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Eco-efficient manufacturing of horizontal tail plane (HTP) structures for next-generation aircrafts – the role of surface pretreatment for adhesive joints

Uwe LOMMATZSCH [1†], Bernhard Schneider [1], Karsten Thiel [1], F.M. de la Escalera [2]
[1] Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Wiener Str. 12, 28359 BREMEN, Germany
[2] Aernnova Engineering Division, Llano Castellano 13 5º, 28039 MADRID, Spain
uwe.lommatzsch@ifam.fraunhofer.de, bernhard.schneider@ifam.fraunhofer.de, karsten.thiel@ifam.fraunhofer.de
federico.martindelaescalera@aernnova.com
† Corresponding Author

Abstract
Hybrid Laminar Flow Control (HLFC) concepts allow to reduce the CO_2 footprint arising from skin-friction. A key technical issue is to build the HLFC structure as light and as cost-efficient as possible. This goal can be achieved by adhesive bonding of a microperforated titanium panel to a composite substructure. High demands on the durability of the adhesive joint exist, requiring adequate surface pretreatment. Here we report on the pretreatment to improve bond strength and bond durability by laser as a pretreatment alternative to chemical tank processing consuming large amounts of energy and harmful chemicals. Surfaces are analyzed by XPS and SEM while fracture toughness is determined from DCB testing. In addition, the successful manufacturing demonstration of the laser pretreatment on an industrial scale is shown.

1. Introduction

Reducing the CO_2 footprint is a key issue for the aero-industry in Europe. Hybrid Laminar Flow Control (HLFC) concepts allow for drag reduction arising from skin-friction. The HLFC technology aims to remove turbulent flow at the main areas of the horizontal stabilizer, the fin, or the wings by means of a suction system. Thereby high-lift performance is improved, additional engine thrust is avoided and consequently extra fuel burn and CO_2 emissions are reduced. A key technical issue is to build the HLFC structure as light and as cost-efficient as possible. This goal can be achieved by adhesive bonding of a microperforated titanium panel to a composite substructure housing the suction system. However, high demands on the structural integrity and durability of the adhesive joint exist. These requirements demand adequate surface pretreatment of the titanium panel, which today is typically achieved by chemical tank processing consuming large amounts of energy and harmful chemicals [1,2]. Here we report on the study of laser treatment to improve bond strength and bond durability as an alternative for this task. In addition, manufacturing aspects of the laser pretreatment on an industrial scale are highlighted.

2. Experimental

The IR laser system was from Cleanlaser (Nd:YAG CL300) with emission at 1064 nm. The UV laser system was from Coherent (CompexPro205 F) with emission at 248 nm (KrF). The titanium surface was analyzed by scanning electron microscopy (SEM) using a LEO Gemini 1530. Grade 2 titanium was bonded with RTM6 resin and cured at 180 °C for 45 min. For DCB testing a sample size of 110x25 mm was used. The thickness of the titanium was 0.8 mm and the thickness of the RTM layer was 0.2 mm. The non-standard cure cycle and specimen dimension were chosen to facilitate a *relative* comparison of the pretreatment.

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3. Results and Discussion

IR laser and UV laser were compared for pretreatment of grade 2 titanium that was subsequently bonded with RTM6 resin. We will report on chemical surface modifications by XPS and EDX measurements with focused ion beam (FIB) preparation for cross-section analysis. Changes of the topography were analyzed by electron microscopy. DCB testing was used to correlate the adhesion properties of the titanium surface with the surface modifications. Testing of samples aged for 3000 h at hot/wet conditions showed no significant decay in fracture toughness and a cohesive failure mode. The results indicate that treatment with IR lasers can potentially be used successfully for pretreatment of titanium to manufacture titanium/composite adhesive joints of high quality and durability as required by the aero-industry. Furthermore, the laser pretreatment provides a « green » manufacturing technology eliminating the need of wet chemical processing of titanium.

For surface preparation the titanium surface was pretreated using the IR laser or the UV laser. Fig. 1 compares the surface modification as observed with a scanning electron microscope (SEM) for the different treatments.

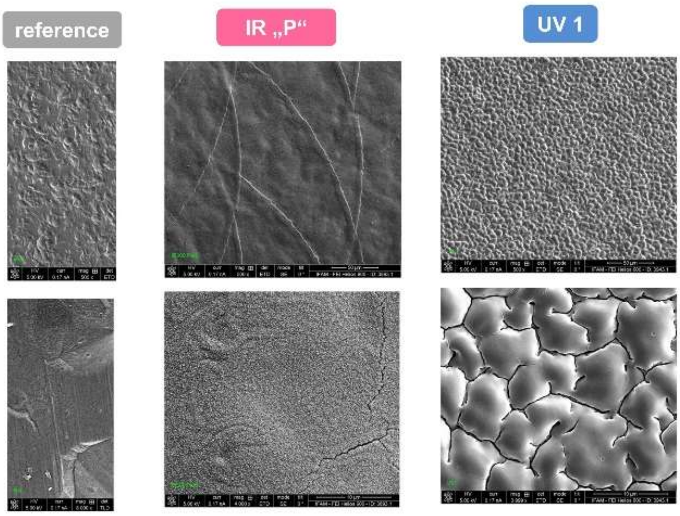

Figure 1: SEM images of the titanium surface. Magnification is 500x and 4000x for top and bottom row, respectively.

In comparison to the reference titanium surface both laser treatments alter the surface topography significantly. The IR laser treatment leads to the formation of a porous-like structure at the surface and the specimens are denoted “IR P” in the following. In contrast, the UV laser treatment induces a clod-like structure with superficial cracks at the surface and the corresponding specimens are denoted as “UV 1”.

To check the durability and bond strength, the surface of titanium specimens were prepared by the different laser treatments shown in Fig.1. Subsequently, specimens were bonded with RTM6, aged under hot/wet conditions (80 °C and 50% rH) for up to 3000 h and then tested using DCB-type testing.

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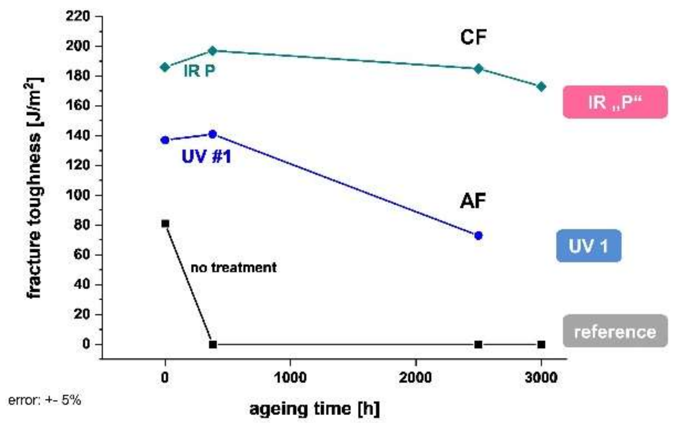

Figure 2: Fracture toughness as a function of ageing duration using non-standard specimen geometry.

Fig. 2 shows the fracture toughness as a function of ageing duration for the different laser pretreatments. Both, the reference samples and the UV laser treated samples show a strong decrease in fracture toughness with ageing duration. Also in both cases an adhesive failure mode (AF) is observed. In contrast, the specimens with IR laser treatment do not show a decline in fracture toughness, even after 2500 h of ageing. As Fig. 3 shows, also a cohesive failure mode (CF) is still observed after this time.

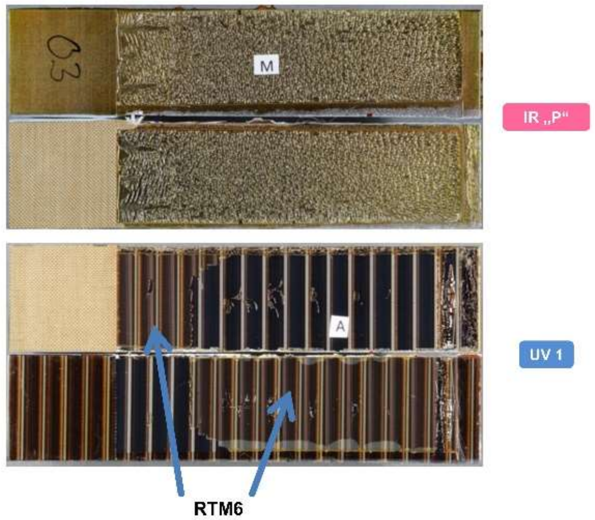

Figure 3: Fracture surface after DCB testing for IR and UV laser treatment after 2500 h of ageing.

The excellent stability of the titanium surface towards hot/wet exposure conditions can be also seen from Fig. 4.

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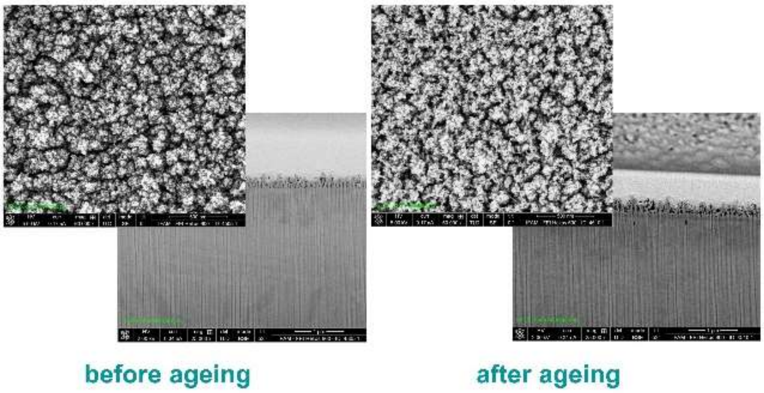

Figure 4: SEM images of the porous titanium surface in top view and as cross-section. (Magnification 60,000 x for top view and 25,000 x for cross section)

Fig. 4 shows the titanium surface after IR laser treatment before and after ageing (1000 h) in top view and as a cross-section. For this experiment the bare titanium surface was exposed to the environment in the climate chamber. No significant change in topography or thickness of the porous titanium layer by the hot/wet conditions is observed. This property of the titanium surface is considered to be essential in achieving a durable adhesive joint as shown in Fig. 2.

The results indicate that treatment with IR lasers can potentially be used successfully for pretreatment of titanium to manufacture titanium/composite joints of high quality and durability as required by the aero-industry. In addition, the laser treatment provides a « green » manufacturing technology eliminating the use of wet chemical processing of titanium. Fig. 5 displays the pretreatment facility in our lab that was used to develop a pretreatment process for leading edge panels up to a length of 2 m with double curvature, as e.g. occuring for the HTP in the Airbus A350. Of key importance for this process is to control the correct focus distance and incident angle of the laser beam hitting the surface. This has been achieved by using a unique laser scanning device that allows to control these parameters computer-controlled by a movable optical system. The time for laser pretreatment of a typical leading edge panel is on the order of 20-50 mins (without mounting effort). This reduces the time in comparision to wet chemical tank processing largely while simultaneously producing nearly no waste and consuming much less energy.

Figure 5: Facility for laser pretreatment of large, complex curved structures at Fraunhofer IFAM.

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