CHARACTERITZATION OF THE INTERLAMINAR SHEAR STRENGTH OF FIBRE METAL LAMINATES WITH REACTIVELY PROCESSED THERMOPLASTIC MATRIX

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ABSTRACT

The interface shear strength of fibre metal laminates with thermoplastic matrix is characterised by edge shear tests. Therefor eleven different surface treatments of the metal surface (DC04) are tested. The treatments are combined in three steps. First, a mechanical or chemical treatment is applied. Second, the mechanical or chemical treatment is combined with an adhesion promoter and at least a mechanical treatment and chemical treatment are combined and finished with adhesion promoter.

1. INTRODUCTION

Formability of fibre-metal-laminates (FML) produced by autoclave processes, like GLARE (Glass Reinforced Aluminium Laminate) or CARALL (Carbon Reinforced Aluminium Laminate), is limited, due to processing restrictions. Further, industrial application of these hybrid laminates is mostly unattractive, as production times are leading to high production costs. Deep drawing combined with a simultaneous thermoplastic resin transfer moulding (T-RTM) process is a new approach to circumvent these restrictions using low viscosity, fast consolidation, lower melt temperature of monomer components compared to the polymer and formability after processing. However, adhesion between thermoplastic polymers and metals is generally complex. Therefore, different methods to improve the interfacial bonding, like surface treatments of the metal component, are investigated regarding the influence on shear strength. Edge shear tests are carried out for characterization [1], [2], [3].

2. EXPERIMENTATION

2.1 Materials and processing

The fibre-metal-laminate (FML) consists of two 1mm steel metal sheets DC04 and four layers glass twill (280g/m², Interglas 92125 FK800) reinforced with reactively processed polymethylmethacrylate (PMMA). Arkema (Elium 150, 2.5% dibenzoyl peroxide with 50% dicyclohexyl phthalate) supplies the Matrix. The FML are produced in wet moulding. Therefor the cavity of 100x100mm² is heated to 90°C and curing pressure is 19 bar over 900s curing time. After demoulding and bevor cutting, the plates are tempered for 1h at 80°C. From the centre region of each plate are twelve edge shear specimen extracted. The fibre volume fraction varies from 32% to 37%.

2.2 Surface treatments

Without surface treatment, there is no technical useful bonding between metal sheet and matrix. The metal sheet delaminates while demoulding or cutting. To increase the adhesion between the metal sheet and the matrix, eleven different surface treatments are tested. Three mechanical treatments (grinding, blasting with glass bead and blasting with corundum) and two chemical treatments (bating in hydrogen chloride and adhesion promoter) are selected. According to DIN EN 13887, the treatments are combined. First, every single mechanical or chemical treatment is tested. In a second step, the mechanical or chemical treatment is combined with the adhesion promoter. The last step is a combination of a mechanical and chemical treatment and at least the adhesion promoter (in this order applied).

The roughness of the surfaces is measured with a confocal microscope and can be found in Table 1. Each surface treatment is measured on four different metal sheets at the centre region, where the edge shear specimens are cut. The measured distance is 4.12mm after DIN EN ISO 3274 and DIN EN ISO 4288. The surfaces with adhesion promoter were not measured.

Table 1: Roughness of used surfaces on bonding side.

surface	*Ra in µm*	*Rz in µm*
untreated	1,335 ±0,032	7,920 ±0,247
grinded	0,468 ±0,017	3,800 ±0,164
grinded, bating	0,557 ±0,046	4,255 ±0,384
blasted corundum	1,028 ±0,058	7,540 ±0,442
blasted corundum, bating	0,952 ±0,020	7,120 ±0,482
blasted glass bead	0,863 ±0,058	6,215 ±0,350
blasted glass bead, bating	0,767 ±0,021	5,155 ±0,191
bating	1,206 ±0,177	7,268 ±0,708

2.2.1 *Mechanical treatments – grinding, blasting*

The metal sheets were grinded according to DIN EN 13887 with abrasive paper (45µm to 106µm) in three steps. First in one direction (so called 0°-direction), then orthogonal to the first direction (so called 90°) and at least with a round muster. Grinding is performed by hand. Aim of this process is to get a uniformly surface roughness independent from the orientation.

Blasting with corundum (63µm to 106µm) and glass bead (40µm to 70µm) is performed with 4bar pressure, 80° from the horizontal metal surface with a distance of approximate 80mm to 100mm and from both sides, to reduce bending through compression stress in the surface.

After the mechanical treatments, the surfaces are cleaned with isopropanol and sealed with the metal primer 3M AP111.

2.2.2 *Chemical treatments – bating, adhesion promoter*

Bating of DC04 is processed in nine steps. Bevor bating, the sheets are cleaned with ultrasonic degreasing with pH9 at 60°C for 180s in Enthone Enprep LCOK. Bating is done in hydrogen chloride (HCl) and inhibitor Actane BO from Enthone 1:1 for 180s at room temperature. After bating, the sheets are cleaned electric cathodic in Slotoclean ELDCG for 120s, electric anodic in Slotoclean ELDCG for 60s at room temperature, purging with water, deoxidation in Decasel for 10s to 15s, purging with water, cured and sealed with metal primer 3M AP111.

As adhesion promoter is Dynasalan Glymo from Evonik used. 2.0% Glymo are mixed for 1h with 87.8% isopropanol, 10.0% distilled water and 0.2% acetic acid. The metal sheets were coated with the mixed adhesion promoter by a brush and dried for 900s at 80°C.

2.3 Experimental set-up

2.3.1 *Test rig*

The interface shear strength is measured by the edge shear test, depicted in Figure 1. The test rig consists of an upper and lower frame. They induce the load into the pressure plates, which are adjustable to change the shear gap width. The support plates define the position of the shear gap on the specimen. To prevent buckling and bending of the specimen, screws can tighten the support plates. To get reproducible forces, an adjustable torque clutch is used.

The force is measured by a load cell installed in the Zwick 100kN universal test machine. The shear displacement is measured with an inductive strain gauge and additionally with digital image correlation (DIC). For this test set-up, only one camera is used. It is assumed, that out of plane movement can be neglected.

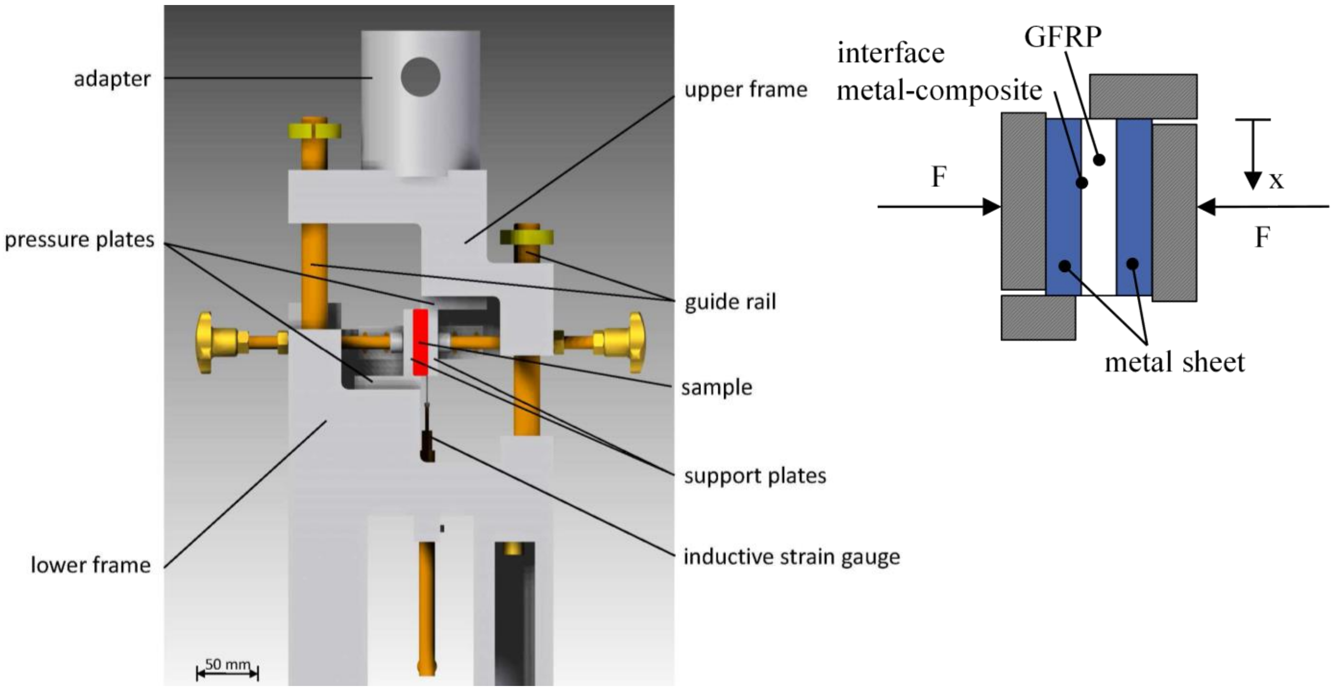

Figure 1: Schematic set-up of edge shear test rig [1] (left). Schematic detail view of shear plane (right).

2.3.2 Test procedure

Before testing starts, it is important to adjust the position of the shear gap (Figure 1) and the normal force through the screws. With the camera of the DIC system, this can be tracked and controlled. When a shear gap is found, only one screw should be moved. In this set-up, the right screw is moved. The tested normal forces are approximate 29N and 88N. All specimens are loaded with 20N preload. In preloaded condition, a reference picture is taken for the DIC measurement. The lower frame moves with a constant velocity of 1mm/min upwards. The pictures for DIC measurement are taken with 5Hz.

2.3.3 Specimen geometry

The specimens are 20mm long, 10mm in width and 3.2mm to 3.4mm in thickness direction, depending on fibre volume fraction.

3. RESULTS & DISCUSSION

3.1 Shear strength and shear energy

In Figure 2 and Figure 3, the shear strength and shear energy of the surface treatments is displayed. The highest average shear strength (34,16MPa) and lowest standard deviation ($\pm$1,94MPa) shows the treatment with blasted corundum, bated and adhesion promoter. Comparable is the shear strength of the treatment with grinding and adhesion promoter (34,12MPa), but with higher standard deviation ($\pm$3,22MPa). Blasting with glass beads and blasting with glass beads combined with adhesion promoter and bating show very low shear strength. While a combination of grinding, bating and adhesion promoter decreases the shear strength (29,08MPa) and raises the standard deviation (±6,48MPa) a more complex surface treatment increase the shear strength and reduces the standard deviation for the blasting with corundum.

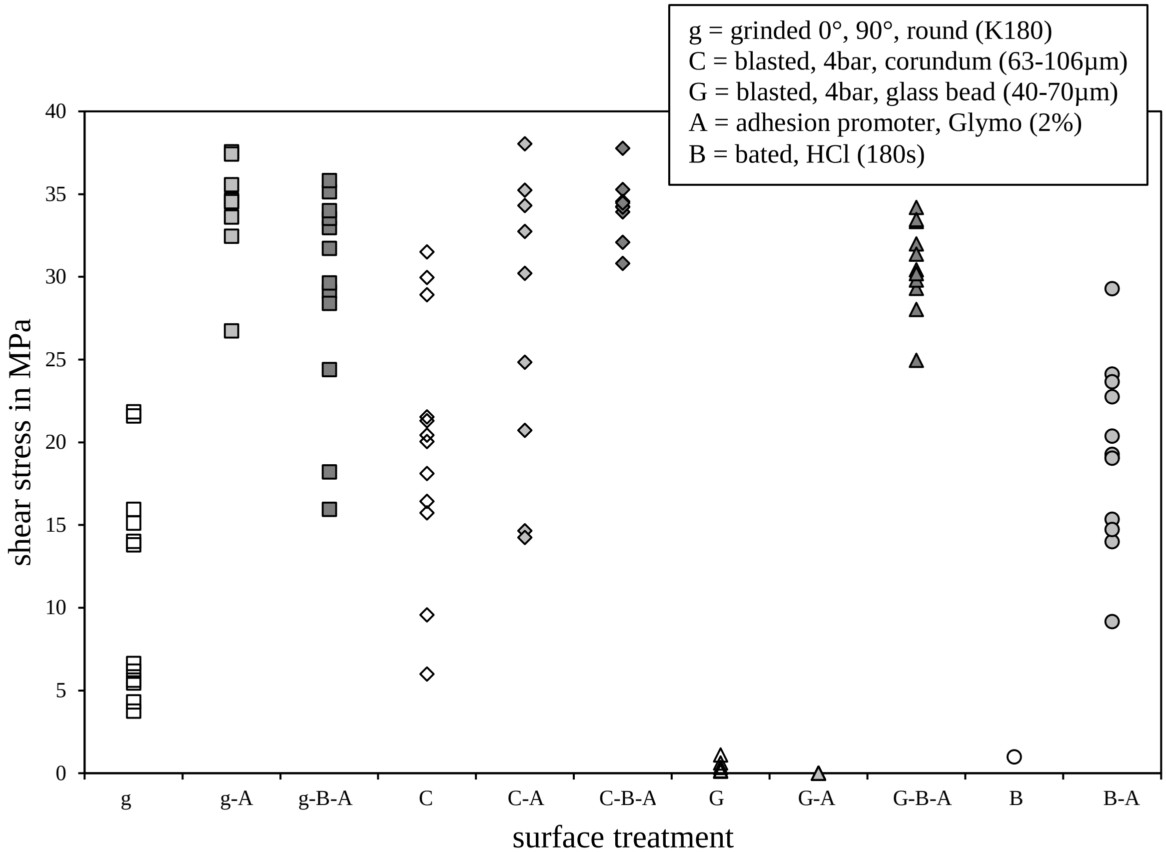

Figure 2: Diagram of shear strength.

Grinding combined with adhesion promoter has the highest shear energy (14299,66J/m²) and a standard deviation of ±3056,96J/m². The treatment with blasted corundum, bated and adhesion promoter reaches comparable shear energy (12320,80J/m²) with lower standard deviation (±2836,73J/m²). The shear energy tendencies correlates with the shear strength tendencies. Bating reduces the shear energy for the grinding treatment and for blasted with corundum the shear energy is increasing with more complex surface treatment.

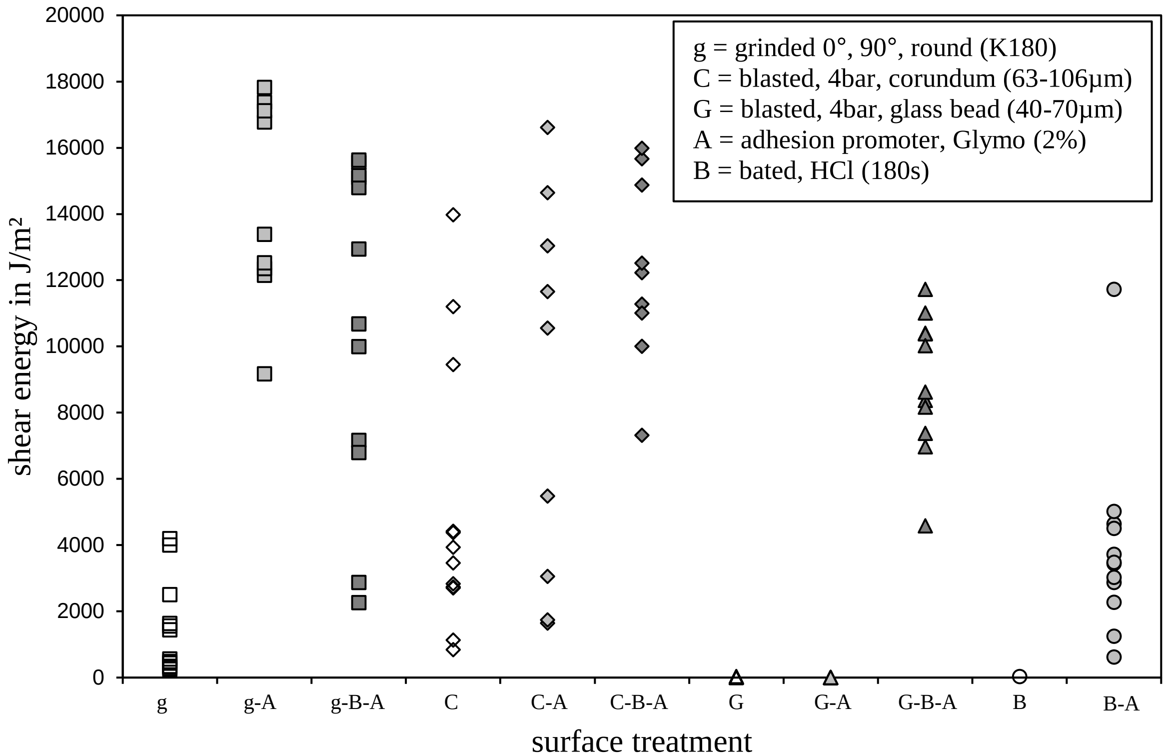

Figure 3: Diagram of shear energy.

4. CONCLUSIONS

The surfaces treatment grinding combined with an adhesion promoter shows in total the best results. The shear strength is equal to blasting with corundum, bating and adhesion promoter, but the shear energy is higher. In addition, the complexity of the surface treatment is lesser. For further investigations, the treatment with grinding and adhesion promoter will be used.

5. ACKNOWLEDGEMENT

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6. REFERENCES

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