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Effect of shear lap joint combined parameters on adhesion strength of epoxy bonded Glass Fibre Reinforced Plastics composite

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Abstract. The present work investigates the shear strength of adhesive-bonded lap joints of glass fibre-reinforced plastics (GFRP) composite plates. The epoxy-based structural adhesive is used to join the two composite plates. The combined effect of adhesive thickness and plate surface preparation method is studied. The complete experiment setup and the selected range of parameters are given in detail. Results have shown that the enhancement of surface preparation combined with the decrease of adhesive thickness can increase the joint strength significantly for the studied case. These results are consistent with prior shear lap joint studies on different materials or adhesives.

1. Introduction

The use of adhesive bonding has been on the rise due to its advantages. Compared to conventional fastening methods, adhesive bonding offers high design flexibility, a high strength-to-weight ratio, structural integrity at a much lower weight, fatigue resistance, and higher connection efficiency [1-2]. Accordingly, adhesives are widely used in many industries including automotive, aerospace, oil, marine, sports, structural engineering, biomedical, shipbuilding, etc. [1-3]. Compared to conventional bolt and riveted joints, adhesive joints have a more uniform stress distribution [4].[3] The performance of adhesively bonded joints is affected by numerous parameters such as surface preparation, material properties (both adhesive and adherends), bonding methods, and substrate parameters (ply angle, adhesive thickness, adherend thickness, overlap area, stacking sequence, etc.). To guarantee structural safety, careful consideration of all these parameters is essential during the design and implementation of bonded joints. In the present work, both the adhesive thickness and surface finish of the substrates are investigated.

Adhesive thickness is one of the most important parameters affecting the performance of adhesively bonded joints. Several attempts have been made to study the effect of adhesive thickness on bonded joints using finite element methods [6-9], analytical models [3], and experimental techniques [2-4], [9],[10]. It was found that the increase in adhesive thickness resulted in a decrease in the lap shear strength of the adhesive joints. For example, Da Silva et al. [10] noticed in a single lap joint testing (SLJ) using steel adherends, for ductile and intermediate adhesives, the joint strength decreases as the adhesive thickness increases. However, for the brittle adhesive, the shear strength increases for adhesive thickness of 0.2 to 0.5 mm, then decreases for thicknesses ranging from 0.5 to 1 mm. This was attributed to the presence of defects such as micro-cracks and voids in the adhesive layer. Furthermore, Banea et al. [9] observed that the lap-shear strength of polyurethane (ductile) adhesive in single lap joints with an adhesive thickness of 0.5 mm is 4% less than that of 0.2 mm thickness. Furthermore, an adhesive thickness of 1 mm had 13% less strength than that of 0.5 mm. Finally, a 2 mm adhesive thickness had a shear strength 31% less than that of a 1 mm adhesive thickness. Yang et al. [2] tested structural epoxy adhesive at two different environmental conditions (Room temperature dry state (RTD) and elevated temperature wet state (ETW)), at four different thicknesses (0.5 mm,1 mm, 1.5 mm, 2 mm), using CFRP adherends. They observed that adhesive tensile shear strength decreases by 21% as the adhesive thickness increases from 0.5 mm to 1.5 mm. However, as the adhesive thickness increases from 1.5 mm to 2 mm, the shear strength increases by 21%. On the other hand, in ETW condition, adhesive shear strength decreased by 52% when adhesive thickness increased from 0.5 mm to 2 mm. Arenas et al. [3] adopted Weibull statistical analysis and found that the optimum adhesive thickness ranges from 0.4 mm to 0.5 mm to obtain the highest mechanical performance and reliability.

Research has also shown that the type of surface treatment applied to the adherend has a great effect on the shear strength of adhesive bonds. It ensures the presence of a strong bond between adhesive and adherend, since it aims to remove contaminates such as dust, corrosion layers, lubricants, and micro-organisms [11]. Surface treatment can be implemented though various techniques including mechanical and chemical surface treatments.

Yang et al. [12] used four different sandpaper grit sizes as a mechanical surface treatment. Sanding the adherend in random direction resulted in the highest shear strength of the adhesive joint. It was observed that SLJ samples sanded by 220 grit size papers had the highest strength which increased by 17.62% and 22.31% compared to grit size 60 and polishing, respectively. Ramaswamy et al. [13] concluded that grit-blasting is an effective surface preparation method for composite-to-metal bonding. The results show that grit-blasting for 20 seconds provided the best adhesion, while blasting for 40 seconds resulted in the lowest adhesion due to excessive fibre damage.

Hu et al. [14] investigated the effect of Sodium Hydroxide (NaOH) and resin pre-coating (RPC) treatments on the shear strength of adhesive bond between an aluminium alloy and CFRP. The process of NaOH etching helps to form hydroxide layers that enhance adhesion. The results from SLJ testing showed that NaOH etching alone without RPC increased the bond strength up to 91%. On the other hand, RPC-treated samples had a range of 8.4% to 11.6% additional strength. Pierre et al. [15] presented a chemical surface treatment approach that includes sulfuric acid etching to enhance the bonding strength of honeycomb CFRP sandwich structures. They observed that etching at 125^{0}C for 10 minutes with 96% sulfuric acid concentration provides the most effective bonding performance while etching at temperatures higher than 140^{0}C resulted in high fibre degradation which reduced bond strength. Their work concluded that sulfuric acid etching can be an adequate alternative to mechanical surface treatment.

This work investigates the effect of various adhesive thicknesses and mechanical surface treatment on lap joint shear strength in composite plates typically found in wind turbine blades and aerospace applications. A two-component epoxy adhesive provided by Sika™ Industries (SIKA ADEKIT A140-1 / H9940-1) is used. Single lap joints made of glass fibre reinforced plastic (GFRP) composite specimens were tested at three different adhesive thicknesses of 1.5, 3.5, and 6.5 mm. Bond surfaces were prepared using sandpaper of three different grit sizes: 180, 320, and 600. SLJ testing followed ASTM D5868 [16] and surface preparation followed ASTM D2093 [17].

2. Experimental work

2.1 Shear Lap Joint (SLJ) Specimen Preparation

GFRP specimens were prepared using the hand lay-up method, as shown in figure 1. Three different grades of surface finish were obtained using abrasive sandpaper with grit sizes of 180, 320, and 600. Three different average adhesive thicknesses, 1.5, 3.5, and 6.5 mm were investigated. A total of 45 single lap shear joints were assembled for testing. However, achieving the exact thickness mentioned before is extremely difficult (especially at large thickness ranges) owing to the variation in the adherend thickness and the effect of adhesive bleeding. These thicknesses were clustered into three categories for the convenience and ease of data interpretation. The epoxy resin was prepared by adding 300 g of hardener to 900 g of epoxy resin, which was then mixed and applied to fiberglass laminates and left to cure for 48 h. Four laminates were used, resulting in an average thickness of 3.5 mm.

Figure 1. Hand layup process

The adhesive/hardener ratio of the structural adhesive was 1:0.9 by weight at room temperature, as stated by the manufacturer in the specification sheet. To adjust the adhesive thickness, a special fixture was developed to achieve different thicknesses as shown in figure 2. This box design allows for precise adhesive thickness control. One adherend is positioned against a fixed datum. Balsa wood plates of varying thicknesses are then used on the opposite side to create the desired adhesive gap. For instance, with fiberglass adherends averaging 3.5mm thick and a target 3mm adhesive layer, a 6.5mm balsa plate is used. The surface preparation was achieved following ASTM-D2093 [17], using sandpapers at three different grit sizes. The first step in the process was surface cleaning using a fabric cloth wetted with acetone. The overlap surface was then abraded by sandpaper, then cleaned again with acetone and left for 10 minutes for the acetone to evaporate. At this stage, the adherends were ready for adhesive placement. Most importantly the wooden box and balsa wood sheets were waxed before the placement of the adhesive on adherend to prevent any sticking between SLJ samples and other components. All samples were cured for a considerably sufficient time of 48 hours to assure full curing during relatively low ambient temperatures of 16-18 ^{0}C.

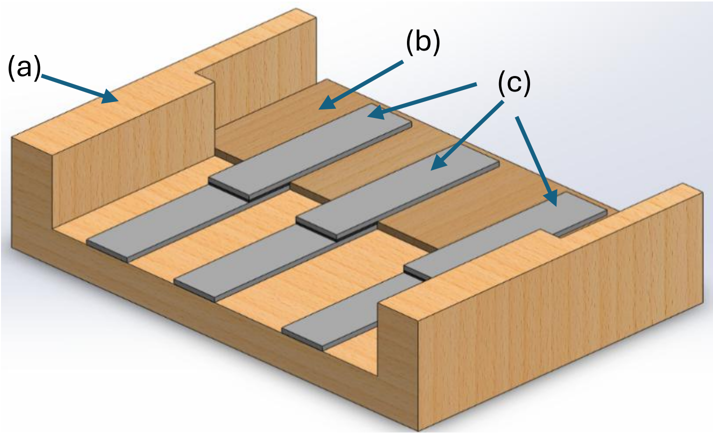

Figure 2. SLJ samples adhesive thickness adjuster setup, (a) Wooden base, (b) Balsa wood plate, (c) SLJ sample.

2.2 Lap Joint Shear testing

All SLJ specimens were tested on a universal tensile testing machine shown in figure 3 at a controlled crosshead speed of 2 mm/minute. End tabs were added to both ends of each sample to assure in-plane loading and no bending during the testing. The 45 SLJ specimens were randomly tested. All samples were marked by numbers for ease of tracking as they were randomly tested. Typical failure modes in SLJ are presented in figure 4 as discussed in Ref. [18] and will be used to categorise the failure in tested samples.

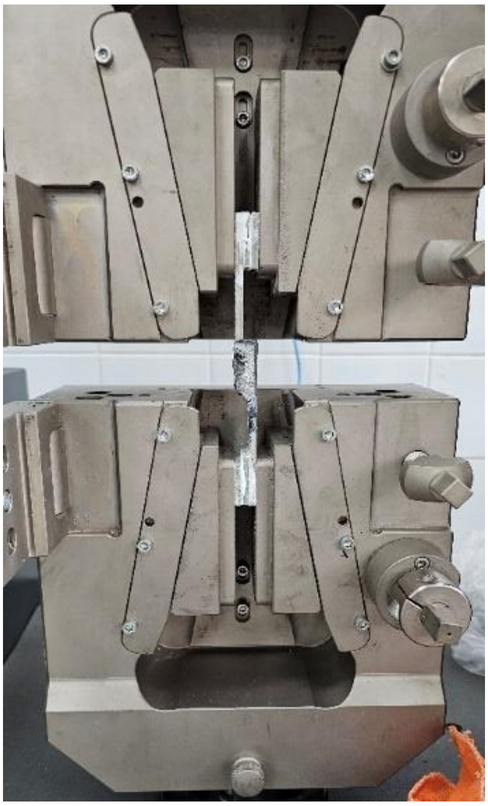

Figure 3. Experimental setup

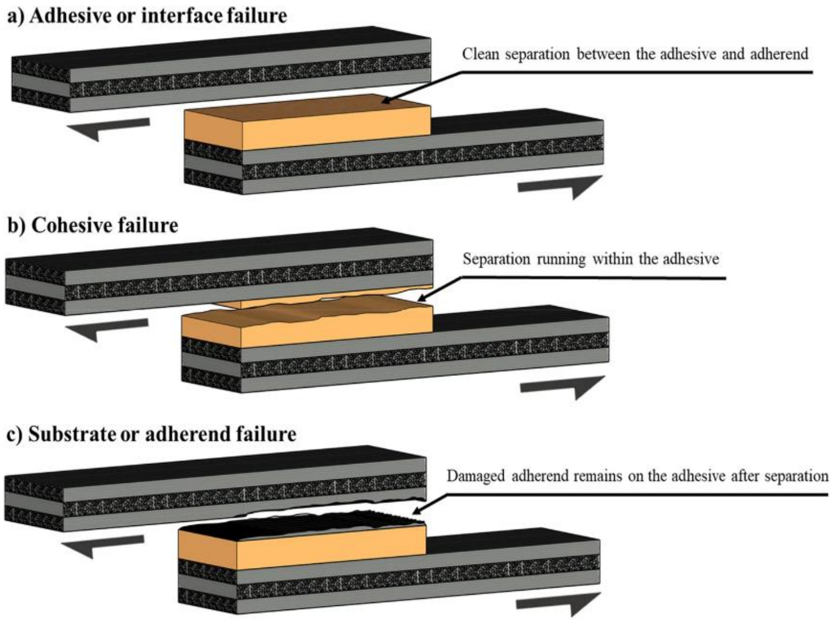

Figure 4. Failure modes of bond line adhesive. Adopted from [18]

3. Results and Discussion

3.1 Thickness 0.9 – 2.2 mm

3.1.1Grit size 180. As can be seen in table 1, as thickness increases (0.9 mm to 2.20 mm) the shear strength decreases by 29.6% (5.3 MPa to 3.73 MPa). In this case, decreasing the adhesive thickness increased the adhesive strength. On the other hand, the main mode of failure was adhesive failure. This could be a result of weak adhesion between the adhesive and adherend surface caused by the coarse nature of the abraded surfaces by the rough sandpaper. This is further confirmed when comparing these specimens to those prepared with grit size 320 and 600, as all of them had either substrate or mixed failure (adhesive and substrate) as shown in figure 5, which is a result of good adhesion between the adhesive and the GFRP. The samples average shear strength is 4.38 MPa.

3.1.2 Grit size 320. In this case, as shown in table 1, the shear strength increases from 9.96 MPa to 11.09 MPa (11.3%) then decreases to 7.94 MPa (28.4%) at thicknesses 0.95 mm, 1.11 mm and 1.38 mm respectively. The main difference is that the sample of thickness 1.11 mm had substrate failure, while the other two had a mixed failure mode. This supports the above observation that strong adhesion leads to substrate failure and maximum shear strength. The average shear strength was 9.66 MPa.

3.1.3 Grit size 600. As apparent in table 1, Sample #22 with an adhesive thickness of 1.02 mm had the highest shear strength of 12.72 MPa which is then decreased to 9.03 MPa (29%) at a thickness of 1.73 mm. However, Sample #40, which has a thickness of 1.12 mm, achieved 27.5% lower shear strength while the adhesive thickness is only 0.1 mm higher. The key distinction between the samples lies in their failure modes: Sample #22 failed due to substrate failure, while Sample #40 showed a mixed failure as shown in figure 5. The average shear strength was 10.23 MPa.

3.2 Thickness 2.5 – 4.3 mm

3.2.1 Grit size 180. An adhesive thickness of 2.64 mm yielded the highest shear strength of 7.97MPa, which was then decreased by 39% at an adhesive thickness of 4.04 mm. Furthermore, these samples perform better compared to the 0.9–2.2mm range of thicknesses. However,

Table 1. SLJ testing results

Sandpaper grade	Sample#	Thickness (mm)	Shear Strength (MPa)	Average Shear Strength (MPa)	Type of failure
180	39	0.90	5.30	4.38	Adhesive
180	33	1.98	4.75		Mainly Adhesive
180	32	2.03	3.73		Adhesive
180	44	2.20	3.73		Mainly Adhesive
180	1	2.64	7.97	6.06	Substrate
180	5	3.40	5.61		Substrate
180	7	4.00	5.79		Substrate
180	16	4.04	4.86		Substrate
180	35	5.92	4.77	5.25	Adhesive
180	23	6.12	5.48		Adhesive
180	17	7.25	6.89		Substrate
180	3	7.30	3.88		Adhesive
320	42	0.95	9.96	9.66	Both
320	27	1.11	11.09		Substrate
320	11	1.38	7.94		Both
320	43	3.70	5.48	5.31	Substrate
320	25	3.90	6.34		Substrate
320	37	3.96	5.19		Substrate
320	4	4.09	4.61		Substrate
320	19	4.30	4.94		Substrate
320	14	5.94	5.41	5.09	Substrate
320	15	6.20	5.14		Substrate
320	45	6.40	5.43		Substrate
320	36	6.60	5.03		Substrate
320	6	6.73	4.47		Substrate
600	22	1.02	12.72	10.23	Substrate
600	40	1.12	9.22		Both
600	38	1.73	9.03		Substrate
600	30	1.91	9.97		Substrate
600	12	3.00	6.49	5.70	Substrate
600	13	3.50	5.70		Substrate
600	20	4.00	5.39		Substrate
600	26	4.10	4.84		Substrate
600	31	4.10	6.09		Substrate
600	29	6.00	5.39	5.17	Substrate
600	9	6.05	6.09		Substrate
600	8	6.35	4.09		Substrate
600	34	6.60	5.54		Substrate
600	21	6.66	4.72		Substrate

reiterating with the observations above, the present failure mode here is substrate compared to the adhesive failure for thickness range 0.9 mm – 2.2 mm. The average shear strength was 6.05 MPa.

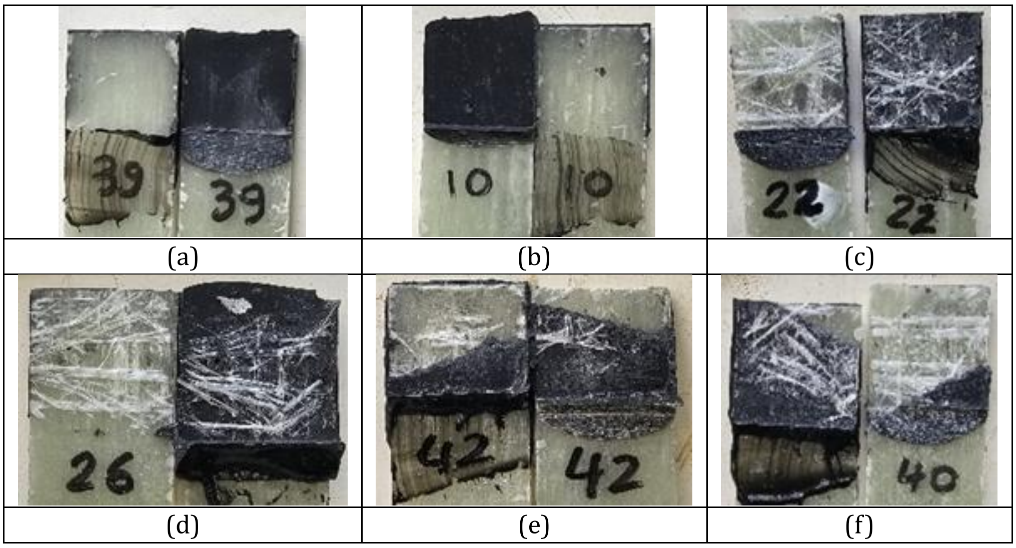

Figure 5. (a) and (b) Sample of adhesive failure, (c) and (d) Sample of substrate failure, (e) and (f) sample of mixed failure. Sample number and test conditions are shown in table 1.

3.2.2 Grit size 320. Failure strength increased from 5.48 MPa to 6.34 MPa at thicknesses of 3.7 mm and 3.9 mm, respectively, then decreased by 22% at a thickness of 4.3 mm. When compared to thickness 0.9 – 2.2 mm, these samples showed a poor performance. This indicates that the adhesive performs better at a higher thickness for surface-finish obtained by a grit size of 320. The average shear strength was 5.31 MPa.

3.2.3 Grit size 600. As can be seen in table 1, as the thickness increases from 3 to 4.1 mm, the shear strength decreased by 25.4%. However, Sample #31 which has a thickness of 4.1 mm, had a shear strength of 6.09 MPa compared to Sample #26 which had a shear strength of 4.84MPa. The high shear strength for Sample #31 compared to Sample #26 could be explained by the strong adhesion between adhesive and adherend surface. The average shear strength was 5.7 MPa. All samples in this batch had a substrate failure.

3.3 Thickness 5.9 – 7 mm

3.3.1 Grit size 180. As shown in table 1, Sample #17 had the highest shear strength due to undergoing substrate failure. However, compared to the other three samples, there was an apparent difference in shear strength, which was lower in Sample #3. It had the highest thickness of 7.3 mm, furthermore, it yielded the lowest shear strength out of all the tested samples while also having an adhesive failure mode.

3.3.2 Grit size 320. As can be seen in table 1, the shear strength in all samples is almost the same except for Sample #6 which had approximately 14.5% lower shear strength at an adhesive thickness of 6.73 mm.

3.3.3 Grit size 600. The shear strength increased by 13% from an adhesive thickness of 6 to 6.05 mm and then decreased by 22.5% at thickness 6.66 mm. All the samples exhibited substrate failure. Compared to the other thicknesses, there is not a large difference in the average stress between the thicknesses of 2.5 – 4.3 mm and 5.9 – 7.3 mm. However, the average stress of thickness 0.9 – 2.2 mm has double the average stress of the other two groups at surface finish of sandpaper grist sizes 320 and 600.

3.4 A comparison across all samples

Figure 6 presents all results obtained under different conditions. This presentation will help in reiterating the findings above and confirming results obtained Budhe et al. [1]. These findings indicated that as the adhesive thickness increases, the shear strength decreases, also the failure mode has a great impact on the shear strength of bond line adhesion. As can be seen the samples of adhesive thickness ranging from 0.9 to 2.2 mm at a surface treatment using 180 grit size paper are not taken in consideration in the trendline to provide clearer observation. Overall, Sample #22 yielded the highest shear strength at 12.72 MPa with a surface finish using grit size 600 and a substrate failure mode, followed by Sample #27 with a shear strength 11.09 MPa with surface finish of grit size 320 and a substrate failure mode. It can also be observed that there is a direct relationship between shear strength and surface finish; as the surface finish becomes smoother, the shear strength increases. Furthermore, SLJ samples with adhesive thicknesses ranging from 3.4 to 6.66 mm have relatively the same average shear strength.

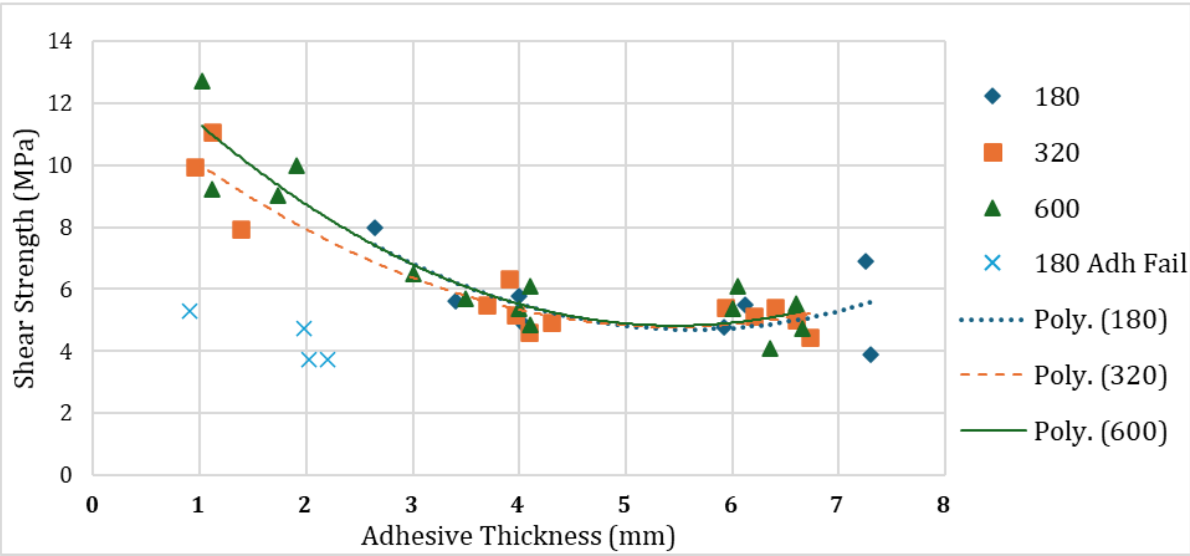

Figure 6. Graph represents Thickness (mm) and Shear Strength (MPa) at different sandpaper grit size surface finish

4. Conclusions

In the present study, the effect of three different epoxy adhesive thickness groups ranging from 0.9 to 7.3 mm were investigated. Their surfaces were prepared using abrasive sandpaper with three different grit sizes of 180, 320, and 600. The results showed that small adhesive thickness for studied joints combined with finer surface finish resulted in higher strength. As an exception, samples of thickness range of 0.9 to 2.2 mm and finished with grit size of 180 had significantly lower shear strength compared to samples finished with grit size 320 (120%) and 600 (133%).

This can be due to the poor adhesion (offered by the coarse nature of lower grit size sandpaper) between epoxy adhesive and adherend surface.

Accordingly, for optimal bonding of composites, it is recommended to maintain adhesive thickness below 6 mm. Achieving a thinner adhesive layer, combined with a smooth adherend surface, will significantly improve the shear strength of epoxy-bonded GFRP.

5. References

[1] Budhe S, Banea M D, de Barros S and da Silva L F M 2017 An updated review of adhesively bonded joints in composite materials *Int J Adhes Adhes* **72** 30–42

[2] Yang K, Feng H, Li P, Ji S, Lv Z and Liu Z 2024 The effects of environments and adhesive layer thickness on the failure modes of composite material bonded joints *Sci Rep* **14** 22776

[3] Arenas J M, Narbón J J and Alía C 2010 Optimum adhesive thickness in structural adhesives joints using statistical techniques based on Weibull distribution *Int J Adhes Adhes* **30** 160–5

[4] Gupta S K 2022 Effect of adhesive thickness and adherend material with a surface roughness on lap shear strength of joints in tensile and compressive loading *Advances in Materials and Processing Technologies* **8** 1023–43

[5] Xu W and Wei Y 2012 Strength and interface failure mechanism of adhesive joints *Int J Adhes Adhes* **34** 80–92

[6] Ji G, Ouyang Z, Li G, Ibekwe S and Pang S S 2010 Effects of adhesive thickness on global and local Mode-I interfacial fracture of bonded joints *Int J Solids Struct* **47** 2445–58

[7] Castagnetti D and Dragoni E 2009 Standard finite element techniques for efficient stress analysis of adhesive joints *Int J Adhes Adhes* **29** 125–35

[8] He X 2011 A review of finite element analysis of adhesively bonded joints *Int J Adhes Adhes* **31** 248–64

[9] Banea M D, Da Silva L F M and Campilho R D S G 2014 The effect of adhesive thickness on the mechanical behavior of a structural polyurethane adhesive *Journal of Adhesion* **91** 331–46

[10] da Silva L F M, Rodrigues T N S S, Figueiredo M A V, de Moura M F S F and Chousal J A G 2006 Effect of adhesive type and thickness on the lap shear strength *Journal of Adhesion* **82** 1091–115

Journal of Physics: Conference Series **3070** (2025) 012014 doi:10.1088/1742-6596/3070/1/012014

[11] Liu J, Xue Y, Dong X, Fan Y, Hao H and Wang X 2023 Review of the surface treatment process for the adhesive matrix of composite materials *Int J Adhes Adhes* **126**

[12] Yang G, Yang T, Yuan W and Du Y 2019 The influence of surface treatment on the tensile properties of carbon fiber-reinforced epoxy composites-bonded joints *Compos B Eng* **160** 446–56

[13] Ramaswamy K, O'Higgins R M, Kadiyala A K, McCarthy M A and McCarthy C T 2020 Evaluation of grit-blasting as a pre-treatment for carbon-fibre thermoplastic composite to aluminium bonded joints tested at static and dynamic loading rates *Compos B Eng* **185** 107765

[14] Hu Y, Yuan B, Cheng F and Hu X 2019 NaOH etching and resin pre-coating treatments for stronger adhesive bonding between CFRP and aluminium alloy *Compos B Eng* **178** 107478

[15] De La Pierre S, Giglia V, Sangermano M, Cornillon L, Damiano O and Ferraris M 2020 Etching of Carbon Fiber-Reinforced Plastics to Increase Their Joint Strength *J Mater Eng Perform* **29** 242–50

[16] Anon ASTM D5868-01 Standard Test Method for Lap Shear Adhesion for Fiber Reinforced Plastic (FRP) Bonding

[17] Anon ASTM D2093-03 Standard Practice for Preparation of Surfaces of Plastics Prior to Adhesive Bonding

[18] Omairey S, Jayasree N and Kazilas M 2021 Defects and uncertainties of adhesively bonded composite joints *SN Appl Sci* **3** 769