Effect of path strategies on metallic parts manufactured by additive process

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Metal deposition processing is well known for cladding by laser or welding process. Nevertheless, these systems are not optimized for direct manufacturing. One of the main lock is the need of dedicated CAD/CAM systems to slice and generate path strategies.
Research at the IRCCYN laboratory (France) focus on the impact of cladding or welding head programming on dimensional properties and microstructure of the manufactured parts. In this context, path strategies are studied and different strategies are proposed and compared.
This paper presents results for welding path strategies. The integration of deposition head on a 6 axis robot system was used to improve slicing strategies and parts.

I. Introduction

One of the most important topics of research leads by the MO2P Team (Modelisation and Optimization of Process of Production, IRCCYN France) on hybrid modular tools is to choose between different processes the best one to manufacture modules **[1-2]**. A way to have a large panel of processes capable is to qualify emergent processes.
Additive processes are now a great tool to manufacture directly metallic parts with high technicality. Technologies like Laser Engineering Net Shaping (LENS), Direct Metal Deposition (DMD), Electron Beam Melting (EBM) or Gas Metal Arc Welding (GMAW) are able to built fully dense parts with great mechanical skills. Additive processes are currently under improvement. T.Wohlers showed that trends in process improvement focus upon material response to additive fabrication, powder-flow studies, tolerance, and machine automation through feedback control. Other process improvements include the design and manufacture of deployable structure, residual stress analysis, part quality and process optimization **[3]**.
Rapid Manufacturing by Gas Metal Arc Welding uses metal fused by a welding torch to manufacture fully dense parts in layers. These parts have excellent mechanical properties and their structure was fully dense with minimal inclusions **[4]**. GMAW can be performed using readily available equipment which has been investigated and is well known. A review of previous works on rapid manufacturing by robotic GMAW showed the main disadvantages are high temperatures of substrates which create warpage and residual stresses, dimensional accuracy and surface quality, weld defects and unfilled voids, difficulty to control the process and geometric instability **[5]**.
Research on this domain shows that precision and thermal conditions are deteriorate when the number of layers grows up. For P.M.Dickens, "inaccuracies in the welding and robot parameters can cause cumulative errors, resulting in the torch being too close or too far away from the surface" **[6]**. I.Kmecko found that geometrical deterioration is due to small defects in the previous layer that become more and more amplified in the subsequent layers **[7]**.
One way to solve geometrical and thermal instability could be to combine GMAW and CNC machining **[8-10]**. For Z.Jandric, the principal disadvantage of this method is its slow speed. For him, if the surface of each deposited layer would be smooth enough, layers could be deposited without introducing the milling operation **[11]**.

Another way to overcome geometrical and thermal problems is to study the effect of weld settings **[4]**, or the effect of weld path strategy **[5]** on the object geometry and mechanical skills. The aim of this paper is to focus on choice of path strategies for GMAW to optimize flatness of parts build by this way.

II. Manufacturing methodology

Starting with CAD model, the first step of the methodology used in this study is to choose the best process by a geometrical analysis. Then, if an additive process is selected (Fig.1), the second step consist in determination of the substrate form. It could be a base plate or an existing part. The use of a mechanically welded or sheet incremental formed preform **[14-15]** as a substrate is a possible way to build part without machining process. Moreover, these substrate forms will be obtained without tooling. The substrate form induces the choice of a slicing strategy. The next step is to find a path strategy and a parameter set that could manufacture part's geometry.

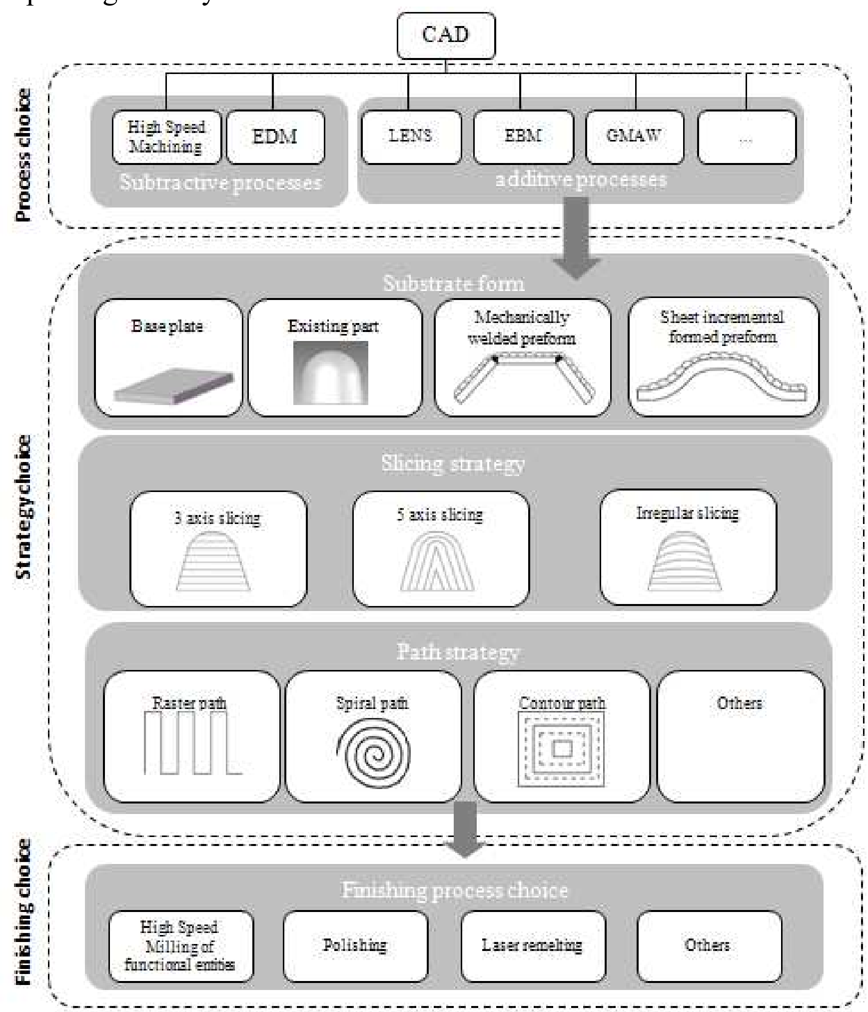

Fig.1: Methodology applied to additive processes

The main objective of this methodology is to find the best way to obtain a fully dense part with good dimensions and a great accuracy. Applying to metal deposition of a rectangular shape part, Gas Metal Arc Welding process has been chosen. A base plate is the best substrate geometry in this case. (Fig.2).

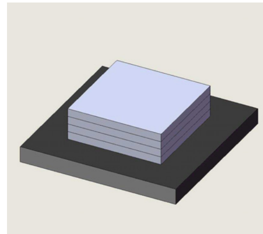

Fig.2: A test part composed by 4 layers with rectangular

Concerning the slicing strategy, the question is to know the best way to obtain a good final geometry. Two strategies will be compared: 3 axis strategy, which consist in stacking planar layer as copy of the final surface and irregular slicing strategy which consist in deposit layers with different forms or thickness.

III. Experimental approach

To have a geometrically stable process, it is important to find a strategy that allows us to obtain a surface flat enough to be a good base for the next layer or a strategy that can cancel the amplification of the deterioration of surfaces. A review of previous works leads in welding techniques to manufacture wide parts shown that a technique called layer filling constrained strategies, like "double spiral overlay welding" **[12]** allow to limit the effect of thermal stresses. These techniques consist in deposit welds in layers with two sets of weld settings. The first set of welds, called ridge welds **[5]**, is used to deposit welds that will constrain the second set. Then, the second one, called through welds **[5]**, is use to fill the space left between ridge welds already deposit. Ridge welds constraint through weld's melt pool (Fig.3).

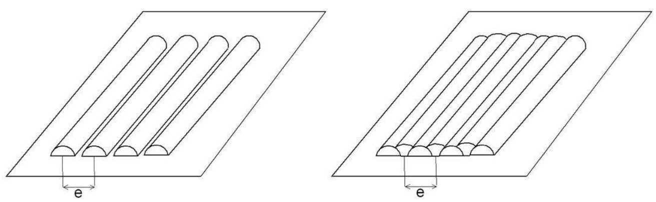

Fig.3: Concept of layer filling constrained strategy

Then, it is possible to let cooling times between ridge and through weld deposition. It is a good technique for the process stability, because the ridge welds are all deposited with the same constraint, and the through welds too. Coupled with a contour strategy (Fig.4), layer filling constrained technique is geometrically stable and had a good thermal stability due to the most cooling stops **[5]**.

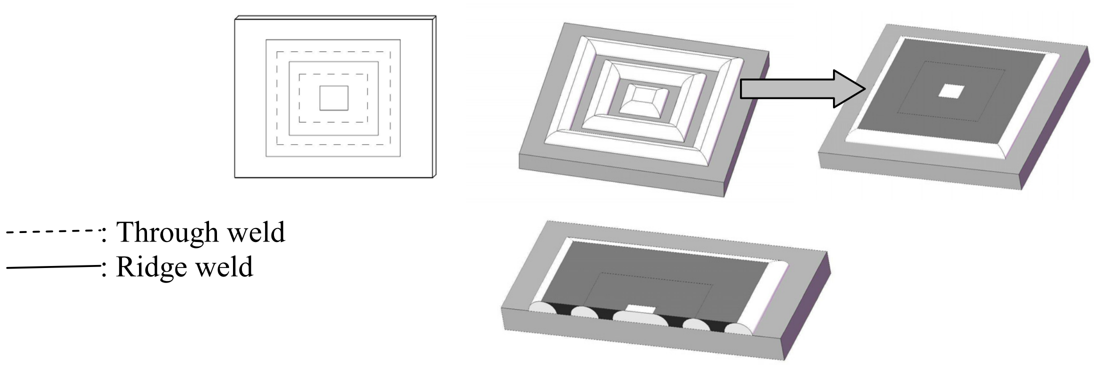

Fig.4: Layer filling constrained strategy coupled with Contour strategy

M.Siminski had shown that "self-constrained" path strategies were fairly flat overall except that they had periodic wave-like shape coinciding with the ridge and through welds. It could be seen that was caused by the through welds being a little too high for the ridge welds, due to imperfectly matched weld settings."**[5].** The first trial made with a GMAW robot confirm this observation (Fig 5).

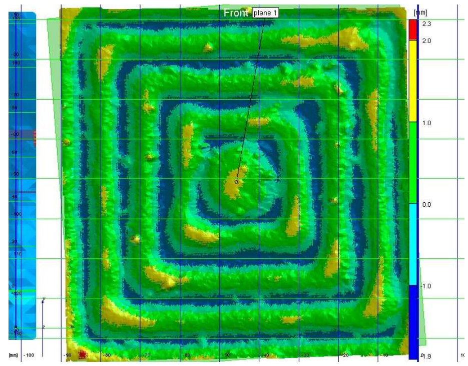

Fig.5: Cartography of wave like effect on first trial

It is important to control this "wave-like shape" by testing different parameters sets to obtain a great level for flatness of the final surface manufactured.

Another way to obtain flat surface has been tested. It consists in alternating or not through and ridge position between each layer (Fig.6).

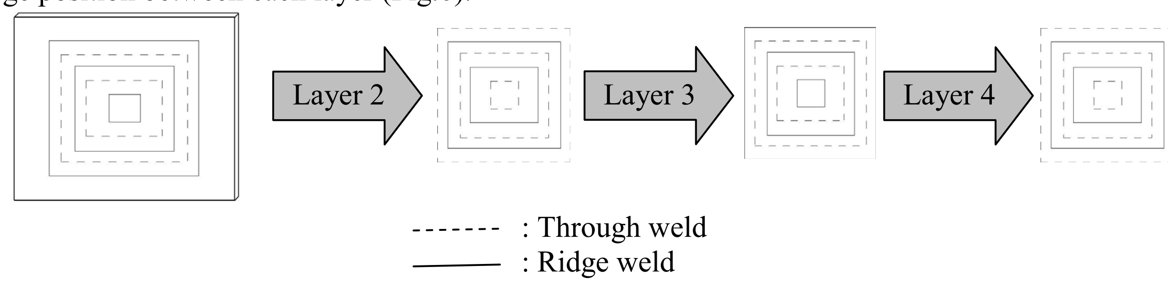

Fig.6: Ridge and through welds inversion

IV. Experimental setup

1) Description

Firstly, a series of solid object weld trials was carried out with a robotic GMAW in order to find more influent parameters of a self constrained contour strategy on:

- Flatness
- Parallelism
- Height

Then, in a second time, the choice was made to focus on optimization of this flatness. The test part selected to test the flatness of layers built by robotic GMAW consisted in a cube composed by 4 layers with rectangular shape. All the experiments was made with a constant parameters set for ridge welds in order to work only on through welds parameters (Tab.1). Due to experiment constraint, like control between two layers deposition, cooling time was fixed. The wire diameter was fixed to 1.2mm.

Ridge welds		
Voltage (V)	Wire feed rate (m/min)	Travel Speed (cm/s)
22	5.3	0.4

Tab.1a: Ridge welds parameters

Through welds		
space between ridge welds (mm)	Voltage (V)	Travel Speed (cm/s)
10 to 15	24 to 26	0.2 to 0.6

Tab.1b: Through welds parameters sets

As the effect of the space between ridge welds on flatness had been tested, length and width accuracy of the process in this paper was not studied. The dimensions of parts manufactured varied with settings. Parallelism and height were controlled only to validate the result of trials.

2) Welding cell and equipment used

The welding robot used for this experiment was a KUKA KRC1 Robot coupled with a Fronius Trans Synergic 4000 welding power supply (Fig.7a). Controls of flatness, parallelism and height were all been made with an ATOS sensor (Fig.7b).

Fig.7a: KUKA KRC1 Robot

Fig.7b: ATOS STD sensor

This flexible optical measuring machine is based on the principle of triangulation. Projected fringe patterns are observed with two cameras. 3D coordinates for each camera pixel are calculated with high precision, a polygon mesh of the object's surface is generated. With this sensor, an accurate 3D mapping of manufactured surface had been made. Then, the soft create least squares plane and compute distances between points and this plane to obtain flatness defect **[13]**.

V. Results

1) Surface topography of the first layer

Twenty three parts had been manufactured with different parameters set to identify some topography types. A choice has been made between those trials to find the most significant parts manufactured that could be the base of the second step of the experiment. Parts chosen must had repeatable results, a regular shape and no welding defect.

The results of surface analysis of the first layer showed two types of surface topography (Fig.8):

- Flat surfaces
- “Wave like shape” surfaces

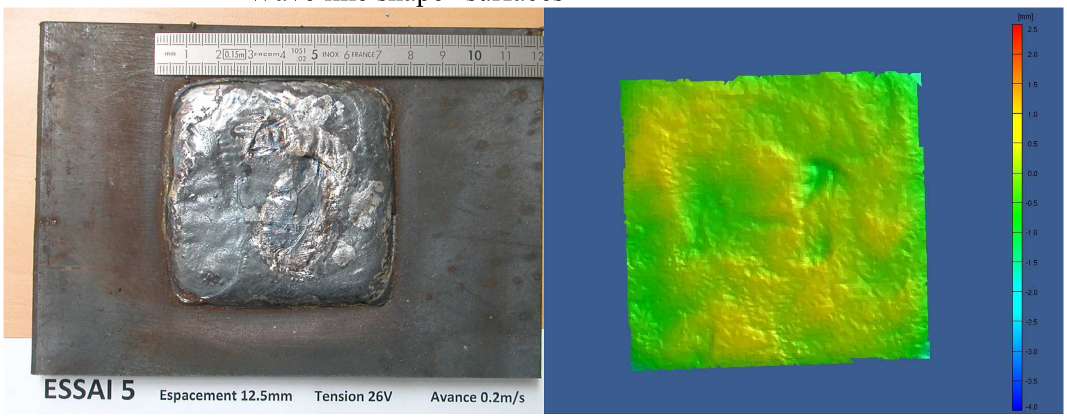

Fig.8a: Flat surface topography (first layer)

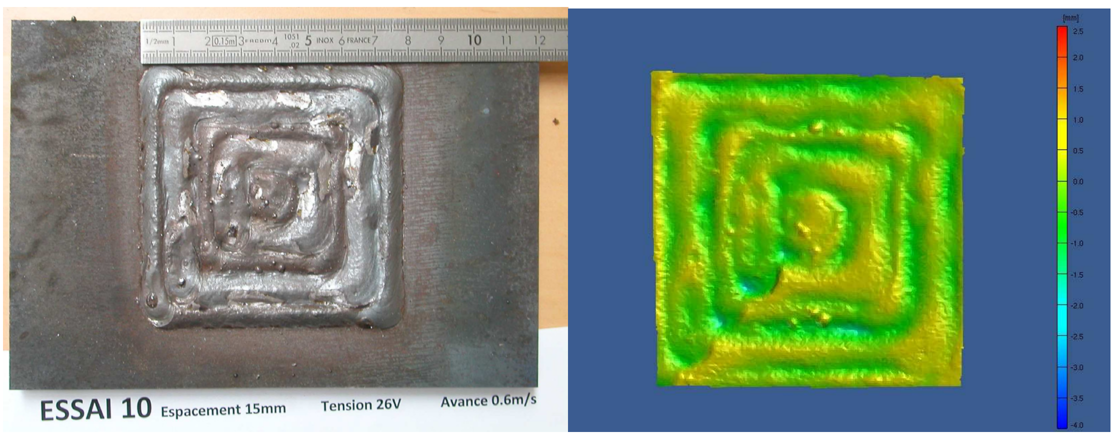

Fig.8b: “Wave like” surface topography (first layer)

Measurement showed a flatness defect value of approximately 1.4mm for flat surfaces and 2.4mm for “wave like shape” samples. But, with the observation of the surface quality, the meltpool size of parts with flat layers grow during weld deposition. For this reason, a collapse of this type of surface topology parts is predictable when the number of layers will grow up.

2) <u>Surface topography of the fourth layer</u>

The next step of the experiment was to test stability of flatness in the subsequent layers. So, the comparison of the use or not of the“Ridge and through welds inversion” strategy on the two surfaces topology was tested. Cartographies of surfaces obtained highlight the growth of the flatness defect for “flat surface topology” parts. The collapse of parts is trivial and appears first with the inversion of weld parameters. This new strategy was not adapted to flat layers. The fabrication was stopped after the second layer for this strategy because sample’s dimensions were no more respected. The other strategy was conducted to the end. (Fig 9)

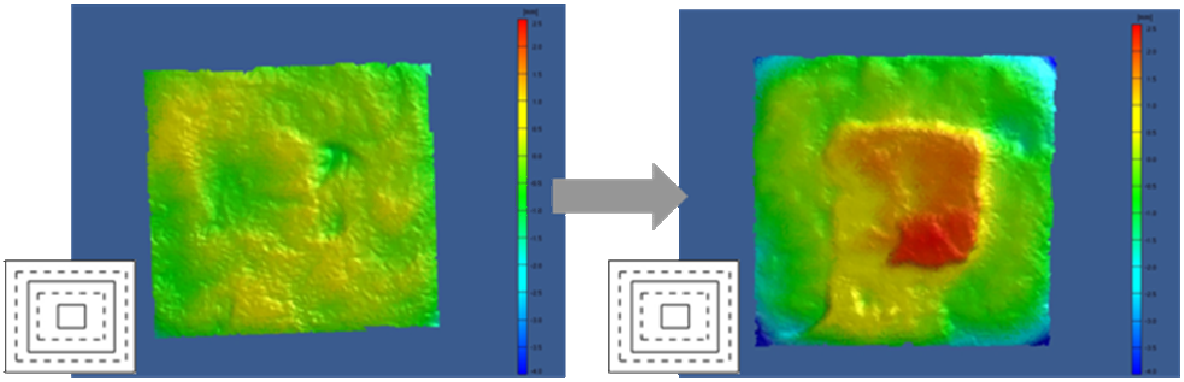

Fig.9: Collapse of “flat” surface topography (fourth layer)

The collapses on “flat” surfaces were due to the weld pool size at the end of the program. The weld pool of the “wave like shape” samples had a constant size. It explains the better stability of those parts.

For “wave like shape” surface topology parts, results show that flatness defect grows less with the new strategy than with the repetition of same layers. (Fig.10)

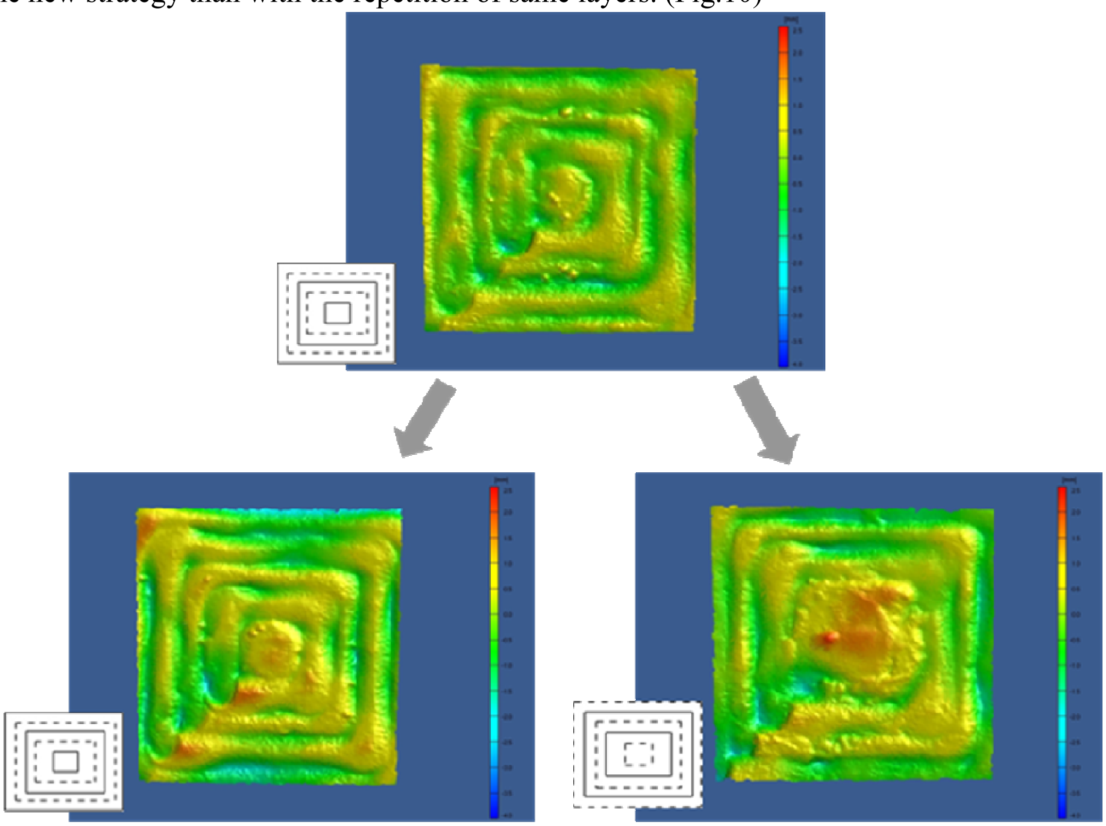

Fig.10a: Flatness defect without “Ridge and through welds inversion” strategy (fourth layer)

Fig.10b: Flatness defect with “Ridge and through welds inversion” strategy (fourth layer)

Flatness defect (in mm)		
Layer n°	1	4
Flat surface without “Ridge and through welds inversion” strategy (Strat.1)	1.4	5
Flat surface with “Ridge and through welds inversion” strategy (Strat.2)	1.4	-
“Wave like shape” surface without “Ridge and through welds inversion” strategy (Strat.3)	2.4	4.4
“Wave like shape” surface with “Ridge and through welds inversion” strategy (Strat.4)	2.4	4

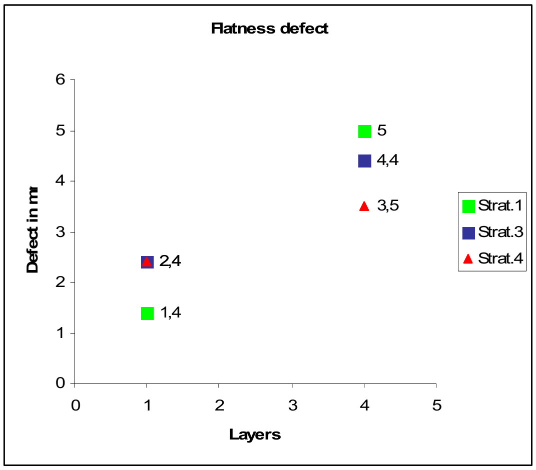

Fig.11: Flatness defect

On each case, higher points are located at corners of each weld. Deeper points of these two cartography are located at the “start and stop” point of each weld. Some method has been developed in literature to solve this problem **[16]**. It will not be treated here. Using the “Ridge and through welds inversion” strategy, Pyramid effect (central area is higher than contour area) can be identified (Fig.10b). It was due to the lack of space let by the first weld to fill the central zone. This could be solved by modified program of through welds. Periphery area had a better flatness than the periphery area of samples which not used this strategy. Height of welds was more regular too. In fact, on parts build without this strategy, there is an offset of welds position due to amplification of defects which caused height variation of welds (fig.12).

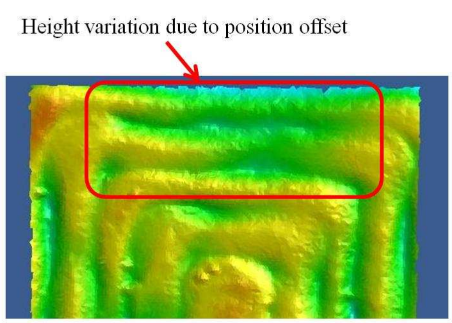

Fig.12: Offset of welds

The “wave like shape” effect is more important, the distance between wave through and wave crest is higher. Flatness measurements show that defects grow with the number of layers, but grow less with “ridge and through welds inversion” strategy than without. In this case, the use of this strategy is efficient.

VI. Conclusion

The “Ridge and through welds inversion” strategy has been applied with success. It reduced the growth of the flatness defect (Fig 11). The interest of this result is that there is no need to start with a perfectly flat surface to obtain a perfectly flat surface at the end of an additive manufacturing process. It highlights the significance of the geometrical study of parts to choose the best slice strategy and path strategy for the manufacturing method developed in this paper. Then, starting with the irregular slicing strategy, it will be interesting to develop a “top to bottom” slicing strategy instead of a classical “upward” strategy (from substrate to skin). The surface cartography is a great tool to obtain flatness information and it permits to know the exact height of points of the part. Then, it is possible to guaranty tool/parts distance in the next layer program. The next step of this study is to optimize parameters set to reduce (or cancel) the defect value and defect growth. The study had been made on simple parts with well known available equipment. It will be interesting to develop irregular slicing strategy with another process, like Laser Engineering Net Shaping (LENS), on more complex geometries, with other substrate forms, as described in manufacturing methodology.

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