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EFFECT OF INITIAL POWDER PROPERTIES ON FINAL MICROSTRUCTURE AND MECHANICAL PROPERTIES OF PARTS MANUFACTURED BY SELECTIVE LASER MELTING

AVERYANOVA, M[aria]; BERTRAND, P[hilippe] & VERQUIN, B[enoit]

Abstract: *Selective Laser Melting is a layer additive process for direct manufacturing of complex shape parts from powder materials. The SLM technology is characterized by different physical phenomenon like local quick heat input, high solidification rate, phase transformations, oxidation, etc. The effect of initial powder material properties, of SLM process parameters, of conditions of SLM machine functioning should be studied. In the present paper, the SLM process thermal modelling shows that for applied optimum process parameters, the thermal effects are the same for all used martensitic 17-4 PH powders. Besides, the final microstructure and properties are different. The results show clearly the effect of initial complex martensitic precipitation hardening powder chemical composition on final parts microstructure, and consequently, on final mechanical parts properties.*
Keywords: *Selective Laser Melting, martensitic precipitation hardening 17-4 PH powder*

1. INTRODUCTION

Selective Laser Melting (SLM) is an Additive Manufacturing (AM) technique that manufactures complex shape parts using metal powders without dies and moulds. The main advantage of SLM is the capability to create new high-added complex objects that would be difficult or impossible to produce using conventional manufacturing techniques (Mumtaz & Hopkinson, 2010). This process is attractive because of the fabrication of components for biomedical, aerospace, tooling etc. fields. New prospects for microstructure-properties variations, functional graded materials and composite materials creation, control of final porosity are possible (Narayan et al., 2008), (Kruth et al., 2007). Potentially, the SLM process could be used like a multifunctional materials manufacturing technique. Besides, the manufacture of metal parts by SLM has still many difficulties. For industrial acceptance the SLM components need to possess a high geometrical precision, necessary microstructure and consequently, necessary mechanical, thermal and other properties. A better understanding of complex physical phenomenon of non-equilibrium SLM process is requested. Currently, the influence of process parameters such as density of energy, layer thickness, scans spacing on final parts characteristics is more studied than the influence of initial powder properties such as chemical composition, powder size and size distribution, thermal properties and environmental conditions such as temperature of the powder bed, protective atmosphere etc. Analyses of parts microstructure and its influence on parts properties are limited and concern namely the Fe-based powders and Ti-alloys (Thijs et al. 2010). The objective of the present work is to analyze the final parts microstructure and mechanical properties using different 17-4 PH powders with the optimized SLM process parameters.

2. EXPERIMENTAL SET-UP

SLM experiments were carried out on PHENIX System PM 100 machine under Argon protective atmosphere. The manufacturing strategy is so called “2 zones technique”. It consists of scanning first time tracks in a distance slightly larger than the width of single track. Then to scan between these just melted/solidified tracks in order to minimise porosity. The part density was analyzed using a method based on Archimedes law (“Hydrostatic weighing”). Hardness and microhardness of the parts was measured using a Vickers tester Buehler (Micromet5104). Mechanical properties were performed using Wolpert testatron 1288 machine. Microstructure of samples etched in Villela reagent was studied by optical (Olympus BH-2) microscopy.

3. RESULTS AND DISCUSSIONS

3.1 Powder characterization

The chemical composition of the investigated 17-4 PH powders was analyzed by plasma emission spectrometry method and is shown in Table 1. The percentage of chemical elements is according to ASTM standard specification A 693-06, but is different for analyzed powders. It is known that if the martensitic steel is reached in γ-stabilize elements like C, Ni, Cr, Cu, an important quantity of residual austenite will be formed. The difference in the percentage of main alloying elements of 17-4 PH powder was observed to be significant. Comparing the chemical composition of Powder1 and Powder2, it could be predicted that using the same SLM process parameters the amount of residual austenite in the part manufactured from Powder2 will be more important than in the part from Powder1.

Powder	**Cr,%**	**Ni,%**	**Cu,%**	**Mn,%**	**Si,%**
N°1	16,23	3,42	4,06	0,392	1,00
N°2	15,06	4,55	4,14	0,576	0,628
Powder	**C,%**	**P,%**	**S,%**	**Nb,%**	**Fe,%**
N°1	0,037	0,020	0,005	0,308	bal.
N°2	0,066	0,015	0,006	0,232	bal.

Tab. 1. Chemical composition of 17-4 PH Powders

Both 17-4 PH powders are spherical (gas-atomized) with a single-modal size distribution. Powder1 (d90<16µm) is finer than Powder2 (d90<25µm). A full analyze of 17-4 PH powder properties for SLM application was reported earlier in (Averyanova & Bertrand, 2009).

3.2 Process parameters

A set of important process parameters like laser power, scanning speed, layer thickness, scan spacing, angle of orientation, scanning strategy were investigated. First, single tracks were manufactured from both powders. The analysis of tracks stability and geometrical measurements were performed. An optimum process parameters domain was restricted. Based on obtained results, the 3D parts from two 17-4 PH powders with exactly the same optimized process parameters and using a scanning strategy “2 zones technique” have been manufactured.

3.3 Numerical simulation

Numerical simulation of heat transfer in the laser bed interaction zone based on the model of coupled radiation transfer and thermal diffusion described in (Gusarov et al., 2009) was used in order to analyze the temperature distribution and cooling rates at the fused layer. The results show that the new deposited layer is completely melted. A part of previous layer is remelted in order to ensure a good adhesion and another part is heated one more. Quenching phenomena appears (Fig. 1).

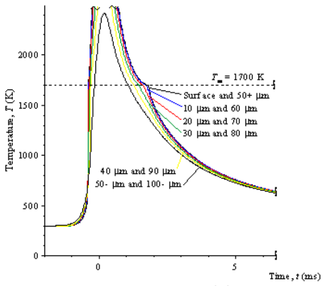
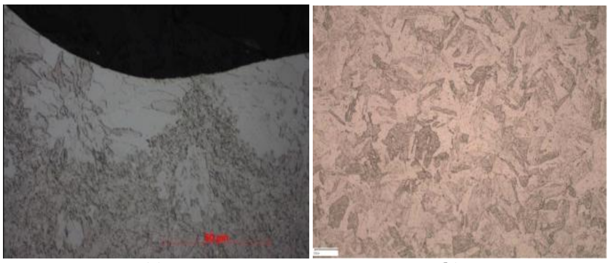


Fig. 1. Temperature distribution in time of fused 17-4 PH powder layer

3.4 Manufactured parts characterization

It is well established that cooling rates influence the microstructural evolution of stainless steel. High cooling rates of SLM process result in non-equilibrium microstructures. Final parts microstructure can be changed by varying powder particle size and size distribution, as well as the percentage of main elements of chemical composition. The complicated thermal cycling of SLM process affects the materials properties, such as residual stresses, mechanical strength. SLM technique selectively vary parts microstructure, mechanical properties and residual stresses within narrow dimensions of several tens of microns. So, the desirable parts properties can be selectively tailored. The results of numerical simulation explain clearly the difference in microstructure and consequently in microhardness of the first, last and layers in the middle of the part (Fig.2). The 17-4 PH powder manufactured by SLM process gives a material with properties different from conventionally obtained (Fig.2 (b)).



(a) (b)

Fig.2: (a) Optical image of last and previous layers of a part manufactured from 17-4 PH Powder2 by SLM process and (b) Optical image of 17-4 PH sample after HT (S17400) produced by conventional manufacturing technology

The density of the manufactured parts from 17-4 PH Powder1 and Powder2 is about 99%. The XRD spectrum of manufactured SLM parts from Powder1 and Powder2 (Tab. 2) show that the relative volume proportion of martensite and residual austenite phases is different; consequently the hardness of parts is also different (Tab. 3).

Stainless steel parts	Volume fraction of α phase,%	Volume fraction of γ phase, %
Powder1	38	62
Powder2	6	94

Tab. 2. Volume fraction of α and γ phases in SLM parts manufactured from 17-4 PH stainless steel powder

Stainless steel parts	Porosity, %	Hardness, HV1
Powder1	Less than 1%	278±57
Powder2	Less than 1%	226±69

Tab. 3. Results of porosity and hardness measurement of manufactured parts from Powder1 and Powder2

The part manufactured from Powder1, containing less residual austenite, has been chosen to analyze the mechanical properties (Tab. 4). The layer alternated scanning strategy (change of the scanning direction from layer to layer) provides more homogeneous melting conditions and consequently, gives a better result.

Powder1-type of scanning strategy	Rm (Mpa)	Rp0,2% (Mpa)	A%
Powder1 – layer alternated scanning strategy	880	614	25%
Powder1-non-layer alternated scanning strategy	569	454	2,0%

Tab. 4. Influence of scanning strategy on mechanical properties for the SLM part manufactured from 17-4 PH Powder1

The specimens exhibit ductile failure morphology. The obtained values correspond to expected values for 17-4 PH samples manufactured by SLM process. Besides, using an appropriate heat treatment the values can be improved.

4. CONCLUSION

It was found that chemical composition of 17-4 PH powder has a significant influence on the final parts microstructure and mechanical properties. The results of numerical simulation show that during SLM process with chosen process parameters the quenching phenomena of the previous layers occur. Consequently, complex microstructure is formed. The parts manufactured from both 17-4 PH powders (17-4 PH Powder1 and 17-4 PH Powder2) using the same optimum process parameters are dense. Besides, different crystalline structures (different proportion of the residual austenite and martensite) and mechanical properties of the parts were obtained. The specimens manufactured from 17-4 PH Powder1 with less volume proportion of residual austenite are dense and give the values of mechanical strength comparable with the values of conventionally fabricated 17-4 PH samples. A range of different microstructure and properties can be obtained using SLM technique by varying initial powder material properties. This opens a way for new industrial application.

5. AKNOWLEDGMENTS

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