MECHANICAL RESISTANCE ASSESMENT OF 316L STAINLESS STEEL ADDITIVELY-REPAIRED STRUCTURES

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Abstract

To quickly characterize the static and cyclic mechanical strength of a structure repaired by additive manufacturing, a specific specimen is developed and then repaired using two processes with adjustable parameters. The fundamental role of the microstructure in the vicinity of the repaired area in the initiation and propagation of cracks is highlighted and discussed

1. Introduction

Actually, whether from an environmental or economic perspective, it is becoming incoherent to use materials without worrying about their manufacturing cost, their lifespan or their reparability. The scarcity of certain materials and the financial and environmental costs of producing high value-added parts naturally raise the question of maintenance and repair. Recently, so-called "additive manufacturing" processes have shown possibilities in the way components can be redesigned from the viewpoint of shaping materials sometimes difficult to access using conventional processes. These processes are also becoming mature to proceed in the repair of damaged structures [1]. Whatever the industrial field considered, the choice of a repair and/or recovery strategy remains a complex problem. The main objective here is, therefore, to provide elements to justify a repair strategy based on experimental protocols aimed at improving the understanding of the phenomenon. In this paper, two repair processes are studied. They are the Laser-Direct Energy Deposition (L-DED) and the Cold Spray (CS). The L-DED uses a coaxial laser with a metal powder flow that is melted at the focal point. The laser power, the deposition rate and the powder flow rate have a strong influence on the quality of the deposited bead, while the overlap between the layers, the substrate thickness and the deposition strategy are of primary importance in the quality of the repair produced [2]. For the CS, the smaller metal powder is sprayed at high speed onto the substrate with adhesion that is then a function of its ductility and the occurence of mechanisms like adiabatic shear quality of the sprayed flux. Here, 316L stainless steel is used both as a base material and as a powder to perform the repair. The powder used for the L-DED has a larger particle size than the one used for the CS, but it also has a higher silicon content.

2. Results

The versatility of the repair processes and the associated post-processing allows to generate large panels of microstructures, so that it becomes time-consuming to proceed to in-depth characterizations. This observation imposes the use of a rapid selection method for the best candidates (materials - deposition processes - deposition strategy - heat treatment). To quickly characterize the repair technique, a specific cylindrical specimen was developed to represent a damaged area through machining, which was then filled with a material deposit of several layers in thickness. These specimens, whose dimensions are based on ASTM standards, were first analyzed in terms of the microstructure of the repaired areas. For the L-DED process, a good metallurgical bond between the substrate and the insert material is noted. However, a detailed analysis of the microstructure reveals some weakened areas but also short cracks similar to ductility-dip cracks. The application of a heat treatment also tends to cause the appearance of large grains at the repair interface instead of recrystallization in the rest of the structure. For the CS process, there is a porosity (quite low in our case) inherent to the repair method and imperfect adhesion with the substrate. The material also shows a high degree of brittleness in the absence of heat treatment. These specimens are then subjected to tensile tests that allow to make a first ranking the repair strategies and underline higher elasticity limits for the CS specimens but a much lower elongation at break and a decohesion of the interface from a certain level of deformation. The presence of defects in the microstructures, likely to cause local plasiticty under cyclic loading, leads to the use of self-heating tests not to determine an endurance limit as it is traditionally done [3], but to discriminate the best candidates in terms of repair and mechanical resistance of the repair interface. After measuring a sufficient self-heating, these tests are carried out until failure under cyclic loading and the initiation and propagation zones are then studied in detail to better understand the role of the repair interface in fatigue damage. In this framework, the strength of the repaired specimens is close to that of a specimen without repair, but with a larger statistical dispersion. Multi-crack initiation at the interface is systematically observed, with a major role played by the defects.

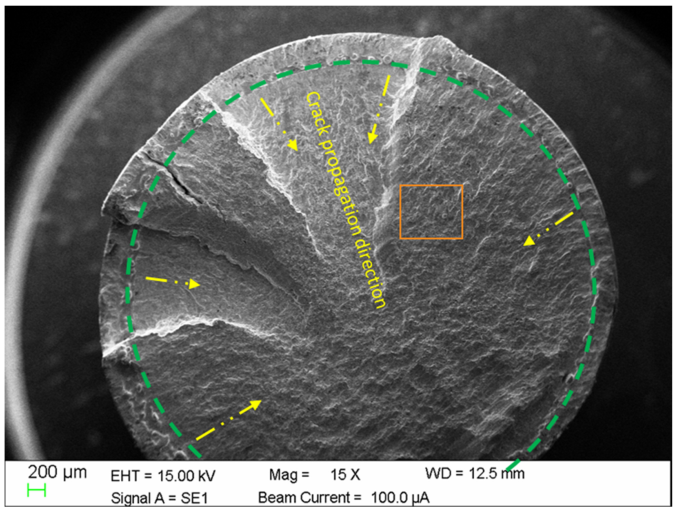

Fig.1 – Post-mortem analysis of a specimen repared by L-DED. Highlighting of defects at the interface and multiple zones of initiation and propagation

3. Conclusions

A rapid characterization of the mechanical strength of L-DED and CS repairs was developed and used to conduct tensile and cyclic loading test campaigns via self-heating tests. A major role of the deposition and post heat treatment parameters on the microstructure has been demonstrated. Despite the presence of many defects in both processes, the cyclic loading resistance seems to be close to that of an unrepaired specimen.

Acknowledgments

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