Failure behavior of novel hybrid bonded-hole hemmed joints in lightweight materials

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Introduction

Enhancing transportation efficiency is critical in a society striving for sustainability. Recently, new joining techniques have been developed to enable the construction of more efficient lightweight vehicles. Following this trend, the current research proposes a novel hybrid joining process via the combination of a newly developed joining process by plastic deformation, called hole hemming (HH), with adhesive bonding [1]. This process, named bonded-hole hemming (BHH), is examined for the joining of AZ31 magnesium and AA6082-T4 aluminium sheets considering different bonded overlaps. Then, the innovative hybrid joints are subjected to single-lap shear tests at different temperatures to assess their mechanical performance [2].

Materials and methods

The BHH experiments were performed in AZ31B magnesium alloy sheets with 0.9mm thickness and AA6082-T4 aluminium sheets with 2mm thickness (Figures 1,2 and 3). The AA6082-T4 sheet was considered as the outer sheet due to its higher ductility while the AZ31 sheet was used the inner sheet as it only undergoes slight deformation in the hemming stage. This helps to avoid fracture during the hole hemming process. An epoxy adhesive with a curing stage of 180ºC for half an hour was used in the experiments. The adhesive has a glass transition temperature (T_g) of 120ºC.

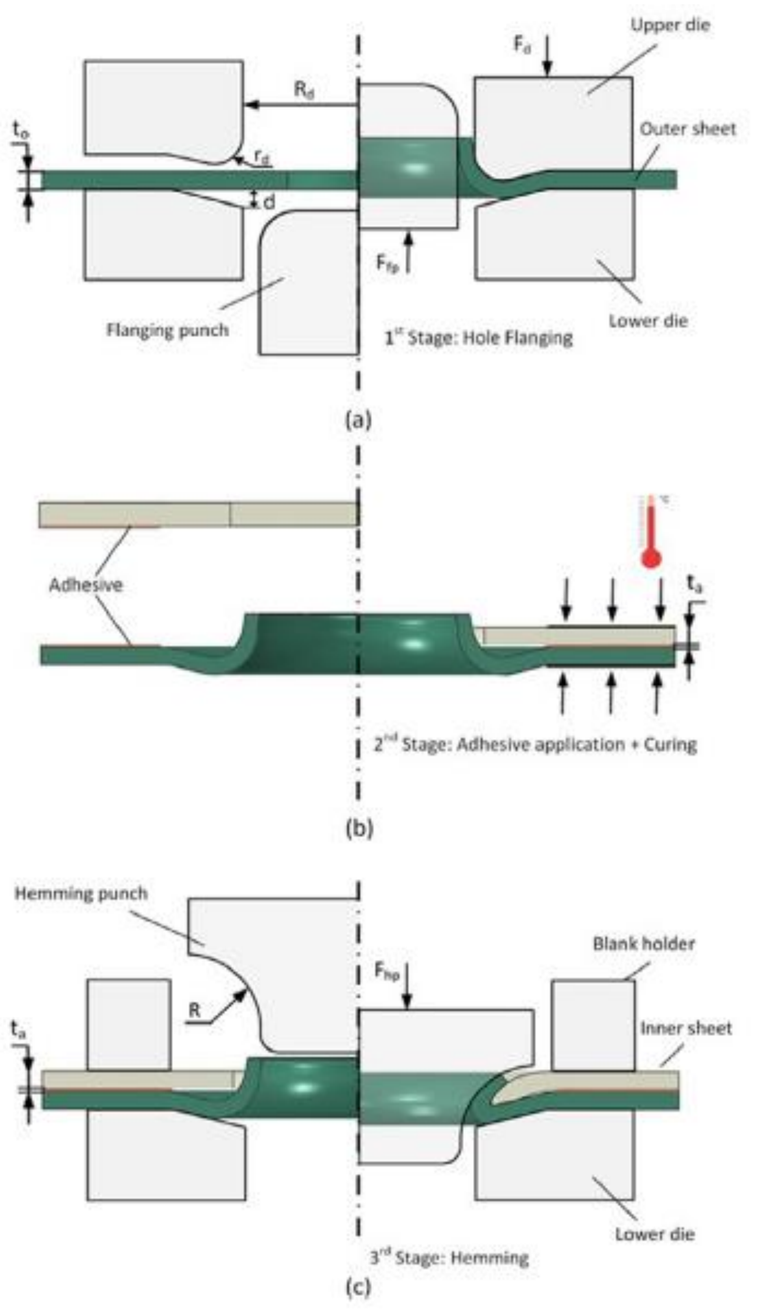

Figure 1 – Bonded-hole hemming

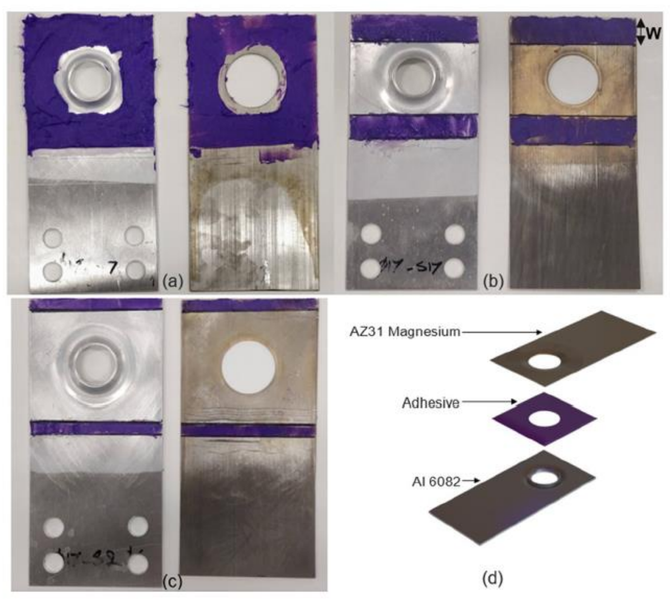

Figure 2 – Different adhesive areas (W=5, 15 and 35mm) and joint pattern

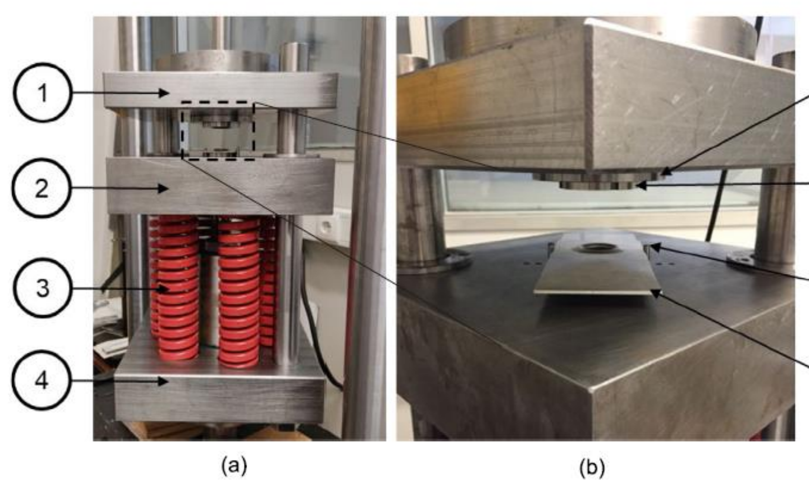

Figure 3 – Hole hemming tool

Results and discussion

As seen in Figure 4, the BHH joints reached a maximum joint strength of at least 11kN, 3.8 times better the HH joint at room temperature. The BHH joints with different widths of the bonded overlap all experienced fracture in the clamped holes of the magnesium substrate due to the high stress in this region, with no failure observed in the bonded overlap or the mechanical interlock. At 150ºC, the adhesive is past the T_g which should drastically affect its mechanical properties.

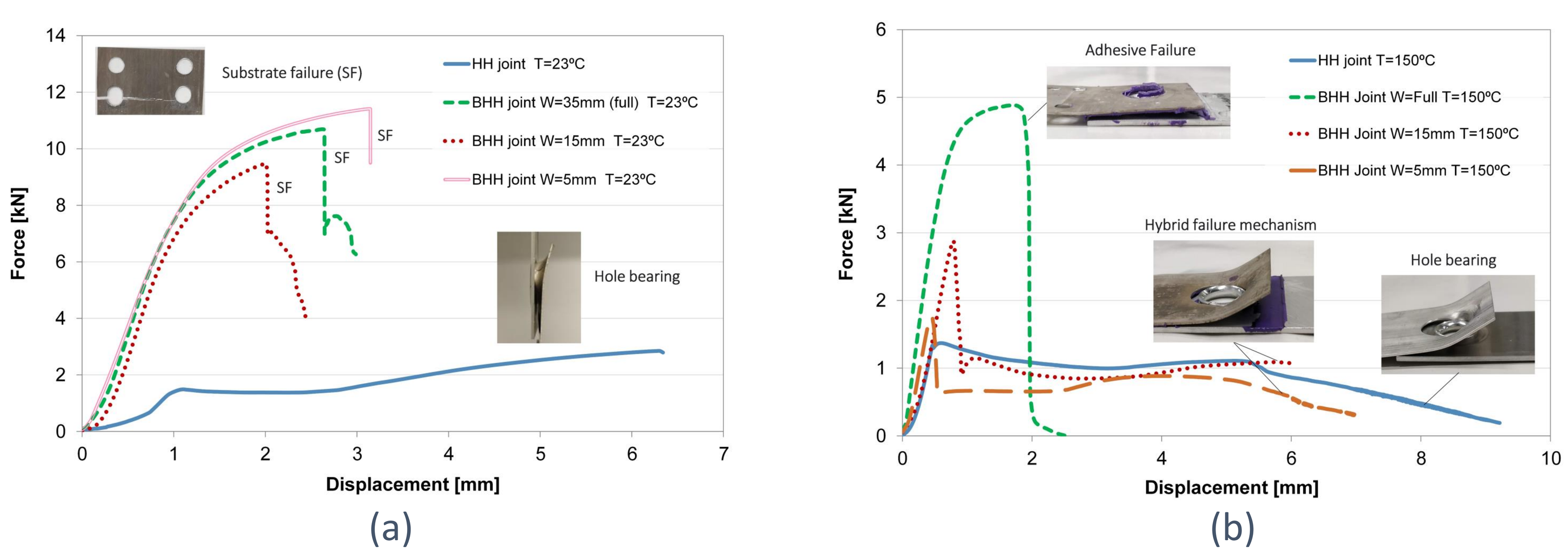

Figure 4 – Effect of bonded overlap width (W) on the shear strength of the BHH and HH joints (a) T=23ºC and (b) T=150ºC

The results show that, although the T_g of the adhesive was surpassed, the adhesive still has an influence on the BHH joints, resulting in a hybrid failure mechanism. In this condition, the width of the bonded overlap is directly proportional to the influence of the adhesive in the joints.

Figure 5 shows that as the temperature rises, the joint becomes weaker and is more susceptible to the failure mechanism of the hole bearing. As a result of this, the joint experiences substrate failure until 90ºC, afterwards, the failure mechanism becomes the hybrid failure mechanism.

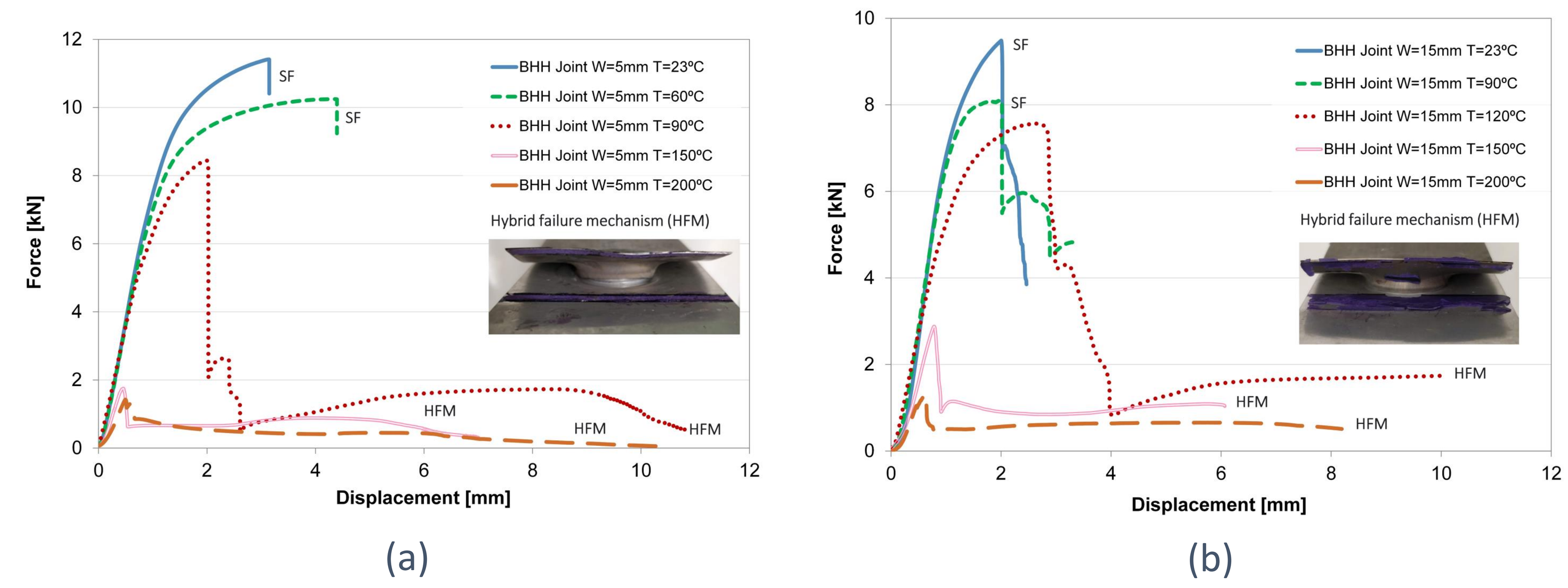

Figure 5 –Effect of temperature (T) on the shear strength of the BHH and HH joints (a) W=5mm and (b) W=15mm

The contribution of the adhesive layer is shown by the increased load capacity of the BHH joint compared to that of the HH joint, and the contribution of the mechanical interlock is demonstrated by the higher displacement at failure, a result of the interlocking mechanism established between the two substrates, similar to that of the HH joint (Figure 6).

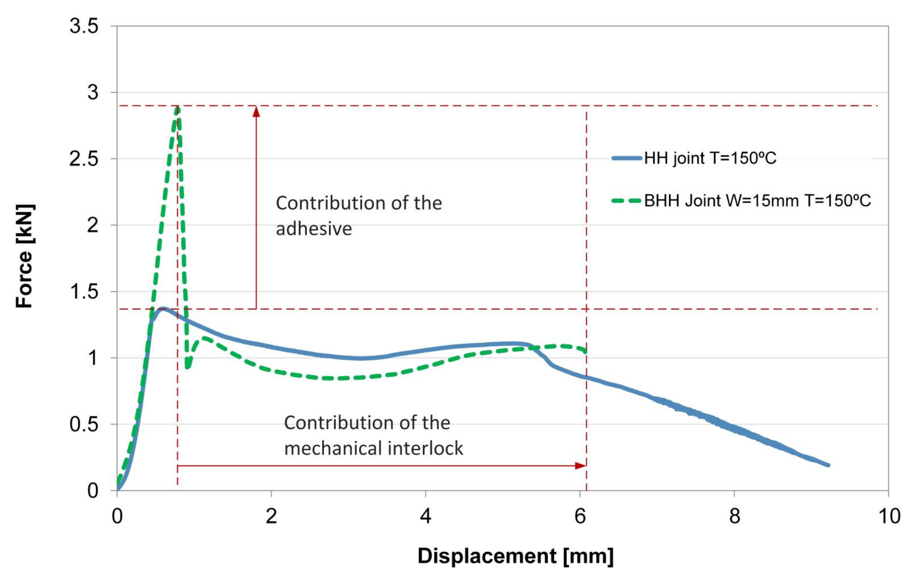

Figure 6 – Contributions of the bonded overlap and the mechanical interlock in mechanical behavior of the BHH joints

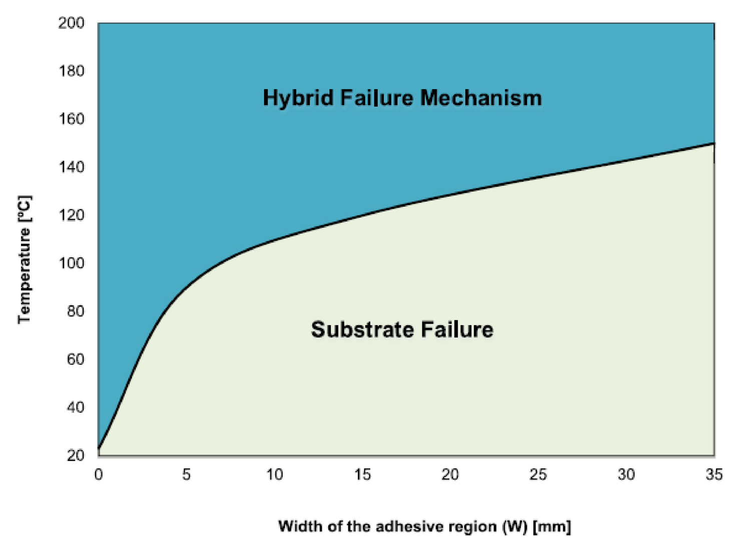

Figure 7 – Process window of the Bonded-hole hemming process

Conclusions

The results indicated that the application of adhesive can increase the strength of the HH joints significantly, by at least 3.8 times at room temperature. However, as the temperature increases, the strength of the hybrid joint decreases due to the weakening of the adhesive, particularly above its T_g. As a result, the failure mode of the BHH joints shifts from substrate failure to a hybrid failure mechanism. As the hybrid failure mechanism is activated, both the bonded overlap and the mechanical interlock contribute to the joint failure, resulting in a higher displacement at failure. In addition, the failure mode of the bonded overlap changes from cohesive failure at temperatures below the T_g to a mixed cohesive-adhesive failure mode at temperatures above the T_g. It was also found that the temperature at which the failure mode changes in the BHH joints increases with the width of the bonded area (Figure 7). According to the obtained results, it can be concluded that BHH joints with a hybrid failure mechanism, including cohesive failure and hole bearing, can be preferable as they provide both high strength and failure displacement.

References

[1] A Haran-Nogueira, MM Kasaei, A Akhavan-Safar, RJC Carbas, EAS Marques, SK Kim, LFM da Silva, Journal of Manufacturing Processes, 95(2023), 479-491.

[2] A Haran-Nogueira, MM Kasaei, A Akhavan-Safar, RJC Carbas, EAS Marques, LFM da Silva, Thin-Walled Structures 189(2023), 110907.