OPTIMIZING COMPOSITE REPAIR TECHNICS

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Abstract

In this paper a brief analysis of the results of a laser ablation repair process is presented in order to investigate the mechanical behavior and properties of scarfed repaired composite specimens and compare them with pristine and damaged specimens. For the material removal, two methods of machining were used, milling and laser, in order to confirm which one provides better surfaces to enhance adhesive bonding. Also, two different repair methods were adapted, the wet repair and the dry repair. Such a process was systematically investigated to the direction of identifying the influential parameters that entails the maximization of the mechanical properties of the repair. On a second step the results of the experiments fed finite element models in order to investigate influence the repair geometry to the repair structure strength showing that the repair geometry influence’s the repair strength.

1 Introduction

The repair of aeronautical structures has always been an issue of the highest technological importance for the aviation industry. Common methods for repair involve the mechanical removal of material usually with a hand-held router. Manual scarfing cannot obtain highly precise geometries and requires a highly skilled technician. Also, after the peel-ply removal, the surface is covered with a relatively thick resin film thus, the adhesive binds to this layer and not directly to the fibres which results in a potential weak layer and hinders direct transmission of force into the fibres.

In this study, a developed laser module was envisaged to perform stepped lap material removal on composite plates. Laser processing can support a precise ply-by-ply removal in composite structures and a complex load path optimized geometry is feasible. This way higher ultimate peel stress and interlaminar tension shear strength of the repaired area are anticipated [1-3]. The interaction of the laser with polymer composites can modify the physical and chemical properties of the material through photo-thermal and photo-chemical processes depending on the laser parameters and material properties [4, 5]. The goal of this study is for the repaired specimens to have recovered a significant portion of the original strength.

2 Repair manufacturing

The results of the repair process (strength and integrity restoration) greatly depend on the conditions under which the repair took place and a test campaign was necessary in order to identify the influence of the material removal process, tool against laser, as well as the repair patch type, wet against dry, on the results. The road map of the test campaign is illustrated in Figure 1.

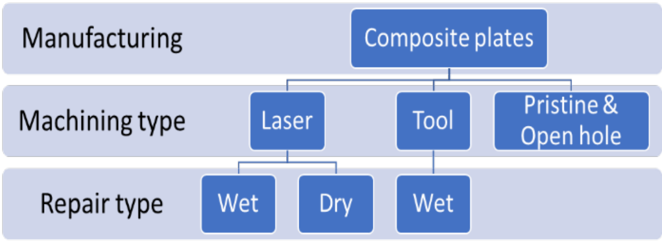

Figure 1 The road map of the test campaign

The material removal setup involved an IPG-GLPN green laser with a mean power of 20 Watt, wavelength at 532 nm, pulse duration <2 nsec and maximum pulse repetition frequency at 600 kHz. A CNC table was used to guide the laser head as well as a special lens with a 150mm focal length was used. A test campaign was necessary in order to identify the influential parameters that affected critical quantities such as the size of the Heat Affected Zone (HAZ) in 3 different areas, the material removal rate (RR) as well as the shear strength (SS) of in-house manufactured CFRP single-lap bonded joints. The near-optimum parameters for the laser process with minimum HAZ, maximum SS and RR as the objective are determined at $f \approx 500\ kHz$, $V \approx 1570\ mm/min$ and $HD \approx 171\ \mu m$ as they extracted from the Response Surface Methodology analysis and the obtained models.

For the material removal, two methods of machining were used in order to confirm which one provides better surfaces to enhance adhesive bonding, Figure 2. One was milling, a conventional machining, and the other was laser machining. The expected result is that the laser machined surface will provide a smoother surface, which enhance bonding. After manufacturing, each plate was inspected under a stereoscope, as is a common method to evaluate the quality of a pretreated surface [6, 7]. This inspection was performed in order to compare the surface quality that was achieved with each of the machining methods (milling, laser machining), Figure 2. As expected the laser machined surface was uniform and of higher quality that the milled one.

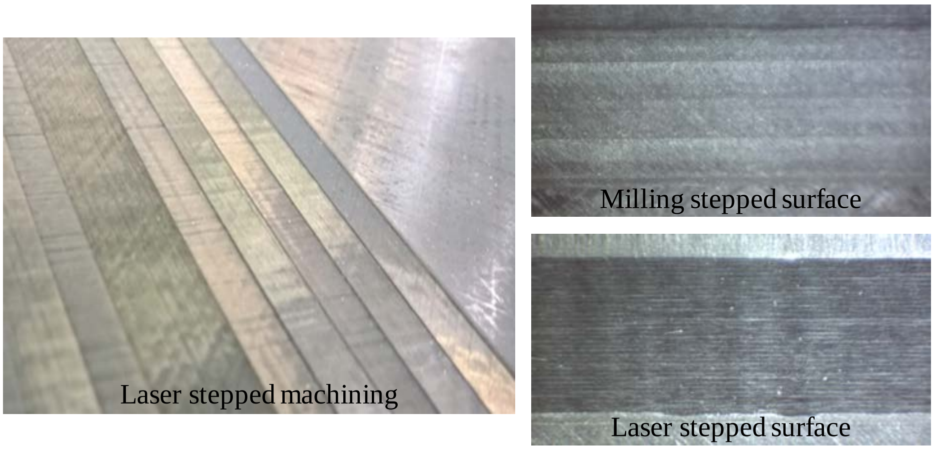

Figure 2. On the left an example of a stepped lap material removal on composite plate is presented. On the right the surface quality of milling and laser stepped surfaces are presented.

After creating the stepped geometry needed for the repair, the patches were fabricated. Pre-pregs were placed using the same stacking sequence as the one of the original plate in the removed cavity and are then cured with a film of adhesive. In dry repair the patch the patch was manufactured by using the contours of all the steps as references. The layer orientation and stacking sequence matched the stacking sequence of the original plate as did in the wet patch approach. The patch was then cured separately in the autoclave. After the autoclave the cured patch was laser machined so as to fit in the cavity steps. The dry patch was applied and bonded with the same adhesive film as in the wet patches.

3 Predicting the repair behaviour

Two step specimens were tested in tension in order to evaluate the adhesion of the bonding. The test results were compared in detail against the numerical findings both at the level of stiffness and strength as can be seen on the left in Figure 3. The effectiveness of stepped repair to damaged fiber reinforced composite materials was investigated by using validated FE numerical models. Attention was given at the actual failure modes of composites including delaminations. All FE models took into account the anisotropy in each ply in the laminate and in the repair patch by splitting the laminates to sublaminates. This method was introduced in order to take into consideration the effect of delamination caused by the failure between the plies due to shear stresses. Parametric studies were carried out in order to compare forces, displacements, stresses and stiffness properties. Namely, models were analyzed depending on the overlap segment's length with repair scarf ratios varying from the value of 20 to the value 60 with a step increase of 10. The FE models allowed a direct comparison of the influence that the step length to ply thickness ratio had to the strength and stiffness restoration of the repaired composite structures, on the right in Figure 3, as well as at the level of full field developed strain around the repair patch at different loading stages. It seems that a repaired specimen with a 1/60 step ratio could increase by 20% the strength of the defective specimen.

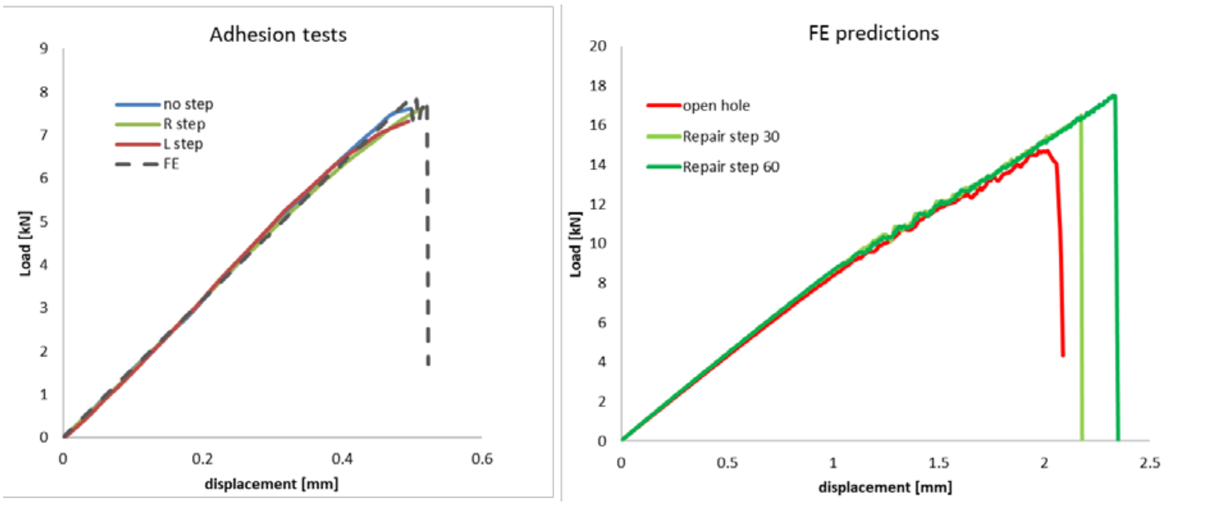

Figure 3. Left: two-step tensile tests are compared with FE model for adhesion modelling evaluation, Right: FE model predictions for open hole and repaired specimens

4 Conclusions

At this study the influence of different repair strategies was investigated. The laser material removal process gave surfaces that were in a higher quality level than the milled ones. On the same time the two-step test didn't reveal a big strength difference but provided helpful input data for the developed models.

At the modelling level, the developed models was fed with real damage data and evaluated the stiffness and strength degradation due to damage showing that a scarf ratio of 60 can increase by 20% the strength of the defective specimen. More results and details can be seen in the conference presentation.

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