Parametric optimization of ultrasonic welding on thermoplastic fibre-reinforced composites by the implementation of statistical analysis of variance method (ANOVA)

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ADVANCED JOINING PROCESSES UNIT

Introduction

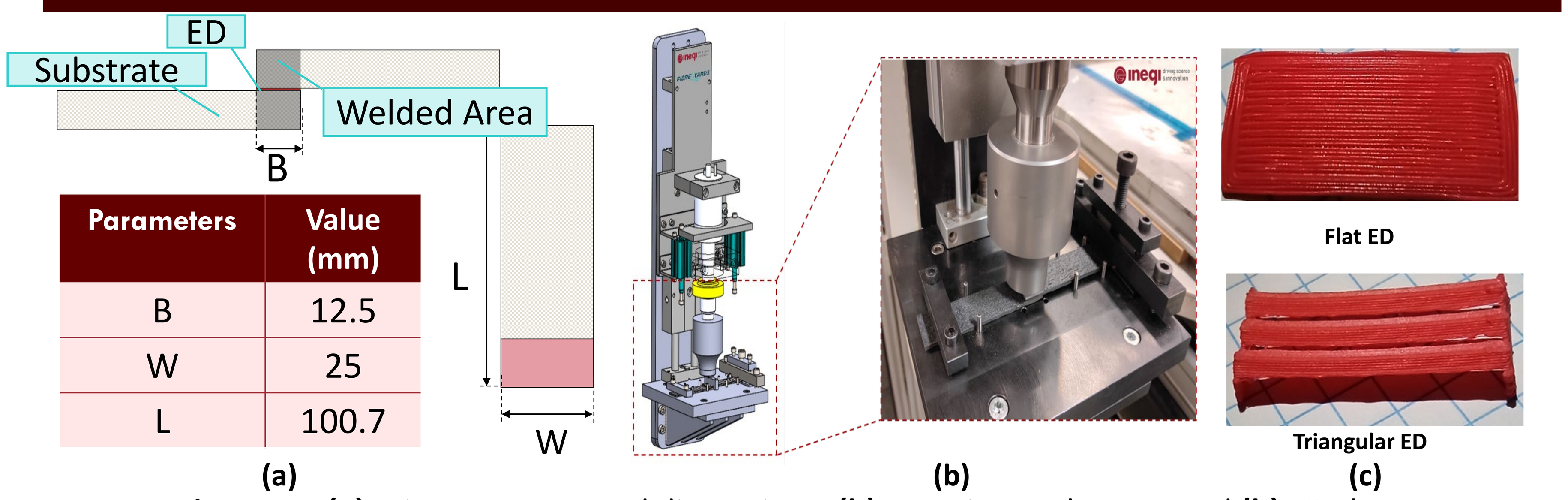
With respect to the remarkable advantages offered by thermoplastic polymers, need for high temperature and pressure for their manufacturing process limits fabrication of thermoplastic structure as a whole configuration which raise demands for using a suitable assembly process. Amongst various methods, high strength, low processing time, and high efficiency of fusion based methods, particularly ultrasonic welding (USW), suits them to be used as more practical joining technique. Frequency (*f*), amplitude (λ), welding pressure (*P*), and welding time (*t*) are four most effective process parameters on the weld quality and strength of the USW joints, especially in the case of fibre reinforced polymers (FRPs) which scatters energy absorption at the interface. In this case usually energy director (ED) is used at the interface to intensify viscoelastic heating by concentrating energy at the interface. The proceeding investigations deals with welding parametric optimization for two FRP materials by considering constant frequency (30Hz) and changing λ, *P*, *t*, and ED shapes. To this aim statistical analysis of variance method (ANOVA) had been used to obtain response surfaces (RS) as well as optimized values.

Material and Properties

Table 1 – Material and stacking sequence of the composites

	Name	Matrix	Type	Fiber	Manufacturing technology	Stacking sequence
	C2.1	Polypropylene (PP)	Thermoplastic	Carbon	Hot Stamping	$[0/45/90/-45]_{3s}$
	C2.2		Thermoplastic	Glass	3D Printing	Reinforced with short fibers

Experimental Procedure



Parameters	Value (mm)
B	12.5
W	25
L	100.7

Figure 1 – **(a)** Joint geometry and dimensions, **(b)** Experimental setup, and **(b)** ED shapes

Results and Discussion

Similar C2.2-C2.2 Joints

Table 2 – Welding Factors and Levels for 3D Printed short glass fiber reinforced PP samples

Parameter	Level 1	Level 2	Level 3
Amplitude (%) (A)	80%	90 %	100%
Pressure (Bar) (B)	6	9	12
Weld Time (Seconds) (C)	1	1.5	2

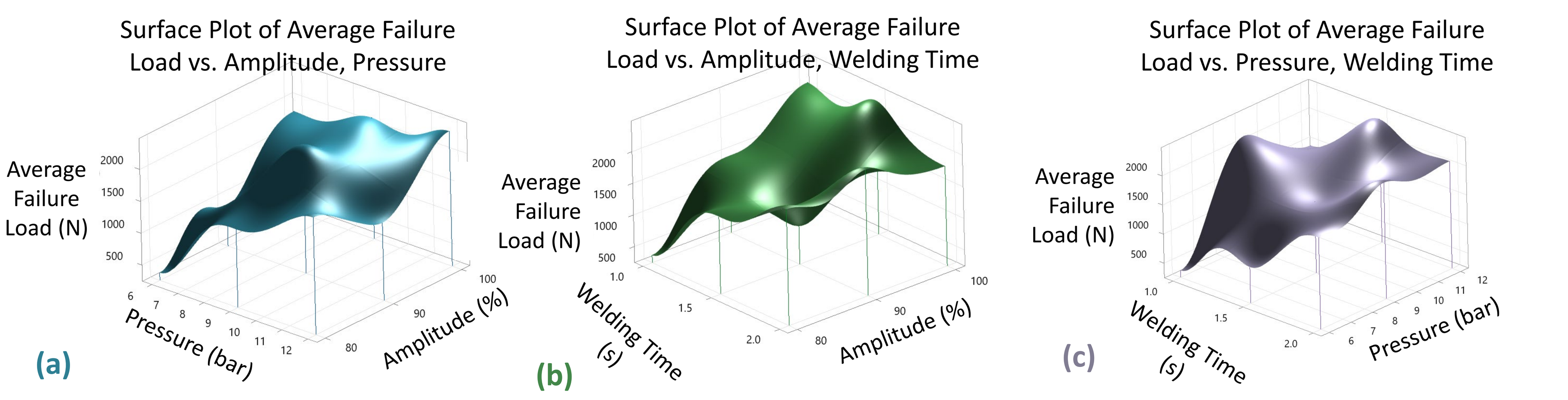


Figure 2 – Surface Plot of failure load versus a) amplitude (%) and pressure (bar), b) amplitude (%) and welding time (s), and c) pressure (bar) and welding time (s)

Group K
Amplitude=90%
Pressure=10 bar
Welding time= 1.5s
Group J
Amplitude=90%
Pressure=10 bar
Welding time= 2s

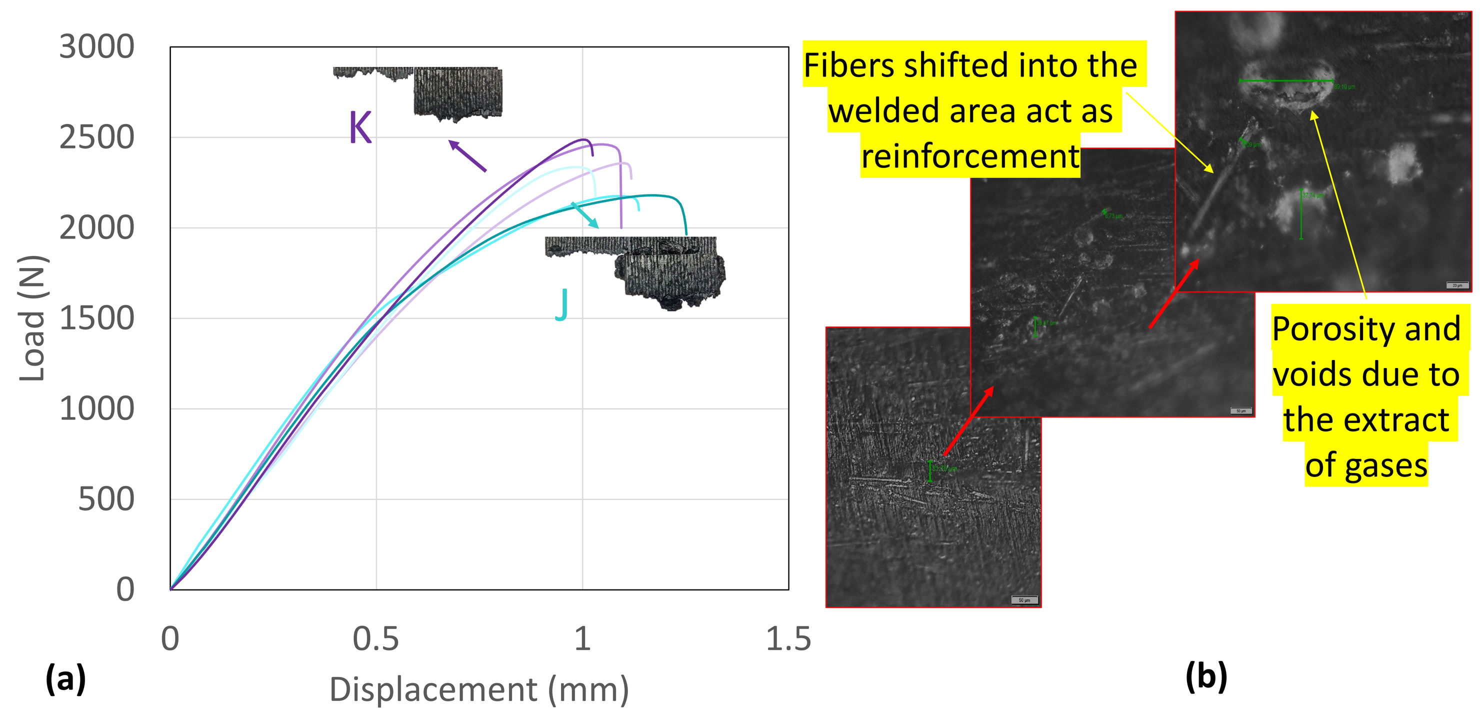


Figure 3 – Typical load-displacement curves of welded joints a)FRP samples b) microscopic images of welded C2.2 composites

Similar C2.1-C2.1 Joints

Table 3 – Welding Factors and Levels for Hot-Stamped continuous carbon fiber reinforced PP samples

Parameter	Level 1	Level 2	Level 3
Amplitude (%)	80%	90%	100%
Pressure (Bar)	9.6	12.8	16
Weld Time (Seconds)	1.5	2	2.5
Energy Director Shape	No ED	Flat ED (▮)	Triangular ED (▲)

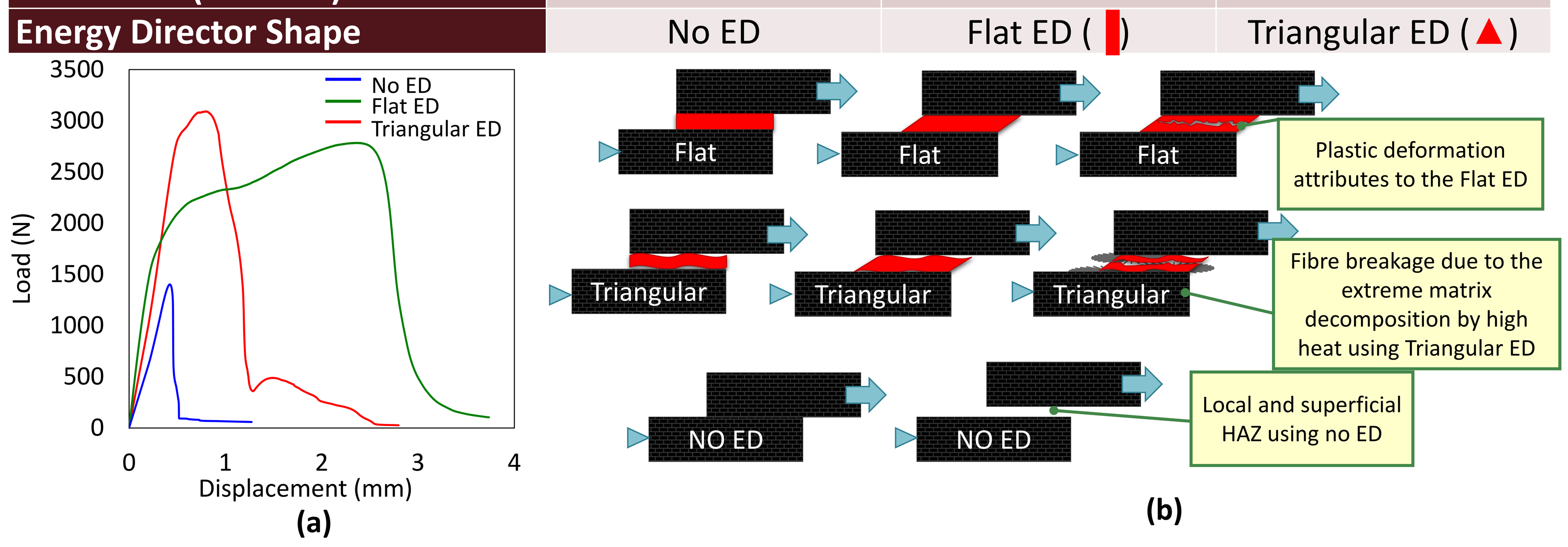


Figure 4 – **(a)** Typical load-displacement curves, and **(b)** schematic illustration of damage evolution in C2.1-C2.1 USW joints

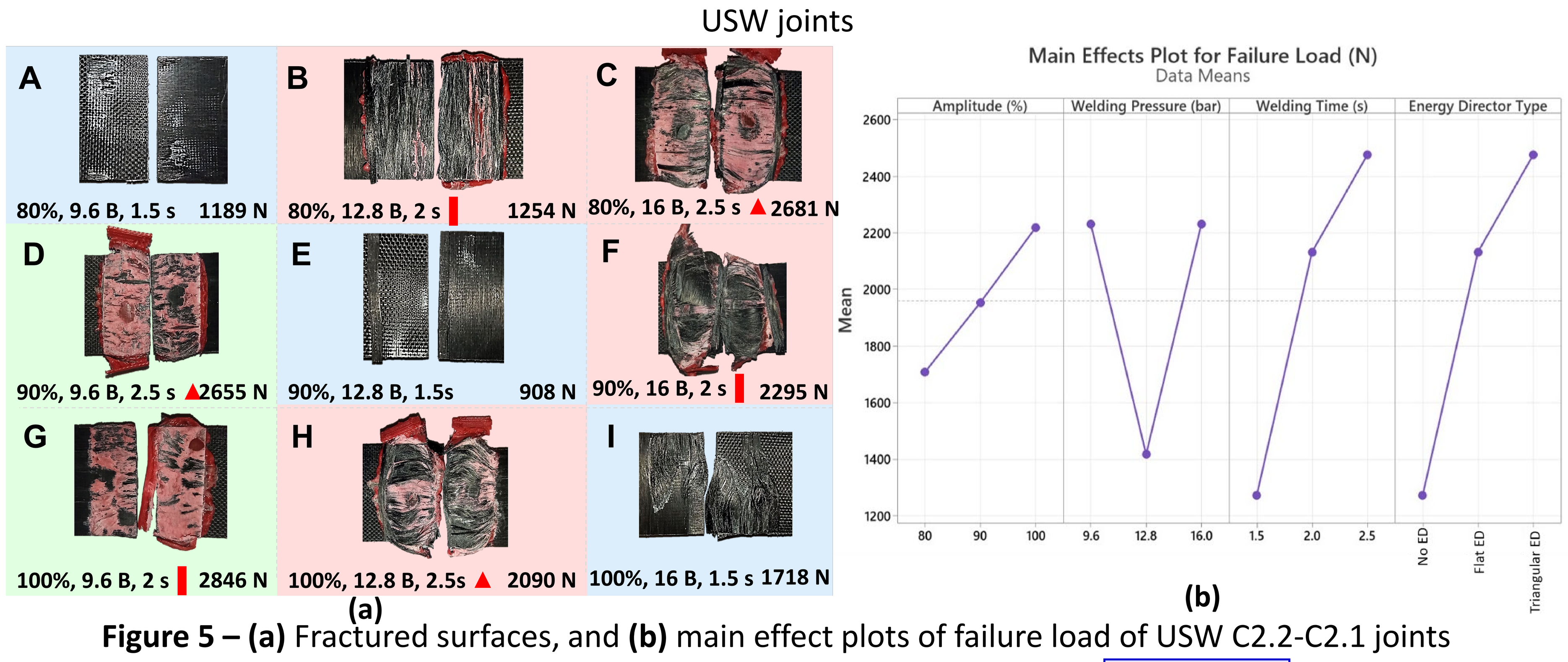


Figure 5 – **(a)** Fractured surfaces, and **(b)** main effect plots of failure load of USW C2.2-C2.1 joints

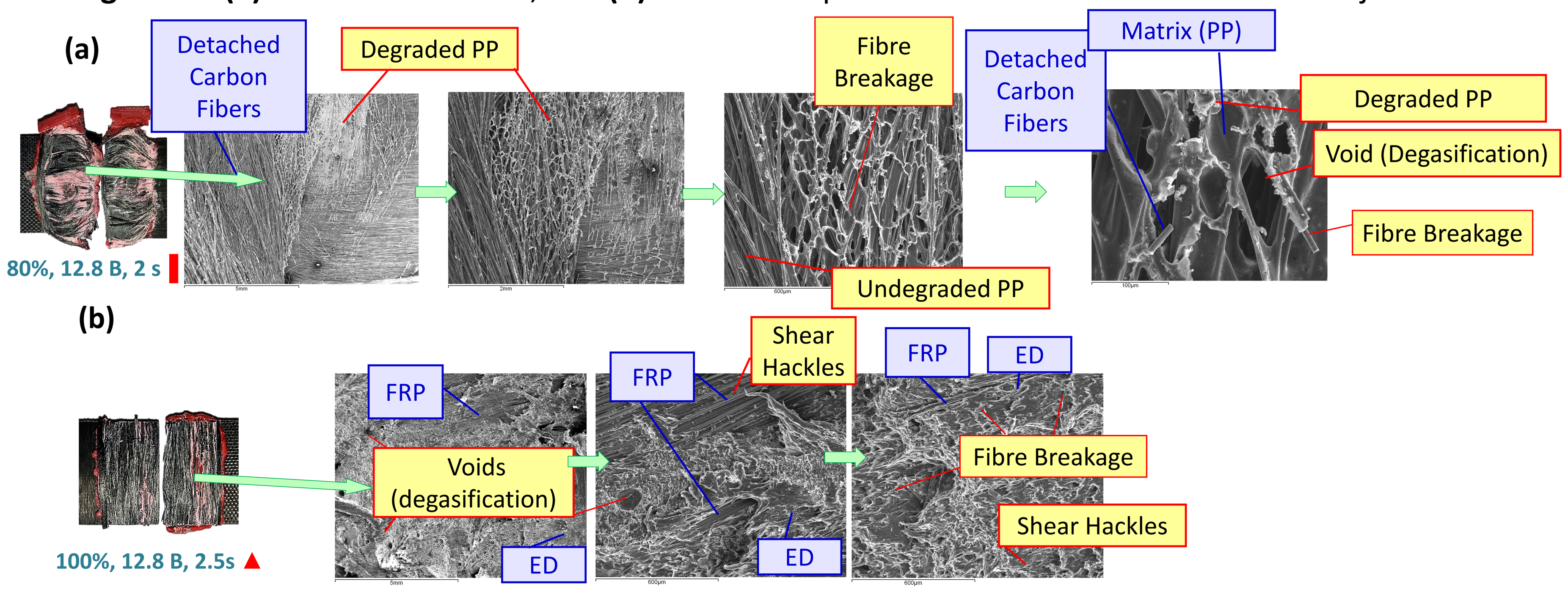


Figure 6 – Electron microscopic images of USW C2.1-C2.1 joints using a) triangular and b) flat EDs

Dissimilar C2.1-C2.1 Joints

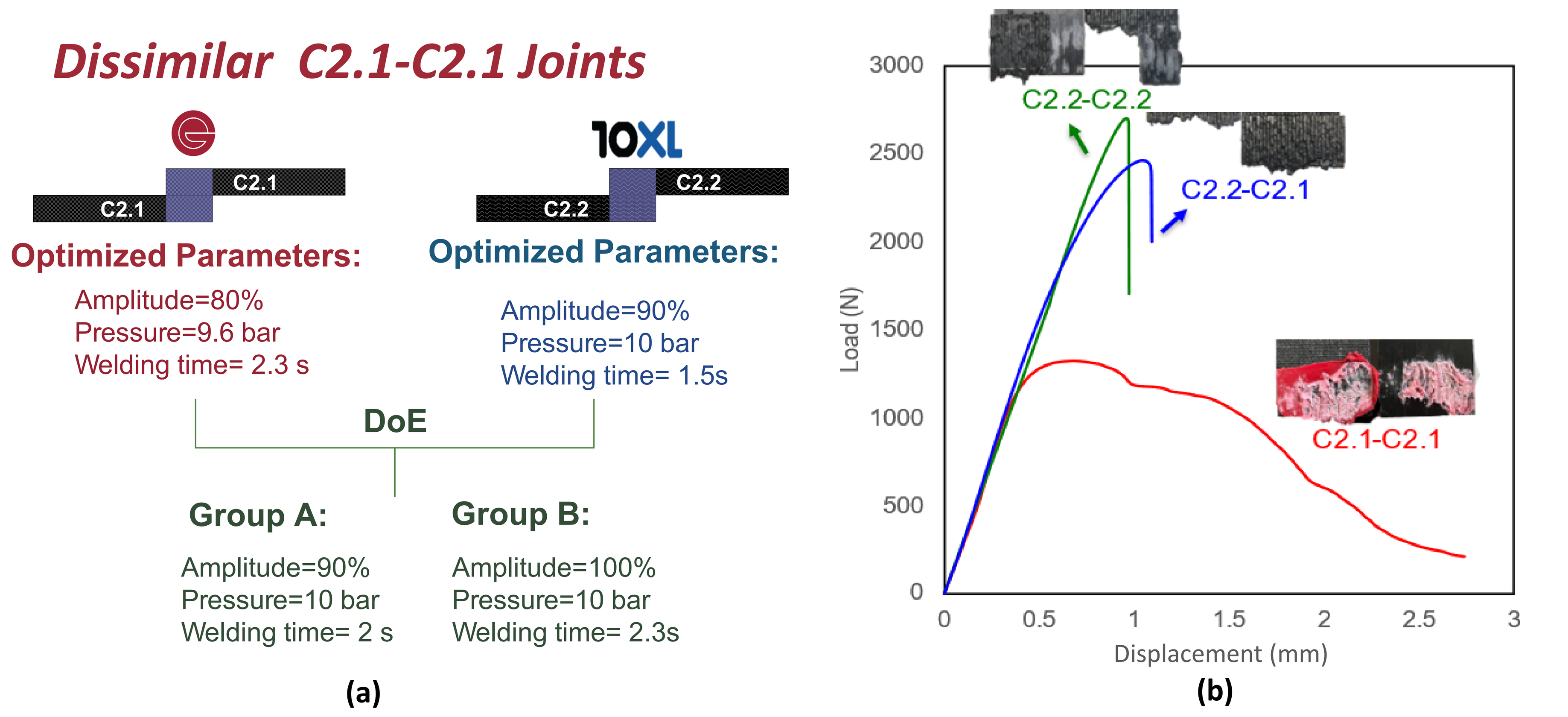


Figure 7 – **(a)** Design of experiments (DoE), and **(b)** typical load-displacement curves of various configurations

Conclusions

Regarding low surface energy and unacceptable adhesion of thermoplastic materials, generally welding techniques are promising. Since weld quality and strength are significantly dependent on the to the welding parameters, optimization method and DoE will be extremely time and cost saving. Whilst USW of GFRPs wasn't noticeably challenging, it was highly complicated in terms of CFRPs due to the high thermal conductivity of carbon fibres which requires using EDs to stimulate viscoelastic heating. In general, a significant interaction between welding parameters had been observed which changes the status of damage from shear hackles in Eds to degasification and decomposition of FRP's matrix.

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