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FRACTURE TOUGHNESS OF A DUPLEX STAINLESS STEEL BUILT BY DIRECTED ENERGY DEPOSITION : EFFECT OF THE DEPOSITION DIRECTION

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Abstract

Additive manufacturing of duplex stainless steels (DSS) has recently seen some research interest. In particular, the use of directed energy deposition (DED) is still new and the fabricated materials remain to be fully characterized. In addition, materials produced by additive manufacturing can present anisotropic fracture properties. This study aims to characterize the fracture toughness of a DSS manufactured by DED, taking into account the orientation with regard to the printing strategy.

1. Introduction

Nowadays, mechanical properties of metals produced by additive manufacturing can meet or even exceed those of their traditionally produced counterparts [1]. Recent studies have shown that some plastics [2] and metallic materials [3] produced by additive manufacturing can present a nearly isotropic elastic behavior coupled with anisotropic fracture behavior, due to their specific microstructure. The elaboration of Duplex stainless steel by Directed Energy Deposition (DED) has recently seen research interest and the properties of the deposited material remain to be fully characterized [4].

The current study aims to investigate the fracture toughness of such a material, taking into account the direction of propagation with regard to the deposition strategy.

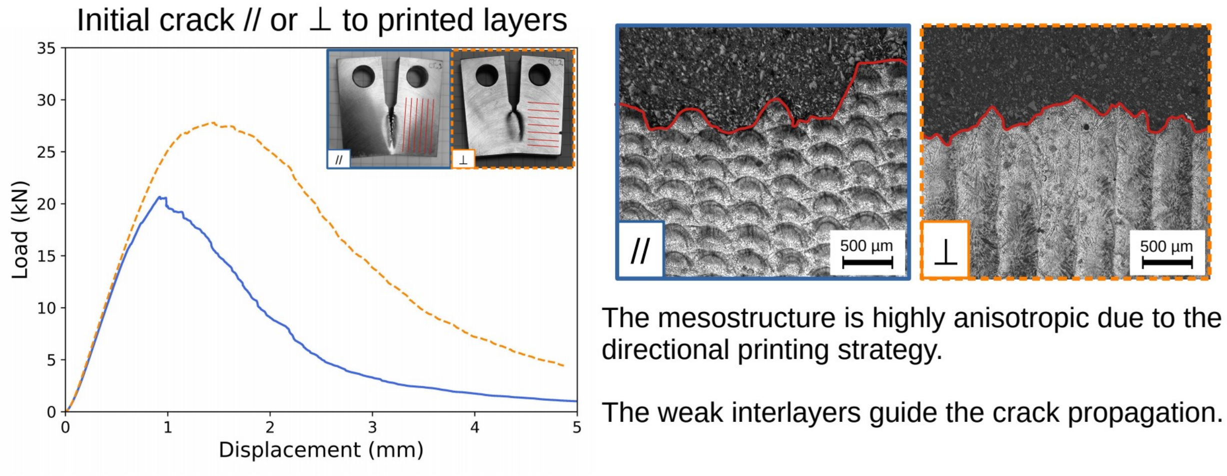
2. Results

Dense volumes are built so that the printed tracks are all mutually parallel. To do so, each layer is printed identically, with a back and forth sweeping strategy. From these volumes, compact tension (CT) fracture specimens are machined, with the notch oriented to be either parallel (//) or perpendicular (⊥) to the layers of the print. Each specimen is pre-cracked in cyclic fatigue. The fracture behavior of specimens for both orientations is then studied through a quasi-static tensile rupture test. A slow growth of the crack is observed during the tests.

The two configurations show noticeably different behaviors (Figure 1, left). The apparent stiffnesses are found similar with identical behaviors in the elastic regime. Meanwhile, the measured maximum loads and estimated fracture toughnesses are significantly different. Additionally, the crack surfaces present different geometries : relatively flat for the // specimens and with shear lips for the ⊥ ones.

Metallographic analysis of the bulk material is performed to evaluate the effect of the building strategy on fracture. The former highlights three scales of interest in the material structure which can potentially explain the fracture anisotropy. First is the whole mesostructure, formed by all the printed layers and tracks, and which is directly imposed by the printing strategy. Second comes the scale of a single track for which heat reaffected zones can be recognized. Finally comes the scale of ferrite and austenite phases, which present different distributions in the heat reaffected zones and in the rest of the material.

An additional observation of a cut perpendicular to the cracks surfaces (Figure 1, right) proves that the interlayers constitute planes of weakness for crack propagation. Therefore, it is the highly oriented mesostructure which dictates the fracture behavior and its anisotropy.



The mesostructure is highly anisotropic due to the directional printing strategy.

The weak interlayers guide the crack propagation.

Fig.1 – Left : Load versus Displacement measured during the fracture tests. Right : Microscope observations of a cut perpendicular to the crack surfaces after electrolytic etching. Red lines indicate the fracture surfaces.

3. Conclusions

These experimental results show that an as-built DSS manufactured by DED presents fracture anisotropy, while the apparent stiffness is isotropic. This anisotropy stems from the mesostructure which is inherited from the strategy of deposition. Therefore, care should be taken in the design of practical pieces elaborated with this process.

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4. References

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