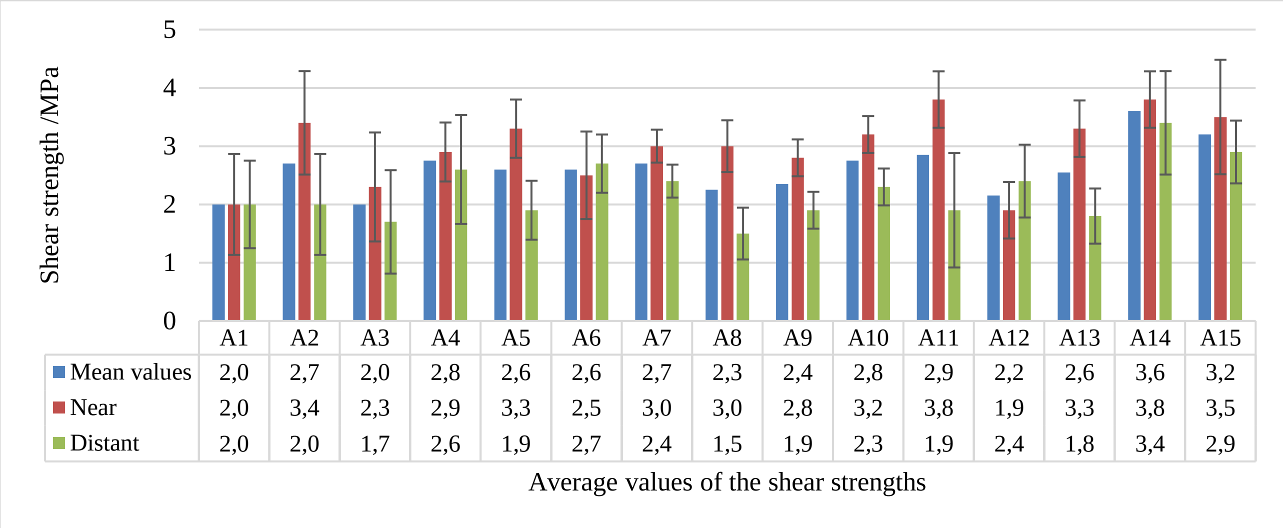

Figure 2: Shear strength of different Grilamid TR60 samples, about the hole part (mean values) and near according to further away from the sprue.

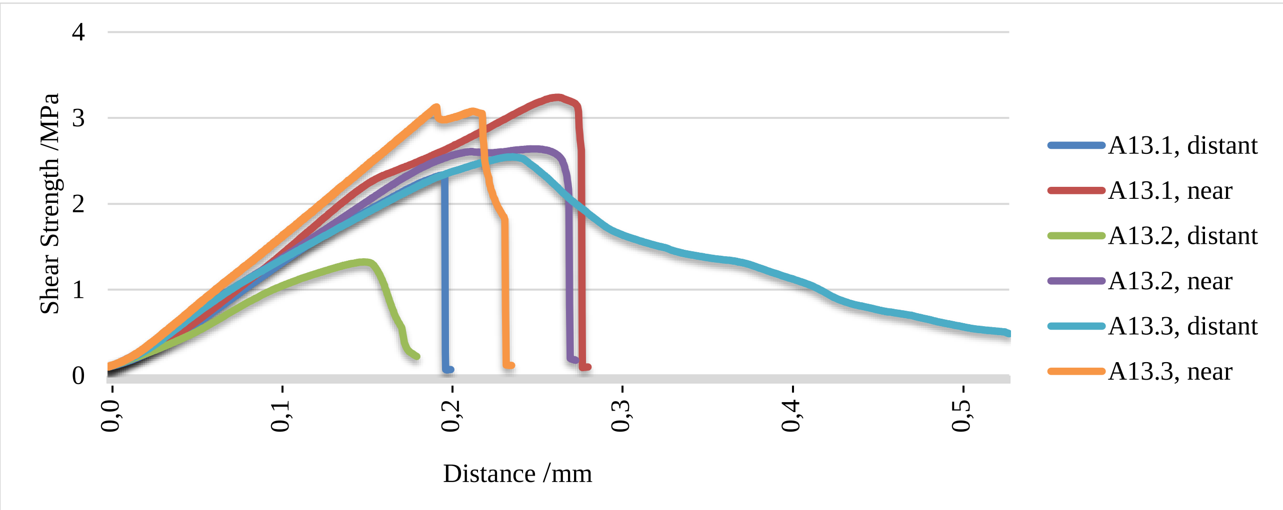

Figure 3: Force-displacement-curve after the shear edge test of three samples (Grilamid TR60) with following parameters, mould temperature 60 °C, holding pressure 650 bar and melting temperature 320 °C.

4.2 Optical analysis

After the shear edge test, the polymer part of most samples is completely removed from the aluminium, but some aluminium sheets have residues of polymer on their surface. Figure 4 a) presents a recording of a polarized, macroscopic analysis of such an aluminium sheet, the area of red polymer is marked. Near the interface, the polymer structure shows cracks like a drop-shaped structure. This can be a reason of the break out of the polymer and can reduce the complete bond strength of the hybrid, compare with Figure 4 b).

A detailed view of such a crack is shown in Figure 5 a). Inside the crack there are filamentary material structures, which remained on pulled apart adhesion promoter. The structure disappears if the electron beam of the scanning electron microscope is on this area for a long, because of the high energy input.

Figure 5 b) shows another border area with drop-shaped structure, adhesion promoter and metal. An EDX analysis cannot be performed because the adhesion promoter and the polymer consist of carbon chains and do not result in different deflections.

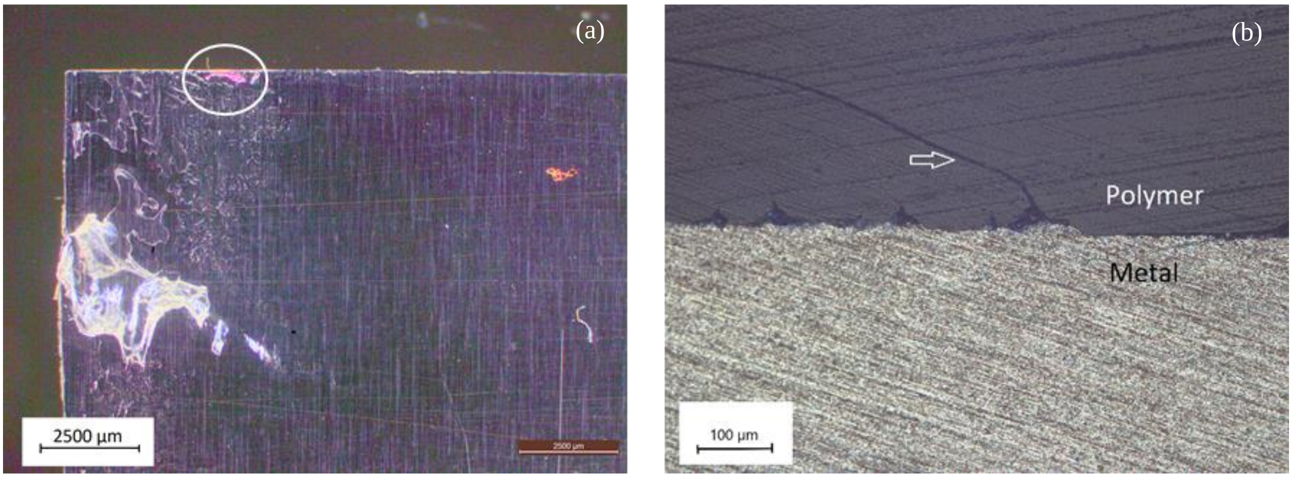

Figure 4: (a) Macroscopic analysis of a shear edge sample with polymer arrears in the white circle, (b) microscopic analysis of the interface with a crack structure inside the polymer like a drop-shaped structure [7].

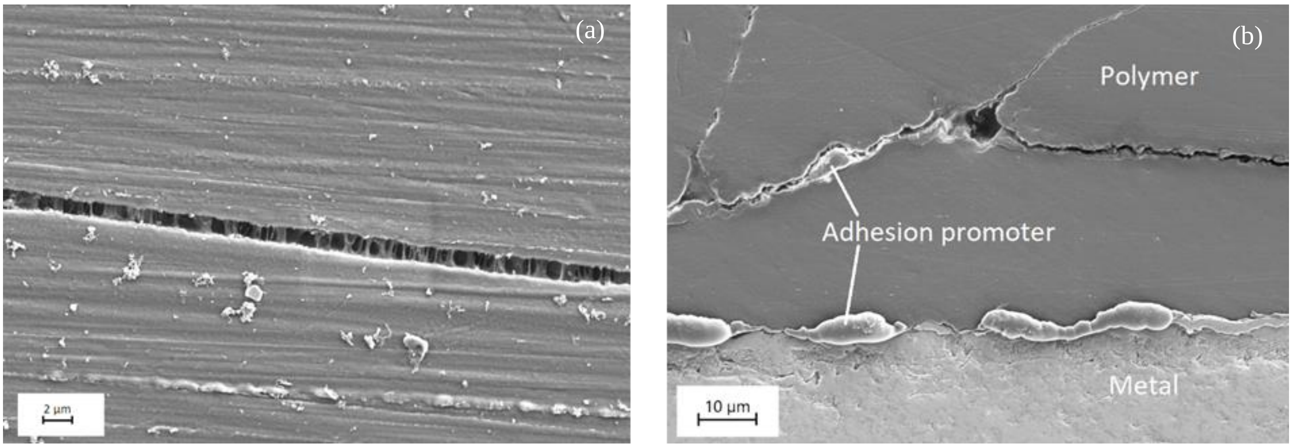

Figure 5: (a) Scanning electron microscope analysis of a fissure, (b) the material transition [7].

5 Discussion

The melting temperature, holding pressure and mould temperature have an influence on the shear strength of the hybrid. The series of experiments show that a higher manufacturing temperature of the whole tool results in higher shear strength. The final shear strength of 3,4 MPa is low in contrast to values of 17 MPa between an aluminium (EN AW-6082) and a polyamide 6 with a NiAl5 coating stated in literature [8]. The coating between the parts can significantly disturb the result of the adhesion between the parts. Other forms of surface treatments, like pin microstructures, realised better shear strengths because they achieved a self-locking between polymer and aluminium after the production [8].

The adhesion coating that was used is activated by a rise in temperature and the polymer cool down depends on the melt path after the mould injection. After investigation of the samples, lower shear strengths were established with increasing length of the melt path. Beside the manufacturing parameters, geometry and size of a component is also important for the final production of a hybrid. The analysis of the interface between polymer and aluminium shows another influence on the polymer promoter inside the polymer matrix, in form of a polymer drop-shaped structure. Because of the carbon compounds of polymer and promoter, a verification by an EDX could not be performed, but the probability that the drop-shaped structure is pure polymer and not a drop of promoter is high. The material quantity of the structures in Figure 4 b) is more than the applied adhesive amount and the analysis of the fissure in Figure 5 a) supports this assumption. By considering the interface, the different structure behaviours of the samples can be explained. If the interface of the shear edge sample has many drop-shaped structures, no ductile slipping occurs but the sample breaks brittle. Ductile slipping results from the parts sliding to each other without an interlock of the interface because of the drop-shaped structure.

6 Conclusion

The present work showed that the resulting process-structure-property relationships of hybrid polymer-metal composites in the injection moulding process can be modified by different manufacturing parameters. If the parameters are in the upper processing range, the properties of the hybrid can be improved, but the material properties and the adhesion promoter must be suitable for injection moulding. To characterize the final influence of the adhesion promoter on the interface, further investigations in form of activation and application possibilities are necessary. A supporting analysis of the temperature profile inside the injection tool during the injection is appropriate for understanding the adhesion promoter effect of the hybrid connection.

7 References

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