Optimizing laser power of directed energy deposition process for homogeneous AISI M4 steel microstructure

Rúben Tome Jardin [1], Víctor Tuninetti [2,*], Jérôme Tchoufang Tchuindjang [3], Laurent Duchêne [1], Neda Hashemi [3], Hoang Son Tran [1], Raoul Carrus [4], Anne Mertens [3], Anne Marie Habraken [1,5,*]

[1] Department ArGEnCo-MSM, University of Liège, Liège 4000, Belgium

[2] Department of Mechanical Engineering, Universidad de La Frontera, Temuco 4780000, Chile

[3] Department A&M–MMS, University of Liège, Liège 4000, Belgium

[4] Sirris Research Centre (Liège), Seraing 4102, Belgium

[5] Fonds de la Recherche Scientifique–F.R.S.-F.N.R.S., Brussels 1000, Belgium

* Corresponding authors: victor.tuninetti@ufrontera.cl (V.T.); anne.habraken@uliege.be (A.M.H.);

Supporting Information

Observations related to Macrocracks

Macro cracks are present in both CP and LPF1 samples and the reasons for the assumption of their post-mortem occurrence is similar for both deposits. Several consistent arguments can be presented, to justify the fact that the cracks observed on the CP and LFP1 samples occurred only after their fabrication.

As the first evidence, it can be reminded that there were no visible cracks on the as-built deposits, as shown in the following figures that are related to sample LPF1 (Fig. S.1). The same result was obtained for sample CP.

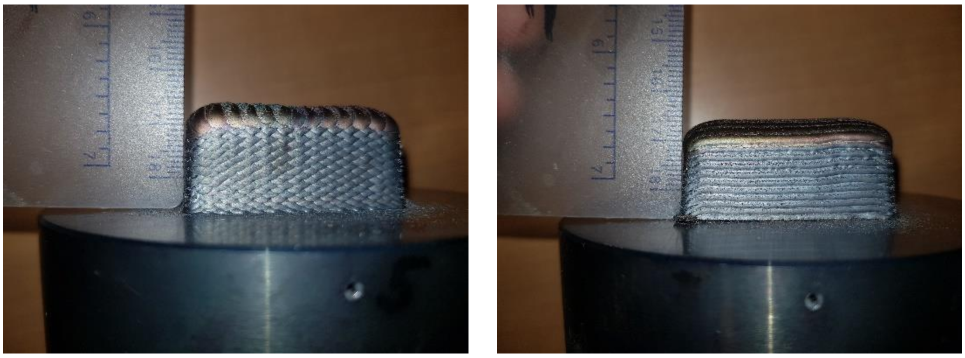

Fig. S.1: Both sides of LPF1 sample in the as-built conditions, with no visible cracks within the As built deposit.

Cracking that occurs during laser processing for multilayer deposit are known as longitudinal cracks that can be found parallel to both the thermal gradient and the building direction. Therefore, both their shape and direction are also linked to this thermal gradient, which is parallel to the building direction [1]. Nevertheless, it has been well established that achieving preheating of the substrate during AM processing can significantly reduce the thermal gradient and thus increase the crack resistance [2,3]. With their horizontal (CP) to oblique orientation (LFP1), none of the cracks present within both samples are parallel to the building direction, which makes the second evidence for the post-mortem assumption (see Fig. 8a).

SEM analyses performed on both CP and LPF1 samples, leads to the third proof of evidence. Within LFP1 sample, the crack path is of intergranular type (see Figs S.2b-c below).

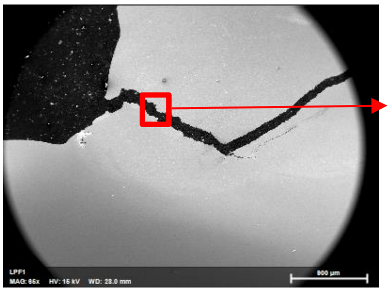

Fig. S.2a: Overview of the crack path on LFP1 (crack origin on the left and propagation to the right)

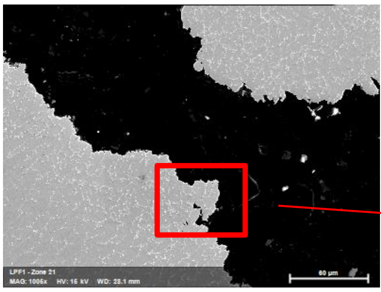

Fig. S.2b: Close-up view of the thinner region of the propagating crack

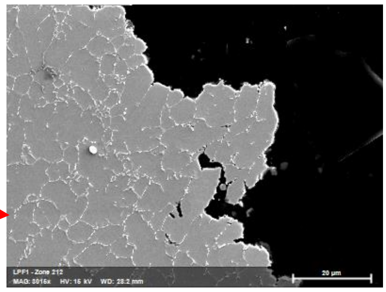

Fig. S.2c: Close-up view of the crack contour, showing an intergranular mode

An EDX mapping carried out on Fig. S.2c shows no preferential presence of oxygen within the crack contour (see Fig. S.3 below). This means that the crack was formed without any oxidation phenomenon, thus assuming the crack to appear only after achieving the deposit printing, when the sample was completely cool down. Again, this third proof of evidence accounts for post-mortem crack assumption.

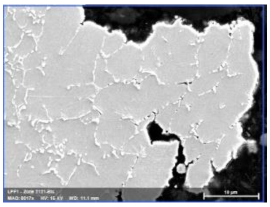

Fig. S.3a : reference for mapping, from Fig. S.2c

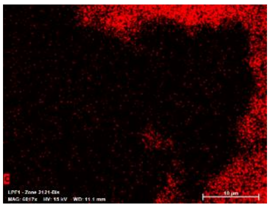

Fig. S.3b: C distribution after EDX mapping

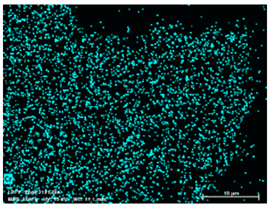

Fig. S.3c: Cr distribution after EDX mapping

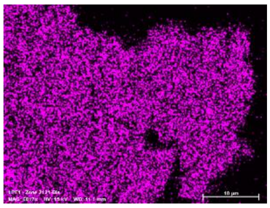

Fig. S.3d: Fe distribution after EDX mapping

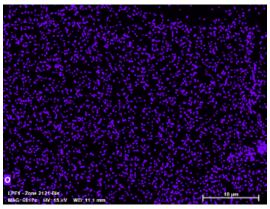

Fig. S.3e: O distribution after EDX mapping

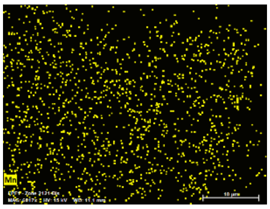

Fig. S.3f: Mn distribution after EDX mapping

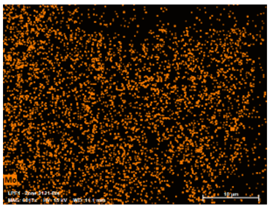

Fig. S.3g: Mo distribution after EDX mapping

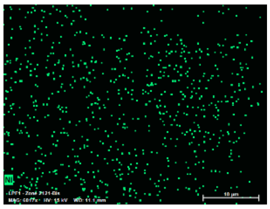

Fig. S.3h: Ni distribution after EDX mapping

Based on the thermal model developed in a previous work and presented within ref. [4], it has been established that due to preheating, it is possible to retain an austenitic phase within the whole deposit step during laser processing. The same result is achieved within the manufacturing of samples CP, LPF1 and LPF2 based on the computed material point histories. Therefore, martensitic transformation occurs only after switching off the laser, during the final cooling stage. Such a transformation yields a dilatation strain that can promote "tensile" residual stresses inside the deposit. But the cooling stage itself leads to contraction within the sample, at the same time. Now considering the work from ref. [5] and depending on the position of critical martensitic transformation points (Ms and Mf), a temporary relaxation of "thermal" residual stresses can occur, which is due to the so-called superplasticity effect appearing at the moment of martensite transformation. The higher heat accumulation achieved within LFP2 sample (see Fig. 7c) compared to both CP and LFP1 (see Fig 7a and b), and the higher homogeneity level within the same sample can be considered responsible for the better superplasticity effect that is achieved within this sample, leading to a better stress relief that avoids a subsequent cold cracking phenomenon. These conditions failed to be present within both samples CP and LFP1, thus leading to their subsequent cold cracking.

References

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