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Thermal–electrical performance and interfacial durability of overmolded polypropylene compound insulation for EV busbars

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INTRODUCTION

Reliable electrical insulation of busbars is essential for the safety and durability of electric-vehicle (EV) battery packs, where polymer–metal interfaces are subjected to high currents, steep thermal gradients, and repeated thermo-mechanical cycling. However, the interfacial adhesion performance of polypropylene-based overmolded insulation under realistic thermal–electrical loading remains insufficiently documented, particularly for aluminium busbars.

This study investigates a glass-fibre-reinforced, halogen-free polypropylene compound (PPC) overmolded onto aluminium busbars, focusing on its thermal–electrical behaviour and interfacial durability. A coupled thermal–electro–mechanical finite element model was developed and validated through high-current experiments up to 1500 A, accurately predicting temperature distributions and identifying mechanically critical regions near the polymer–metal interface. Interfacial shear tests conducted after controlled thermal cycling showed only a modest reduction in strength; however, an early degradation trend of approximately 7–12% after 10 cycles indicates sensitivity to cumulative thermal exposure. A systematic strength disparity between the gate and opposite sides of the overmolded layer was also observed, consistent with mould-flow-induced variations in local compaction. Overall, the results demonstrate effective short-term insulation while highlighting the need for extended cycling to assess long-term durability.

EXPERIMENTAL DETAILS

The busbars were fabricated from a structural 6xxx-series aluminium alloy. Their insulation layer was made of a polypropylene-based compound reinforced with 30% glass fibber and formulated with halogen-free flame retardants (see Figure 1).

FIGURE 1. Specimen busbars analysed.

The setup used a 1.5 kVA transformer to apply up to 1500 A, heating the specimens via the Joule effect. Temperatures were tracked in real-time using a Fluke Ti25 thermal camera. This system provided high-resolution measurements with an accuracy of ±2 °C or 2% (see Figure 2).

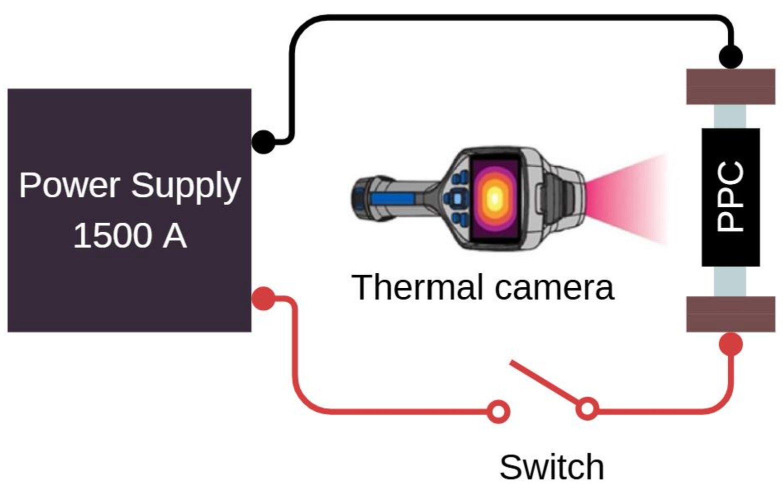

FIGURE 2. Thermal-electrical setup used.

NUMERICAL ANALYSIS

An Abaqus® finite element model was developed to simulate the busbar's thermal-electrical behavior, evaluation of temperature evolution and internal stresses (see Figure 3).

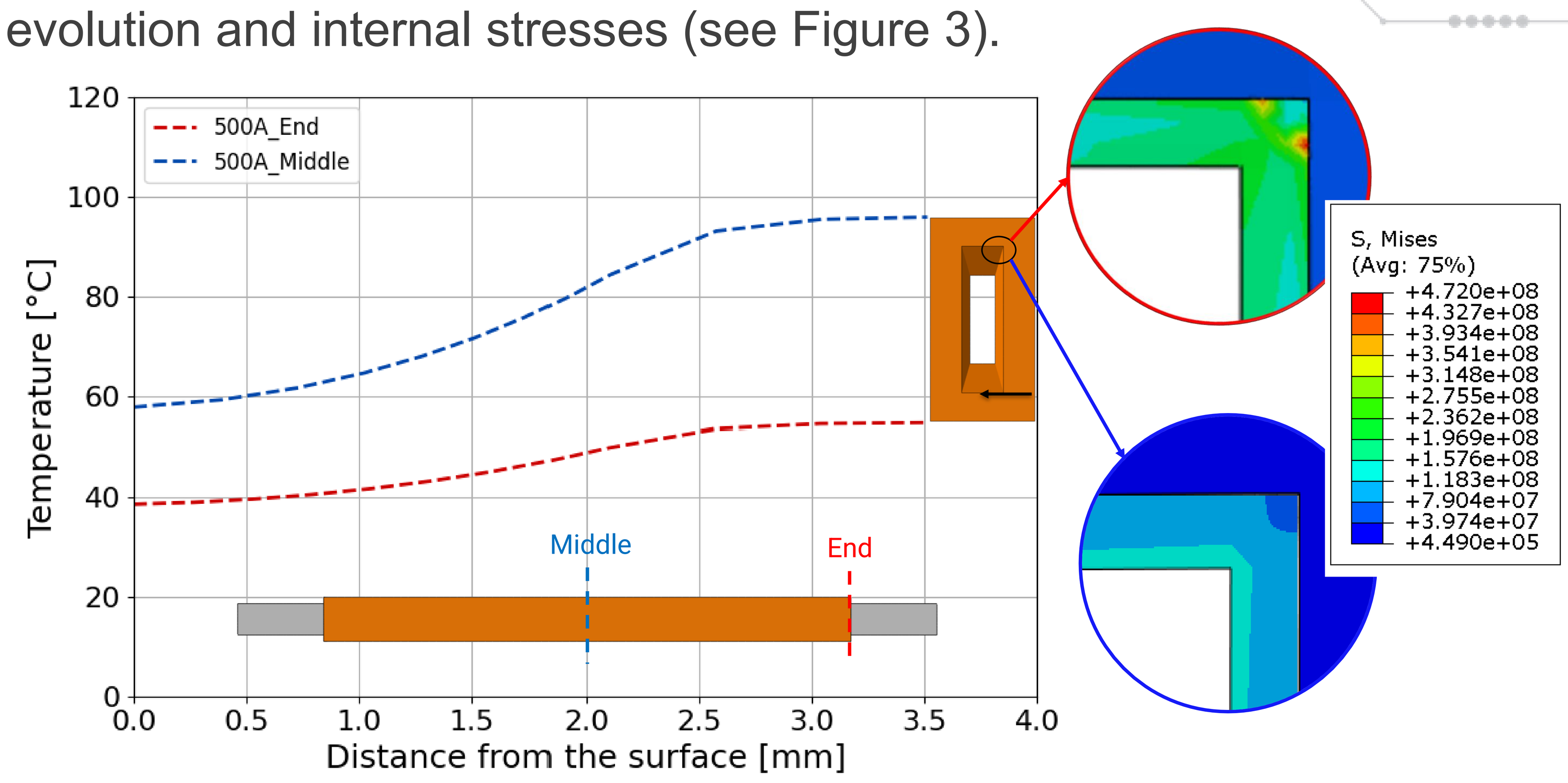

FIGURE 3. Temperature profiles and stress distribution (von Mises), from the Z-oriented cross-sections of the PP insulator —end and middle of the isolated area.

EXPERIMENTAL RESULTS

Tests focused on 500 A current cycles, evaluated via shear tests (see Figure 4). The model showed that when the visible busbar surface reaches 63 °C, the insulated core hits the 120 °C limit.

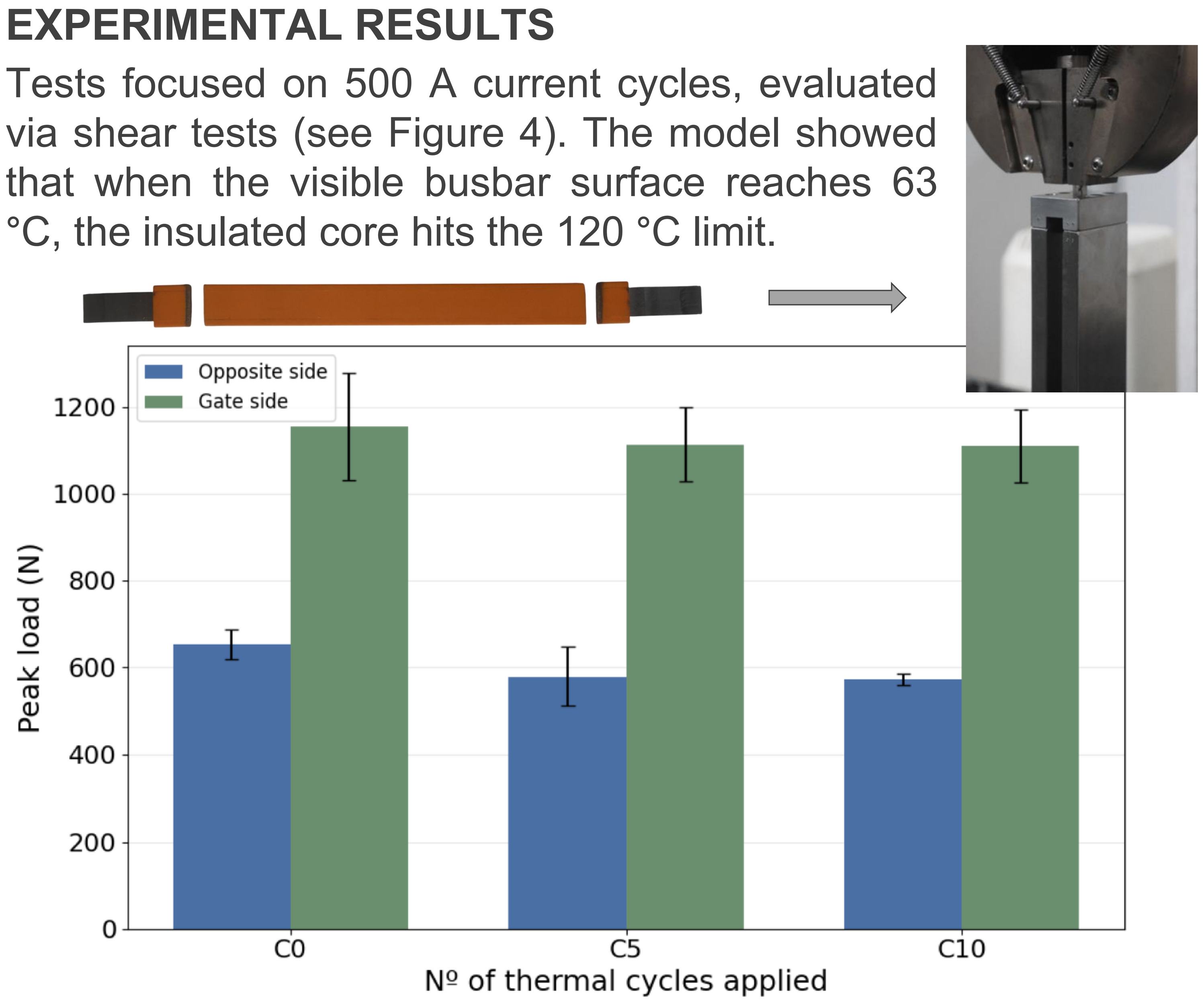

FIGURE 4. Peak pull-out loads measured on the gate and opposite sides of the PP-coated busbars after 0, 5, and 10 thermal cycles.

CONCLUSION

- PPC slowed heat penetration, keeping the outer surface cooler;
- PPC showed a slight reduction in peak load after a few thermal cycles, suggesting an early degradation trend;
- Differences in thermal expansion between aluminum and PP created critical stress zones near the insulation interface;
- Post-cycling shear tests showed a 7–12% reduction in interfacial strength after only 10 cycles;
- The combined experimental-numerical approach effectively evaluates busbar reliability.

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