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SURFACE MORPHOLOGY OPTIMIZATION OF THERMOPLASTIC COMPOSITES FOR STRUCTURAL BONDING USING ABRASIVE WATERJET TEXTURING

Pierre Fréquelin^{1,2,3}, Rédouane Zitoune¹, Julien Jumel² and Agathe Jaillon^{3,*}

¹Institut Clément Ader (ICA), CNRS UMR 5312, 3 Rue Caroline Aigle, 31400 Toulouse, France

²Institut de Recherche Dupuy de Lôme (IRDLD), CNRS UMR 6027, 2 Rue François Verny, 29200 Brest, France

³BAYAB Industries, 10 Allée de Longuetterre, 31850 Montrabé, France

*Corresponding author: a.jaillon@bayab.fr

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Abstract

The controlled surface modification of composites with thermoplastic matrices is essential for improving their adhesive bonding performance. Abrasive Waterjet (AWJ) texturing is a promising technique for reliable surface functionalization, as it can create optimal surface morphology without heating the material or inducing fibre delamination. This study aims to explore the possibility of using AWJ for structural bonding applications. The influence of surface roughness on the adhesive performance of carbon fibre reinforced thermoplastic samples with an epoxy adhesive is investigated through single lap joint tensile tests. The results show that AWJ texturing significantly improves the strength of CFR-PEKK / FM 300M bonds for a wide range of parameters and with good repeatability, leading to predominantly cohesive failure inside the adhesive.

1. Introduction

The increasing proportion of high-performance thermoplastic composites in the transportation industry has led to a growing interest in surface modification techniques to improve their adherence to adhesives [1–3]. Thermoplastic polymers are appreciated for their impact resistance, recyclability, and low manufacturing constraints, but their weak adherence to most adhesive substances is slowing down their development [4]. Without chemical affinity to form strong bonds, it is generally recommended to increase substrate roughness to favour mechanical anchoring of the adhesive [5]. Techniques such as grit blasting or sanding are often employed to prepare surfaces before adhesive application. However, they can be challenging to industrialize, notably because of harmful particles and waste management issues.

Abrasive Waterjet (AWJ) can create intricate texturing patterns on most materials from the consecutive impacts of abrasive particles accelerated through a high-speed stream of water. It is a possible alternative to current standards for reliable surface functionalization, as the water flux accompanying the particles impedes heating of the material, cleans the surface, and contributes to reducing the number of embedded particles [6]. Some optimal surface morphology is to be found, as overpronounced asperities will not allow for a good penetration of the adhesive and lead to voids [7]. Usually, surface roughness is quantified using the arithmetical mean height (Ra) or its areal field equivalent (Sa). However, less common parameters can be more relevant in certain contexts, depending on the texturing process, substrate material and adhesive. In fact, a parabolic relationship seems to exist between the crater volume generated by AWJ texturing on 3D woven carbon fibre reinforced polymer (CFRP) and the critical energy release rate of CFRP/CFRP bonded assemblies [8].

As the abrasive particles in the jet reach the target-surface, they form micro-craters whose average geometry and number density will vary with the process parameters (i.e., pump pressure, particle size, jet traverse velocity). Similarly, significative variations in crater morphology, coupled with impact overlapping mechanisms, will produce major differences in the measured roughness of the surface. In order to study the influence of surface topography on the adhesive performance of carbon fibre reinforced thermoplastic samples bonded with an epoxy adhesive, the single lap joint tensile strength associated with four relevant AWJ configurations was assessed. The results were then compared to three industrial reference states.

2. Materials

The substrate material used in this study was a quasi-isotropic layup of carbon fibre-reinforced poly-ether-ketone-ketone (CFR-PEKK) composite laminates, with a total thickness of approximately 4.5 mm. A commercially available FM 300M film adhesive (with random mat) was used to bond the textured CFR-PEKK substrates. The adhesive film had a nominal thickness before curing of 0.13 mm, for which the manufacturer’s datasheet mentioned an expected mechanical strength of 29.8 MPa at 24°C. Two common grades (#220 and #120) of Barton HPX garnet (cf. **Figure 1**) were used as the abrasive media in the waterjet texturing process.

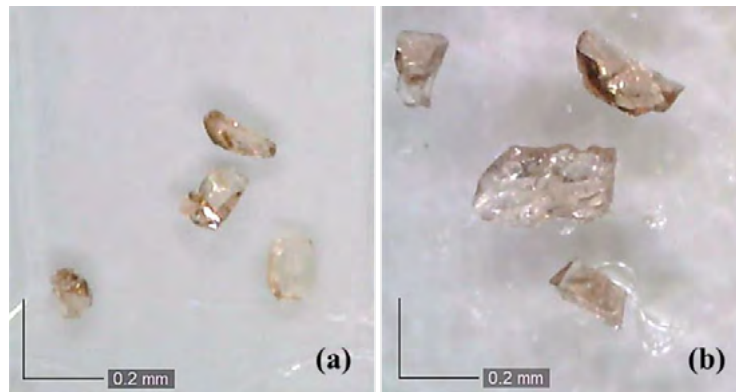


Figure 1. Micrography of the (a) #220 and (b) #120 grades of garnet abrasive used in this study.

3. Experimental procedure

Three different preparation processes were considered: (i) degreasing with isopropyl alcohol (IPA), (ii) cleaning with pure waterjet (PWJ) and (iii) texturing with abrasive waterjet (AWJ). The PWJ configuration utilized only water, while the AWJ configurations incorporated the garnet abrasive. Otherwise, both types of treatment were performed in the exact same conditions, using a 0.18 mm diamond orifice, and a mixing tube of length 50.8 mm and diameter 0.56 mm. The standoff distance was set to 200 mm to maximize jet spread, allowing for a stepover distance of 2 mm with no apparent striations. Three different sets of AWJ parameters were investigated, varying the particle size, pump pressure and tool traverse speed to obtain significative differences in Sa (cf. **Table 1**), which were measured via white-light confocal profilometry according to ISO 25178. For each configuration, the optimal abrasive flowrate was calculated using a proprietary model, similar to the one described in [9].

Table 1. Parameters associated with the tested textures.

Tested configuration	Mesh size of particles (#)	Water pump pressure (MPa)	Tool traverse velocity (mm/s)	Arithmetical mean height Sa (µm)
PWJ	N/A	60	167	0.8
AWJ (light)	220	80	207	6.0
AWJ (medium)	120	60	79	8.9
AWJ (harsh)	120	100	62	13.5

To assess the quality of the prepared surfaces, the mechanical strength of the bonded assemblies was tested using the Single Lap Joint test (ISO 4587). The geometry and average dimensions of the tested specimens are shown in **Figure 2**. The adhesive film was cut to size and placed between the prepared adherend surfaces. The assembled specimens were held in position inside a vacuum bag at 70 kPa and then cured for 60 minutes in a forced-air oven at a temperature of 177°C, as per the manufacturer's recommendations.

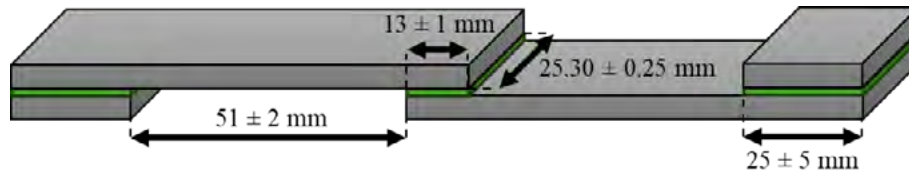


Figure 2. Geometry and dimensions of the tested Single Lap Joint samples.

Three bonded single lap specimens for each of the six surface preparations were tested for joint strength at ambient temperature using an Instron 8561 machine with a 10 kN loadcell. The specimens were loaded in tension at a constant speed of 2 mm/min until failure occurred. The apparent shear strength of the joint was calculated using the maximum load recorded during the test divided by the bonded area, which was systematically measured (post-mortem) for each sample.

4. Results & discussion

As presented in **Figure 3**, the “as received” (untreated) substrate yielded at approximately 60% of the expected strength of the FM 300M adhesive, with apparent adhesive failure throughout the bonded area. The IPA and PWJ treatments increased the average bond performance by respectively 35% and 45%, with mixed failure patterns at the joint. Therefore, it appeared that the high-speed waterjet had a cleaning effect at least as effective as that of the IPA solvent.

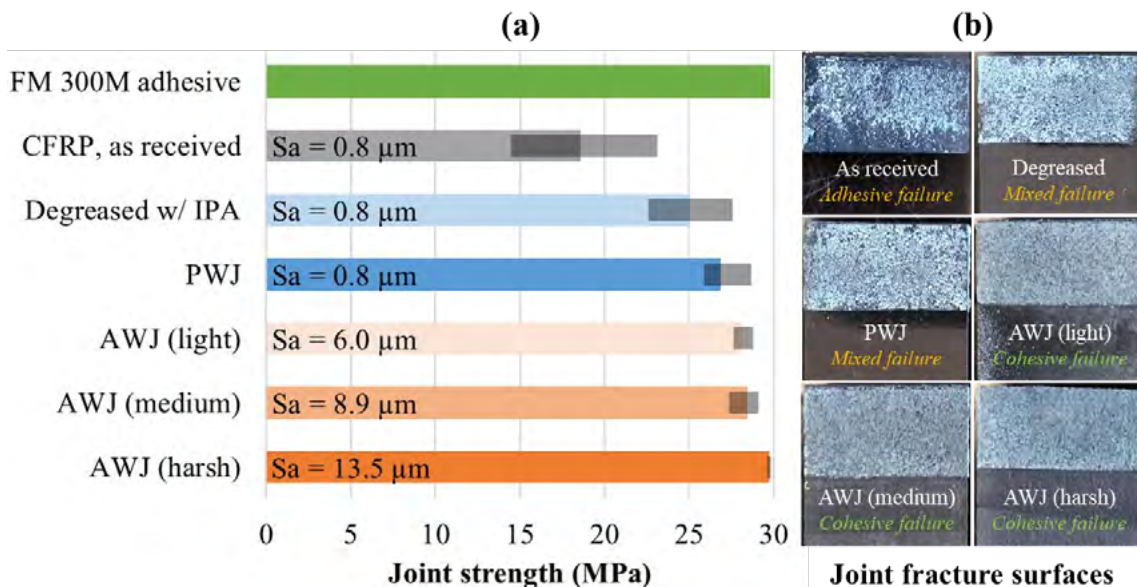


Figure 3. (a) measured apparent shear strength of the single lap specimens with different surface preparations and (b) corresponding fracture surfaces.

Texturing with the AWJ process further improved the strength of the CFR-PEKK / FM 300M bonds for all three configurations, and with very good repeatability. In fact, fracture surfaces showed exclusively cohesive failure inside the adhesive, meaning that the strength of the interface exceeded the cohesive strength of the adhesive. Therefore, despite minor differences in the measured failure stresses, all three AWJ preparations were considered to have equally maximized the mechanical strength of the bonded

assemblies. Consequently, no clear link could be made between morphology and bond strength, as the interface was not the locus of failure.

4. Conclusions

AWJ texturing appeared as a promising technique for improving the adhesive bonding performance of thermoplastic composites. The following conclusions could be drawn from the present work:

- A simple degreasing of the CFR-PEKK surfaces prior to bonding with FM 300M was insufficient to utilize the full mechanical strength of the assembly, as indicated by the mixed fracture patterns observed on joint surfaces.
- Even at an elevated standoff distance of 200 mm and relatively low operating pressure of 60 MPa, the pure waterjet treatment appeared to have significant influence on joint strength, as it outperformed the sample that had simply been degreased with isopropyl alcohol. This suggests that, although no erosive power subsisted in the jet, there was still a cleaning effect of the pure waterjet on the substrates. Yet, the PWJ treatment still produced mixed fracture surfaces.
- The different AWJ treatments showed only a slight increase in joint strength, as compared to PWJ. However, as complete cohesive fracture was observed in these cases, it is important to consider that the fracture stresses were necessarily limited by the mechanical strength of the adhesive itself, such that the actual bond strength could not be measured. Therefore, it can be concluded that all AWJ preparation resulted in substrate adherence at least equivalent to the cohesive strength of the FM 300M adhesive.
- Moreover, AWJ could produce a wide range of surface roughness values (S_a of 6.0 to 13.5 μm) with standard process parameters. However, further research would be needed to establish a clear link between surface morphology and bond strength, as well as to optimize the process parameters for specific applications.

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