Exploring adhesive performance in horseshoe bonding through advanced mechanical and numerical analysis

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MODERNIZING HORSESHOEING WITH ADHESIVE BONDING

The equine sector still relies on traditional horseshoeing and thus less invasive methods are required. This study characterizes the mechanical properties of two commercial acrylic adhesives used for horseshoe applications under quasi-static conditions. Tensile, shear, and fracture properties were tested, followed by in-joint behavior analysis using single lap joints (SLJ) with both similar (Steel - St, Aluminum - Al) and dissimilar adherends. A validated numerical model was developed using cohesive zone modelling (CZM) for similar joints. This research aims to lay the groundwork for exploring alternative adhesive solutions to overcome the limitations of current methods.

ADHESIVES PROPERTIES

Both acrylic adhesives were mechanically characterized following tensile and shear (TAST) test standards: ASTM D412, ISO 11003-2, respectively. The fracture energy in mode I was determined using double cantilever beam specimens (DCB) and following ISO 25217 standards. The fracture energy in mode II was estimated according to literature values [1]*.

TABLE 1. Mechanical properties of the acrylic adhesives

PROPERTY	UNITS	ADHESIVE A	ADHESIVE B
Young's Modulus, E	MPa	572 ± 38	639 ± 68
Poisson's ratio, ν	-	0.35	0.35
Tensile failure strength, σ_f	MPa	12.5 ± 0.7	11.5 ± 0.7
Tensile failure strain, ε_f	%	85.0 ± 7.9	64.6 ± 6.0
Shear Modulus, G	MPa	211 ± 17	235 ± 63
Shear failure strength, τ_f	MPa	9.0 ± 0.2	8.8 ± 0.4
Shear failure strain, γ_f	%	61.8 ± 7.6	68.4 ± 6.9
Toughness Mode I, G_{Ic}	N/mm	1.3	1.2
Toughness Mode II, G_{IIc}	N/mm	6.0*	6.0*

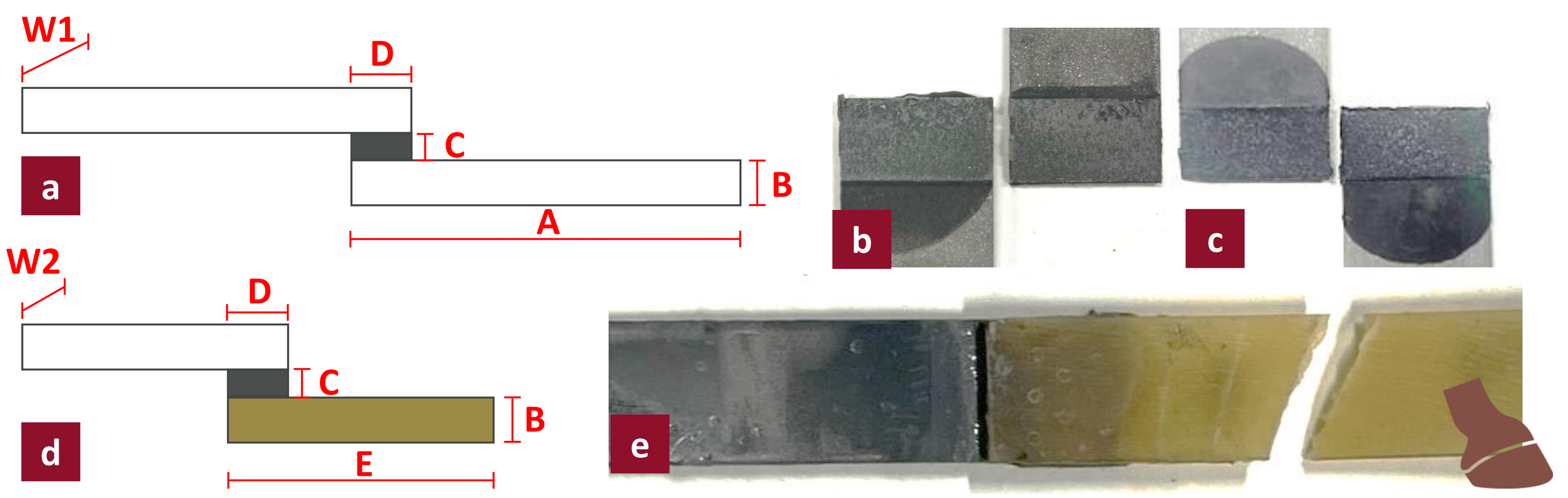

FIGURE 1 – Geometry of a) similar SLJ and failure mode of adhesive A (b) and adhesive B (c) – cohesive failure; Geometry of d) dissimilar SLJ and failure mode (e) – adhesive failure

TABLE 2 – Lap shear strength for the SLJs tested

Adherend combination	Lap shear strength [MPa]	
	Adhesive A	Adhesive B
St-St	13 ± 0.2	12.8 ± 0.3
Al-Al	13.4 ± 0.5	12.2 ± 0.2
St-HW**	30.9 ± 2.9	-

**HW – Horse hoof wall

TABLE 3 – Dimensions of SLJ geometry

Dimensions, mm			
A	107.5	W1	25
B	2	W2	12
C	0.2		
D	12.5		
E	57		

NUMERICAL MODELLING

Due to the similar mechanical properties of both adhesives, only adhesive A was selected for the numerical model. A CZM triangular shape law presented suitable results for representing the elastic behavior of the material in mode I. However, in mode II, the material exhibited an elastoplastic behavior and therefore a trapezoidal law with increasing stresses was implemented.

Damage initiation

$$\left\{\frac{\langle t_I \rangle}{t_I^0}\right\}^2 + \left\{\frac{t_{II}}{t_{II}^0}\right\}^2 = 1$$

Quadratic nominal stress

Energy criterion

$$\frac{J_I}{J_{Ic}} + \frac{J_{II}}{J_{IIc}} = 1$$

Linear law

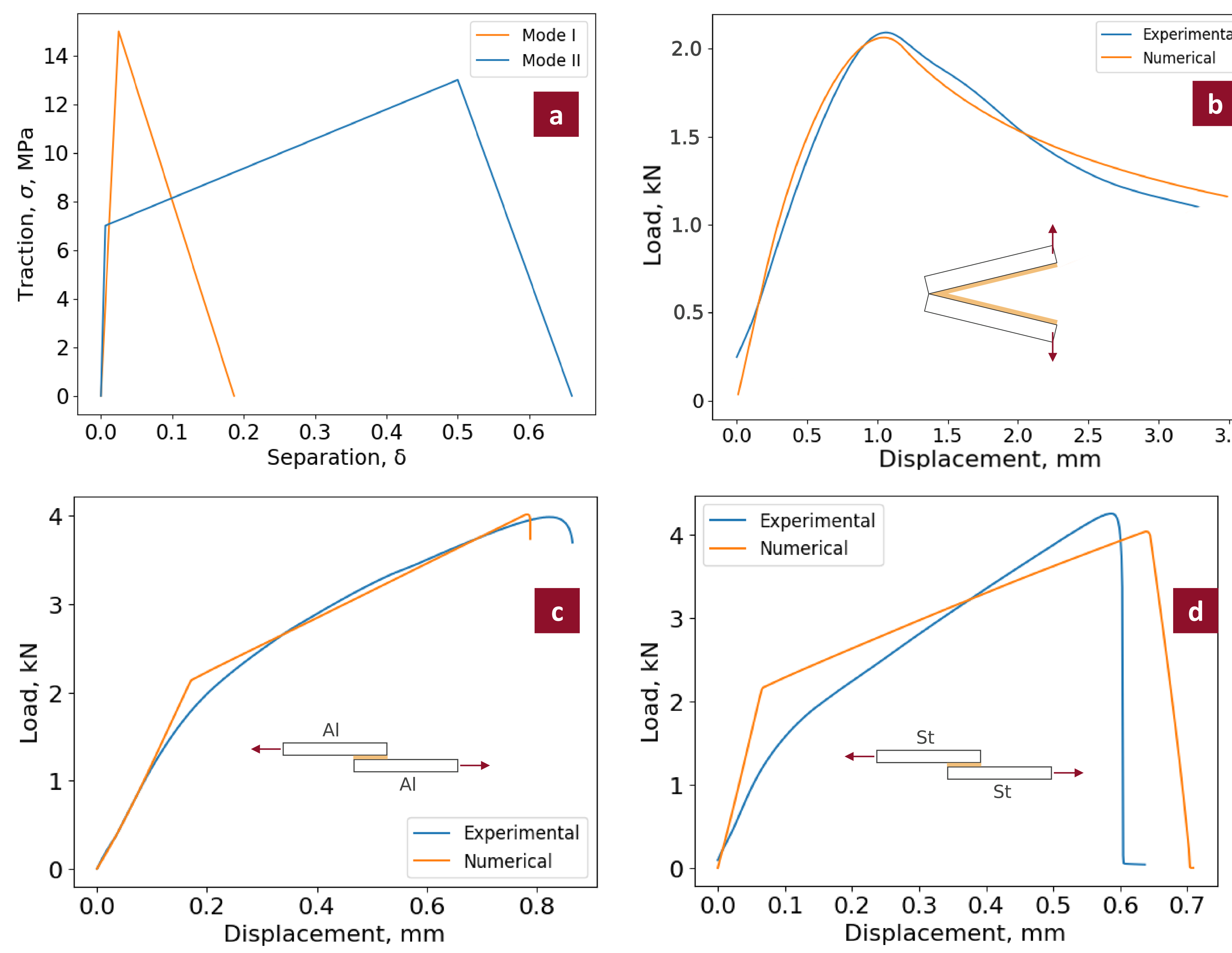

FIGURE 2 – Experimental versus numerical output data for the tested models: a) Shape of the cohesive laws; b) P-δ curve for DCB in mode I test; c) Al-Al SLJ 12.5 mm overlap; d) St-St SLJ 12.5 mm overlap

CONCLUSION

- Dissimilar SLJ were tested using St and HW specimens from the *stratum medium* region of a horse hoof, chosen for its similarity to the surface to which horseshoes are typically attached.
- All joints failed within the hoof substrate, suggesting that the commercial adhesive used is stronger than the hoof material itself.
- CZM laws used could moderately predict the in-joint behavior of the adhesive under quasi-static conditions, specially for Al-Al SLJ.

ACKNOWLEDGEMENTS

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[1] Pinto AMG, Magalhães AG, Campilho RDSG, de Moura MFSF, Baptista APM. Single-Lap Joints of Similar and Dissimilar Adherends Bonded with an Acrylic Adhesive. The Journal of Adhesion. 2009;85:351–76.

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