Void detection in bonded joints with computed damage metrics from Electromechanical impedance spectra

A. F. G. Tenreiro (INEGI, Porto, Portugal), A. M. Lopes, L.F.M. da Silva

ADVANCED JOINING PROCESSES UNIT

Introduction

Adhesives are adopted in component joining of vehicular structures, improving energetic and mechanical performance [1]. Non-Destructive Tests (NDT) are used for damage detection in adhesive joints, but they are unreliable in this task. Structural Health Monitoring (SHM) methods aim to overcome NDT by performing continuous monitoring, such as the Electromechanical Impedance Spectroscopy (EMIS), where piezoelectric elements (PZT) are used for their coupled electromechanical behaviour: the PZT electrical impedance spectra yield information on the structural integrity, such as described by this simplified mathematical model.

$$Z_e(j\omega) = \left[j\omega \frac{w_P l_P}{h_P} \left(\underbrace{\bar{\varepsilon}_{33}^T}_{\text{Passive component}} - \underbrace{\frac{Z_{m,s}(j\omega)}{Z_{m,s}(j\omega) + Z_{m,P}(j\omega)} d_{31} \bar{Y}_{11}^E}_{\text{Active component}} \right) \right]^{-1}$$

The passive component is insentivite to the structure, while the active component of Z_e is related to the mechanical properties of the structure. Algorithms can process the electric impedance spectra to detect damage. One approach is to use damage metrics, such as the Root Mean Square Deviation, *RMSD*, that correlate the spectra of a pristine joint and of a joint that might be damaged [2].

Damage metrics normally use the real component of the measured impedance, Re(Z_e), given that it is sensitive to damage. However, by removing the passive component, one may have improvements in both real and imaginary parts, Re(Z_e) and Im(Z_e), respectively [3].

Experimental details

Structural Adhesive – Nagase T-836/R-810 (One-part crash-resistant adhesive)
Adherend– Aluminium Alloy 6082
Sensor Adhesive – Plexus MA 422 (Two-part methacrylate adhesive)
Piezoelectric Sensor – PIC 255 piezoceramic

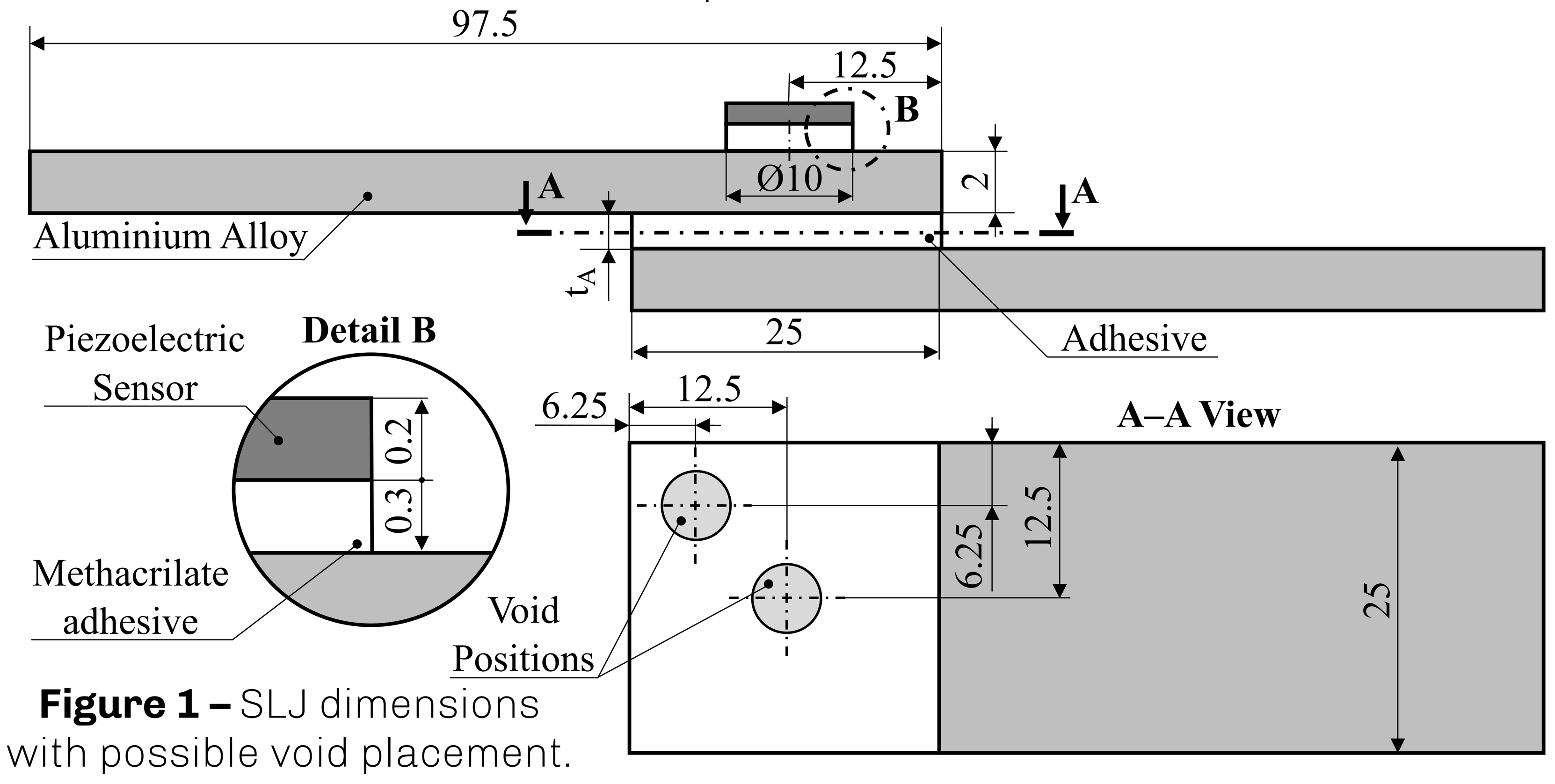

Figure 1 – SLJ dimensions with possible void placement.

Damage Metrics

Root Mean Square Deviation, RMSD

$$RMSD = \sqrt{\frac{\sum_{i=\omega_i}^{\omega_f} (\mathrm{Re}(Z_e) - \mathrm{Re}(Z_e^0))^2}{\sum_{i=\omega_i}^{\omega_f} \mathrm{Re}(Z_e^0)^2}}$$

- ω_i and ω_f are, respectively, the initial and final frequency of the impedance spectra;
- $\mathrm{Re}(Z_e)$ and $\mathrm{Re}(Z_e^0)$ are the real component of the measured electric impedances from the joint under evaluation and from the reference joint, respectively.

Complex Root Mean Square Deviation, cRMSD

$$cRMSD = \sqrt{\frac{\sum_{i=\omega_i}^{\omega_f} (\mathrm{Re}(Z_{e,A}) - \mathrm{Re}(Z_{e,A}^0))^2}{\sum_{i=\omega_i}^{\omega_f} \mathrm{Re}(Z_{e,A}^0)^2}} + \sqrt{\frac{\sum_{i=\omega_i}^{\omega_f} (\mathrm{Im}(Z_{e,A}) - \mathrm{Im}(Z_{e,A}^0))^2}{\sum_{i=\omega_i}^{\omega_f} \mathrm{Im}(Z_{e,A}^0)^2}}$$

- $\mathrm{Re}(Z_{e,A})$ and $\mathrm{Re}(Z_{e,A}^0)$ are the real components of the active electric impedances from the joint under evaluation and from the reference joint, respectively.
- $\mathrm{Im}(Z_{e,A})$ and $\mathrm{Im}(Z_{e,A}^0)$ are the imaginary components of the active electric impedances from the joint under evaluation and from the reference joint, respectively.

Experimental Results

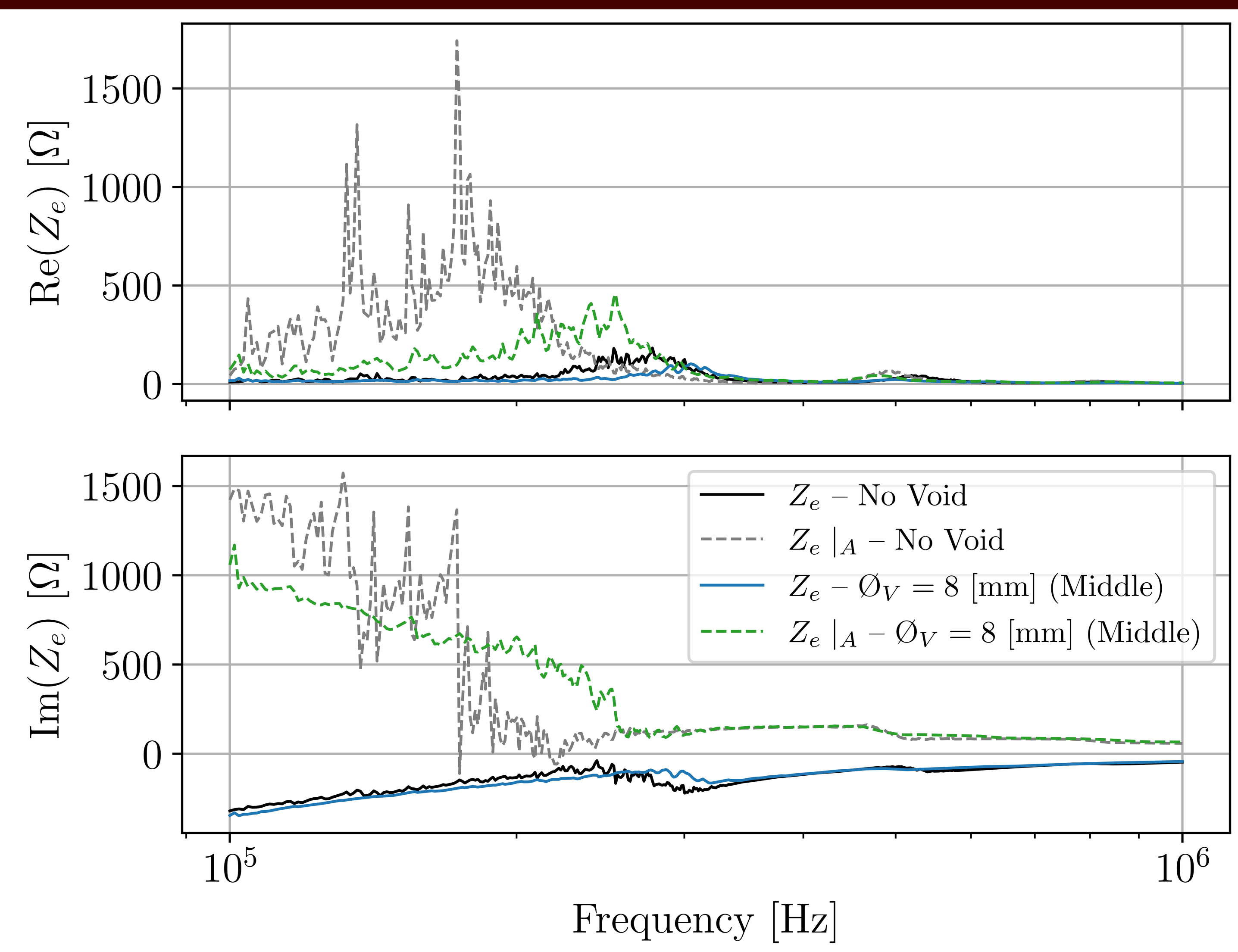

Figure 2 – Measured and Active Impedances.

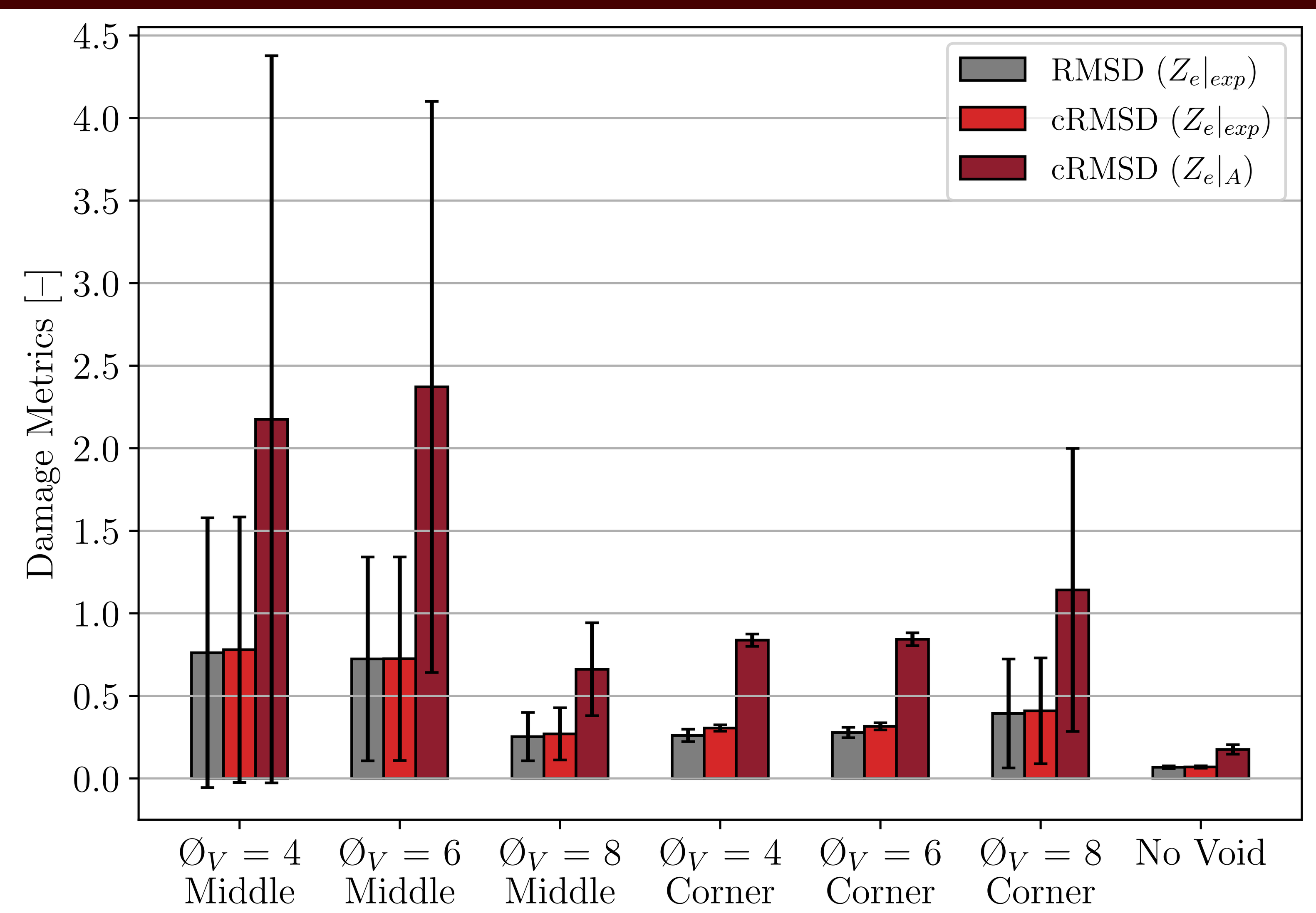

Figure 3 – Metric Results (void diameter in mm).

References

[1] da Silva, L.F.M, Öchsner, A., Adams, R.D. Handbook of adhesion technology. 2nd edition. New York: Springer, 2018.
[2] A. F. G. Tenreiro, A. M. Lopes, L. F. da Silva, "A review of structural health monitoring of bonded structures using electromechanical impedance spectroscopy," Structural Health Monitoring, 21(2), pp. 228–249, 2022.
[3] S. Bhalla, A. Surendra, C. K. Soh, "Influence of structure-actuator interactions and temperature on piezoelectric mechatronic signatures for NDE," in Proc. Vol. 5062, Smart Materials, Structures, and Systems, 2002.

Acknowledgements

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

Conclusions

- Overall, traditional *RMSD* metric demonstrates good damage detectability results, but **small overlap occurs between some damaged and undamaged joints**.
- A novel cRMSD metric is proposed, but, **when using impedance measurements directly, no improvement is observed**, since the real measured impedance component, $\mathrm{Re}(Z_e)$, is sensitive to damage.
- The cRMSD presents a **significant improvement** in damage detection, **when using the active impedance part**. Furthermore, no overlap occurs between damaged and undamaged SLJs.