

Proceedings

4th International Conference

Hybrid 2020

Materials and Structures

28 – 29 April 2020

Web-Conference, Germany

<https://hybrid2020.dgm.de>

DGM

Table of Contents

Basics	7
INHYB – AN INTRINSIC HYBRID LAMINATE FOR CYCLICALLY LOADED COMPONENTS <i>R. Brandt, A. Busch, S. Haller</i>	8
RESIDUAL STRESS MEASUREMENTS IN GFRP/STEEL HYBRID COMPONENTS <i>T. Wu, S. R. Tinkloh, T. Tröster, W. Zinn, T. Niendorf</i>	14
STUDY ON HYGROTHERMAL AGEING BEHAVIOUR OF HYBRID CFRP/AL JOINTS: INFLUENCE OF PRE-TREATMENT, ADHESIVE COMPOSITION AND AGEING PROCESS <i>J. Schanz, S. Kambach, D. Meinhard, A. De Silva, D. K. Harrison, H. Riegel, V. Knoblauch</i>	21
Characterization	32
MECHANICAL CHARACTERIZATION OF AN INTERPENETRATING METAL-MATRIX- COMPOSITE BASED ON HIGHLY HOMOGENEOUS CERAMIC FOAMS <i>J. Schukraft, C. Lohr, K. A. Weidenmann</i>	33
CHARACTERIZATION AND MODELLING OF THE VIBRATION AND DAMPING BEHAVIOR OF CARBON FIBER-METAL-ELASTOMER LAMINATES BY USING MODAL ANALYSIS IN CANTILEVER SETUP <i>V. Sessner, A. Jackstadt, W. Liebig, L. Kärger, K. Weidenmann</i>	40
EVALUATION OF SURFACE MODIFIED ALUMINIUM/POLYAMIDE-6 FIBRE-METAL-LAMINATES <i>F. Thum, A. Monden, M.G.R. Sause</i>	46
MECHANICAL PROPERTIES ON IN-SITU POLYMERIZED FIBRE-METAL-LAMINATES <i>H. O. Werner, W. Liebig, K. A. Weidenmann</i>	53
INFLUENCE OF SURFACE TREATMENT ON INTERFACIAL STRENGTH AND TENSILE PROPERTIES OF THERMOPLASTIC BASED HYBRID LAMINATES <i>M. Trautmann, S. Mrzljak, F. Walther, G. Wagner</i>	59
INFLUENCE OF SURFACE TREATMENT ON FATIGUE PROPERTIES OF THERMOPLASTIC BASED HYBRID LAMINATES <i>S. Mrzljak, M. Trautmann, G. Wagner, F. Walther</i>	65
FATIGUE DAMAGE BEHAVIOR OF CONTINUOUS-DISCONTINUOUS FIBER REINFORCED SHEET MOLDING COMPOUNDS <i>M. Bartkowiak, W. Liebig, K.A. Weidenmann</i>	71

MICROSTRUCTURAL CHARACTERIZATION OF GLASS FIBER REINFORCED SMC BY NANOINDENTATION AND SINGLE-FIBER PUSH-OUT TEST <i>B. Rohrmüller, P. Gumbsch, J. Hohe</i>	78
SURFACE HYBRIDISATION OF SEMI-POROUS PARTICLE FOAMS <i>W. Koshukow, M. Stegelmann, M. Krah, M. Gude, L. Enneking, C. Buske</i>	84
ON FIBER ORIENTATION STATISTICS FOR WOVEN FABRICS IN FIBER METAL LAMINATES <i>P. Pinter, H.O. Werner, K.A. Weidenmann, W. Liebig</i>	90
MICROSTRUCTURE CHARACTERIZATION OF DISCONTINUOUS FIBER REINFORCED POLYMERS BASED ON VOLUMETRIC IMAGES: FIBER BUNDLE TRACKING AND WELD LINE INVESTIGATION <i>L. Schöttl, W. V. Liebig, K. A. Weidenmann, K. Inal, P. Elsner</i>	97
DETECTION OF DAMAGE IN GLASS FIBRE-REINFORCED THERMOPLASTICS USING ACTIVE LOCK-IN THERMOGRAPHY <i>S. Poleschke, B. Engel</i>	102
COMPARISON OF ANOMALY CAPABILITIES OF PULSE PHASE THERMOGRAPHY IN TRANSMISSION AND REFLECTION SETUP ON SHEET MOLDING COMPOUND <i>L. Bretz, M. Wilke, B. Häfner, G. Lanza</i>	108
Design and Layout	117
SURROGATE MODELLING OF HYBRID MATERIAL PAIRINGS INCLUDING ORGANIC SHEETS <i>M. Richter, H. Gese, H. Dell, G. Oberhofer, F. Duddeck</i>	118
NUMERICAL INVESTIGATION OF THE HOLE-DRILLING METHOD APPLIED TO INTRINSIC MANUFACTURED METAL-CFRP HYBRIDS <i>S. Tinkloh, T. Wu, T. Tröster, T. Niendorf</i>	126
A HOLISTIC APPROACH TO OPTIMIZATION-BASED DESIGN OF HYBRID MATERIALS <i>M. Triebus, T. Tröster</i>	132
Intrinsic Hybrid Composites	137
HYBRID FIBRE REINFORCED THERMOPLASTIC HOLLOW STRUCTURES WITH A MULTI- SCALE STRUCTURED METAL LOAD INTRODUCTION ELEMENT <i>V. Würfel, R. Grützner, F. Hirsch, D. Barfuß, M. Gude, R. Müller, M. Kästner</i>	138
DESIGN & QUALITY ASSURANCE OF INTRINSIC HYBRID METAL-CFRP LIGHTWEIGHT STRUCTURES <i>L. Bretz, F. Günther, H. Jost, M. Schwarz, V. Kretzschmar, M. Pohl, L. Weiser, B. Häfner, J. Summa, H.-G. Herrmann, M. Stommel, G. Lanza</i>	144
QUANTITATIVE PASSIVE THERMOGRAPHY FOR EVALUATION OF FATIGUE DAMAGE IN AN INTRINSIC HYBRID COMPOSITE <i>J. Summa, F. Grossmann, H.-G. Herrmann</i>	160

Manufacturing 166

MANUFACTURING OF HYBRID COMPONENTS BY VARTM-PROCESS USING NEW SEALING TECHNIQUE DEVELOPED <i>Deviprasad C J, T. Stallmeister, Z. Wang and T. Tröster</i>	167
SCREENING TESTS OF AN ONE-SHOT FORMING PROCESS OF FIBRE-REINFORCED THERMOPLASTICS AND STEEL SHEETS TO DETERMINE THE GEOMETRICAL ACCURACY <i>P. Kabala, M. Demes, T. Ossowski, J. Beuscher, K. Dröder</i>	173
COMBINED DURING AND DEEP DRAWING OF FIBRE METAL LAMINATES TO SPHERICAL HYBRID COMPONENTS <i>H. Sapli, T. Heggemann, W. Homberg</i>	180
HYBRIDIZATION FOR SERIES PRODUCTION - CONTINUOUS PROFILE PRODUCTION BY PULTRUSION <i>D. Löpitz, M. Knobloch, D. Wagner, W.-G. Drossel, M. Gedan-Smolka, K. Schubert, A. Marschner</i>	186
PROCESS ANALYSIS OF THERMOPLASTIC-METAL COMPOSITE STRUCTURES IN 3D-HYBRID TECHNOLOGY - A COMBINED APPROACH TO QUALITY ASSURANCE FOR ROBUST MANUFACTURING PROCESSES <i>D. R. Haider, M. v. Unold, M. Krahl, M. Gude</i>	194
INFLUENCE OF THE MORPHOLOGY OF NANOPOROUS SILICON DIOXIDE BASED SURFACE COATINGS ON THE INTERFACIAL STRENGTH OF INJECTION-MOULDED POLYMER-METAL HYBRIDS <i>M. Laux, Y. Löhr, R. Dreher, R. Emmerich, F. Henning</i>	200
A HIGHLY ECONOMICAL INDUCTIVE JOINING TECHNOLOGY FOR FIBRE COMPOSITE CONNECTIONS <i>A. Fröhlich, M. Kroll, P. Rochala, V. Kräusel,</i>	206
INFLUENCE OF CONTINUOUS WAVE SURFACE STRUCTURING AND ZINC COATING ON BOND STRENGTH OF HYBRID JOINTS MADE OF STEEL AND TP-FRPC <i>S. Weidmann, P. Mitschang</i>	212
THERMAL JOINING OF METAL-POLYMER HYBRID STRUCTURES BY USING CONVENTIONAL WELDING PROCESSES <i>A. Haelsig, W. Georgi, E. Brueckner, P. Thieme, M. Gehde</i>	221
DETERMINATION OF THE MECHANICAL PROPERTIES OF A SINTERED CFRP CONNECTION MODULE JOINED BY A THREAD FORMING SCREW <i>A. Marx, T. Hutsch, P. Schiebel, D. Feltn, F. Hoffmeister, A. Babbel, A. Herrmann, T. Weißgärber</i>	227
JOINING OF ADDITIVELY MANUFACTURED TITANIUM WITH DIFFERENT SURFACE STRUCTURES WITH FIBER-REINFORCED PEEK FOR LIGHTWEIGHT DESIGN APPLICATIONS <i>J. Moritz, P. Götze, T. Schiefer, A. Klotzbach, J. Standfuß, E. López, F. Brückner, C. Leyens</i>	237

MULTI-COMPONENT HIGH PRESSURE DIE CASTING (M-HPDC): INFLUENCING FACTORS ON BOND QUALITY OF METAL-PLASTIC HYBRIDS AND ITS NECESSITY OF PROCESS DATA LOGGING <i>P. Messer, U. Vroomen, A. Bührig-Polaczek</i>	243
EXPERIMENTAL INVESTIGATION OF THE LOAD BEARING CAPACITY OF INSERTS EMBEDDED IN THERMOPLASTIC COMPOSITES <i>J. Troschitz, R. Kupfer, M. Gude</i>	249
INVESTIGATIONS ON POSSIBLE JOINING PROCESSES FOR LIGHTWEIGHT BODY STRUCTURES FOR COMMERCIAL VEHICLES IN MUNICIPAL SERVICE OPERATIONS <i>T. Schiefer, A. Mahlme, D. Theis, B. Ganbaatar, M. Sauer, F. Zimmermann, A. Klotzbach, J. Standfuß, M. Zimmermann</i>	255
INVESTIGATION OF AUTOMATED NIBBLING AS AN ALTERNATIVE CUTTING TECHNOLOGY FOR MACHINING OF FIBER-REINFORCED POLYMERS <i>J. Langer, M. Gerstenmeyer, V. Schulze</i>	261
STUDY ON WATER JET CUTTING OF FIBRE-REINFORCED-PLASTICS-METAL-LAMINATES <i>V. Reichel, F. Rothe, F. Franke, D. Lattek, J. Beuscher, K. Dröder</i>	268
Oral Poster Presentation	275
CONTRIBUTION TO STRUCTURAL MECHANICS OF PATCH-BASED COMPOSITES <i>A. Baumer, A. Baeten</i>	276
PART AUTOMATED METHOD FOR REPAIRING COMPOSITE PARTS <i>B. Manin, A. Raina, T. Quadflieg, T. Gries</i>	282
MATERIAL SELECTION FOR TEMPERATURE SENSITIVE ACTUATORS MANUFACTURED FROM SHAPE MEMORY ALLOY WIRES EMBEDDED IN POLYMER STRUCTURES <i>P. Eyer, A. Trauth, K.A. Weidenmann</i>	288
PROCESSING RELATIONSHIPS OF HYBRID POLYMER-METAL COMPOSITES IN THE INJECTION MOULDING PROCESS <i>A. Schwarz, W. Liebig, K. Weidenmann, P. Elsner</i>	296

Evaluation of surface modified aluminium/polyamide-6 fibre-metal laminates

F. Thum¹, A. Monden¹, M.G.R. Sause¹

¹ Institute of Materials Resource Management, University of Augsburg, Augsburg

Abstract:

The aim of this study was to investigate the bond strength between thermoplastic carbon fibre reinforced polymers (CFRP) and aluminium alloys with different surface modifications. The materials examined were sandwich laminates consisting of unidirectional carbon fibre reinforced polyamide-6 composites and two different types of aluminium alloys. The configuration chosen for studying the interfacial adhesion is symmetrical with one 0.3 mm thick aluminium foil at the neutral axis of the stack. Various surface modifications like laser structuring, diamond-like carbon (DLC) coating, corundum blasting and different chemical treatments were applied to the aluminium layer. In addition, polyamide-6 interlayers with and without glass-fibres were investigated as an electrochemically insulating layer between aluminium and carbon fibres. The specimens were evaluated using a short beam 3-point bending test to determine the apparent interlaminar shear strength (ILSS). For this purpose, three groups of specimens were stored under standard climate, in a vacuum oven and in hot/wet conditioning for one week, respectively. In addition, potentiodynamic corrosion measurements were performed on the aluminium alloys to evaluate the electrochemical barrier resulting from surface treatments and interlayers. It was observed that 1050 aluminium alloy performed better than 2014 alloy in this aspect. Compared to the configurations without an additional interlayer, interlayers with glass fibre insulation exhibited slightly lower ILSS values with mainly cohesive interfacial failure.

1 Introduction

Due to their specific mechanical properties, Fibre-Metal-Laminates (FML) are increasingly gaining importance with the growing demand for lightweight materials. Compared to conventional fibre reinforced polymers (FRP), the combination of metal and FRP leads to advantages like superior bearing strength, fatigue resistance, transverse fracture toughness and impact resistance [1]. There are different well-established examples for commercial FMLs, like GLARE® ([2], [3]) which is made of glass fibre/epoxy reinforced aluminium alloy or ARALL® [4] (aramid fibre/epoxy reinforced aluminium laminates). We replaced the glass/aramid-fibres with carbon-fibres, expecting to yield higher strength and stiffness. In addition, instead of a thermoset matrix, a thermoplastic polyamide-6 (PA6) matrix was used. This leads to advantages regarding production time and costs. Further, this offers the possibility of thermoforming semi-finished products. However, these modifications result in new challenges regarding the risk of contact corrosion as well as adhesion promotion between aluminium and PA6. Therefore, we studied surface treatments to increase adhesion, protective layers of a polymer (e.g. PA6) or glass-fibre reinforced polymers to prevent contact corrosion. To demonstrate the influence of the surface modifications used in this study, a short-beam shear (SBS) test was chosen to determine the apparent interlaminar shear strength (ILSS) following the conceptual work in [5]. For the evaluation of the electrochemical barrier, potentiodynamic corrosion measurements were conducted on a shortlist of material combinations after the SBS testing.

2 Experimental

2.1 Specimen design and preparation

For the experimental investigations, sandwich plates were produced using a symmetrical layup of eight layers of SIGRAPREG TP C U157-0/NF-T340/46% with a PA6 matrix on two sides of an aluminium foil with a thickness of 0.3 mm. The specimens for the SBS testing procedure of 20 x 10 mm were cut from plates of 100 x 100 mm using a wet cutting table saw. All samples were immediately dried to avoid any water absorption. Due to the different interlayer materials, the resulting thickness ranged from 2.8 – 3.3 mm as shown in Figure 1.

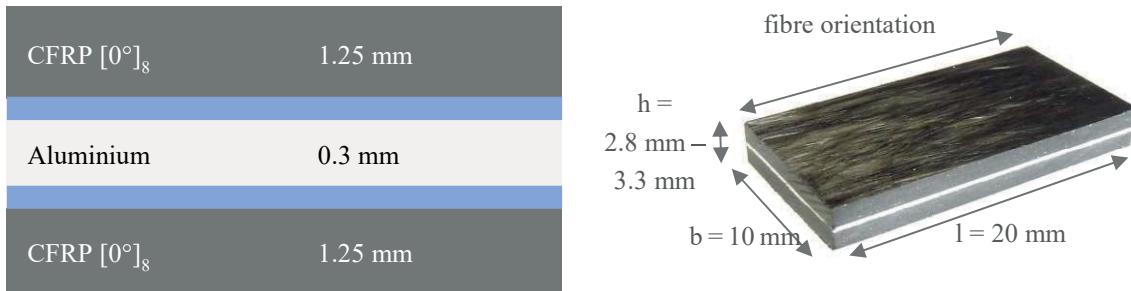


Figure 1: Stacking sequence of the FMLs (left) with schematic interlayers (blue) and specimen dimensions for SBS testing

In this paper, eight combinations of different alloys, surface treatments and interlayers are presented (cf. Table 1). As aluminium alloys, Al 1050A was chosen due to its electrical and mechanical properties and Al 2024 T3 as it is a widely used standard alloy in the aviation industry with good mechanical properties [3].

Laser treatment was used to prepare the metal surfaces for adhesive bonding as well as to clean potentially remaining impurities on the aluminium layer after the cleaning process. The increased surface area and modified topology leads to better mechanical interlocking and increases intermolecular bonding [6]. As a second surface treatment, a silane coupling agent was applied to the aluminium surfaces. On the oxide-surface of the aluminium, the silanes form a layer through covalent bonds [7]. The contact to the CFRP layer (or polymeric interlayer respectively) is improved via chemical bonds which connect to the thermoplastic matrix. The potential difference between aluminium and carbon fibres may lead to galvanic corrosion in case there is direct contact between these materials. To minimize the risk of corrosion, interlayers of PA6 and glass-fibres (GF) with PA6 matrix were added in some cases. As reference, two plates without any surface treatment or interlayers were produced.

Table 1: Configurations of tested FMLs

No.	1	2	3	4	5	6	7	8
Alloy	Al 1050			Al 2024				
Surface treatment	No treatment	Laser treatment	Silane treatment	Silane treatment	Silane treatment	No treatment	Laser treatment	Silane treatment
Inter-layer	-	-	-	PA6	PA6 + GF	-	-	-

Before testing the specimens in SBS, three different conditioning environments were chosen to compare their influence on the FMLs. One part of the samples was conditioned in standard climate for

160 hours, another part was dried in a vacuum oven ($T = 80\text{ }^{\circ}\text{C}$, 160 hours), the third part was stored in a hot-wet environment ($T = 80\text{ }^{\circ}\text{C}$, 95 % humidity, 160 hours). In 3.1, we present the results of standard climate and hot-wet conditioning, as the ILSS values from vacuum drying are similar to the standard climate results.

2.2 Methods

2.2.1 Screening via short-beam tests

After conditioning for one week, the FML specimens were investigated via SBS tests following the principles of DIN EN 2563. Load is applied at the centre of the specimen with a given length l_v between the support which depends on the thickness of the investigated specimen (Figure 2). To evaluate the testing process, the interlaminar shear strength (ILSS) τ is calculated from the force at delamination onset P_R :

$$\tau = \frac{3P_R}{4bh} \quad (1)$$

The maximum shear stress is induced at the specimen's centre plane, where the aluminium layer is located. For thin aluminium layers the ILSS formula gives a reasonable approximation for the actual shear stress at the interfaces between aluminium and CFRP [8]. However, for this study, the calculated values are solely used for comparison between the material configurations, not as actual interlaminar shear strength values. For each configuration, five samples were tested.

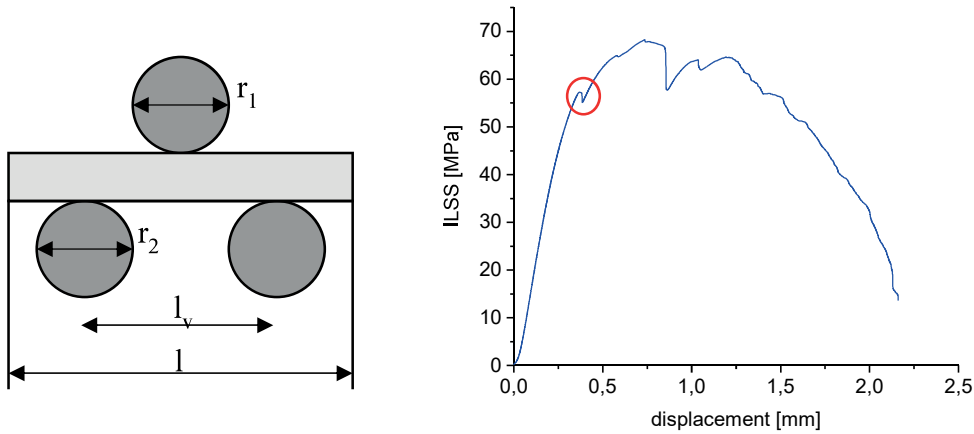


Figure 2: The short beam shear test is used for comparison of the ILSS values. The first signature within the stress-displacement curve (red circle) indicates the initial failure of the specimen and is used for further evaluation.

2.2.2 Corrosion measurements

The aluminium alloys and the surface modifications were investigated using potentiodynamic polarization. Samples were immersed in a sodium chloride solution ($c = 0.5\text{ mol/l}$) and a scan rate of 5 mV/s was chosen for the measurement using the *Interface 1000* by *Gamry Instruments*. As reference, a saturated Ag/AgCl electrode and as counter electrode a platinum wire was used. The aluminium samples were cut into $10 \times 10\text{ mm}$ pieces and cleaned before putting them into the

corrosion measuring setup (Figure 3). The electric current flows between the Platin counter electrode and the sample, which represents the working electrode. The polarization of the sample is varied in the range of -1.2 V to 0 V. For evaluation, the voltage is plotted against the logarithmic current as Evans diagram (Figure 5Figure 5).

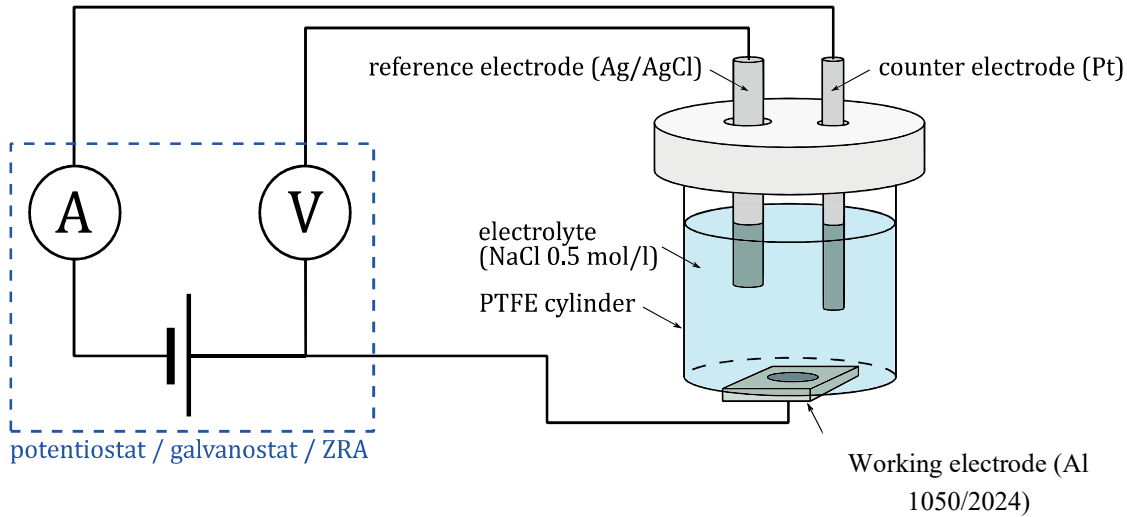


Figure 3: Schematic setup of the potentiodynamic corrosion measurement following [9]

3 Results

3.1 Short-beam shear test

After conditioning in a Hot/Wet climate chamber, the FML samples without any surface modification showed delamination at the interface to the aluminium layer and thus could not be tested. The SBS results presented in Figure 4 show the mean value of five samples for each configuration for the remaining six FMLs.

Two main failure mechanisms could be observed on the SBS samples after testing. For the configurations with silane and additional interlayers, the specimens showed mainly cohesive failure within the CFRP. The samples with laser treatment on the surface showed mainly adhesive failure. The laser treated samples show slightly lower ILSS values when compared to silane treated samples (without additional interlayers). This proves an increased delamination resistance for silane treatment which was also observed in earlier studies with steel/epoxy-based CFRP hybrid laminates [5], [8]. The ILSS values of Al 2024 based configurations consistently lie below the Al 1050 values, especially after Hot/Wet conditioning. This result is corresponding to the better galvanic corrosion resistance of Al 1050.

Despite the use of unreinforced PA6 and GF with lower mechanical properties compared to PA6 based CFRP, these samples in the SBS configuration performed almost as good as the FMLs without additional layers regarding their ILSS values and thus delamination resistance.

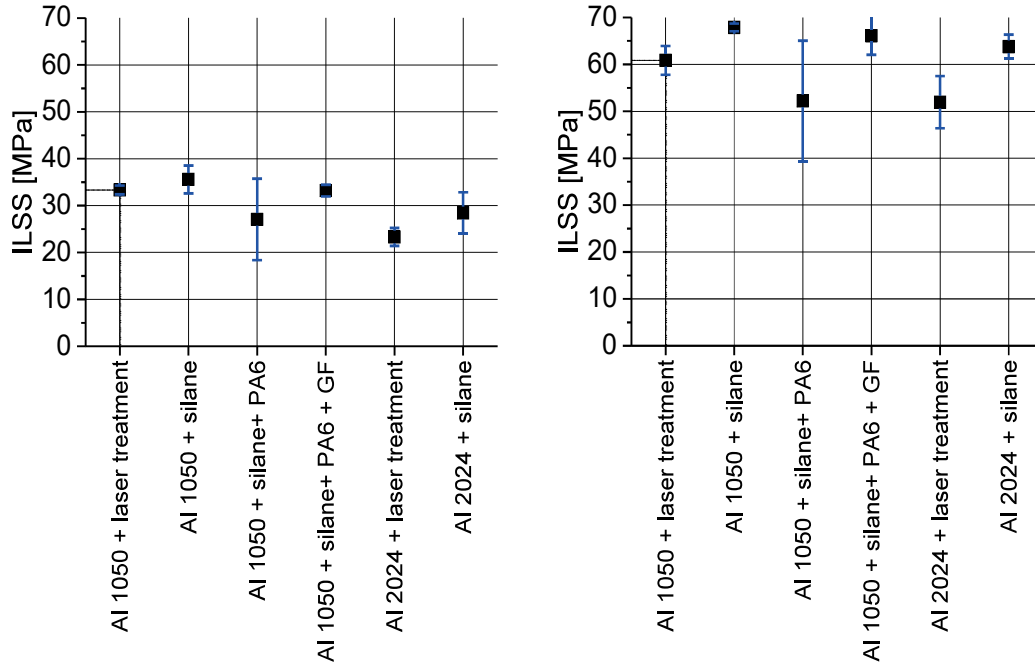


Figure 4: ILSS values obtained with SBS tests after standard climate conditioning (left) and after Hot/Wet conditioning (right). Five Samples were tested for each configuration.

3.2 Corrosion measurements

Based on the SBS test results, a subset of configurations was examined via potentiodynamic corrosion measurements. Al 2024 was solely used as a reference in two different configurations. The results of the potentiodynamic corrosion measurements of three surface configurations as well as the bare Al 1050 and Al 2024 samples are shown in an Evans diagram (Figure 5), showing the voltage plotted against the logarithmic current. The corrosion potential E_{corr} and corrosion current I_{corr} of all configurations are summarized in Table 2.

The polarization curves in Figure 5 show a slight decrease of electrical current for the silane treated Al 2024 specimen throughout the curve while the laser treated Al 1050 specimen stays at almost the same level. However, the E_{corr} values are in the same region for both alloys as well as the surface treatments. Only the specimen with PA6 interlayers show a clear indication for improved corrosion resistance. Here, the current decreases by several orders of magnitude and E_{corr} is significantly below the levels of non-treated aluminium samples as well as the ones with surface treatments only.

Table 2: Overview of the extracted corrosion parameters E_{corr} and I_{corr}

FML	Al 1050	Al 1050 + laser treat- ment	Al 1050 + silane treat- ment	Al 1050 + silane treat- ment + PA6	Al 1050 + silane treat- ment + PA6 + GF	Al 2024	Al 2024 + silane treat- ment
E_{corr}	-0.85	-0.86	-0.8	-0.53	-0.58	-0.79	-0.8
I_{corr}	1.36×10^{-8}	4.26×10^{-8}	8.17×10^{-9}	2.01×10^{-11}	1.35×10^{-11}	5.8×10^{-8}	2.26×10^{-8}

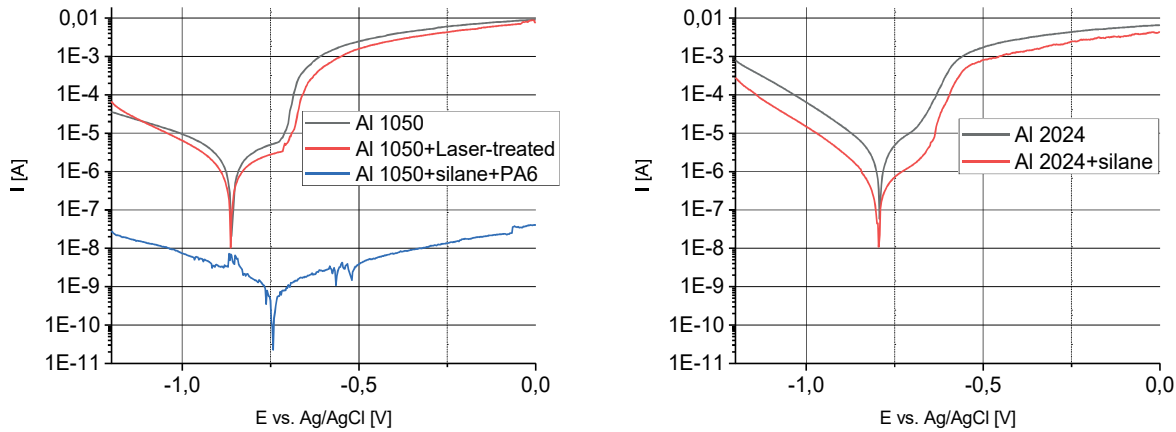


Figure 5: Evans diagrams showing the polarizarion curves for the differently pre-treated aluminium alloys

The E_{corr} values for Al 1050 with interlayers of PA6 and GFF are shifted to -0.53 V to -0.58 V compared to the samples without interlayers (surface treatment only), where E_{corr} is in the region of -0.8 V. In addition, the current rate is significantly below the other samples without interlayers. Therefore, the interlayers decrease the electrochemical potential difference between the carbon fibres and the metal core, which allows to expect a reduced corrosion rate.

4 Conclusions

Eight FML configurations were prepared and conditioned for SBS testing. Furthermore, promising combinations especially with Al 1050 were investigated with a potentiodynamic corrosion testing method.

The surface treatment of both Al 1050 and Al 2024 leads to significantly better performance regarding the interfacial adhesion, which was evaluated using SBS tests to determine ILSS values. In direct comparison, the Al 1050 FMLs show increased adhesion, especially after conditioning the samples in a Hot/Wet environment. FMLs with additional interlayers perform mechanically slightly worse than the ones without interlayers. However, the E_{corr} values for these samples show good corrosion resistance after potentiodynamic measurement. To investigate the corrosion resistance furthermore, a long term Hot/Wet ageing has been started.

5 Acknowledgement

The authors would like to thank Fabian Schubert from SGL Carbon for providing the Institute of Materials Resource Management with the Fibre Metal Laminates investigated in this study. The authors would like to thank the Bavarian State Ministry of Economic Affairs and Media, Energy and Technology (StMWi) for its financial support within the framework of Campus Carbon 4.0. Further thanks go to the project management organization Jülich (PtJ) and the MAI Carbon cluster management for their support in the project implementation of MAI CC4 Hybrid.

6 References

- [1] E.C. Botelho, R.A. Silva, L.C. Pardini, M.C. Rezende, A Review on the Development and Properties of Continuous Fiber/epoxy/aluminum Hybrid Composites for Aircraft Structures, *Mat. Res.* 9 (2006) 247–256.
- [2] Vogelsang, L.B., Vlot, A. Development of fiber metal laminates for advanced aerospace structures. *Journal of Materials Processing Technology* 103 (2000) 1-5
- [3] Vlot, A.: Historical overview, In: Vlot, A. (Hrsg.), Gunnink, J. W. (Hrsg.): *Fibre metal laminates / an introduction*, Verlag Springer Netherlands, 2001, S. 3-21
- [4] Vermeeren, C. A. J. R., Beumler T., de Kanter, J. L. C. G., et al.: *Glare Design Aspects and Philosophies*, *Applied Composite Materials*, 10(4/5):257–276, 2003.
- [5] Monden A.: *Adhäsion zwischen epoxidharzbasiertem CFK und oberflächenmodifiziertem Stahl: Grenzschichtversagen von Hybridlaminaten unter Mode I, Mode II und Mixed-Mode Belastung*. PhD thesis, University of Augsburg, 2016.
- [6] Peng Z., Nie X.: Galvanic corrosion property of contacts between carbon fiber cloth materials and typical metal alloys in an aggressive environment. *Surface and Coatings Technology*, 215(0):85–89, 2013.
- [7] Critchlow G. W., Yendall K. A., Bahrani D., Quinn A., Andrews F.: *Strategies for the re-placement of chromic acid anodizing for the structural bonding of aluminium alloys*. *Inter-national Journal of Adhesion and Adhesives* 26(6):419-453, 2006
- [8] Monden A., Sause M.G.R., Hartwig A., Hammerl C., Karl H., Horn S.: *Evaluation of Surface modified CFRP-Metal Hybrid Laminates*. In: *Proceedings of Euro Hybrid Materials and Structures 2014*, 2014.
- [9] Hartwig A.: *Titandioxid als Korrosionsschutz von X5CrNi18-10 Edelstahl und dessen Einsatzmöglichkeit in CFK-Metall Hybridstrukturen*. PhD thesis, University of Augsburg, 2015.