Additive Manufacturing of graded steels : fatigue and corrosion properties

I. Context, positioning and objective(s) of the project

Often, two materials are welded together to provide continuity in the structural part. However, these processes mechanically weaken the part and the corrosion resistance is often reduced. An example from the nuclear industry where austenitic stainless steels type 316L are used in areas requiring good corrosion resistance and martensitic steels, which are cheaper and stronger, are used in lower temperature areas. Today, additive manufacturing techniques are opening up a new route for joining materials. This was mainly highlighted by Flore Villaret in her thesis, using the Directed Energy Deposition (DED) process, which enabled her to produce steels with a chemical composition gradient (316L/9Cr) by controlling the dilution zones between the beads. The part was shown to have a chromium content gradient and therefore a hardness gradient, although the microstructure could not be completely controlled.

The proof of concept was limited to a few specimens, without being able to measure the complex mechanical (impact, fatigue) and functional (corrosion) properties. These properties are however essential from an application point of view and also raise several questions related to the role of the chromium gradient (and other diffusing elements such as carbon) on the mechanical and electrochemical behaviour of these new gradient junctions. From a mechanical point of view, the variation in mechanical properties suggests a competition between ductility and plasticity, particularly in fatigue. From a corrosion resistance point of view, a preliminary study on the materials resulting from the thesis revealed the susceptibility of the 9Cr steel to crevice corrosion. The overall electrochemical behaviour of the different materials developed did not reveal any galvanic coupling between the two materials (316L and 9Cr). A study of the local reactivity, using the electrochemical micro-cell and a preliminary result obtained by electrochemical microscopy (resolution of the order of a powder particle) confirmed the behaviour obtained at the larger scale.

II. Program

The goal is to develop chemically graded materials, and to characterise and understand their mechanical and corrosion behaviour, by linking chemical composition, microstructure and gradient properties. The steps of the thesis and the issues related to mechanics and corrosion are given below and schematised in Figure A-1.

1/ Step 1: Development of reference samples

Samples with homogeneous composition and chromium gradients will be developed by powder compaction (CIC) and laser melting of sprayed powders (DED-LMD-p). The two types of processes produce sufficiently different microstructures to expect different fatigue and corrosion behaviour. The powder compositions and manufacturing parameters will be modified to control the severity of the composition and property gradient.

2/ Step 2: Characterisation of electrochemical behaviour

The samples developed in stage 1 will be characterised electrochemically, from the global to the local scale. The focus will be on characterising the interfaces between the grains (presence of oxide or interdiffusion zone). The development of a traction device mounted on the electrochemical microscope could be envisaged.

3/ Stage 3: Characterisation of mechanical behaviour

The mechanical behaviour will be quantified on homogeneous samples and then on samples with a composition gradient:

(i) tensile mini-tests with digital image correlations, in order to highlight the microstructure/composition/properties link in the gradient

(ii) tensile/tensile fatigue tests and analysis of fracture surfaces and cracking path;

4/ Step 4: Optimisation of the chemical composition of the gradient according to the results obtained during the characterisations. This last step will aim to modify the chemical composition of the gradient by changing, for example, the chemical composition of one of the two powders in order to improve the properties (corrosion and/or fatigue) of the manufactured materials. This will depend on the nature of the results from the first campaign. The new powder composition identified could be produced by gas atomisation at INSA.

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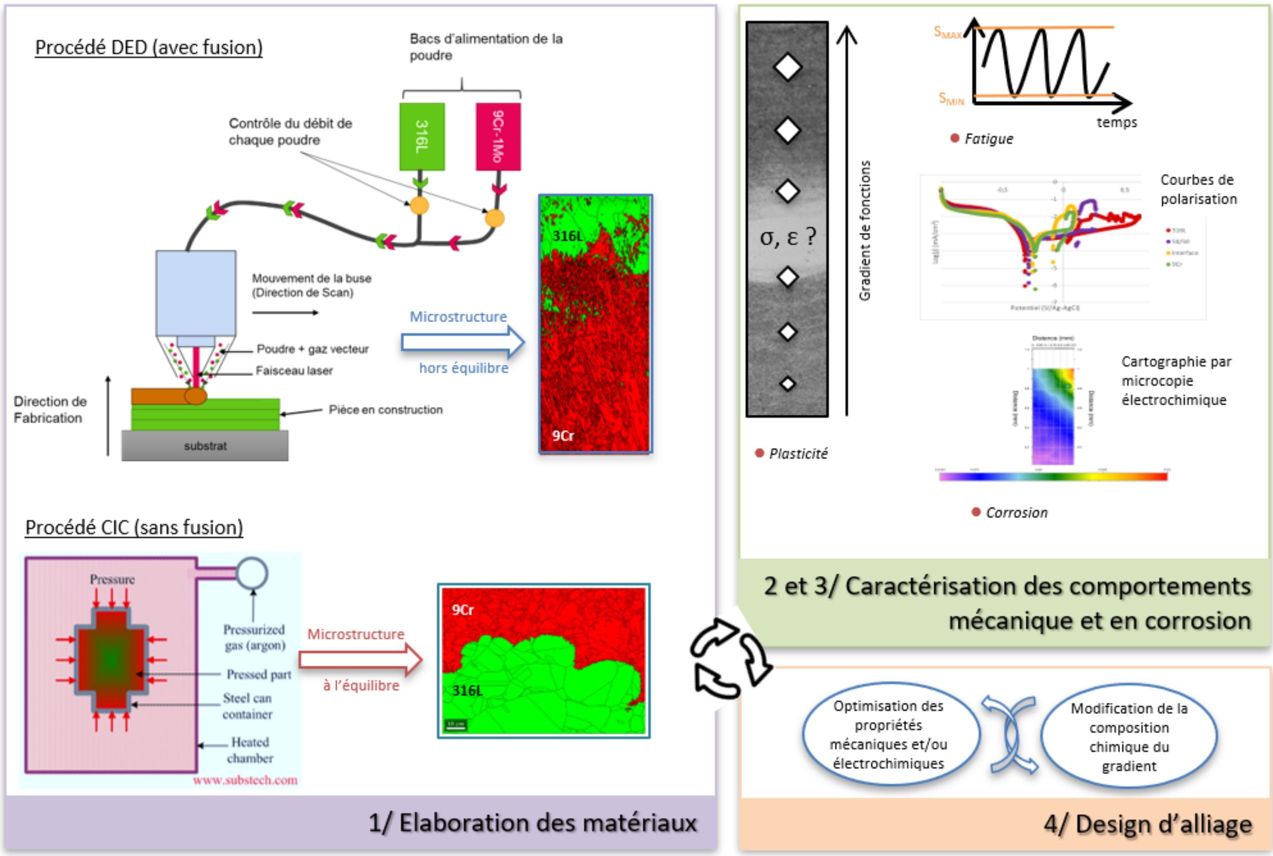

***Figure A-1** : Thesis program (in french !)*

Two labs involved :

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Salary :

- 1650-1700 net / month
- Possible to make lectures and practical works at INSA Lyon (complementary salary in that case).

Application to be sent before 2d of may, 2023 (CV and marks from Masters 1-2).