Possibilities of joining metals and CFRP/GFRP composites

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Abstract: *The paper discusses the possibilities of joining thin-walled metals and composites reinforced with bidirectional carbon/glass fibres. The experimental part of the paper contains metallographic sections and results of load-bearing capacity testing of pilot metal-composite joints with thermoplastic matrix and glass and carbon fiber reinforcement, formed by thermal drilling technology. As a result, a sequential joining method is proposed which can achieve the optimum joint geometry with a hem to keep the joint from opening under tensile stress.*
Keywords*: METAL – COMPOSITE JOINING, MECHANICAL JOINING, CFRP, GFRP, THERMAL DRILLING*

1. Introduction

The need for joining dissimilar materials is a response to the demands of creating ultra-lightweight structures, usually custom-made, where different materials are used in different zones of the product to fully exploit their potential [1-8].

In many applications where the weight and load capacity of the structure is a critical factor, the material design takes into account "specific strength", which is the strength-to-weight ratio of the material, rather than simple mechanical strength. Al, Mg, Ti alloys, as well as epoxy matrix composites reinforced with various types of continuous bidirectional fibres (glass, carbon, aramid) are excellent for use in the design of ultralight materials according to this characteristic. These materials, together with different grades of progressive steels, need to be combined into functional units, which brings new challenges due to the different material nature.

The possibilities of joining metals and composites can be divided into two main categories, Fig. 1.

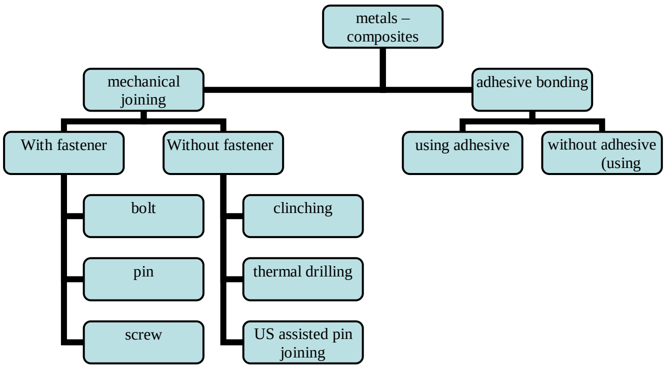

Fig. 1 *Metals – composites joining methods overview [8]*

Either mechanical fasteners or adhesives, or a combination of both, are used to join composites to metals. Mechanical fasteners may be rivets, pins, bolts, etc. When adhesive bonding of composites and metals, various physical treatments of the surface of the composites are used to improve adhesion, or the metal and composite are bonded together without the use of an adhesive, only through the heated thermoplastic matrix of the composite.

The paper focuses on the verification of the possibility of making joints of aluminium alloy and composites with thermoplastic matrix reinforced with continuous fibres in two directions by thermal drilling technology. The joint is to be made without the use of a screw (bolt), only by means of a metal bushing made of aluminium alloy, without disruption of the fibres in the composite material. The process of thermal drilling and joint formation will be carried out at temperatures above the melting temperature of the thermosoftening matrix of the composite to allow the fibres to deflect from their position and allow penetration of the tool without breaking the integrity of the fibres, Fig. 2. The joints geometry was investigated metallographically, and the load-bearing capacity was determined by tensile shear testing of single lap joints.

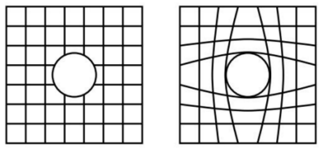

Fig. 2 *Making holes by cutting or drilling (left) and by deflecting the fibres without breaking (right) [21]*

2. Materials and methods

The following materials were used for the research:

Metal:

- Aluminium alloy EN AW 6082 T6 (AlSi1MgMn), 1 mm thick sheet (hereafter Al).

Composites:

- polypropylene matrix composite reinforced with glass fibre, 1.5 mm thick organosheet (hereafter PP-GF)
- polypropylene matrix composite reinforced with carbon fibre, 1,5 mm thick organosheet (hereinafter PP-CF)

A bench drill machine and a Flowdrill long Ø 5.3 mm tool were used for joining the selected materials. The shape and dimensions of the test joints were determined based on the diameter of the Flowdrill tool according to ISO 12996:2013 and are shown in Fig. 3.

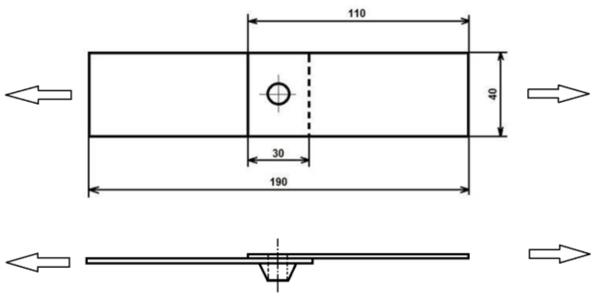

Fig. 3 *Shape and dimensions of the test joints*

The procedure for making the joints was as follows: heating the fixture and the materials to be joined in the furnace to 170°C, transferring the fixture and materials to the drilling machine (the temperature after removal from the furnace is maintained locally with a heat gun), fixing, drilling of the overlapped materials, with the Al sheet in the upper position of the joint.

After the joints formation, the geometry of the joints was investigated metallographically and the load-bearing capacity of the joints was tested on a universal tensile testing machine at a loading rate of 10 mm.min^{-1}.

2. Results

The metallographic section of the Al - PP GF joint is shown in Fig. 4.

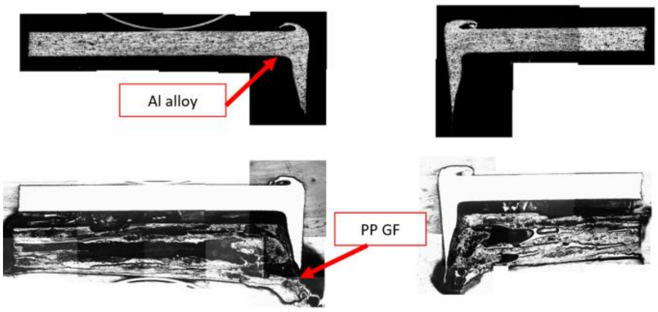

Fig. 4 *Metallographic section of the Al - PP GF joint*

Fig. 4 shows that the thermal drilling perforated both the metal and the composite, the Al bushing went through the entire thickness of the glass fiber composite. However, the underside of the composite was delaminated when the bushing and tool penetrated, which caused the bushing, although of sufficient length, not to be visible on the underside of the joint. A solution could be to turn the joint over in next step and use the same tool to create a hem on the formed bushing, Fig. 5.

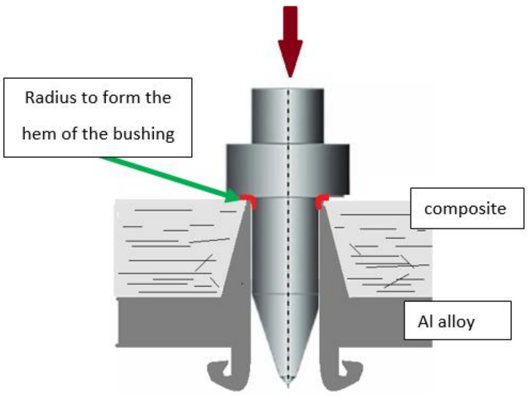

Fig. 5 *Method of hemming and closing the joint*

The Al - PP GF joint was formed by the above procedure with a hemming and is shown in Fig. 6.

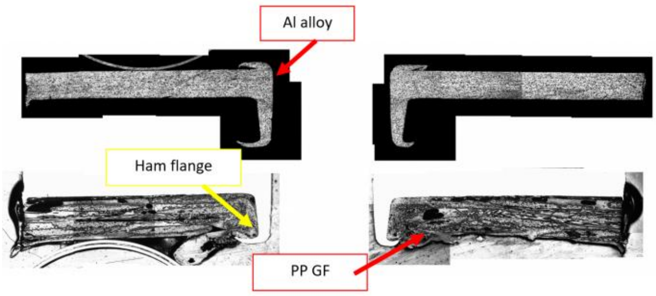

Fig. 6 *Metallographic section of the Al - PP GF with hem*

On the metallographic section, the hem of the Al bushing is visible, which encloses the composite material. The hemming on the opposite side of the joint has fulfilled its purpose and closed the joint, thus insuring it against opening due to the forces applied during tensile loading.

Fig. 7 shows a metallographic section of an Al - PP CF joint with a hem.

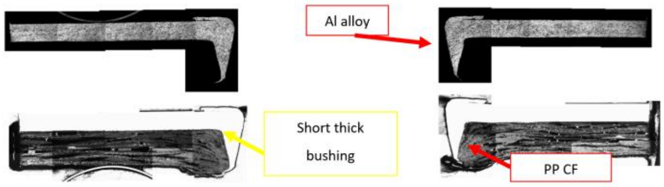

Fig. 7 *Metallographic section of the Al - PP CF with hem*

The figure shows that the joining of Al with the carbon fibre composite did not produce a long enough bushing. This resulted in the formed hem also not being sufficient, so we decided to try the sequential drilling and joining method.

To create a longer bushing, long enough to form a hem, the sequential joining method was tested, which consists of the following steps:

- creating a hole in the heated composite with a drill tool,
- covering the composite with Al sheet,
- forming the hole and bushing in the Al with a drill tool,
- turning the assembly,
- forming the hem - closing the joint.

The joints formed by the sequential method are shown in Figs. 8 and 9.

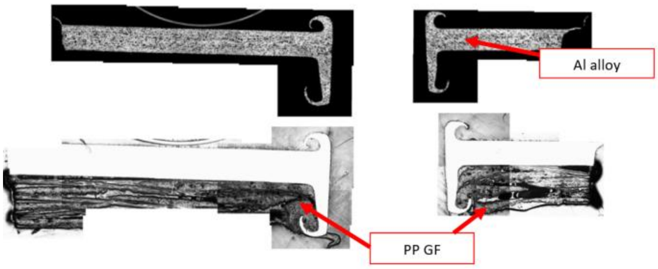

Fig. 8 *Metallographic section of the Al - PP GF joint formed by the sequential method*

The picture shows a formed bushing of sufficient thickness and length, the end of which, thanks to the reverse hemming, forms a tight bond with the composite and prevents delamination.

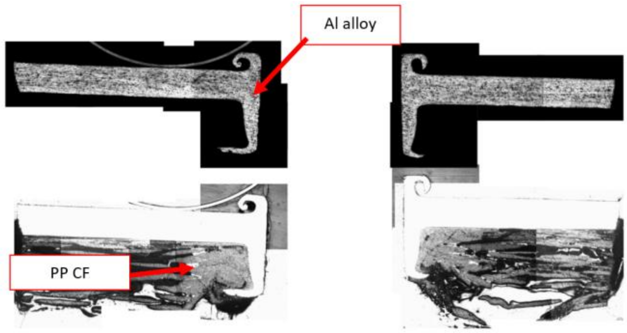

Fig. 9 *Metallographic section of the Al - PP CF joint formed by the sequential method*

Perfectly formed bushing can be seen again in this metallographic section. The hem is fulfilling its purpose, preventing delamination of the composite and closing the joint.

The results of the joints load-bearing capacity testing are shown in Figs. 10 and 11.

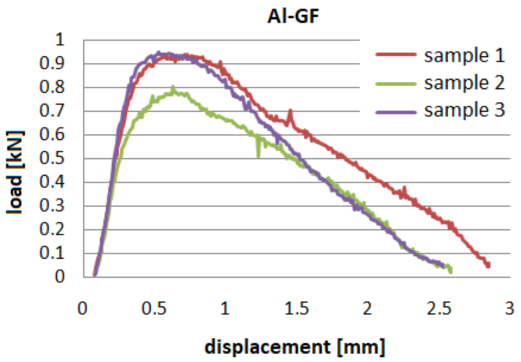

Fig. 10 *Load-displacement curves of Al – PP GF joints*

The curves show a linear increase in force up to Fmax, followed by a short stagnation of force around Fmax, which corresponds to the beginning of the failure of the joint - sliding of the composite out of the hem, and the curve continues with a gradual decrease, which also includes the failure of the adhesive bond of the composite to the metal over the entire surface of the overlap. The appearance of the joint surfaces after failure is shown in Fig. 11.

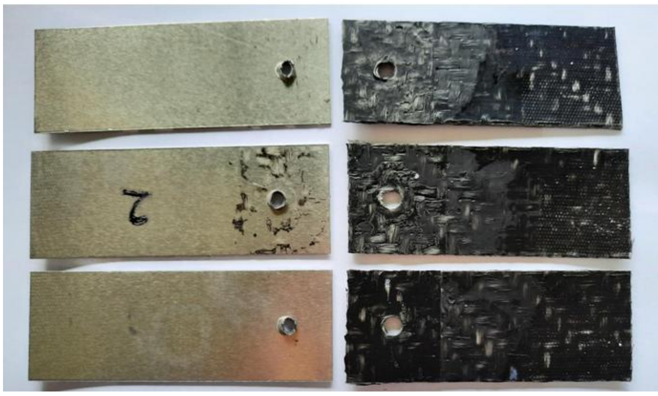

Fig. 11 *Appearance of Al - PP GF substrates after load capacity test*

The joints failed in the bushing area after static tensile load testing without major damage of the involved materials. The GF composite adhered to the Al alloy at a given temperature (>Ttav PP) at the overlapped area and contributed to the load-bearing capacity of the joints.

Fig. 12 shows the loading history of the Al - PP CF joints.

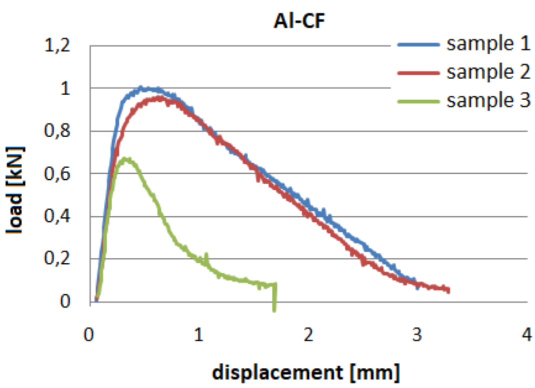

Fig. 12 *Load-displacement curves of Al – PP CF joints*

Again, the curves show a linear increase in force up to Fmax. Subsequently, the onset of failure of the joint is visible - sliding of the composite out of the hem. The curve continues with a gradual decrease, which includes the failure of the adhesive bond of the composite to the metal over the entire area of the overlap.

The appearance of the joint areas after failure is shown in Fig. 13.

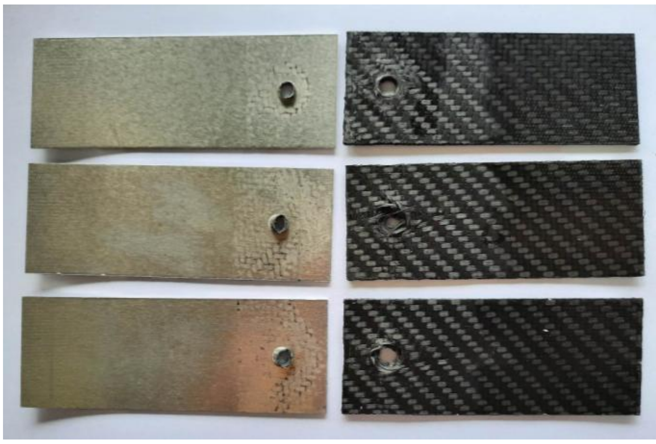

Fig. 13 *Appearance of Al - PP CF substrates after load capacity test*

During tensile testing of Al alloy and PP CF joints, the joint failed at the thermal drilling point. Some bushings were deformed and pressed. Carbon fibre damage - fibre pull-out - is also visible on the composite in the middle sample.

Conclusions

Based on the results obtained, the following information was found:

- The formed joints of the aluminium alloy and the two tested composites had approximately the same load-bearing capacity, about 1 kN, which includes not only the mechanical connection by the bushing, but also the adhesive forces between the softened PP matrix and the Al alloy over the entire overlap area, while the contribution of the mechanical and adhesive forces to the total load-bearing capacity of the joint is not easy to estimate.
- No fibre breakage was visible on the glass fibre composite specimen, but for the carbon fibre composite there were broken fibres around the hole. However, the failure occurred during the load capacity testing of the joints, not at the joint formation stage.
- The size and shape of the hem, which fixes the composite plate in the joint, appears to be a significant limiting factor affecting the load capacity of the joint. When the joint is subjected to tensile stress, the hem straightens, the Al alloy bushing deforms in the direction of the stress, in some cases leaving part of the separated hem in the hole of the composite.
- Metallographic sections of the formed joints showed that the sequential joining method has a positive effect on the geometry of the formed bushing and hem and contributes to the load carrying capacity of the joints.

Acknowledgement:

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3. References

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