EXPERIMENTAL INVESTIGATION OF FIBRE PRETENSION ON MINITUARISED LOOP CONNECTIONS FOR INTEGRAL CFRP-ALUMINIUM JOINT

A. Lang[1*], A. S. Herrmann[1]

[1]*Faserinstitut Bremen, University Bremen, Am Biologischen Garten 2, 28395 Bremen, Germany*
**lang@faserinstitut.de*

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Abstract (Times New Roman 12 pt, bold, single-line spacing, left-aligned text)
The increasing application of hybrid structures in lightweight design requires a joining technology appropriate to the material. Novel intersection structures for integral CFRP-aluminium joints are currently being studied with five interdisciplinary projects at the University of Bremen. This paper deals with the so-called fibre concept, which represents a parallel arrangement of miniaturised loop connections. A material combination is chosen with preliminary tensile tests. In the next step the influence of the process parameter "pretension" on the joint strength is investigated.

1 Introduction

The overall demand for ecological efficiency requires weight saving. This leads to an increased application of hybrid structures. Different materials are contributing properties and complementing the other ones. Carbon fibre reinforced plastics (CFRP) offer excellent specific material properties. Metal materials are superior, though, e.g. in terms of impact resistance and in terms of material and processing costs. Depending on the operating requirements the best material for the component is chosen. Hence, an application of metal and composite materials in one design is inevitable in lightweight design. Joint design between the components is essential, since they have an influence on the weight efficiency for the whole design. Conventional connections of components are adhesive or mechanical joints [1-5]. In load application zones the joints are often accomplished by conventional conjunctions like riveting. The drilled hole interrupts fibres respectively the load path. The anisotropic material is not able to divert and withstand the load, which causes a thickening. Due to bypass and transfer loads the carrying capacity of bolted joints is depending on bearing and shear stress. Since laminates possess low properties against bearing and shear stress the coupling efficiency is not optimal. To ensure a continuous load path and to exploit the potential of lightweight design interconnection structures between metal and CFRP have to be developed and optimised suitable to the fibre reinforced material.

Figure 1 compares a conventional riveting joint to a lean CFRP-Al joint. In accordance with design principles of HSB [6] geometrical dimensions for the influenced area by riveted joints are determined. These dimensions are transferred to a joint with a lean, integral intersection zone. To minimise the risk of corrosion, titanium is implemented to avoid the contact of

CFRP with aluminium. As a result of a lean joint the weight could be reduced theoretically about 50 %. The potential of weight saving by means of a FRP optimised joining technology has not been tapped fully yet. [7]

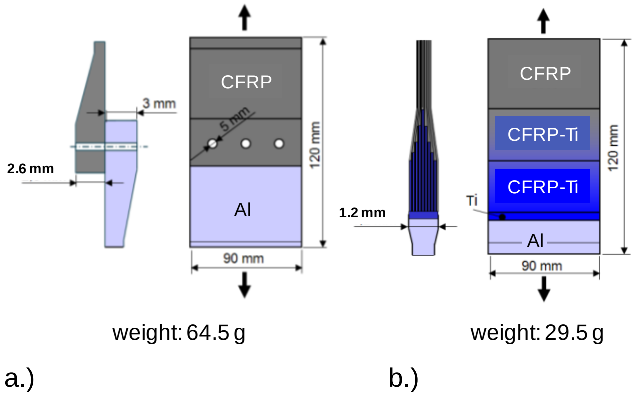

Figure 1. potential of an integral CFRP-Aluminium joint (b) compared to a conventional riveted joint (a)

Within the investigations of the researcher group "Schwarz Silber" (FOR 1224) funded by the DFG (German Research Foundation) novel intersection structures for integral CRFP-aluminium joints are currently being studied with five interdisciplinary projects at the University of Bremen. The objective of the researcher group is the conceptional design and analysis for highly loaded, reliable, lightweight, and corrosion resistant joints.

2 Design Concepts

For the development of integral CFRP-Al intersection structures approaches like form material closure or frictional connections are possible. In terms of these approaches different concepts are combining textile, welding or casting techniques. In Figure 2 an overview of three different concepts is shown. The wire and fibre concepts represent a parallel arrangement of miniaturised loop connections, which can be found for high punctual load applications in FRP structures [8, 9]. The second concept is based on comprehensive investigations of CFRP-Ti (titanium) -laminates [10, 11, 12, 13, 14]. Neither the design of these kinds of interface structures, the determination of failure criterions nor production technologies for the joining methods have been investigated before. In the first three years of the project the concepts will be analysed with respect to quasi static tensile loading and orienting corrosion tests will be conducted. Further load cases and corrosion tests are foreseen for the second project phase.

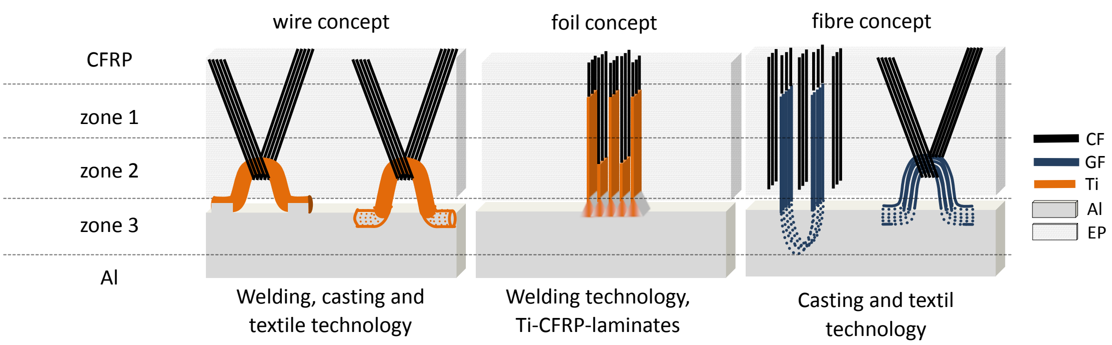

Figure 2. concepts for FRP-aluminium compounds in load application zones

The fibre concept is characterised by joining a textile made of CF and GF (glass fibre) to an aluminium sheet. A CF loop is threaded through a GF loop by textile technologies, it is a form closure connection (zone 2). The flanks of the GF loops are attached to an aluminium component by casting (zone 3). The following investigation deals with the influence of the pretension, which is applied onto in production process, on the joint strength.

3 Theoretical influence of pretension

The tangential deformation in the crest of a loop is increasing with increasing radii ratio of outer to inner radius (Figure 3). Due to Hooke's Law an increasing deformation leads to an increasing tension. The over-tension in areas of deformation's peak causes a decreasing average grade of connection.

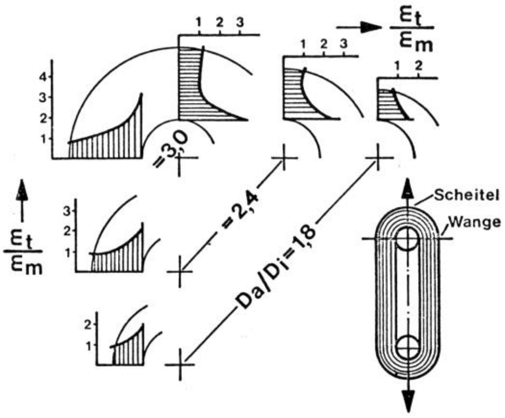

Figure 3. measured tangential deformation depending on radii ratio [15]

During the production process of the fibre concept a pretension is applied onto the loop. This could influence the joint strength, because the radii ratio could be varied. If the pretension is insufficient, on the one hand fibres are not elongated (Figure 4). During injection the fibres are able to move sideward, in the end they are not in direction of load and can cause delaminations. On the other hand resin will accumulate in the loop's crest between the GF and CF (Figure 4). The direct load transmission from roving to roving is not assured, why a high standard deviation is expected. With an increasing pretension, the GF loop deforms (Figure 5). The radii ratio increases, which leads to an over-tension. On the one hand the joint strength decreases due to the over-tension, on the other hand fibres could be already damaged while manufacturing process. Hence, the applied pretension in manufacturing process could have an influence on the joint strength. By means of simplified specimens, i.e. of a CFRP-GFRP loop connection this effect is investigated under tensile load.

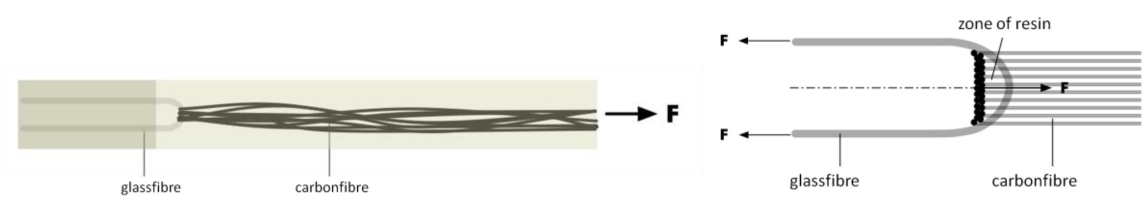

Figure 4. low pretension on loop connection

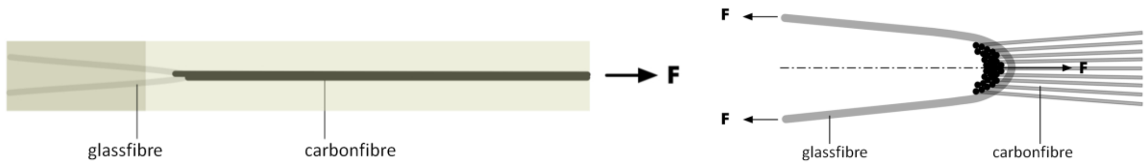

Figure 5. high pretension on loop connection

4 Approach

The combination of the loop material was determined by tensile tests of "dry" carbonfibre (CF) / glassfibre (GF) loops. Depending on the failure load as well as the failure mode the combination was chosen for the resin injection. The epoxide resin RTM 6 is chosen for producing the simplified specimens. The geometry of specimens is according to ASTM [16].
Before resin injection process GF-loops are stabilised by the tailored fibre placement technology, fixed on pins and threaded with CF-rovings. Different pretensions are applied onto the CF-roving (Figure 4). The range of pretension is based on forces occuring during manufacturing process, which is recently investigated.

Figure 6. Application of pretension on loop connection in manufacturing process

5 Results

5.1 Material combination

Nine different material combinations were tensile tested. For the combination HTS 24k / S glass 2400 tex the highest failure loads occured (Figure 7). A mixed failure mode is in the sense of lightweight design because any part is loaded and structural exploited. Only for the combination HTS 24k / S-glass 2400 tex a mixed failure mode was observed. Hence, this combination was chosen for the GFRP-CFRP loop connections.

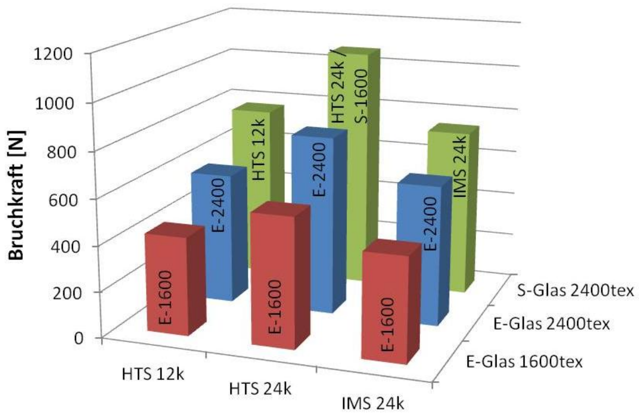

Figure 7. failure load of "dry" GF-CF loops depending on material combination

5.2 Pretension variation

Tensile tests of GFRP-CFRP loops with different pretensions are conducted. The average failure load for all tested pretension is on similar level (figure 8), which causes an almost linear characteristic for the process window. The standard deviation decreases with an increasing pretension (table 1).

F_{pre} [N]	F_{aver} [N]	ν [%]
2	2321	7.55
4	2174	5.29
6	2369	4.00
8	2319	3.53

Table 1. average failure load with standard deviation depending on pretension

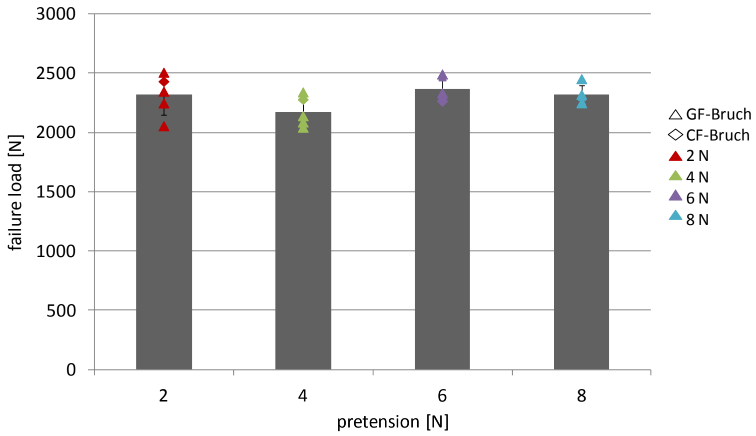

Figure 7. failure load depending on pretension for CFRP-GFRP loop connections

5 Conclusion

The low standard deviation between 3.5% and 7.6% represents the accuracy of the sensitive threading process. A repeatable production is assured. From the linear characteristic of the failure load depending on the pretensions derives, that the pretension in the investigated range has no impact on the joint strength. In terms of tolerance management this is advantageous for production process. Considering the described deformation of the geometry a decreased joint strength for higher pretensions is expected due to a varied radii ratio. Hence, in a next step the boundary value will be determined.

References:

[1] Lee, M.M.K., Deng, J. Fatigue performance of metallic beam strengthened with a bonded CFRP plate. *Composite Structures*, **Volume 78** (2007), pp. 222-231

[2] Kelly, G. Quasi-static strength and fatigue life of hybrid (bonded/ bolted) composite single-lap joints. *Composite Structures*, **Volume 72** (2006), pp. 119-129

[3] Casas-Rodriguez, J.P., Ashcroft, I.A., Silberschmidt, V.V. Delamination in adhesively bonded CFRP joints: Standard fatigue, impact fatigue and intermittent impact, *Composites Science and Technology*, ***Volume*** **68** (2008), S. 2401-2409

[4] Kabche, J. P., Caccese, V., Berube, K. A., Bragg, R. Experimental characterization of hybrid composite-to-metal bolted joints under flexural loading, Original Research Article, *Composites Part B: Engineering*, **Volume 38**, Issue 1 (2007), S. 66-78

[5] Lim, T. S., Kim, B. C., Lee, D. G. Fatigue characteristics of the bolted joints for

unidirectional composite laminates, *Composite Structures*, **Volume 72**, Issue 1, (2006), S. 58-68

[6] HSB. *Handbuch für Strukturberechnungen*

[7] Schimanski, K., Schumacher, J., Lang, A., Schiebel, P., von Hehl, A., Bomas, H., Zoch, H.-W., Herrmann, A. Bauweisen für CFK-Aluminium-Übergangsstrukturen im Leichtbau, *Verbundwerktoffe*, Chemnitz 2011

[8] Havar, T. Beitrag zur Gestaltung und Auslegung von 3D-verstärkten Faserverbundschlaufen, Institut für Flugzeugbau, Uni Stuttgart, 2007

[9] H. Conen, "Deformation und Versagen von GFK-Strangschlaufen". *Kunststoffe,* ***Volume 56***, pp. 629–631

[10] Kolesnikov, B., Herbeck, L., Fink A. Fortschrittliche Verbindungstechniken von Faserverbundstrukturen, Deutsches Zentrum für Luft- und Raumfahrt e.V., Baunschweig

[11] Fink, A,. Kolesnikov, B. Hybrid Titanium Composite Material improving Composite Structure Coupling, ESTEC, Noordwijk, 2005

[12] Kolesnikov, B., Herbeck, L., Fink, A. CFRP/titanium hybrid material for improving composite bolted joints, *Composite Structures*, **Volume 83**, Issue 4, June 2008, Pages 368-380

[13] Willard, N. Titanium: Polymer Hybrid Laminates, United States Patent, Patent Number 5,866,272, Sealttle1999

[14] Fink, A. Lokale Metall-Hybridisierung zur Effizienzsteigerung von Hochlastfügestellen in Faservbundstrukturen, *Forschungsbericht 2010-14*, Deutsches Zentrum für Luft- und Raumfahrt, 2010

[15] Niderstadt, G. *Krafteinleitungselemente*, "Verstärkte Kunststoffe in der Luft- und Raumfahrttechnik", Kohlhammer, Stuttgart 1986

[14] ASTM International, Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials, Designation: D 3039/D 3039M - 00²