Proposal of CSC thesis

Development of the laser cladding process for additive manufacturing of pieces with composition gradients – experimental and modeling approaches

Proposed by
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Context: This multidisciplinary project aims at developing an innovative additive manufacturing process for the fabrication of pieces with composition gradients (*i.e.,* such as transition from a first metal or alloy to another one). The suggested system will be complementary in comparison with processes already available at UTBM (i.e., selective laser melting: SLM) since several years. SLM machines use a laser beam displaced by mirrors driven by stepper motors to melt selectively a powder bed and elaborate pieces by deposition of successive layers, each one consisting of juxtaposed welds. However, it is difficult to envisage the fabrication of pieces with composition gradients by SLM for many reasons. In particular, this type of machines often uses a single powder tank to deposit the successive layers of powder, and the thickness of each solidified layer is of the same order in comparison with the powder size itself. It is thus difficult to envisage the use of two distinct powder tanks to deposit a mixture of powder with a regularly graded distribution across the thickness of the piece to manufacture. For this reason, it is here envisaged to use an alternative strategy. Facilities available in the ICB platform of Le Creusot (LTM team) will be used to manufacture pieces with composition gradients by a different way. In particular, the platform is equipped with a high power continuous laser (TRUMPF Trudisk 6001, *i.e.*, up to 6 kW with a 100 µm (or higher) beam diameter) and a cladding head allowing melting and deposition of powder injected around the laser beam. In addition, two different powder distributors may allow varying simply and progressively the rate of two distinct powders during the manufacturing process, thus allowing manufacturing simply pieces with composition gradients.

Technological objectives: the main idea of this thesis project is thus to manufacture pieces with composition gradients. One can imagine for example a wall (or a duct) with 316L stainless steel on one side and invar or titanium (examples among others) at the other side. This process with thus allow avoiding welding the two materials with a subsequent fast transition giving rise to strong metallurgical problems. In the default facility available at LTm, the laser beam if transported (by optical fiber) to a machine equipped with the cladding head and a table allowing to displace the piece to manufacture. However, an alternative approach is also envisaged, consisting in moving the cladding head (and thus the laser beam) with a robot to manufacture a fixed part. Concerning this part of the work, two different KUKA robots (namely KR6 and KR60 type) are already available in the platform. Although these robots were mainly used for TIG and CMT welding operations up to now, they are perfectly usable for the present application.

Modeling work: the suggested process will be studied by both experimental and modeling approaches. In particular, strong deformations may take place during the manufacturing process, due

to the materials solidification and fast cooling. The elaboration process (full piece manufacturing) will thus be studied with the FEM ANSYS software (available on both sites, *i.e.,* ICB-LERMPS of Belfort and ICB-LTm of Le Creusot). The adopted strategy will be the progressive activation of elements during the part manufacturing to follow progressively deformations. Objectives of these modeling works will be to define requirements (in terms of cooling or heating devices for example) to minimize stresses, strains and subsequent deformations. A general FEM model will be developed allowing to consider both the present process based on additive manufacturing by powder cladding, as well as manufacturing by conventional SLM prototyping. For these reasons, the thesis works will be performed on both platforms (*i.e.,* LERMPS and LTm) with an estimated time of about 50/50 on both sites.
The DIC (Digital Image Correlation) method will be implemented and used to follow the piece deformations and **validate modeling works**. In addition, the "hole drilling method" will also be used to quantify strains and stresses, thus allowing comparisons with the model. These two techniques are available in the LTm site as well as a fast camera.

Scientific advances:
At the end of the thesis works, the main expected scientific advances are the following ones:
- understanding the distribution of strains and stresses in the manufactured parts
- study of metallurgical aspects associated with composition gradients and fast cooling rates (phases, orientation of grains, etc.)
- feasibility to manufacture pieces with composition gradients by powder cladding and (or) SLM processing

Conclusion and perspectives:
Additive manufacturing processes are in huge development and may evolve strongly during the coming years: the possibilities are infinite. For this reason, we are still at the beginning of works and establishment of future technologies. One may be sure that very large pieces will be manufactured by additive manufacturing technologies in the future. With these perspectives, the role of robots to deposit materials with different processes (not only laser cladding but also FRONIUS CMT for example) is more and more obvious. This thesis will be devoted to make a step in the development of additive manufacturing technologies, especially concerning prototyping of materials with composition gradients, which have numerous industrial applications.

Skills: the PhD student will have to be interested by both numerical modeling (FEM with ANSYS) and experimental works (additive manufacturing technologies).

Bibliography LTm laser cladding / prototyping:

1) S. Ignat, P. Sallamand, A. Nichici, A.B. Vannes, D. Grevey, E. Cicala, $MoSi_2$ laser cladding—a comparison between two experimental procedures: Mo–Si online combination and direct use of $MoSi_2$, Optics & Laser Technology 33 (2001) 461–469
2) S. Ignat, P. Sallamand, A. Nichici, B. Vannes, D. Grevey, E. Cicala, $MoSi_2$ laser cladding—elaboration, characterization and addition of non-stabilized ZrO_2 powder particles, Intermetallics 11 (2003) 931–938
3) S. Ignat, P. Sallamand, A. Nichici, B. Vannes, D. Grevey, E. Cicala, $MoSi_2$ laser cladding—A new experimental procedure: double-sided 2 injection of $MoSi_2$ and ZrO_2, Surface and Coatings Technology 172 (2003) 233–241
4) F. Moures, E. Cicala, P. Sallamand, D. Grevey, B. Vannes, S. Ignat, Optimisation of refractory coatings realised with cored wire addition using a high-power diode laser, Surface & Coatings Technology 200 (2005) 2283 – 2292