Failure analysis of hybrid busbars produced by a novel joining process

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Introduction

With the increasing awareness of climatic changes and change to more sustainable practices, nowadays the vehicles industry has shifted away from fossil fuel cars to electric vehicles. However, integrating a battery pack onto an EV body poses challenges aimed at reducing costs and improving performance, safety, and reliability. In this work, the failure behaviour of copper-aluminum joints created by a novel joining process by plastic deformation, named hole hemming (Figure 1) [1], will be studied in shear tests. The aim is to determine their potential for manufacturing hybrid copper-aluminum busbars.

Materials and methods

The hole hemming experiments were conducted in AA6082-T4 aluminum and Cu-ETP R240 copper sheets, with a thickness of 2 mm and 1 mm, respectively (Figure 2). The AA6082-T4 sheet was chosen as the outer sheet, while the Cu-ETP R240 sheet was used as the inner sheet. The hybrid hole-hemmed joints (HHH joints) were tested via single lap shear tests. The hole hemming process and shear test were modelled using the commercial finite element software Abaqus, while the ductile damage was predicted by the Modified Mohr-Coulomb (MMC) model for both copper and aluminum (Figures 3 and 4).

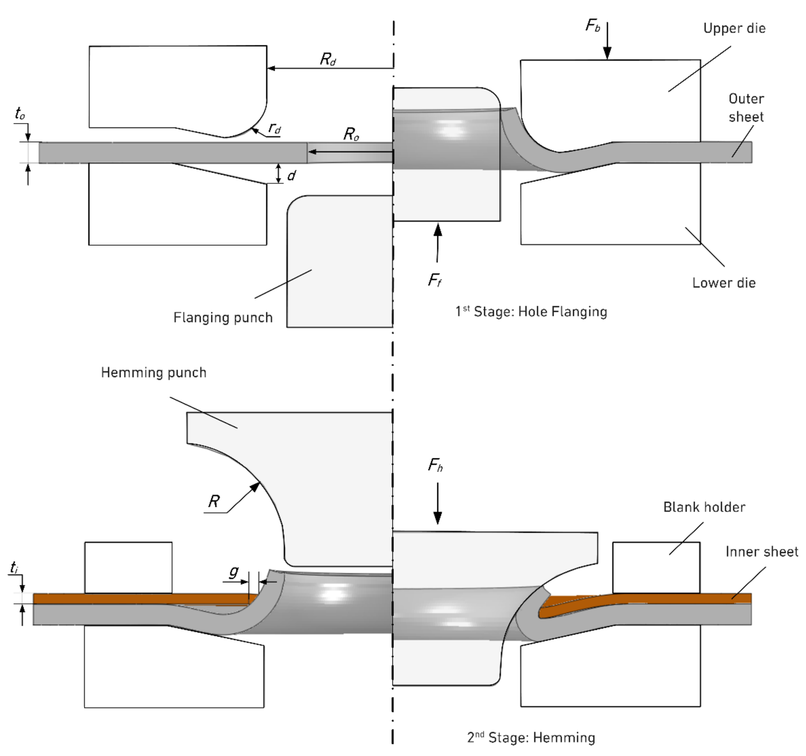

Figure 1 – Hole hemming process

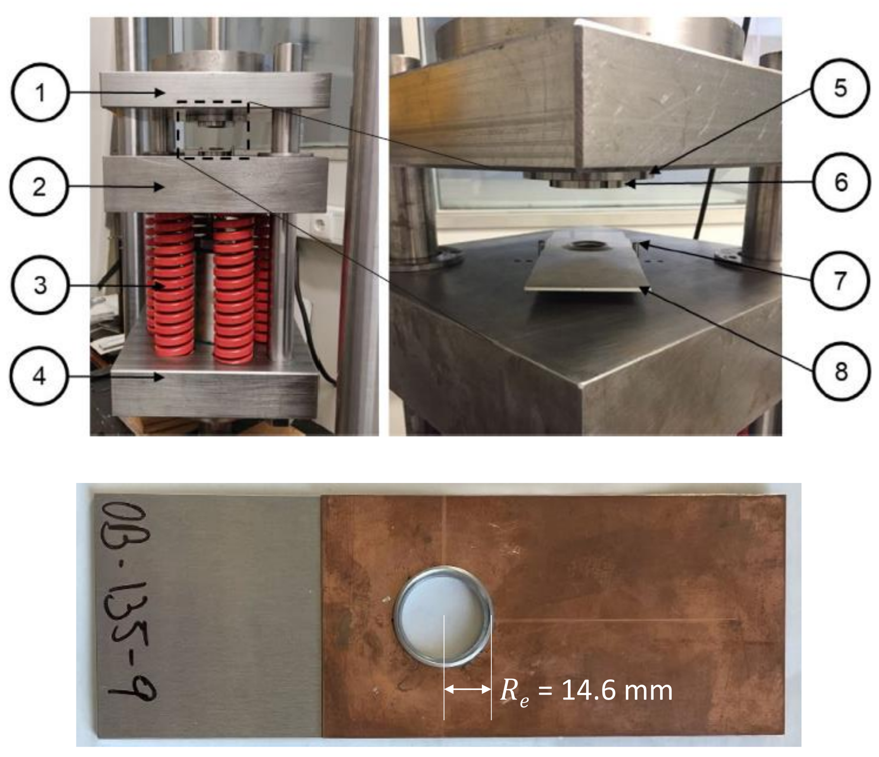

Figure 2 – Hole hemming experiments

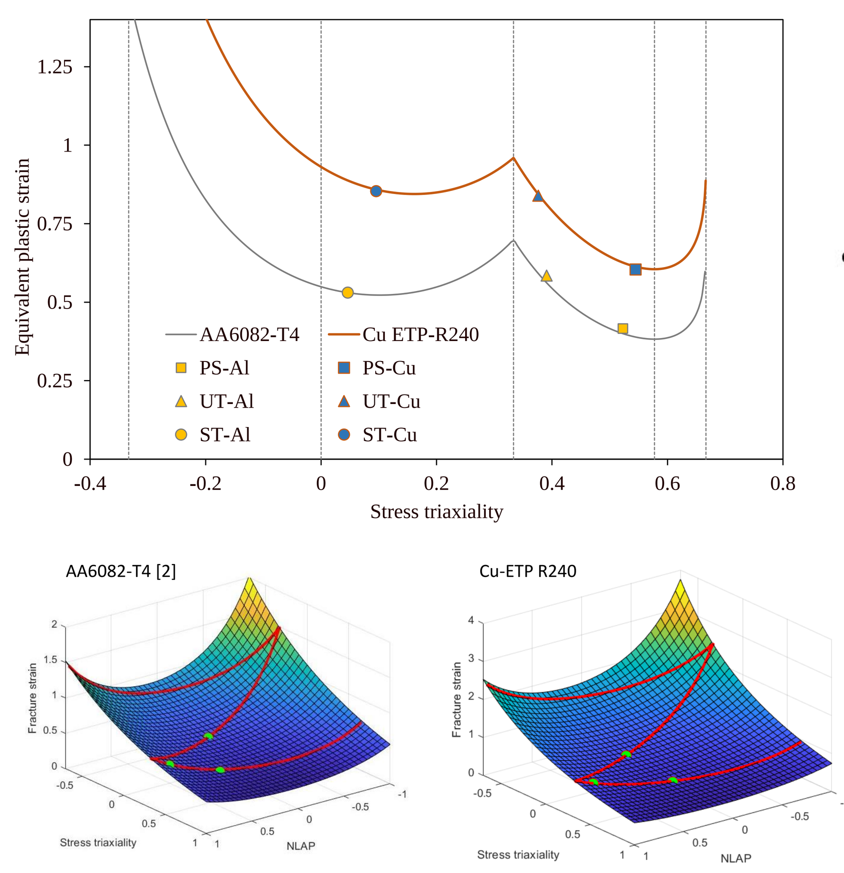

Figure 3 – MMC fracture envelopes

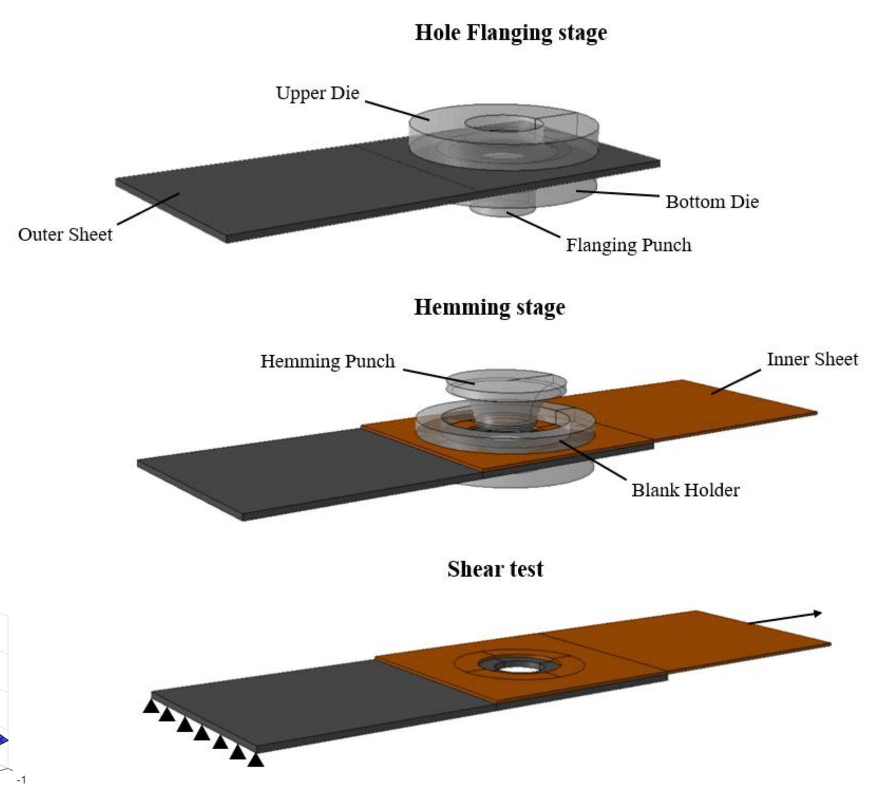

Figure 4 – Hole hemming and shear test simulation

Three different joints were simulated, with varying values of flange edge radius (R_e). As seen in Figure 5, increasing R_e results in a better mechanical interlock between the sheets.

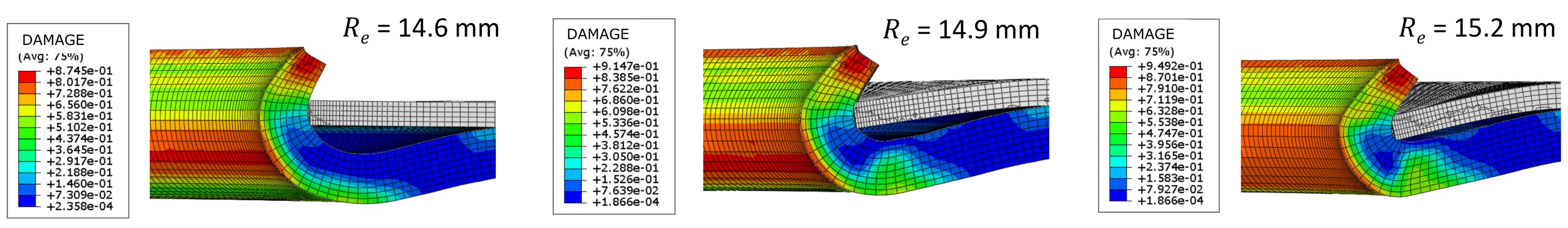

Figure 5 – Mechanical interlock for different values of R_e

Results and discussion

Figure 6 shows the experimental (only for R_e of 14.6mm) and numerical load-displacement curves. An overall good agreement was achieved for a R_e of 14.6mm. First there's a rapid increase in load, with the elastic deformation of both sheets. Then the copper sheet starts to bend, and its hole deforms against the flange, increasing the contact surface, and resulting in a force increase. Finally, the load drops significantly. However, no cracks appear for this joint, as observed in Figures 7 and 8. Figure 7 presents the critical region of the joint, which is located in the contact zone between the copper's hole and aluminum's flange, which aligns with the fact that the inner sheet hole deforms against the flange. Figure 8 shows the damage for both sheets.

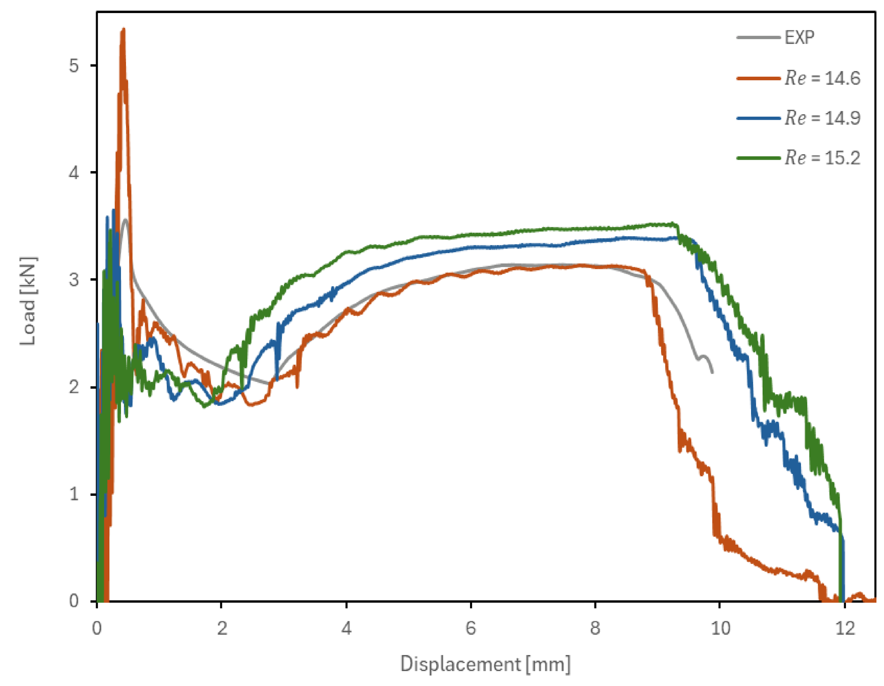

Figure 6 – Experimental and numerical load-displacement curves

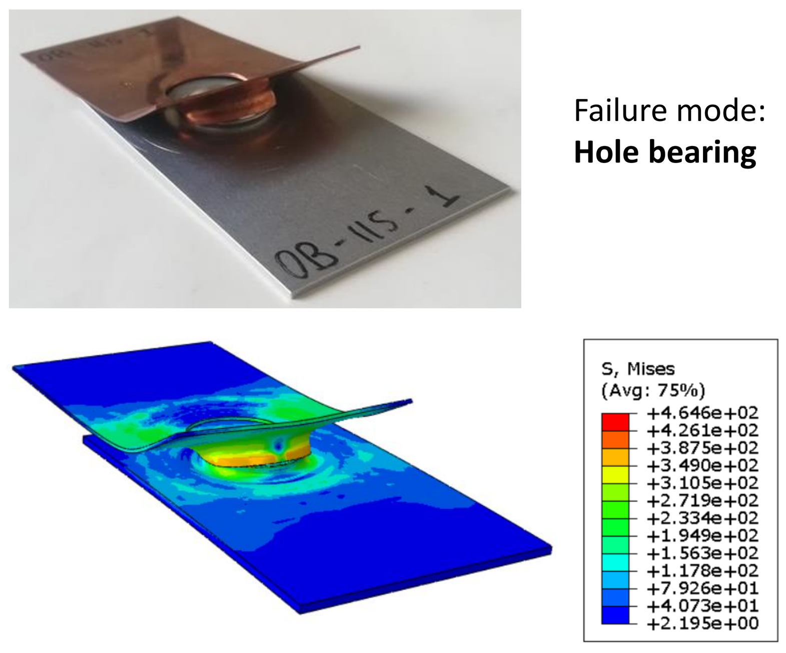

Figure 7 – Critical region of the joint with R_e = 14.6 mm

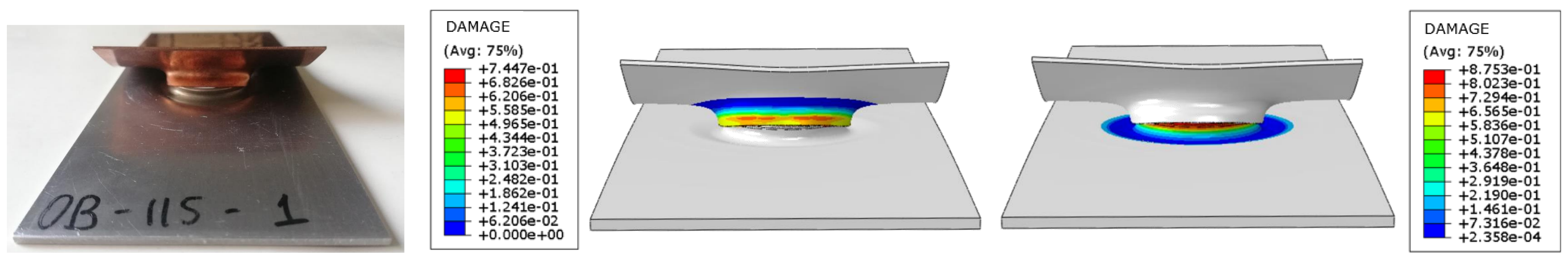

Figure 8 – Damage distribution of the joint with R_e = 14.6mm

With an increased flange edge radius (R_e), the mechanical performance of the joint increases, achieving a higher maximum load in the end, as well as a higher fracture displacement. A better mechanical interlock prevents the copper sheet from disengaging from the lock after deformation, leading to better results, as it can be seen in Figure 9.

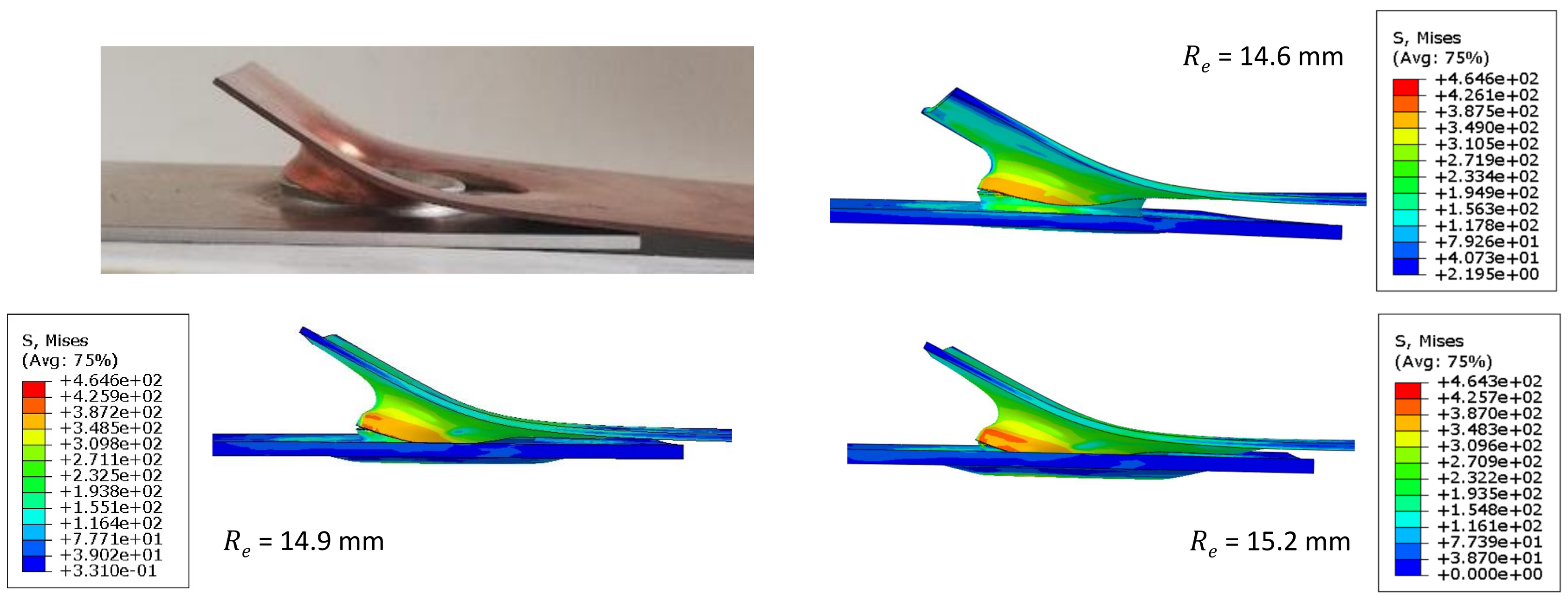

Figure 9 – Side view of the joints with different values of R_e

Conclusions

The experimental results demonstrate that the novel copper-aluminum joint efficiently withstands load in single shear tests, achieving a maximum force and displacement of 3.56kN and 9.30mm, respectively. The FE analysis reveals that R_e, controlled by the hemming punch displacement, significantly impacts the performance of the novel joints. A higher R_e leads to greater failure displacement and load, although it decreases the load level at the beginning of the test. These findings indicate that, from a mechanical performance perspective, hole-hemmed joints have the potential for use in constructing hybrid busbars for EV batteries.

References

[1] MM Kasaei and LFM da Silva, J Materials: Design and Applications 2022, 236(6) 1321–1332.

[2] JAC Pereira, MM Kasaei, RJC Carbas, EAS Marques, and LFM da Silva, Thin-Walled Structures, 187(2023), 110758.