INFLUENCE OF INJECTION MOULDING PROCESS PARAMETERS ON THE JOINT STRENGTH OF HYBRID FIBRE-REINFORCED THERMOPLASTIC WITH LASER-STRUCTURED METALS.

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Abstract

Metal surfaces structured by laser radiation in combination with thermoplastic injection moulding processes can be used for manufacturing intrinsic hybrid structures. Therefore, suitable injection moulding process parameters are to be identified to provide optimized hybrid joints. Laser-structures with different orientation were applied to steel sheets and implied to injection moulding producing In-Mould assembled hybrid sheets (steel-PA6). Injection moulding parameters such as melt temperature and flow rate as well as glass fibre content of the injection moulding material were varied. After manufacturing, specimens were extracted and characterized in single-lap tensile shear tests comparing different process parameters and material configurations. It is shown that the joint strength is extremely sensitive to process parameters, varying from no adhesion up to a joint strength of max. 8.8 MPa. Best results were obtained with a glassfibre content of 30 % with high flow rates and melt temperatures.

1. Introduction

Multi-material-design allows the combination of advantageous properties of different materials. Therefore, metals in combination with fibre-reinforced thermoplastics provide high degrees of freedom in design and performance. Metallic inserts or substructures facilitate application of force into thermoplastics and show very low creeping effects. However, metals are often not the suitable for complex designs with function integration feasibilities due to their manufacturing and processing. A combination of both in efficient one-shot processes can create additional benefit and is desirable for many technical applications.

However, the significantly dissimilar physical and material-related properties are challenging for manucturing processes of multi-material parts. For Post-Mould Assembly (PMA) processes, the mix

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of materials is mainly realized by mechanical joining or bonding. However, these methods have disadvantages such as a large number of process steps or additional weight by connecting elements. Punctual mechanical joining, for example flow drill screwing of multi-metal structures (e.g. steel – aluminium) demands additional process steps and results in high local stresses. Most of thermoplastic-metal hybrids are realized by In-Mould Assembly (IMA) processes like injection and compression moulding, in which joints are created by overmoulding [1] or due to adhesion promoters [2-4]. In [5] promising results on selective laser pre-treatment of metals for Post-Mould joined thermoplastic metal hybrids are shown. The laser-structured surface leads to a strong mechanical interlocking between thermoplastic and metal [6].

2. Laser-structuring

The dual-phase stainless steel (DP600) is structured with a nanosecond pulse laser with a wavelength λ of 1064 nm and a beam diameter d_b of about 40 µm. For the experiments, a repetition rate f of 60 kHz and an average laser power P_a of about 10 W are used. The deflection of the gaussian beam is realized by a galvano scanner, whereby the maximum structure depth d_s of 45 ± 5 µm (see Fig. 1b) is generated by scanning the surface ten times with a scan speed s of 300 mm/s. The distance between two structures is definied by the used hatch distance h of about 70 µm. The pre-treatment is performed to investigate how line-patterned surfaces affect the joint strength of injection moulded thermoplastic metal hybrids. Therefore, the structure depth is kept constant, wherby the structure orientation is varied (see Fig. 1a). Structures parallel, perdenticual and with an angel of 45 degree to the flux of force are used.

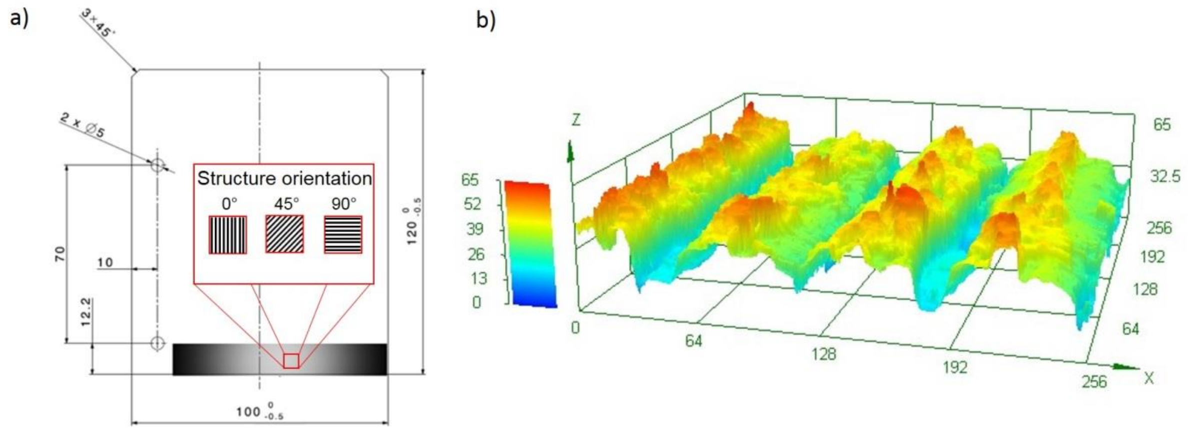

Figure 1. a) Schematic illustration of laser-structured specimens with detailed information about the varied structure orientation; b) laser scanning microscope image of laser-structured dual-phase steel

3. Injection moulding

To obtain knowledge about the mechanical behaviour of hybrid fibre-reinforced thermoplastic with laser-structured metal sheet, a comprehensive manufacturing program with settings, concerning melt temperature, flow rate and structure orientation was performed. The steel sheet used for the metal part of the hybrid was laser-structured with different orientation (0°, 45°, 90°) over an area of 80 x 12.5 mm. Unreinforced LANXESS Durethan B30s as well as glassfibre-reinforced LANXESS Durethan BKV30 and LANXESS Durethan BKV50 set the thermoplastic material in each case. The Durethan material has a polyamide 6 matrix system, while the fibres are up to 2 mm long. All selected materials are commonly used in industry.

In relation to the manufacturing process, injection moulding has been realised on an injection moulding machine by KraussMaffei Technologies GmbH and a mould with a volume of about 220 cm³ to achieve industry-oriented manufacturing conditions. Thus, a short cycle time and parameter monitoring over the process were possible. The injection-moulded part shown in Fig. 2 was

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completely filled and subsequently cut at the rib to gain hybrid specimen for characterisation, which obtained three samples each with a width of 25 mm

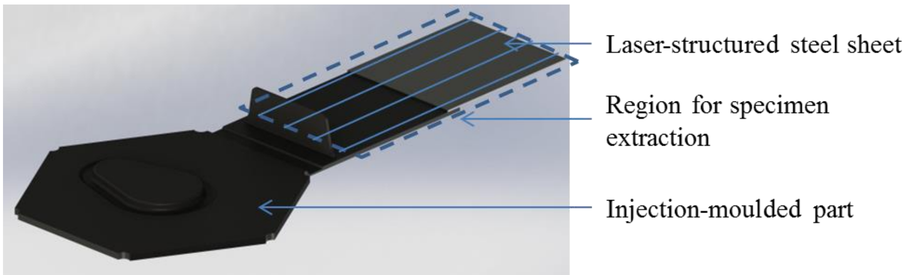

Figure 2. Injection-moulded part with metal sheet for injection mould process

In the first step, a manufacturing array, which concluded varying structure orientation, melt temperatures and flow rates for the different thermoplastic materials was created and is shown in Table 1. The intention to mould all materials with comparable parameters (especially the flow rate) was refuted by pretests showing that each material has to be treated with different process parameters to provide a joint. Therefore, mould temperature has been kept constant 100 °C and structure orientation has been focused on the orientation 0°, so that only a quarter of all sheets had a 45° and 90° orientation. Furthermore, as a result of the different physical properties of the thermoplastic materials, flow rate for Durethan B30s was adapted and melt temperature determined on the basis of the data sheets. Each parameter setting for each thermoplastic material was double executed, so that six samples were possible to receive.

Table 1. Manufacturing array

Material Type	Mould temperature [°C]	Melt temperature [°C]	Flow rate [cm/s]	Structure orientation [°]
Durethan B30s	100	260 – 280	200 – 350	0; 45; 90
Durethan BKV30	100	270 – 290	200 – 250	0; 45; 90
Durethan BKV50	100	270 – 290	200 – 250	0; 45; 90

For manufacturing, the steel sheets were inserted into the mould and heated up to mould temperature by thermal conduction. To reach short cycle times and realistic production conditions, injection time filling the mould was set under 1 s by chosing high flow rates and cooling time was varied between 60 – 80 s.

Compared to Durethan BKV30, less successfully realised hybrids could be obtained with Durethan B30s and Durethan BKV50. Sheets with Durethan B30s warped strongly because of its high shrink characteristics, which could affect the single lap shear test results negatively. Furthermore, there was no joint of 45° sheets regardless to material and process parameters. After water jet cutting the samples, the following parameter settings for each LANXESS material resulted in a joint (Tables 2-4). The Number in brackets represents the number of available samples.

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Table 2. Tested samples Durethan B30s

	Flow rate				
Structure orientation	200 cm/s	250 cm/s	270 cm/s	300 cm/s	350 cm/s
0°	260 °C (3)	280 °C (3)	280 °C (3)	270 °C (3)	260 °C (2)
90°	-	-	-	270 °C (5)	-

Table 3. Tested samples Durethan BKV30

	Flow rate	
Structure orientation	200 cm/s	250 cm/s
0°	270 °C (5) 290 °C (5) -	270 °C (2) 280 °C (3) 290 °C (5)
90°	280 °C (5)	280 °C (5)

Table 4. Tested samples Durethan BKV50

	Flow rate	
Structure orientation	200 cm/s	250 cm/s
0°	270 °C (2) 290 °C (2)	280 °C (2) 290 °C (4)
90°	280 °C (4)	-

4. Joint characterization

The next step was to investigate joint strength in a single lap shear test according to DIN EN 1465 (Fig. 3). Therefore, single samples were clamped in a Zwick/Roell ZMART PRO® tension/shear material testing machine for maximum forces up to 5 kN after conditioning 24 hours in standard atmosphere. A 50 kN load cell measured the force and the elongation was determined.

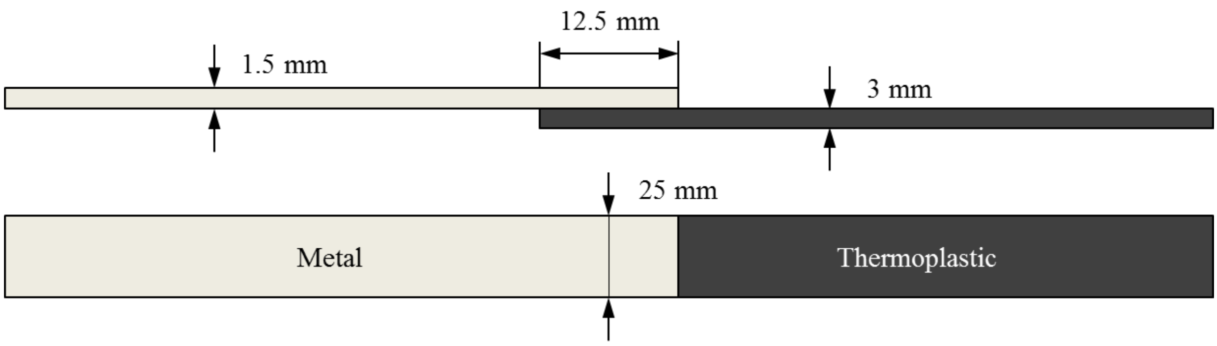

Figure 3. Sample geometry

After testing six several parameter settings for Durethan B30s, tensile shear strength shown in Fig. 4 were measured. The maximum of 4.1 MPa is significantly lower than for fibre-reinforced materials and can be a result of higher shrinking as well as comparably low stiffness. High variances of tensile shear strength values is apparent. It can be associated with the position of the sample at the sheet. In all tests it is noticed that the sample next to the unstructured part of the position hole showed significantly lower values.

Even though interpretation of the results is difficult, high flow rates until a maximum of 350 cm/s have positive influence on the tensile shear strength. In contrast, effects of varying melt temperatures and modification of the structure orientation are less sentitive.

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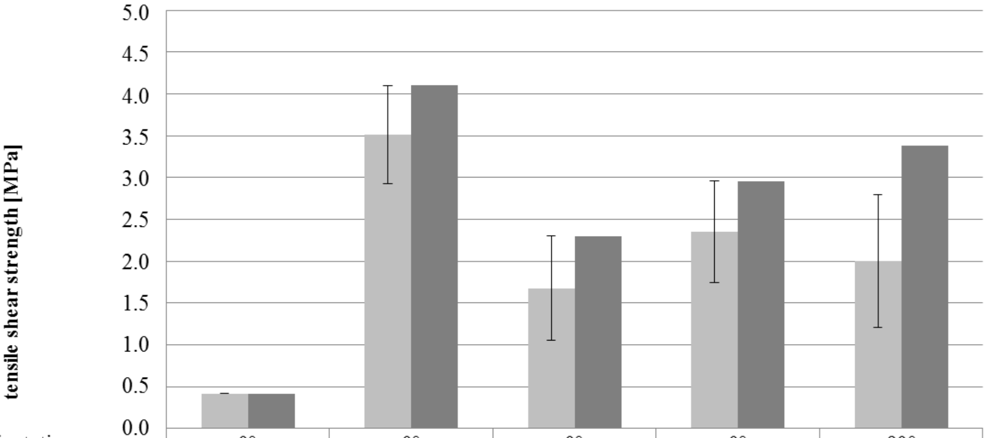
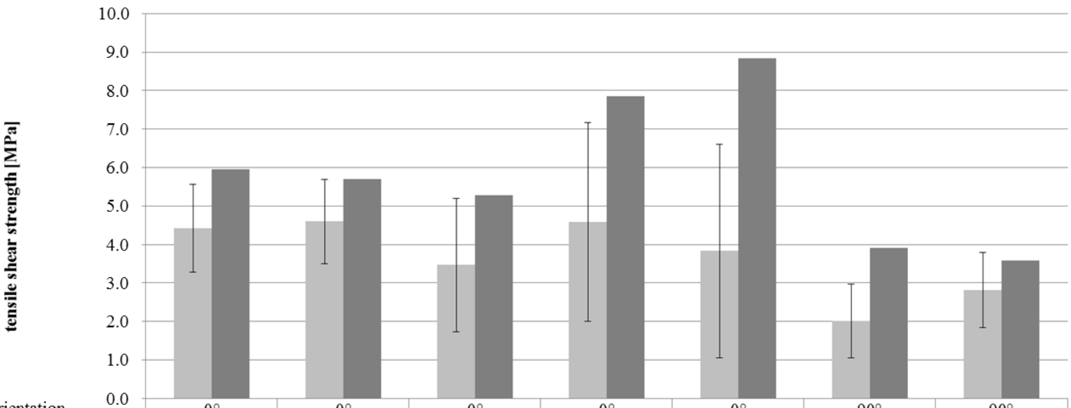


structure orientation	0°	0°	0°	0°	90°
flow rate [cm/s]	200	350	300	270	300
melt temperature [°C]	260	260	270	280	270
shear strength average [MPa]	0.4	3.5	1.7	2.4	2.0
shear strength maximum [MPa]	0.4	4.1	2.3	3.0	3.4

Figure 4. Tensile shear strength for Durethan B30s depending on manufacturing parameters

Durethan BKV30 showed more promising results for maximum values of tensile shear strength. Besides the large number of available samples still connected after the manufacturing process, a maximum tensile shear strength of 8.8 MPa indicates a high potential (Fig. 5). Similar to the results of Durethan B30s, the extremely varying range of the maximum tensile shear strength has to be eliminated by further research for more detailed analysis. Again, the specimens position of the sample at the sheet was sensitive to the obtained results.

However, it is also recognisable that the best results for maximum force have been achieved at 290 °C material temperature due to better flowability. Less shrinking appears in contrast to B30s leading to lower warping effects. Furthermore, it can be detected that for fiber reinforced Durethan BKV30, the structure orientation had an influence on the tensile shear strength. Because the 90° structure and the applied load are directed towards the same orientation, values are significantly lower. Concerning the flow rate, less influence is apparented.



structure orientation	0°	0°	0°	0°	0°	90°	90°
flow rate [cm/s]	200	250	250	200	250	200	250
melt temperature [°C]	270	270	280	290	290	280	280
shear strength average [MPa]	4.4	4.6	3.5	4.6	3.8	2.0	2.8
shear strength maximum [MPa]	6.0	5.7	5.3	7.9	8.8	3.9	3.6

Figure 5. Tensile shear strength for Durethan BKV30 depending on manufacturing parameters

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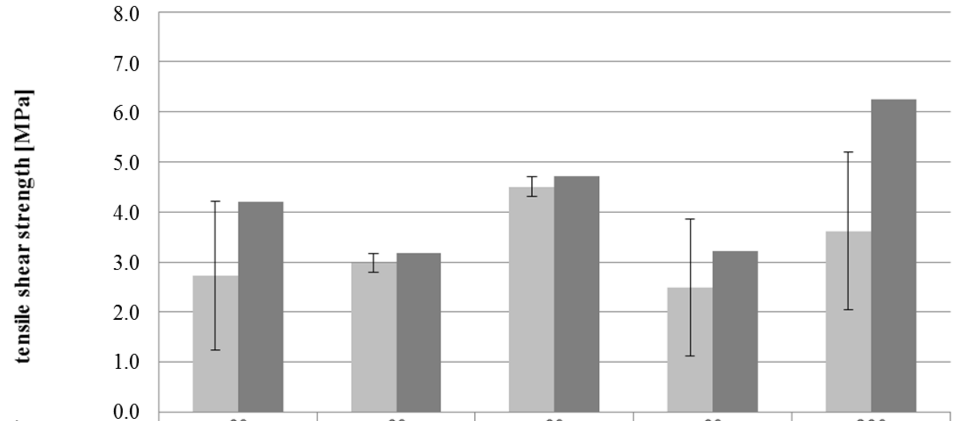
The results for the tensile shear strength of the 14 samples of Durethan BKV50 are represented in Fig. 6. Besides difficult processing of the material with 50 % fibre-reinforcement, the achieved maximum tensile shear strength of 6.2 MPa can be sorted in the same range as the Durethan B30s material. Considerable is the high value for 90° structure orientation, yet comparing the maximum average values there is no significant difference between the structure orientations. On the basis of the high variance of the values and the low number of samples, it is not possible yet to make an profound statement to the behaviour of specific melt temperature or flow rate. Further tests are following to provide deeper understanding of adhesion phenomena.



structure orientation	0°	0°	0°	0°	90°
flow rate [cm/s]	250	250	200	250	200
melt temperature [°C]	270	280	290	290	280
shear strength average [MPa]	2.7	3.0	4.5	2.5	3.6
shear strength maximum [MPa]	4.2	3.2	4.7	3.2	6.2

Figure 6. Tensile shear strength for Durethan BKV50 depending on manufacturing parameters

High variances were observed for all specimens and production parameters. Therefore, micrographs were made to evaluate the joint. It could be observed that for many specimens, pre-damage occurred leading to a separation of steel and thermoplastic due to demoulding or water-jet cutting (Fig. 7). However, the micro-structure could be filled with moulding material for all observed specimens.

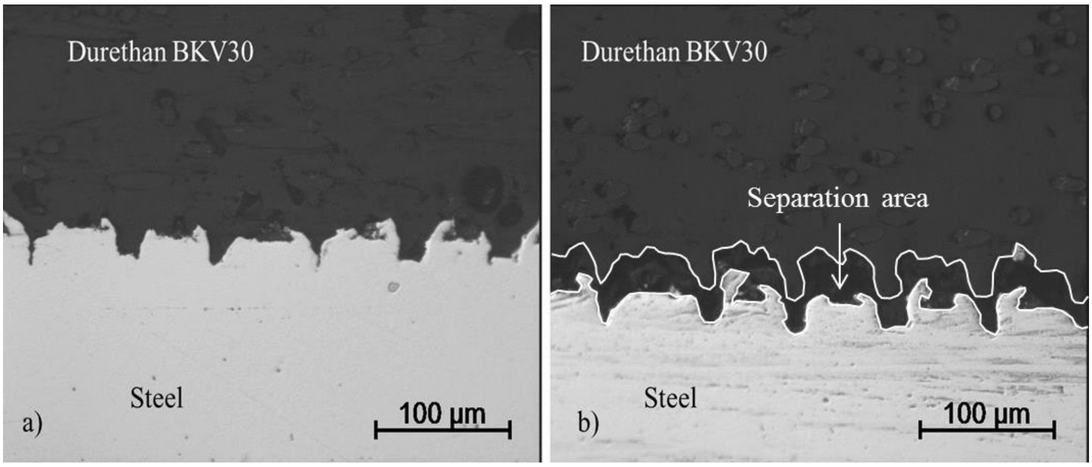


Figure 7. Separation of materials after specimen preparation: a) non-damaged specimen; b) specimen with pre-damaged interface

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5. Conclusions

In the presented work, In-Mould assembled hybrid sheets (steel-PA6) were manufactured and tested. Laser-sturcturing of the metal provided a joining after overmoulding. First conclusions for suitable manufacturing and parameter settings for each thermoplastic material could be drawn. Thereby, the melt temperature, flow rate and orientation of the laser-structuring were varied. Besides, single lap shear tests according to DIN EN 1465 have been performed for unreinforced and reinforced thermoplastic materials. Furthermore, a tensile shear strength up to a maximum of 8.8 MPa for Durethan BKV30 proved the mechanical potential of this intrinsic hybridisation method. Focussing on the parameter settings, which led to effective joints and good mechanical results, additional investigations have to be made to reduce variance in the results, confirm the measured tensile shear strength and to identify sensitive parameters. It is assumed that the demoulding process or water-jet cutting of the specimens are problematic since non-reproducable pre-damage occurred in the specimens. Nevertheless, the first test series demonstrated a high potential of injection moulded hybrid with laser-structured metal as an alternative to adhesive bonding.

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