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PROCESS PARAMETERS OPTIMISATION OF THE DIRECT LASER METAL DEPOSITION TECHNIQUE

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Abstract: *Direct Laser Metal Deposition (DLMD) is actually one of the most attractive techniques in the group of Material Accretion Manufacturing (MAM) processes.*
The objective of this work was to study the effect of two DLMD process parameters, hatch spacing and step height, on the quality of built parts, in terms of density and microhardness. The experimental equipment was constituted by a 6 axis CNC laser machine and by a pneumatic system for the distribution of the powder. The powder chosen for the experimentation was the atomized Colmonoy 227-F, a nickel alloy especially designed to manufacturing moulds.
Results of experimentation showed that it is possible to produce parts having properties comparable with those obtainable with conventional processes.

Key words: *Direct Laser Metal Deposition, metal powders, nickel alloy, laser processing*

1. INTRODUCTION

Direct Laser Metal Deposition is an additive process belonging to the group of Material Accretion Manufacturing (MAM) technologies. The main feature of MAM processes is the selective creation of several kind of materials, from plastics to metals (Choi & Chang, 2005).

The development of the Direct Laser Metal Deposition technology was pursued at the same time from several researchers for about ten years, and finally it generated, between the 1995 and the 1996, three processes, known actually as Directed Light Fabrication (DLF), Light Engineered Net Shaping (LENS) and Direct Metal Deposition (DMD). They were developed respectively at Los Alamos National Laboratory of Los Alamos (New Mexico - USA), at Sandia National Laboratory of Albuquerque (New Mexico – USA) and at the University of Michigan of Ann Arbor (Michigan – USA) (Lewis & Schlienger, 2000; Milewski et al, 1998; Angelastro et al., 2007).

The DLMD technology, as DLF, LENS and DMD, puts together CAD/CAM systems, CNC, laser, powder metallurgy and sensors for the retroactive control with the purpose to realize, repair and restore directly from the 3D CAD model, in a rapid and economic way, objects, moulds and tools using a great variety of metals, including those very difficult to work with the conventional techniques.

Even if this technology differs for some aspects from other MAM technologies, it preserves the main MAM characteristic, that is the layer by layer methodology.

The starting point of the process is represented by the CAD file that is converted in STL file (solid to layer); the STL file is later subjected to the “slicing” process, providing the necessary information for the movements of the laser, as in SLS.

A metallic substrate, with high conductivity in order to loose heat rapidly, is used for the construction of the pieces. In DLMD, laser beam is focused and moved on the top surface of the substrate producing a molten pool where a metal powder flow is injected.

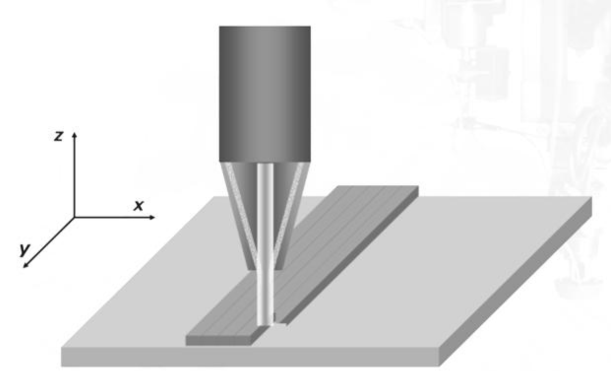

Fig. 1. Schematic drawing of the process

Powder totally melts and then quickly re-solidifies creating a high compact and joined to the substrate track. First layer is realized depositing tracks one next to the other (Fig.1). After deposition of the first layer, laser head, that includes focusing lens and powder delivery nozzle, is incremented in the positive Z-direction and starts deposition of the second layer. Therefore, process recurs, line-by-line and layer-by-layer, until the entire component is built up.

The quality of the parts that can be achieved with DLMD is strongly influenced by numerous process parameters. The problem of determining what are the parameters that influence the final properties and in what measure is complicated by the significant interactions between them (Choi & Chang, 2005).

A careful control of process parameters becomes crucial to obtain products having good mechanical properties.

Previous studies (Angelastro et al., 2010) investigated the effect of the main laser parameters (power, scanning speed, specific energy) and of the powder flow rate in order to find out the DMLD process windows work.

The aim of this work was to study the effect of other two parameters, hatch spacing (H_s) and step height (S_h), on the quality of built parts, in terms of density and microhardness.

2. MATERIAL POWDER

The powder chosen for this study was a nickel alloy, the Colmonoy 227-F, usually used for manufacturing moulds, especially those for the production of glass bottles.

This material, mainly characterized by an elevated hardness (22-27 Rockwell C), a density of 8.53 g/cm^3, and a melting point of 915 °C, is able to tolerate extreme job conditions because of the elevated resistance to abrasion, to corrosion, to stresses and to high temperatures. This is the reason this material is particularly suitable for surface treatments, for regeneration of moulds (for glass containers) and for reconstruction of frictions components in the auto field. Thus, Colmonoy 227-F is generally furnished in powder form with granules of spherical shape. The powder used in this work was characterised by granules with a maximum size of 106 µm.

3. EXPERIMENTAL TESTS

3.1 Process parameters and experimental plan

The experimental equipment was constituted by a 6 axis CNC laser machine, normally used for cutting and welding, and by a pneumatic system for the distribution of the powder, specifically designed and built to create a DLMD apparatus.

The quality of the parts that can be obtained with DLMD is strongly affected by several process parameters; thus, a careful control of process parameters is necessary to obtain products having good mechanical properties.

Previous studies (Angelastro et al., 2010) investigated the effect of some laser parameters (power, scanning speed, specific energy) and of the powder flow rate in order to find out the DMLD process windows work. It was found that good 3D parts could be built setting laser power to 500 W, powder flow rate to 20.1 g/min, pressure of the carrier gas to 2.8 bar and scanning speed to 0.8 m/min.

In this work the variation of other two parameters (H_s and S_h) was considered and the effect on the quality of built parts was studied.

H_s is defined as the distance between the vectors drawn from the center of the laser spot in two parallel and consecutive tracks; S_h is the height displacement, along the z axis, assigned to the laser head to obtain a new layer.

A full factorial plane 3^2, with H_s and S_h changed on three levels (respectively 150-225-300 µm and 100-150-200 µm), was planned for this purpose. Thirty layers samples were built for every combinations of the parametrs.

3.2 Analysis of results

The quality of the parts, in terms of density and microhardness was evaluated.

The density of samples was measured using a precision balance that works by applying the principle of Archimedes. For each sample nine measurements were performed and then the average density was calculated.

The average values of density obtained ranged from a minimum of 8.24 gr/cm^3 to a maximum of 8.34 gr/cm^3. These values were compared with that of the same bulk nickel alloy, which is equal to 8.53 gr/cm^3. It was found that the relative density varied from a low of 96.6% to a maximum of 97.7%.

Vickers micro-hardness tests were conducted using a REMET HX1000 machine and applying a load of 100 grams for 15 seconds. Test results showed that the average micro-hardness of the deposited material was 344-375 HV. It was interesting to note that the starting material powder had a theoretic hardness of 248-279 HV. This means that the process allows an increase of about 39% in the hardness of the metal used for deposition.

Later on it, the Analysis of Variance (ANOVA) was used to evaluate the influence of the considered two process parameters on both density and microhardness. The General Linear Model was used for ANOVA and the probability value α was set to 0.05. Table 1 shows p-values coming from ANOVA.

It is evident that density was affected by both step height and hatch spacing; microhardness, on the opposite side, was not influnced by the two parameters. Moreover, the main effects plot for density (Fig.2) shows that reducing hatch spacing from 300 µm to 225 µm density is practically constant, while increasing even more the overlapping, that is switching hatch spacing to 150 µm, there is a very pronounced decrease of this material characteristic.

Factors	Density	Microhardness
Hatch spacing	$0.004 < \alpha$	$0.922 > \alpha$
Step height	$0.005< \alpha$	$0.319 > \alpha$

Tab. 1. p-values

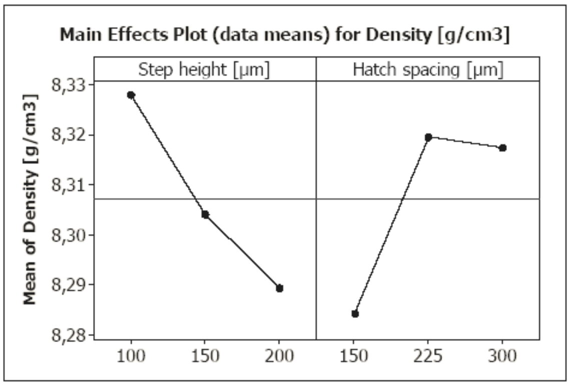

Fig. 2. Main Effects Plot for density

A plausible reason to explain this reduction in density may be that the reduction of hatch spacing, resulting in an increase in the thickness of the layers, led to a deposition with a laser out of focus, then with a lower energy density per mass unit.

In addition, the Main Effects Plot shows that the density decreases with the increase of step height.

In conclusion, the density was highest when hatch spacing was in the range 225 – 300 µm (overlap of 25% - 0%) and step height was equal to 100 µm.

4. CONCLUSION

A statistical analysis was implemented in order to study the effects of two DLMD process parameters on the quality of built parts in terms of density and Vickers micro-hardness. It was found that a relative density of 97.7% can be reached setting H_s = 225 µm and S_h = 100 µm. Moreover, values of 344-375 HV were found for HV microhardness. These values, compared with those of the starting material powder, showed an increase of about 39%. Some future developments will concern the process optimization to make three-dimensional pieces with complex geometries on which evaluate the dimensional accuracy achievable. Farther, changes in the experimental equipment can be made to obtain, using at the same time different powders, functionally graded materials, with composition and properties varying point to point.

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