

# DIRECT JOINING OF LASER-TEXTURED TITANIUM ALLOYS AND CFTPCS

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## Abstract

Transport industry is dominated by the light-weight challenge driven by both environmental concerns (increase the fuel efficiency and reduce the CO<sub>2</sub> emissions) and cost reduction. Using mixtures of materials and multi-material design of components provides an opportunity to develop products which could achieve this challenge. A critical aspect in multi-material fabrication is the surface condition and joining. In this work, CFTPCs (carbon fibre reinforced thermoplastic composites) made of CF-PEEK tapes were joined to an aeronautic titanium alloy. Different laser textures were used and compared with other surface treatments like chemical etching and grit blasting. Hot-press was used to optimize the fabrication of CFTPCs laminates to choose the better parameters to join them to the metal directly. Tensile tests and Optical Microscopy were used for testing their quality. For joining the CFTPCs to the titanium, the use of a PEEK film was also considered. The surface optimization and quality of joining were studied using single lap joint tests. Different surface conditions yield several shear strength results. Particularly, with grit blasting very poor values are obtained. However, laser texturing improves significantly the joint strength, above all when a PEEK film is used. In this case, structural resistances over 20MPa were obtained.

## 1. Introduction

Multi-Material approach can improve the functionality of components by making feasible more complex designs having higher structural integrity to weight ratio than bulk materials [1]. Joining technology plays a key role in the multi-material design, especially in metal/CFPCs (carbon-fibre polymer composites) joints, due to several challenges such as poor adhesion because of a low chemical affinity between metal and TPCs; corrosion problems arise when using electrically conductive fibres; tight requirements on time and temperature in the TPCs joining. Titanium/CFPCs joints are especially important in the aerospace industry [2]. Mechanical fastening using rivets or bolts is still one of the main methods currently used for joining components. Fasteners are a popular choice due to their strength is quite predictable and safe. However, holes in composites are counterproductive because they produce defects as burrs and delamination around the holes and point-load stress concentration [3]. TPCs is growing in the aeronautic sector mainly due to their inherent OoA (Out of Autocalve) processing, and better fatigue and impact response. Also, they can be welded, disassembled and they can be joined directly to metals. But, a specific topography on the surface is needed to enhance the “adhesive” behaviour of the surfaces by means of micro-mechanical interlocking because of the absence of chemical interactions [4]. Laser texturing is one of the most promising techniques to create a controlled roughness on the metallic surface to achieve a good adhesion between metals and CFPCs [5-7]. However, not many works deal with the laser texturing of metallic surfaces for the bonding with TPCs without using adhesives. In this work, CFTPCs were joined to laser textured aerospace titanium alloy by hot-press and compared with other more

conventional surface treatments. The effect of adding a PEEK film into the joint was analysed in terms of adhesion strength and type of failure.

## 2. Experimental Procedure

The metallic material used in this study was a commercial annealed titanium alloy (Ti6Al4V S/ABS5326C) supplied by Technalloy in the form of 2 mm plates. The nominal composition of this alloy is Ti-6,38 wt.% Al-4,01 wt.% V-0,008 wt.% C-0,20 wt.% Fe- 0,159 wt.% O-0,002 wt.% N and <0,001 wt.% Y. The mechanical properties are: YS of 943MPa, UYS of 1037MPa, E of 11,5%. Young's Modulus of 109 GPa. CF-PEEK tapes were provided by SUPREM (SUPREM™ 55% AS4/PEEK-150) and are made of a PEEK matrix with a 55±3% (by volume) of uni-directional carbon fibres. Thickness of the tapes is 0.14 mm (nominal).

Titanium specimens were treated using different surfaces procedures to promote adhesion. The surface treatments used were: chemical etching (E), grit blasting (GB) and laser texturing (T1 and T2). For the chemical etching, the Ti specimens were treated with 3% hydrofluoric acid and 3% nitric acid for one minute following the typical procedure used in Aerospace (AIPS 09-02-005: Pickling of Titanium and its alloys). The chemical etching treatment was applied to the bare surface and also to the laser textures. For grit blasting, Ti specimens were placed in a Clemco's suction blast cabinet PULSAR III-S and were treated with abrasive grits (angular, 500 µm) using a speed of 10min/m<sup>2</sup> and 5 bars of pressure.. The laser texturing was carried out using a continuous wave (CW) laser: TruFiber400 from TRUMPF (Ytterbium-doped single mode fibre, max. Power of 400W, WV1070 nm) equipped with a galvanometric scanner adapted to the power density. Laser textures T1 and T2 were obtained with a laser power of 200W and a scanner speed of 600 and 400mm/s respectively. The roughness for all the surface treatments was measured. In the case of the grit blasting and chemical etching a contact profilometer DEKTAK 8CSM was used due to the high precision for measuring lower roughness. For the textures obtained by laser, a non-contact 3D surface profiler (S-neox from Sensofar) was used.

Titanium plates were cut as 100x25 mm<sup>2</sup> specimens to carry out Single Lap Joint (SLJ) Tests following the standard ASTM D5868:2014 "Standard Test Method for Lap Shear Adhesion for Fibre Reinforced Plastic (FRP) Bonding". In order to enhance the adhesion of the CFTPCs to the titanium, the use of a PEEK film was also considered. The PEEK film was supplied by Goodfellow (Ref. EK301012) with a thickness of 12 µm. Several layers of film were placed until to reach different thickness depending on the laser texture roughness. For T1 200 and 400 µm were considered while 60 and 120 µm were studied for T2. To check the type of failure after the SLJ tests, some pictures on the interface were taken. Some details on these interfaces were also captured using a 5M 300x digital microscope (Model UM012C) from MUSTECH.

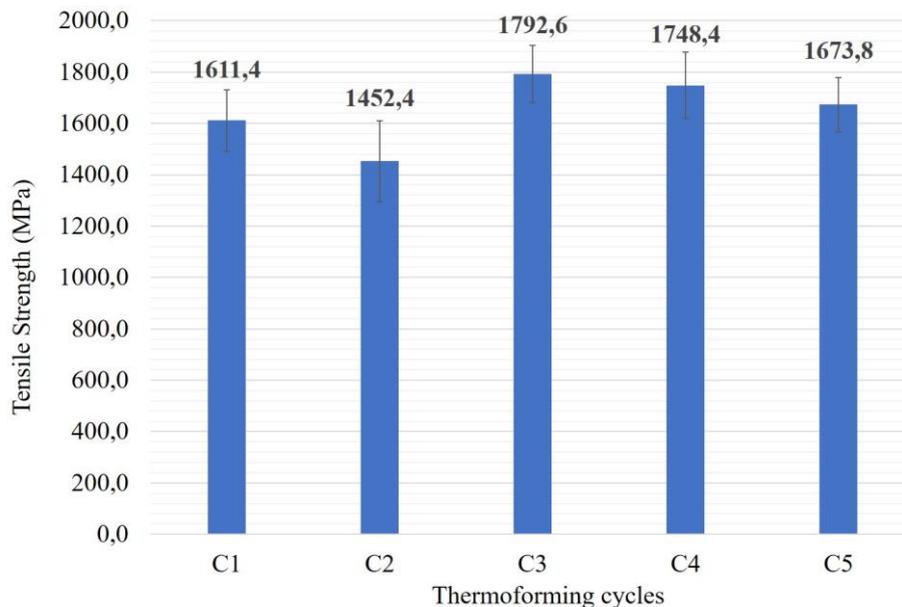
CFTPCs were joined to the treated titanium specimens using hot-pressing. For this, a press FONTIJNE LabPro1000 was used. To choose the better parameters to join the CFTPCs to the metal directly, first some CFTPCs laminates were fabricated varying the parameters of Table 1, fixing others such as: temperature of 390°C, heating rate of 15°C/min, cooling rate of 5°C/min and using always 6 layers of tape to obtain 1 mm of laminate thickness. The quality of the laminates was measured by means of 0° tensile tests type A, following the ISO 527-5:2012 standard (Plastics – Determination of tensile properties. Part 5: Tests conditions for unidirectional fibre-reinforced plastic composites) and throughout optical microscopy using a microscope REICHERT MEF 4A. All the dissimilar joints were manufactured with the best combination of parameters.

**Table 1.** Parameters CFTPCs laminates manufactured by hot-pressing.

Cycle Number	<i>P</i> (Bar)	<i>t</i> (min)
C1	10	20
C2	5	20
C3	15	20
C4	10	10
C5	10	5

### 3. Results and discussion

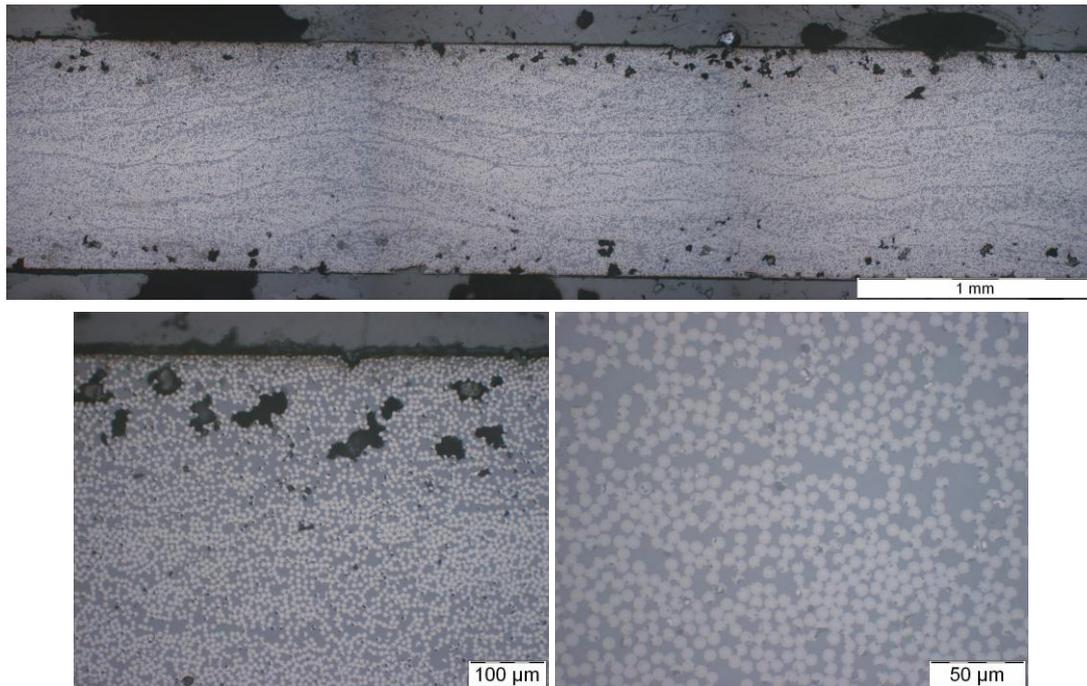
Fig. 1 shows a graph with the tensile strength values in MPa for the different hot-press cycles for the manufactured CFTPCs laminates.



**Figure 1.** Tensile Strength of the CFTPCs laminates manufactured with different hot-press cycles.

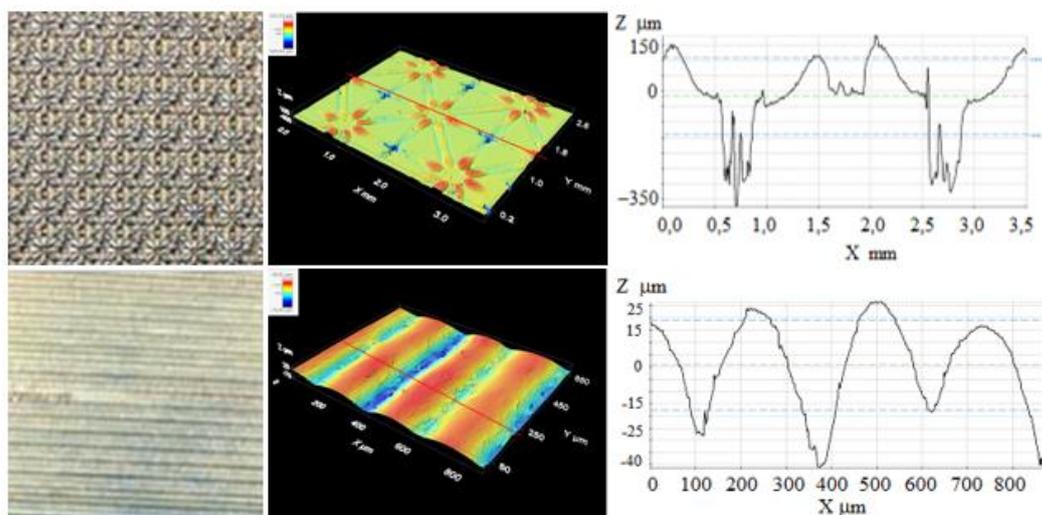
According with this graph, cycle 3 is the one which gives the highest value. So, parameters selected for manufacturing the joint were  $P= 15$  bar and  $t= 20$  min, at  $390^{\circ}\text{C}$ .

In addition, microstructural characterization of the laminates with the different cycles was carried out. Fig. 2 shows the cross section of the laminate with the better properties (cycle 3) where the 6 layers of the 1 mm plate can be observed. In this figure, voids in the edges of the laminates were detected although the total porosity is less than 5%. On the other hand, a good adhesion between tapes and no delamination were observed. Micrographs confirmed the good quality of the manufactured laminates.



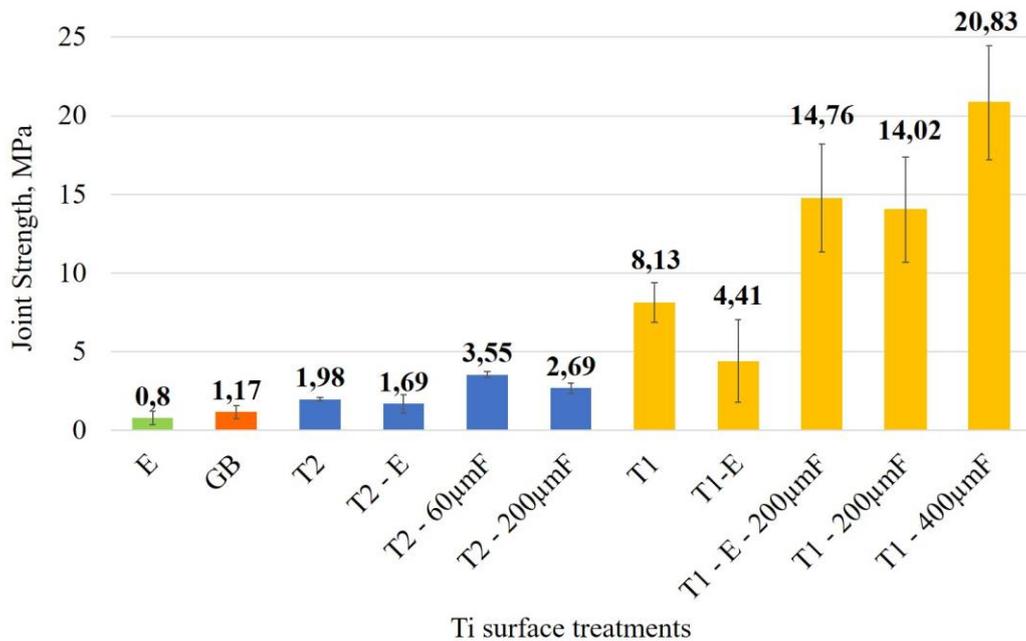
**Figure 2.** Optical micrographs cross sections at different magnifications of the CFTPC manufactured using the cycle 3.

As roughness is a crucial factor determining the adhesion, it was measured for all the surface treatments. The roughness  $R_z$  measured for the grit blasted and chemical etched specimens was  $14,18 \pm 1,16$  and  $1,79 \pm 0,63$   $\mu\text{m}$  respectively. Fig. 3 shows the pictures and the corresponding confocal microscope images for both laser textures. These images are an isometric coloured topography and a 2D profile of the section cut by the red line is shown in each image. For T1 and T2 laser textured samples, the mean roughness  $R_z$  was  $431 \pm 26$  and  $28,66 \pm 9$   $\mu\text{m}$  respectively. According to these results, it is concluded that the roughness for the laser textures is higher than for conventional treatments.



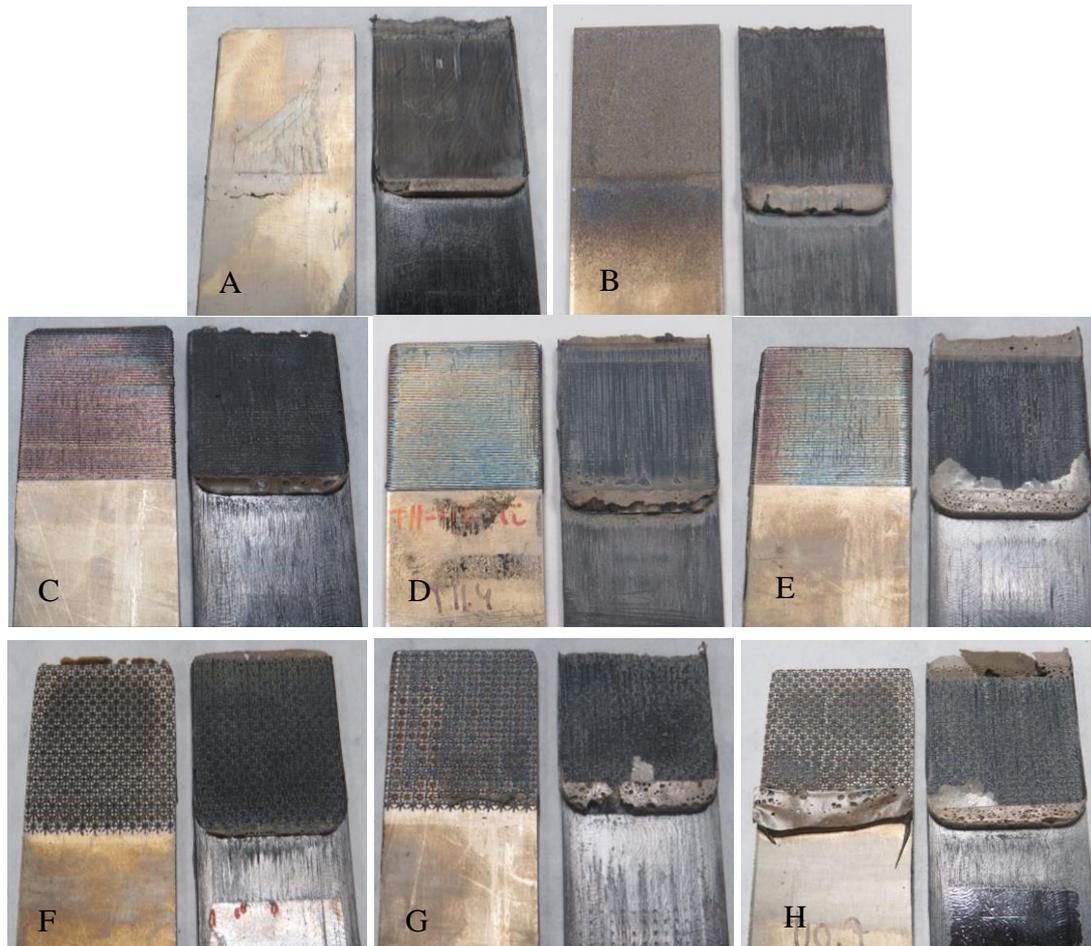
**Figure 3.** T1 and T2 pictures with the confocal microscope 3D maps and the corresponding section 2D profiles.

With C3 parameters, SLJ samples were manufactured between CFTPCs and the Ti with the four surface treatments and the PEEK film put on the interface. The results are shown in Fig. 4.

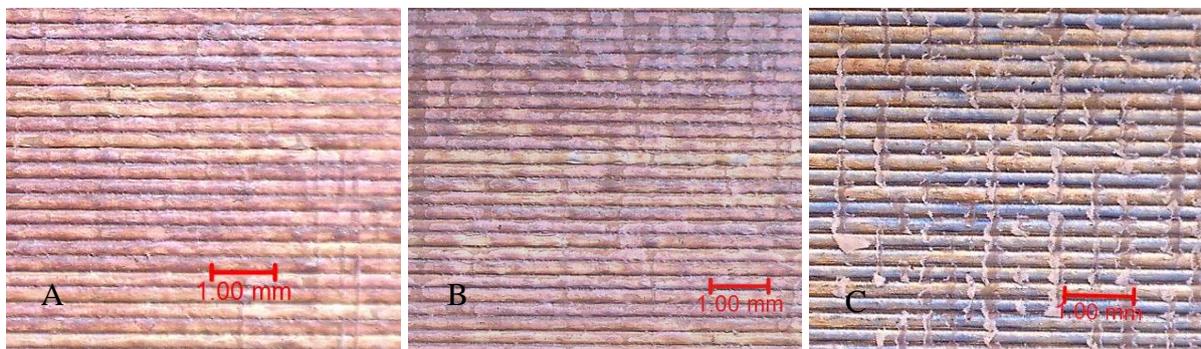


**Figure 4.** Mechanical results obtained from the Shear Lap Joint Tests for the Ti-CFTPCs direct joints as a function of the different surface treatments and film thickness.

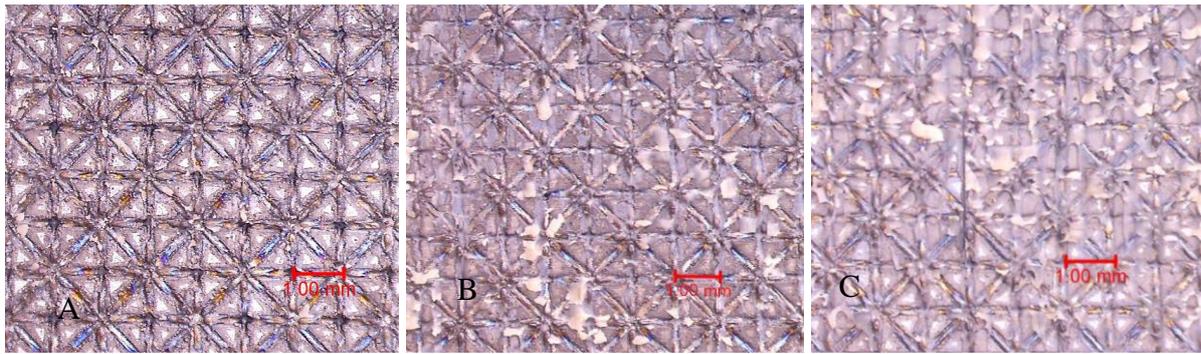
According to the values presented in Fig. 4, the joint strength is clearly related with the Ti surface roughness. For the lower roughness values (E, GB, T2), the joint adhesion is very poor, not reaching in any case structural values. For the etched titanium and the grit blasting the failure is completely adhesive (see Fig. 5-A and B). So, these treatments seem hardly not to have a large effect on the adhesion. Indeed, when etching treatment is applied to the laser textures, the joint strength diminishes or has a slightly effect. Regarding laser textures, both enhance the resistance of the joint. However, T2 laser treatment does not have the enough roughness to create a strong mechanical interlocking with the composite laminate. Finally, putting a PEEK film in between of the laser treated-titanium and the composite favours the adhesion between both counterparts becoming the failure more cohesive (see Fig. 5-C and D). This effect is especially significant in the T1 laser treatment due to high roughness of the surface (Fig. 5-E and F and G). The beneficial effect of the film is probably because the tape has a high content of carbon fibres, so not enough resin is available to create a strong joint. This is more noticeable in the case of T1 in which some deep cavities are presented on the surface and should be filled in. (Fig. 3). Fig. 6 and 7 show some details of the laser textures interfaces where the effect of the film on the type of failure is clearly shown, remaining part of the resin on the titanium face for both textures, mainly in T1. In conclusion, with T1 laser treatment, the increase of the mechanical resistance compared with the etching and the grit blasting is between 595-916% respectively. With a 400 µm PEEK film for T1, this percentage is even increased up to 2500% compared with the etching treatment.



**Figure 5.** Interface of the Ti-CFTPCs joints after the SLJ tests for the etching and laser textures surface treatments: (A & B) Etching and grit blasting, Failure: 100% adhesive; (C) T2 without film, failure: 100% adhesive; (D) T2 with 60µm and (E) T2 with 200 µm film, failure: mostly adhesive; (F) T1 without film, failure: mixture of adhesive and cohesive; (G) T1 with 200 µm film and (H) T1 with 400 µm film; failure: mostly cohesive.



**Figure 6.** Details of the interface for the T2 laser texture after the SLJ tests showing resin remains on the samples with film: (A) T2 without film; (B) T2 with a 60 and (C) T2 with a 200 µm film.



**Figure 7.** Detail of the interface for the T1 laser texture after the SLJ tests showing more resin remaining on the samples with and without film: (A) T1 without film; (B) T1 with a 200 and (C) T1 with a 400  $\mu\text{m}$  film.

#### 4. Conclusions

The effect of laser textures on the joint strength of titanium alloy-CFTPCs based on PEEK direct joints has been analysed. This effect is compared with other surface treatments like chemical etching and grit blasting. Laser textures enhance the adhesion of the dissimilar joints due to the higher roughness on the surface that favours the mechanical anchoring of the PEEK matrix on the surface. Putting a PEEK film on the interface increase even more the joint strength reaching values between 14 and 20 MPa in the case of the T1, values that are considered structural. The joint strength is increased by a 2500% putting a 400 $\mu\text{m}$  of PEEK film compared with the etching surface treatment. For T2 using a large thickness of film creates a detrimental effect on the strength. This effect is due to the thickness is quite larger than the roughness value of the surface. In general, putting a PEEK film in between of the laser treated-titanium and the composite favours the adhesion between both counterparts becoming the failure more cohesive.

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