Investigating the combined effects of geometrical and material properties on fatigue performance and failure mechanisms of composite-steel adhesive joints

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Introduction

The durability of bonded joints remains a challenge, limiting confidence in the technology. As a multi-material structure, the performance of adhesive joints is dependent on both the adhesive and the substrate materials. Moreover, it is also significantly affected by joint geometry, since adhesive joints are almost invariably subjected to complex multiaxial stress states. Fatigue studies have mostly focused on the individual analyses of the various aspects that affect fatigue life and contrasting trends have been reported [1]. The goal of this study is to perform a comprehensive analysis of the various parameters that influence the fatigue life of bonded joints and improve the understanding of the combined influence of joint geometry, adhesive and substrate materials on fatigue performance.

Experimental methodology

To achieve this, single lap joints (SLJ) (Figure 1), with different adhesives (epoxy and methacrylate) and substrate materials (glass fibre reinforced polymers and steel) and geometric parameters were tested under fatigue. Table 1, presents a summary of the tested conditions.

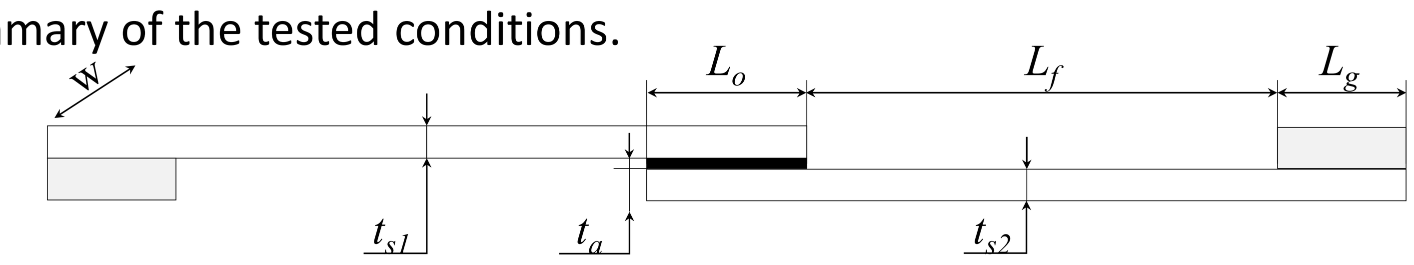


Figure 1 – Schematic representation of the tested SLJs .

Table 1 – Summary of tested conditions (dimensions in mm).

#No	Adhesive	Substrates	t_{s1}=t_{s2}	t_a	L_o	L_f	w
#1	Methacrylate	HSS | HSS	2	0.3	12.5	70	25
#2	Methacrylate	HSS | GFRP	2	0.3	12.5	70	25
#3	Methacrylate	GFRP | GFRP	2	0.3	12.5	70	25
#4	Epoxy	HSS | HSS	2	0.3	12.5	70	25
#5	Epoxy	HSS | HSS	2	0.3	50	70	25
#6	Epoxy	HSS | HSS	2	0.3	12.5	68.75	38
#7	Epoxy	HSS | HSS	2	0.3	25	62.5	38
#8	Epoxy	HSS | HSS	2	1	25	62.5	38

Experimental results

Influence of substrate material

The fatigue results for configurations with different substrate materials are shown in Figure 2. As expected, joints with similar composite substrates presented lower fatigue strength. This is due to an increase of both shear and peel stress in adhesive layer caused by the lower stiffness of the substrates. However, in the case of the dissimilar joints, an increase in performance was observed when compared to steel ones. In this case, despite being subjected to higher stresses, the increase in not very significative due to high plastic deformation of the adhesive. Moreover, this was compensated by a decrease of the stress triaxiality (due to lower restriction of the flexible substrates).

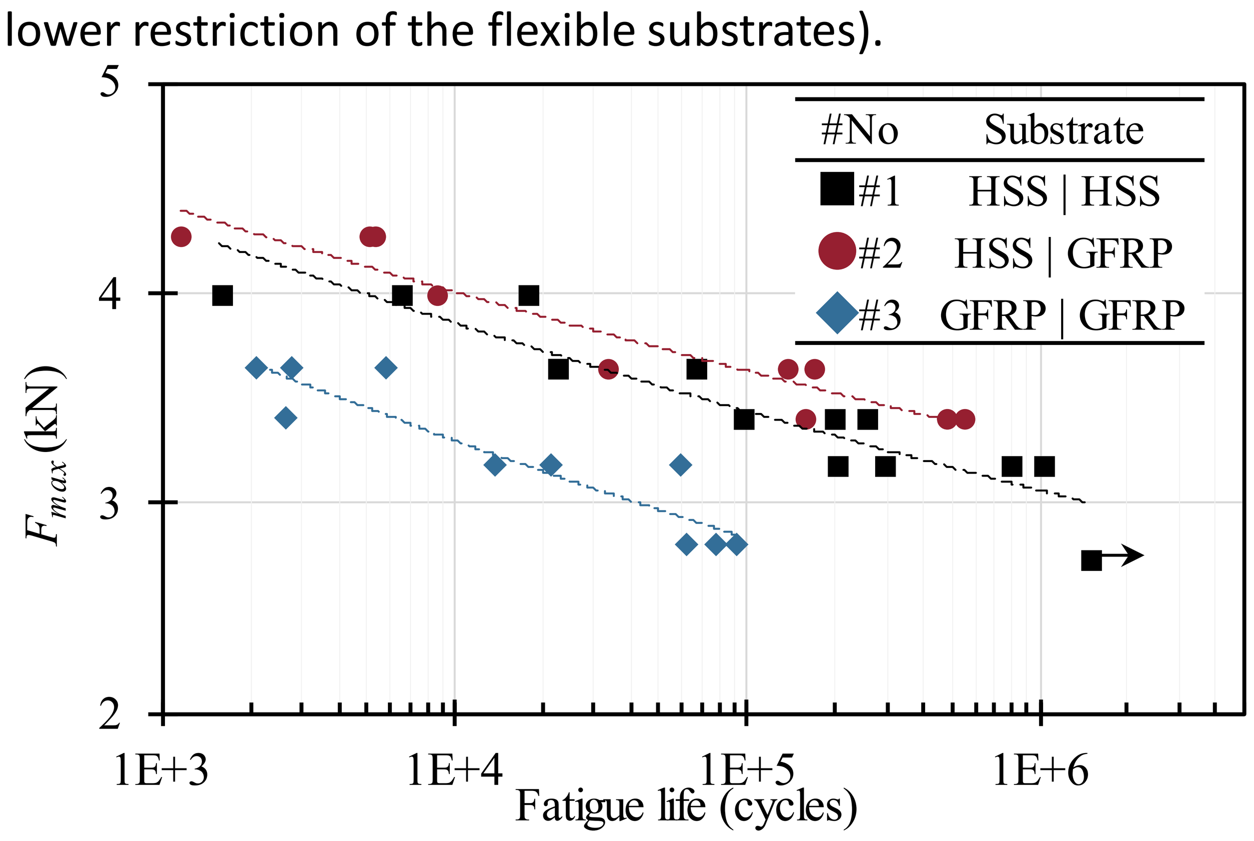


Figure 2 – Fatigue results for configurations with different substrates.

Influence of adhesive material

The fatigue results for joints bonded by different adhesives is presented in Figure 3. The epoxy adhesive presents a higher strength. However, in terms of load level (fatigue load normalized by static failure load), the methacrylate adhesive outperforms the epoxy one. The more ductile methacrylate presents a lower sensitivity to load variation which is shown by the lower slope of the S-N curve. Such behaviour is associated to the lower sensitivity to stress concentration and higher resistance to crack initiation due to its high plasticity.

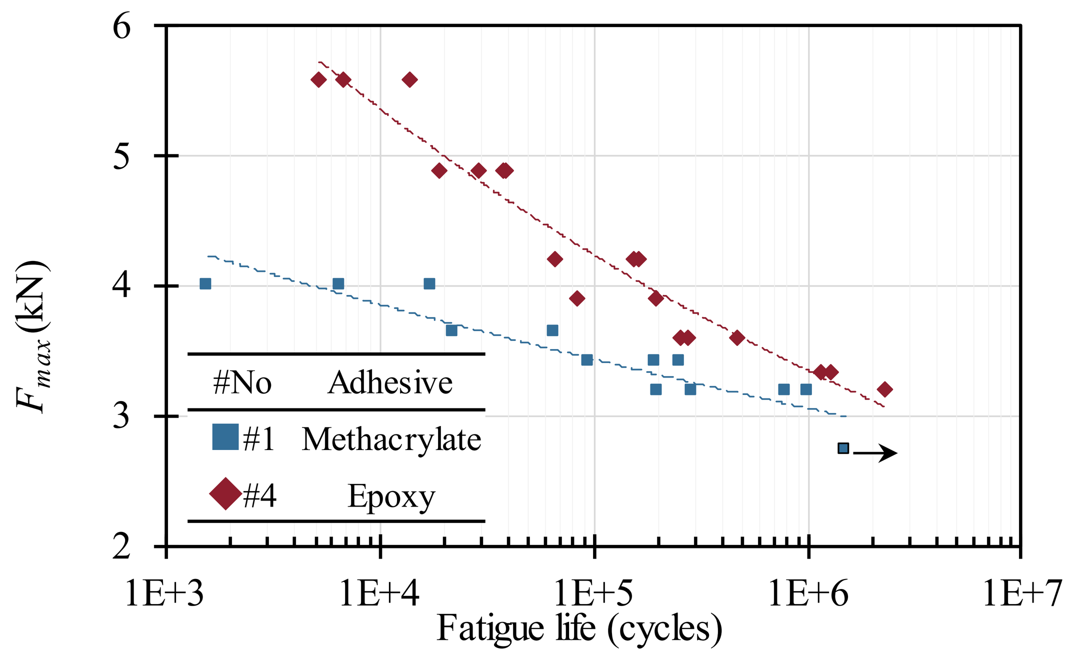


Figure 3 – Fatigue results for configurations with different adhesives.

Influence of overlap length

Figure 4 presents the fatigue results of joints with different overlap length. Despite increasing the overlap leads to an increase in fatigue life for the same load, this is not proportional to the overlap increase. Therefore, when analysed in terms of the nominal shear stress, joints with smaller overlap present a better performance.

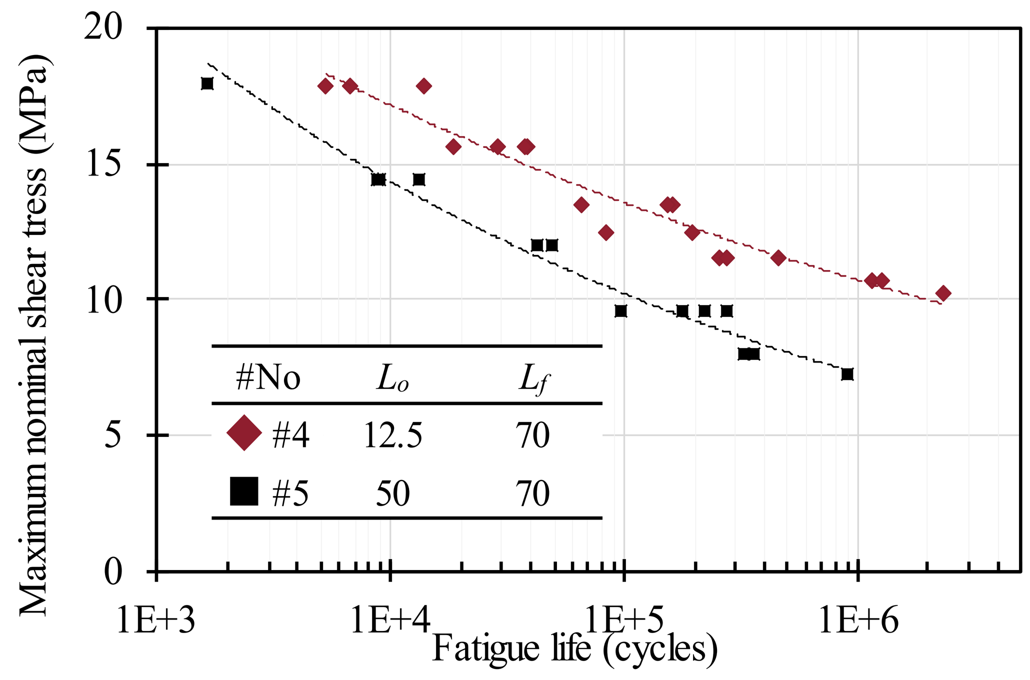
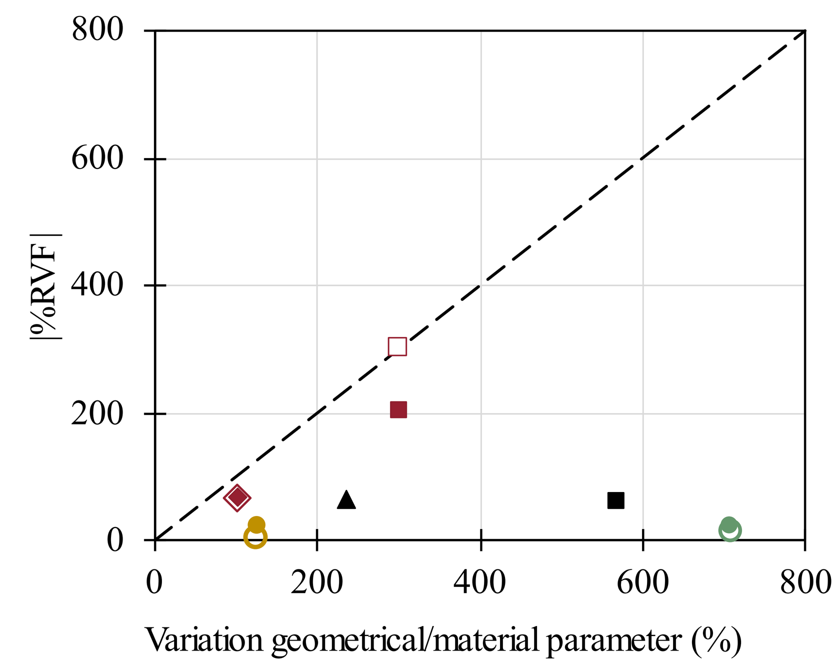


Figure 4 – Fatigue results for configurations with different overlap length.

Parametric analyses

A parametric analyses, considering the relative variation in load for the same life was performed to understand which parameters influence more the fatigue life of the joints, Figure 5.



Parameter		%RVF Fatigue	%RVF Static
L_o (mm)	12.5 → 50 (#4 & #5)	+201%	+300%
L_o (mm)	12.5 → 25 (#6 & #7)	+67%	+67%
t_a (mm)	0.3 → 1 (#7 & #8)	-62%	-
t_a (mm)	0.3 → 2 ([2] #15)	-59%	-
t_s (mm)	2 → 4.5 [19]	+20%	+2%
E_s (GPa)	26 → 210 (#1 & #3)	+21%	+13%

Figure 5 – Relative variation in load (|%RVF|) as a function of the percentage variation of each geometrical or material parameter (Fatigue life =10^5cycles)

Conclusions

From the parametric analysis it was observed that in all cases the variation of the material or geometric parameter was greater than the variation they caused in the fatigue life of the joints for a given fatigue life. Nevertheless, of the parameters analysed, the overlap length was the one that most influenced the fatigue performance. Furthermore, despite the discrepancies, static results can still provide a rough estimation of the influence of a certain parameter in fatigue strength of a joint.

References

[1]M. Abdel Wahab, “Fatigue in Adhesively Bonded Joints: A Review,” ISRN Mater. Sci., vol. 2012, 2012, doi: 10.5402/2012/746308.
[2]F. Castro Sousa, A. Akhavan-Safar, R. Goyal, and L. F. M. da Silva, “Fatigue life estimation of single lap adhesive joints using a critical distance criterion: An equivalent notch approach,” Mech. Mater., vol. 153, p. 103670, 2021

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