Experimental and cohesive zone modelling of highly ductile adhesive joints under extreme thermal and dynamic conditions

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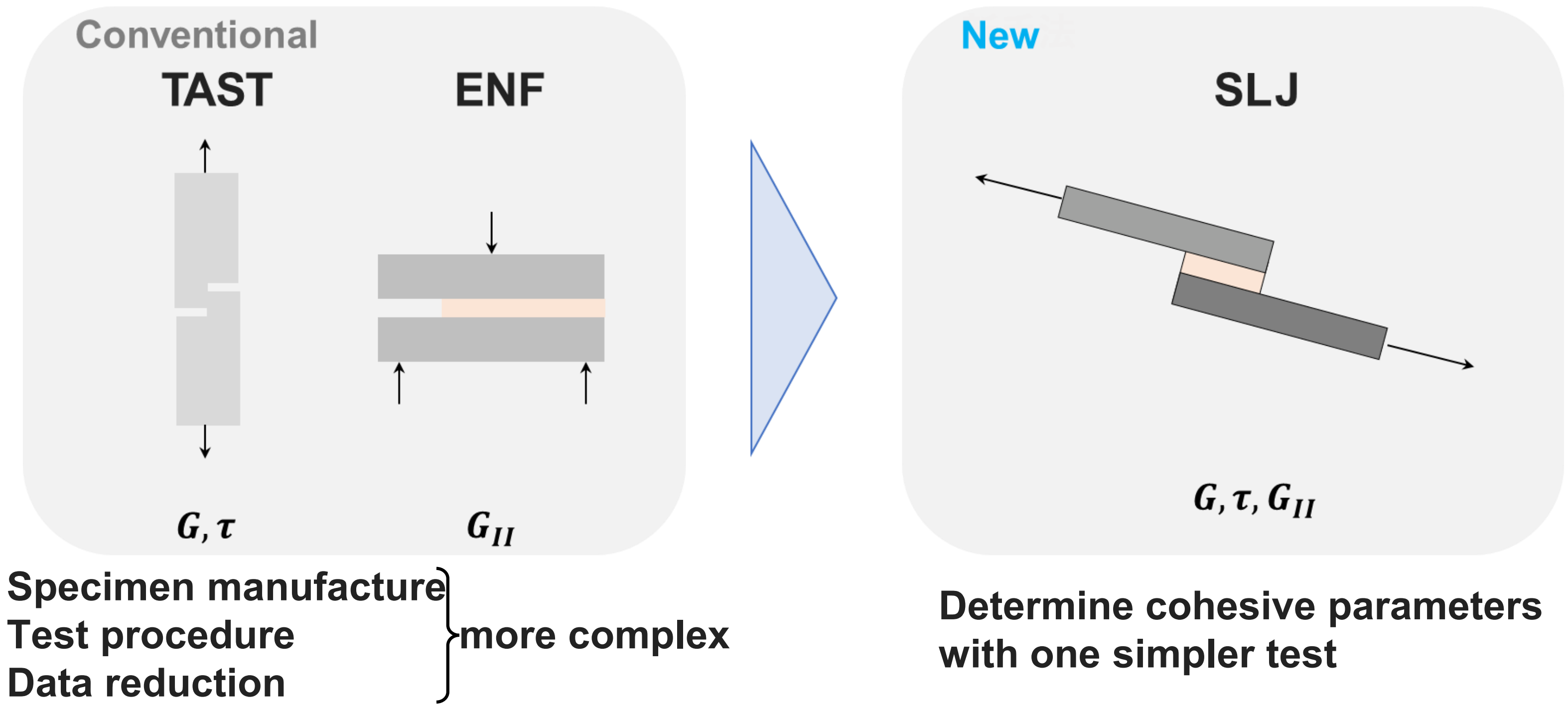
INTRODUCTION

Highly ductile polyurethane (PU) adhesives are increasingly used in automotive structures, including battery enclosures, because they improve crashworthiness and enable lightweight design. However, their mechanical performance strongly depends on temperature and loading rate due to their viscoelastic nature [1], making reliable joint design under extreme service conditions challenging. This study investigates the combined thermal and dynamic effects on single lap joints (SLJs) and proposes a simplified cohesive zone modelling (CZM) approach for efficient industrial application.

METHODS

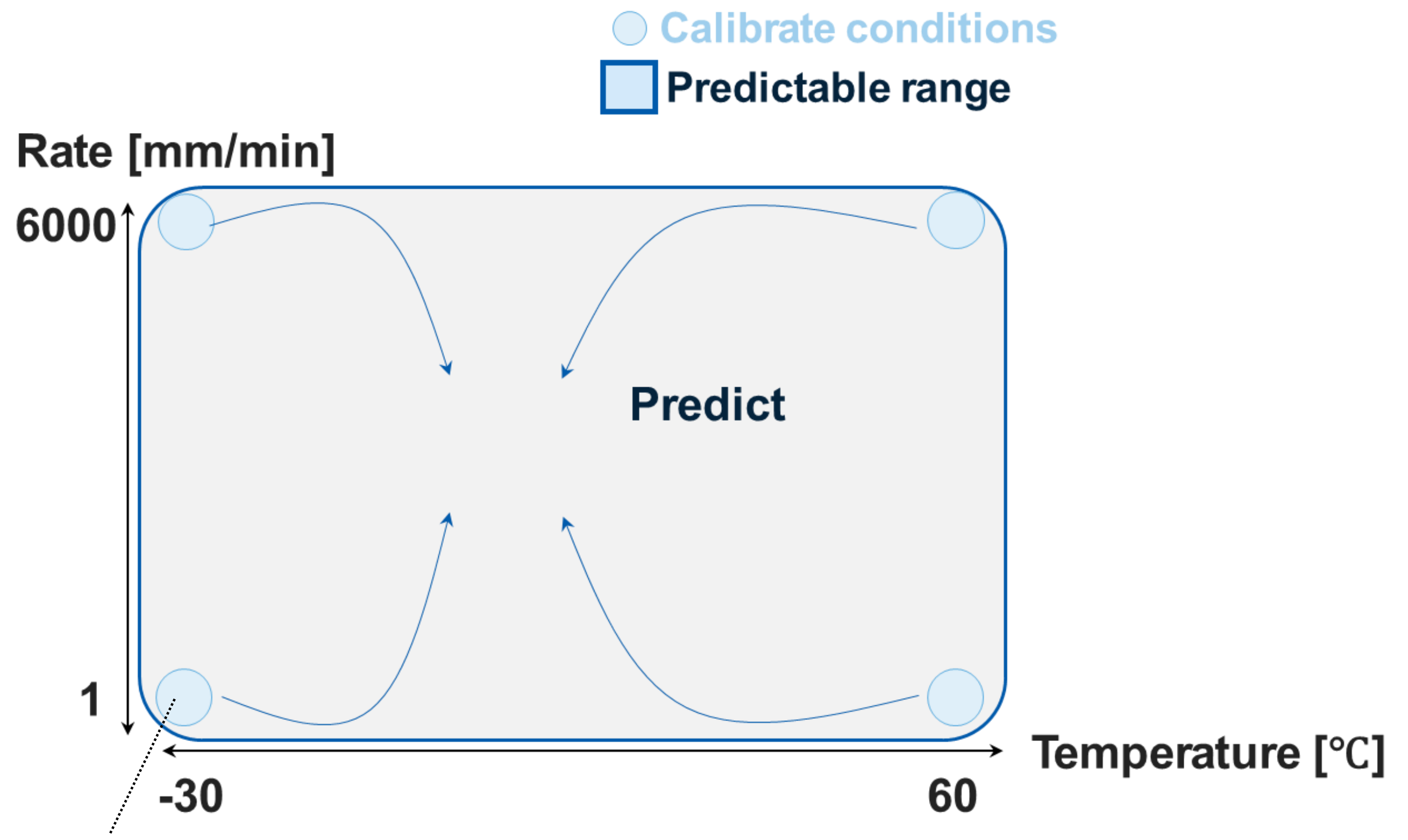
SLJ tests using high strength steel and a two-component flexible polyurethane adhesive were conducted at −30 °C, 23 °C, and 60 °C with loading rates of 1, 200, and 6000 mm/min. To enable efficient industrial application, a simplified CZM with a triangular traction-separation law was developed. Cohesive parameters were identified by matching SLJ experimental and simulation load-displacement curves, avoiding conventional Mode II fracture tests (Figure 1). To further reduce experimental effort, only extreme conditions were experimentally calibrated, while intermediate conditions were estimated by interpolation (Figure 2).



Specimen manufacture
Test procedure
Data reduction
} more complex

Determine cohesive parameters with one simpler test

Figure 1 – Proposed method for identifying cohesive parameters (mode II).



Ⅰ. Calibrate CZM parameters for extreme conditions
Ⅱ. Interpolate CZM parameters and perform simulation for intermediate conditions

Figure 2 – Schematic illustration of the calibration framework across temperature and loading rate.

RESULTS

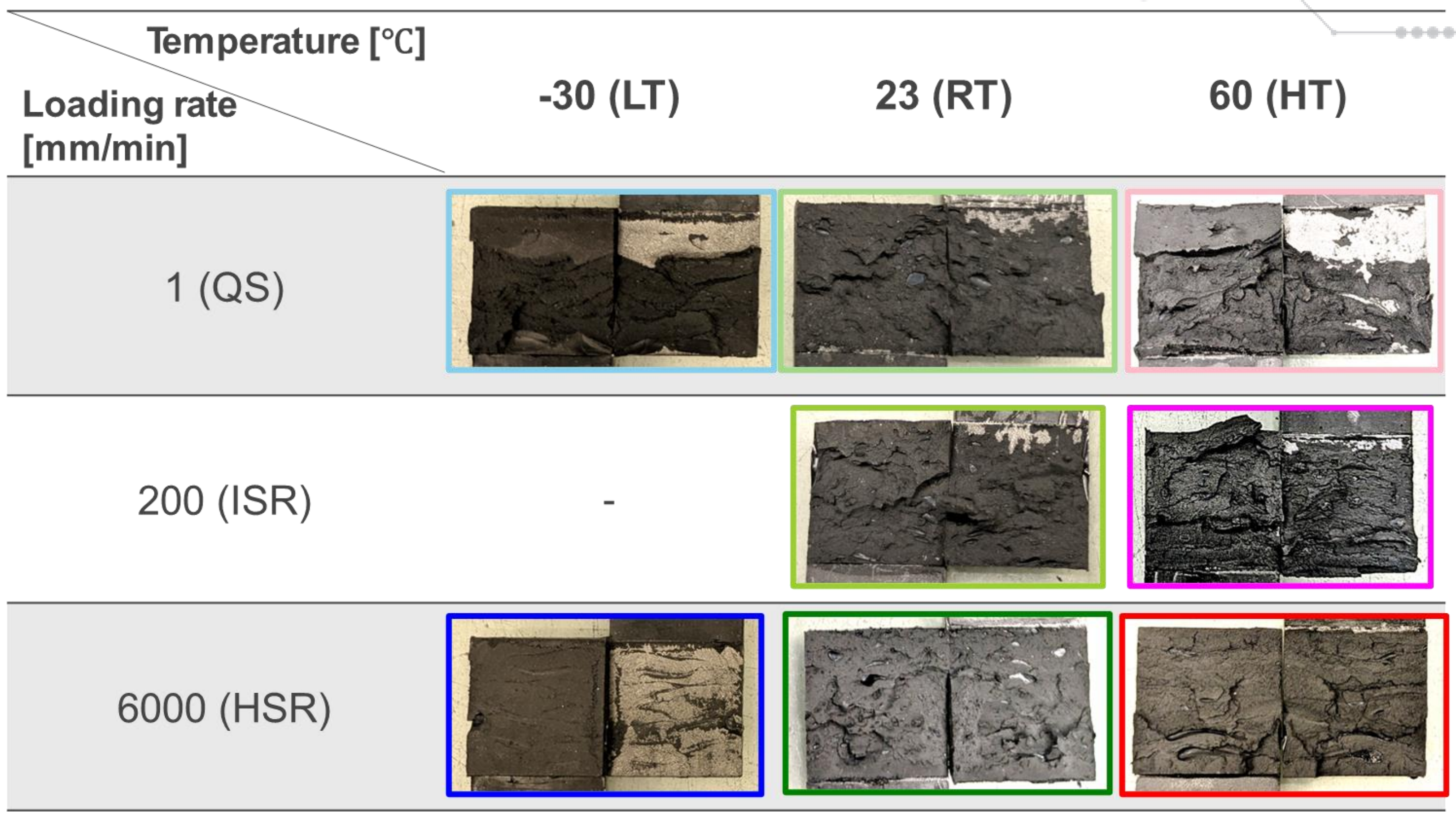


Figure 3 – Fracture surfaces under different test conditions, showing predominatnly cohesive failure.

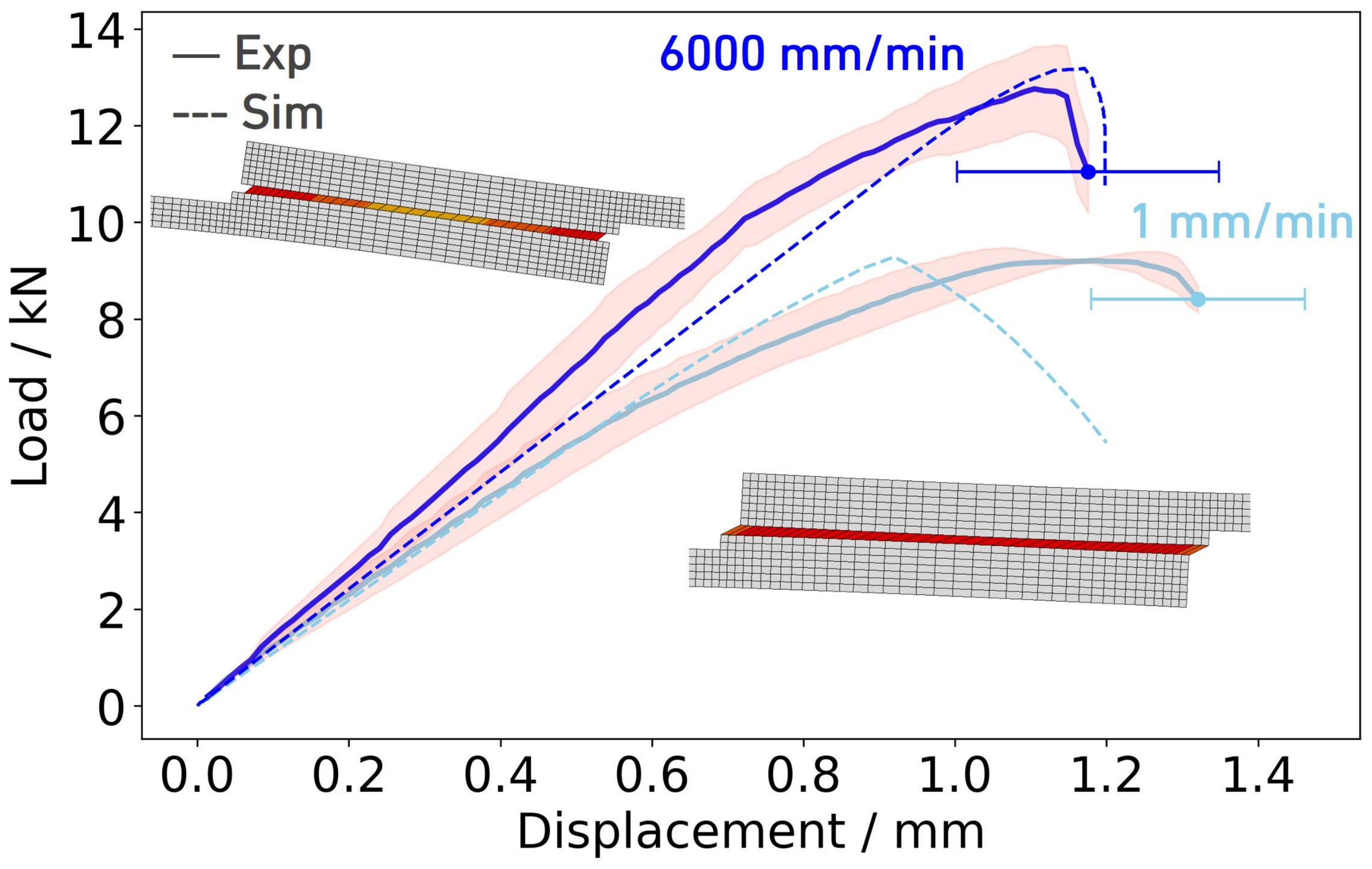


Figure 4 – Comparison of experimental and simulated load–displacement curves for the calibration condition (-30 °C).

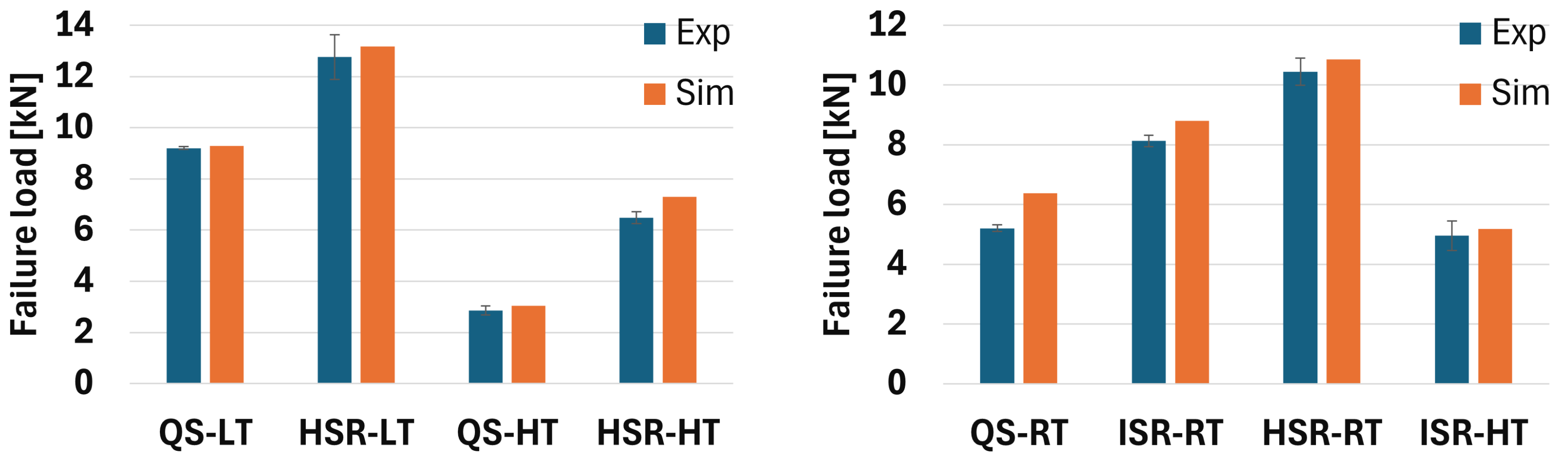


Figure 5 – Comparison of experimental and simulated failure loads for the calibration (left) and validation (right) conditions.

CONCLUSIONS

- LSS increased with decreasing temperature and increasing loading rate.
- The proposed interpolation scheme accurately predicted failure loads within 10 % error under predominantly cohesive failure conditions.

REFERENCES

[1] M. Ribas, A. Akhavan-Safar, P. Adam-Cottard, R.J.C. Carbas, E.A.S. Marques, S. Wenig, L.F.M. da Silva, Theoretical and Applied Fracture Mechanics, 130, 104274 (2024).

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