Damage metrics for void detection in adhesive joints using electromechanical impedance measurements

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Introduction

Adhesive joining is being adopted in vehicular structures to achieve energy efficiency and mechanical performance [1]. Non-Destructive Tests (NDT) are used for damage detection in structural adhesive joints, but current NDT tools are unreliable in detecting all damage sources. Structural Health Monitoring (SHM) aims to overcome NDT by continuously monitoring a structure for damage. One such SHM method is the Electromechanical Impedance Spectroscopy (EMIS), where piezoelectric (PZT) elements are used due to their coupled electromechanical behaviour.

Algorithms can process the electric impedance spectra to detect damage in a structure. One approach is to use damage metrics, thus correlating the spectra of a pristine adhesive joint and the measured spectra from joints that may or may not be damaged [2]. A commonly used damage metric is the Root Mean Square Deviation, *RMSD*, which is defined as

$$RMSD = \sum_{i=\omega_i}^{\omega_f} \sqrt{\frac{\left(Re(Z_i) - Re(Z_i^0)\right)^2}{Re(Z_i^0)^2}}$$

where $Re(Z_i^0)$ and $Re(Z_i)$ are the real part of the electrical impedance from the pristine structure and from the evaluated structure, respectively.

Experimental details

1. Materials

Structural Adhesive – Nagase T-836/R–810

- Type of adhesive: One-part crash-resistant modified epoxy adhesive
- Cure Cycle: 3 hours at 160°C

Adherend – Aluminium Alloy 6082

Sensor Adhesive – Plexus MA 422

- Type of adhesive: Two-part methacrylate adhesive
- Cure Cycle: 24 hours at room temperature

Piezoelectric Sensor – PIC 255 piezoceramic (PRYY + 1119 model)

- Curie Temperature: 350°C

2. Single Lap Joint (SLJ) Geometry

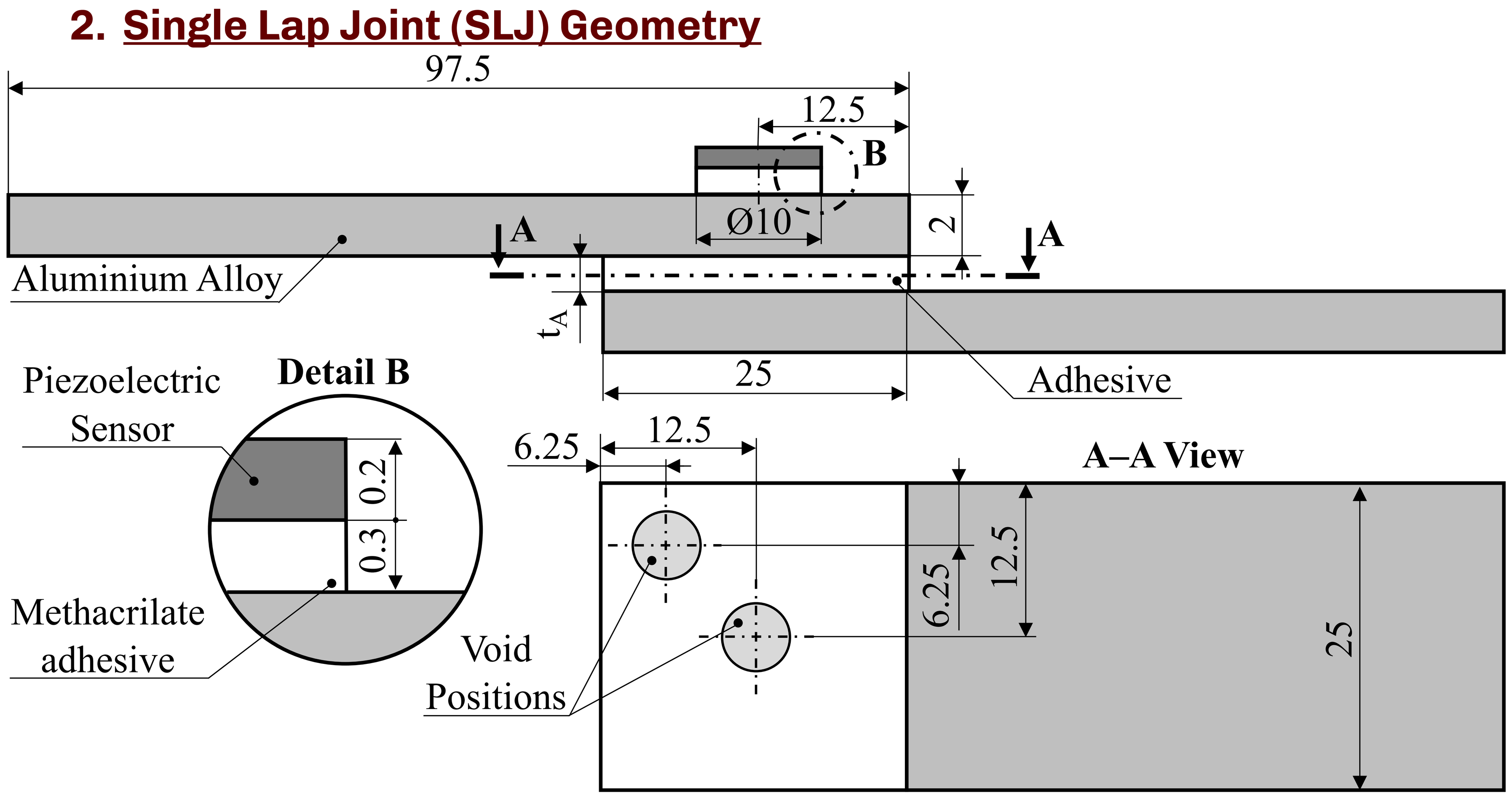

Figure 1 – SLJ dimensions with possible void placement.

3. Measurement procedure

- **Measurement equipment:** Hioki 3570 impedance analyser

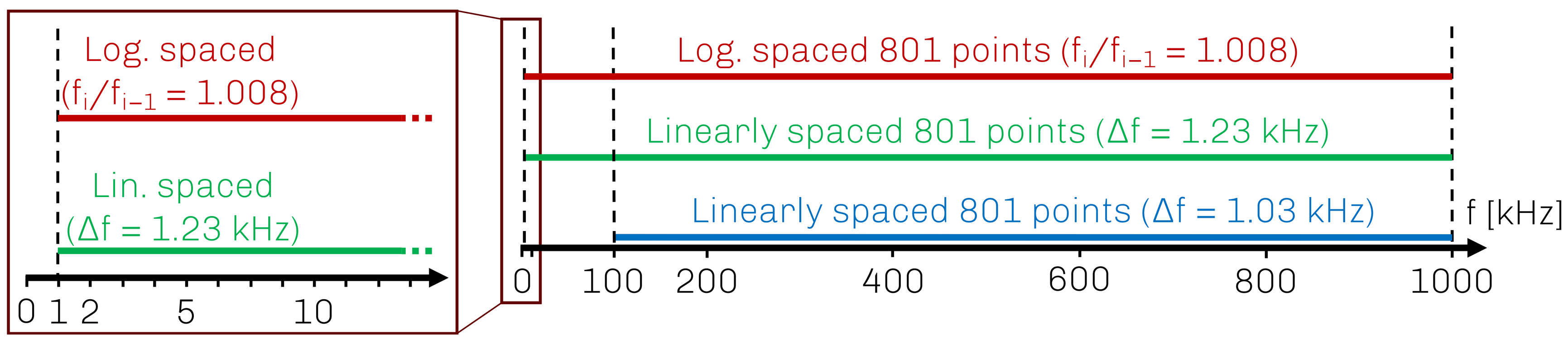

Figure 2 – Measurement conditions.

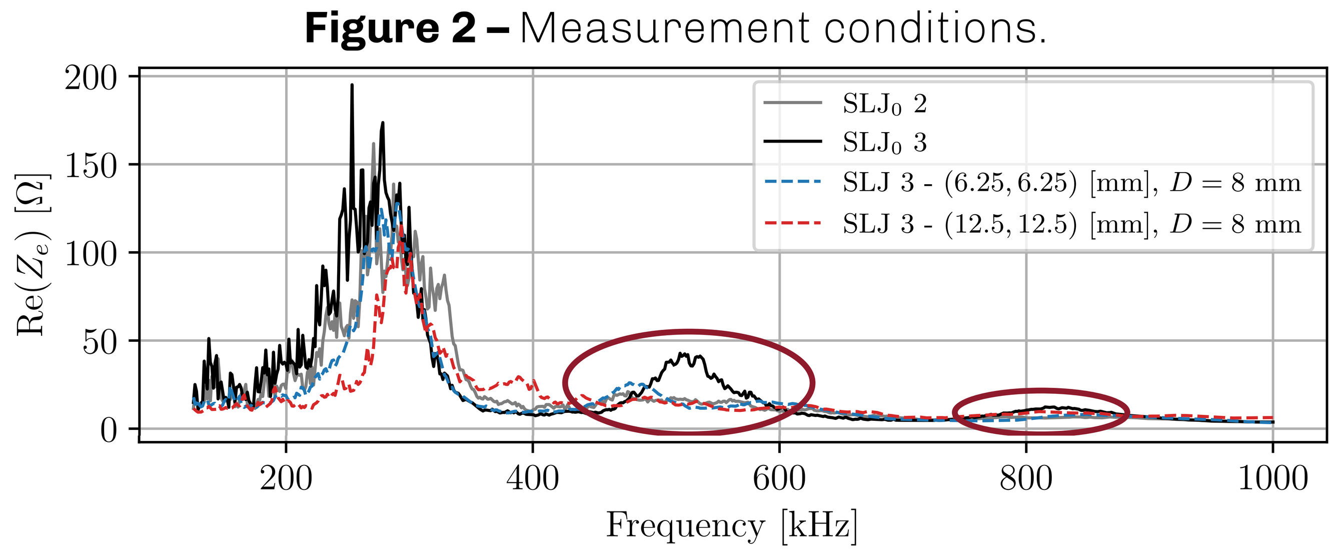

Figure 3 – Spectra of damaged and pristine SLJs.

Experimental results

- Linearly spaced 801 points – 1kHz to 1MHz

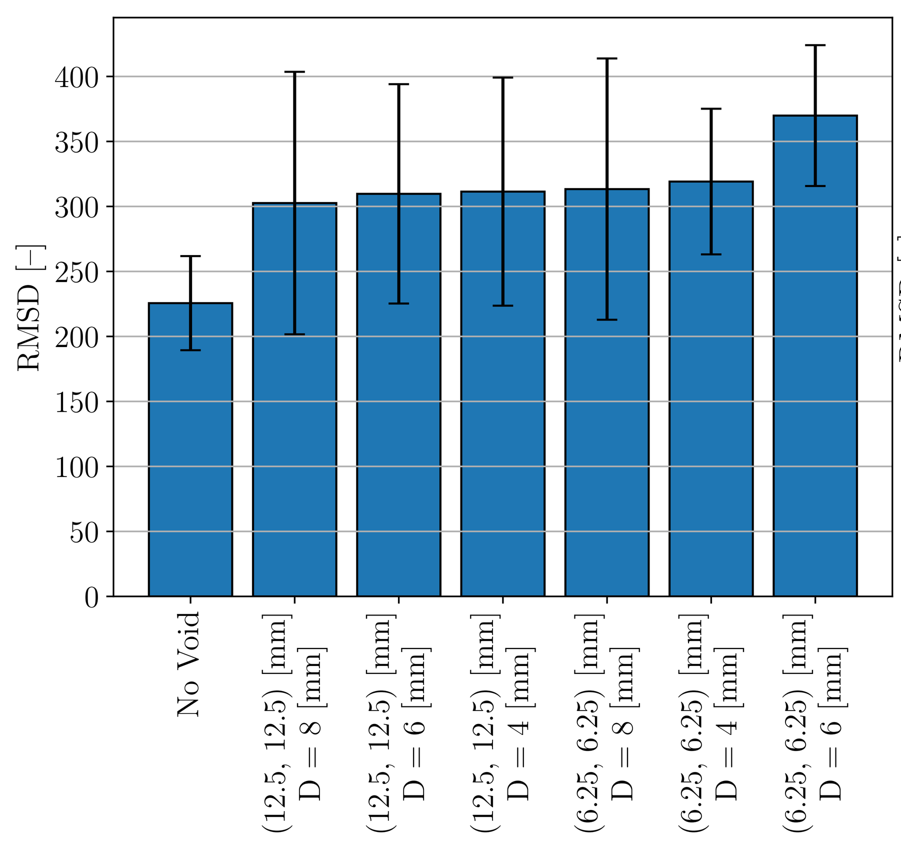

Figure 4 – Mean of all metrics.

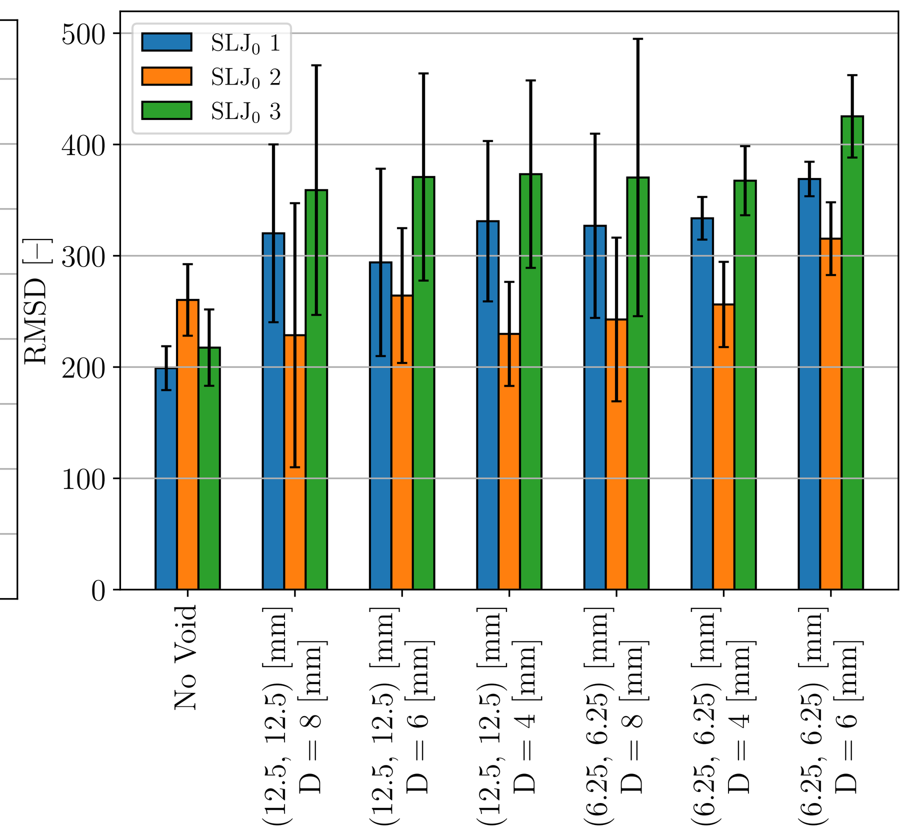

Figure 5 – Mean per reference SLJ.

- Logarithmically spaced 801 points – 1kHz to 1MHz

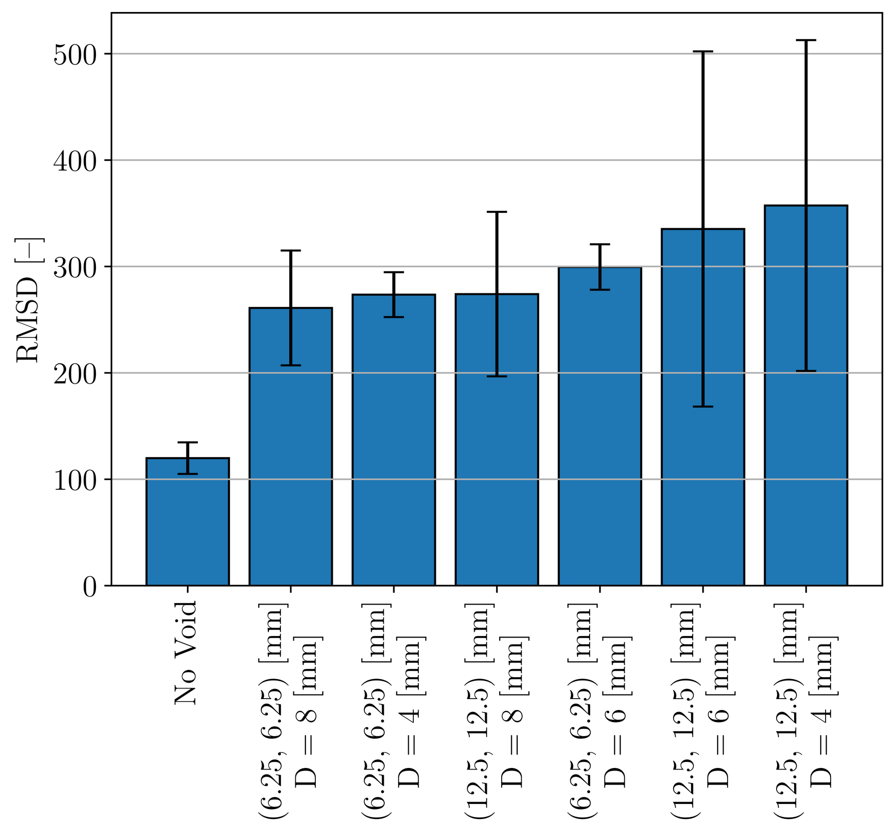

Figure 6 – Mean of all metrics.

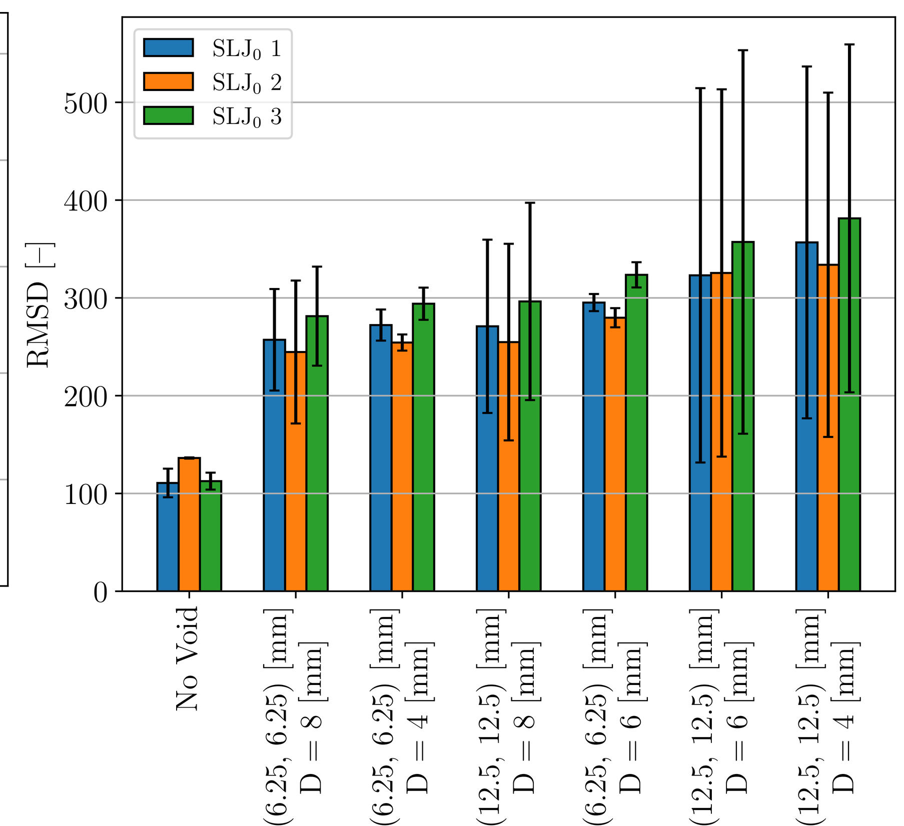

Figure 7 – Mean per reference SLJ.

- Lineally spaced 801 points – 100kHz to 1MHz

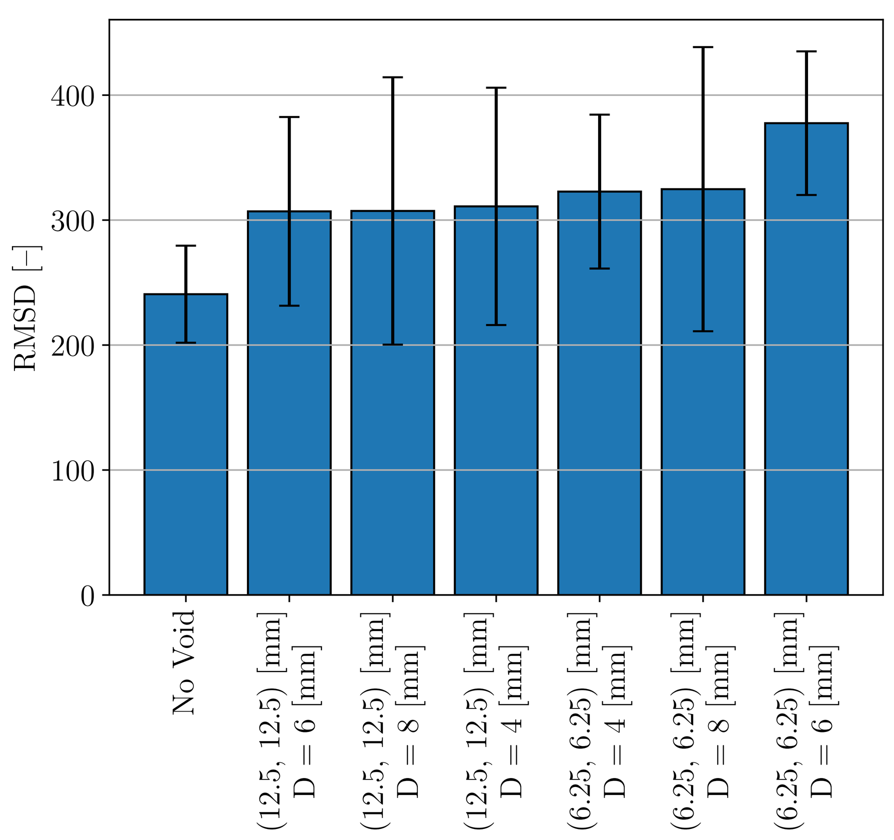

Figure 8 – Mean of all metrics.

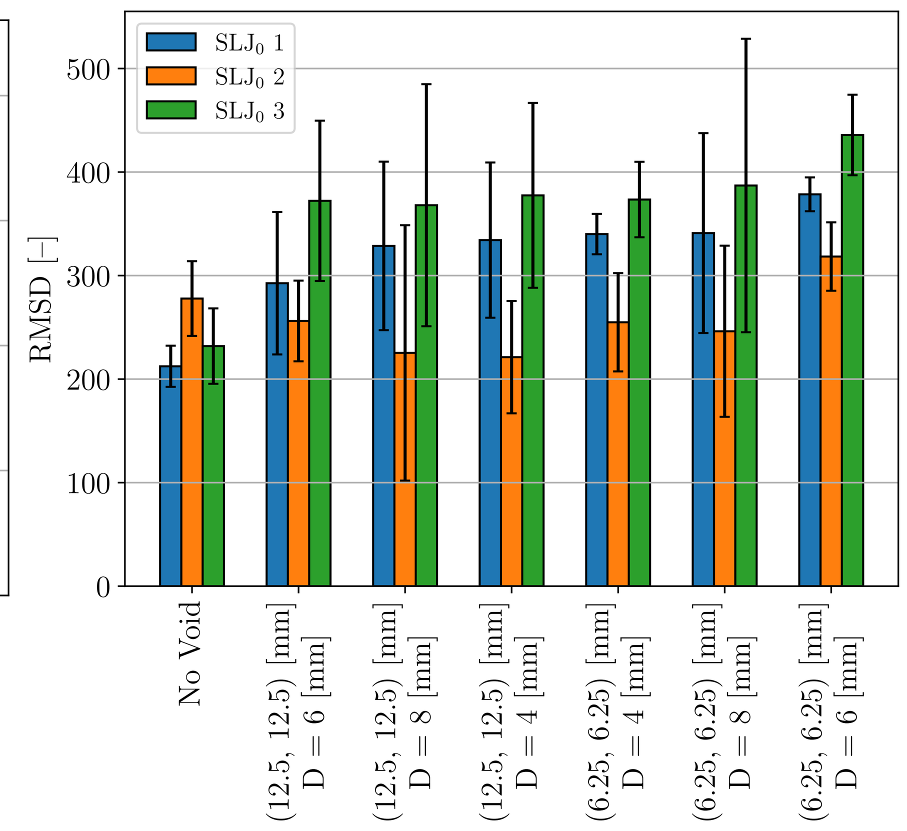

Figure 9 – Mean per reference SLJ.

References

[1] da Silva, L.F.M, Öchsner, A. and Adams, R.D. Handbook of adhesion technology. 2nd edition. New York: Springer, 2018.

[2] Tenreiro, A.F.G., Lopes, A.M., and da Silva, L.F., "A review of structural health monitoring of bonded structures using electromechanical impedance spectroscopy," Structural Health Monitoring, p. 147592172199341, 2021.

Acknowledgements

The authors acknowledge the funding FCT through the grant 2021.07689.BD.

Conclusions

- RMSD metric calculated from logarithmically sampled impedance spectra better distinguish damaged and pristine cases, since each order of magnitude is given equal importance.
- RMSD metrics from linearly spaced measurements (reference: SLJ_0 2) do not distinguish damaged and pristine cases, because of weighted representation of higher frequencies, and because of variability in measurements.