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Fatigue analysis of adhesive joints with laser treated substrates

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Abstract

Recent literature works focused on the analysis of laser irradiation on the strength of adhesive joints under quasi-static loading conditions. It has been demonstrated that laser surface preparation allows to remove impurity and weak boundary layers from the mating substrates and, depending on the energy density, it is also able to modify surface morphology promoting mechanical interlocking. In previous works, the authors assessed the effect of Yb-fiber laser ablation over the quasi-static strength and toughness, of aluminum and stainless steel adhesively bonded joints. The experimental results demonstrated the ability of laser irradiation to improve the mechanical properties of the joints. The aim of this work is to extend the scope of previous investigations to fatigue loading. Double Cantilever Beam (DCB) samples with laser treated aluminum substrates have been bonded with a two component epoxy adhesive. For comparison standard degreasing and grit blasting have been also deployed for samples preparation. The results have been compared in terms of cycles to failure and the fracture surfaces have been analyzed by means of Scanning Electron Microscopy (SEM) in order to investigate the mechanism of failure.

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1. Introduction

Adhesive bonding is widely used in several industrial fields since it usually allows good mechanical performances, cost reduction and lightweight design if compared with traditional techniques. In general, the mechanical strength of a bonded joint depends on the strength of the adhesive itself (i.e. cohesive strength) and on the strength of the interface between the adhesive and the substrate (i.e. adhesive strength).

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Nomenclature

P	Laser nominal power [W]
f	Lasing Pulse Frequency [kHz]
LS	Line spacing [µm]
d_S	Laser Spot Diameter [mm]
v	Lasing Speed [mm/s]
B	Joint Width [mm]
W	Joint Length [mm]
H	Substrate Thickness [mm]
t_a	Adhesive Thickness [mm]
a	Crack Length [mm]
a_0	Initial Crack Length [mm]
E_S	Substrate Young Modulus [MPa]
υ_S	Substrate Poisson Ratio
E_A	Adhesive Young Modulus [MPa]
υ_A	Adhesive Poisson Ratio
P_{max}	Maximum Load in a fatigue cycle [N]
P_{min}	Minimum Load in a fatigue cycle [N]
ΔP	Load Range in a fatigue cycle [N]
R	Load Ratio
δ	Opening measured by the omega clip gauge [mm]
G_{max}	Maximum Strain Energy Release Rate in a fatigue cycle [N/mm]
G_{min}	Minimum Strain Energy Release Rate in a fatigue cycle [N/mm]
ΔG	Strain Energy Release Rate Range in a fatigue cycle [N/mm]
λ_σ	Parameter of the Krenk (1992) model [mm^{-1}]
S_a	Surface Roughness [µm]

For a given adhesive, the joint strength can be improved by means of the several surface treatments that have been proposed in recent literature work, see for instance Alfano et al (2012), Chiodo et al (2014,2015) and Rotella et al (2016). These treatments aim to clean the surface by removing oxides and impurity and to induce modification in surface chemistry so that to achieve long-term durability.

Mechanical treatments usually consist of sand or grit blasting and their effectiveness on joint strength was evaluated for example by Mandolfino et al (2013). The variety of chemical treatments is instead wider, and the choice mainly depends on the kind of substrates selected for bonding. An overview of the available chemical treatments for aluminum substrates was provided by Critchlow and Brewis (1996).

However, these methods show a few drawbacks especially in terms of process control and repeatability, and from an environmental point of view (i.e. disposal of hazardous chemical waste). Therefore, cleaning and activation processes based on the use of plasma or laser beams represents nowadays a promising alternative to traditional methods. The effect of laser ablation over the quasi-static strength of bonded joints was investigated by Rechner et al (2010), Kim et al (2010), Wong et al (1997) Alfano et al (2012), Chiodo et al (2014, 2015). It was observed that laser ablation enhances the adhesion strength by removing impurity and promoting mechanical interlocking. However, several works analyzed the joint behavior under quasi-static loading while the effect of cyclic fatigue loading received less attention.

This work aims to fill this gap and is devoted to the characterization of the mode I fatigue resistance of adhesive bonded aluminum Double Cantilever Beam (DCB) bonded joints before and after laser surface irradiation. In particular, for comparison grit blasted and degreased joints were also prepared and tested in order to understand the effectiveness of the laser treatment. The results were compared in terms of fatigue crack growth rate as a function of the applied range of strain energy release rate.