euspen's 18th International Conference & Exhibition, Venice, IT, June 2018
www.euspen.eu

Analysis of Different Process Control Strategies of the Hybrid Contact Laser Sintering Process

Tobias Montag[1], Jens Wulfsberg[1], Frank Gärtner[2], Thomas Klassen[2]

[1]*Institute of Production Engineering, Helmut-Schmidt-University, University of the Federal Armed Forces Hamburg)*
[2]*Institute of Material Technology, Helmut-Schmidt-University, University of the Federal Armed Forces Hamburg)*

tobias.montag@hsu-hh.de

Abstract
The Hybrid Contact Laser Sintering Process is advantageous for manufacturing micro work pieces out of amorphous metal powder. This study shows all possible process control strategies and identifies the most promising one to be used for conducting the full test plan for process development. The results show that a concurrent start and end of laser heating and powder pressing is advantageous for low duration of the process and good impact on heat conduction and exceeding glass transition temperature.

Keywords: laser, sintering, powder, laser micro machining

1. Introduction

Due to the absence of grains, amorphous metal is not underlying the size effect which is called "grain size/thickness" ratio. This effect leads to decreasing accuracy of the part dimensions during manufacturing processes, so amorphous metal is advantageous to be used as material for small scale and micro parts, providing high hardness, elasticity and stability [1,2].

To successfully manufacture parts from amorphous metal powder, the Hybrid Contact Laser Sintering (HCLS) Process was developed [3]. The heat source is a laser beam which is transmitted through a stamp out of sapphire to directly heat the metal powder (see figure 1). Due to its compressive strength this stamp is also used for transmitting the pressing force to reach full densification of the material.

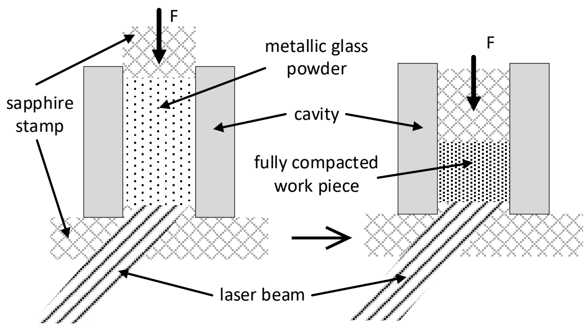


Figure 1. Setup of HCLS-Process

Both main process functions – laser heating and powder pressing – can be varied independently in duration and starting time. The difference in starting time is expressed with the input parameter "delay" with the following values:

- positive: delayed start of powder pressing
- negative: delayed start of laser heating
- zero: concurrent start of laser heating and powder pressing

The aim of this paper is to identify the most promising process control strategy of duration and delay of laser heating and powder pressing. Additionally the slow rising of laser energy is discussed. The results are the base for the following process development.

2. Methodology

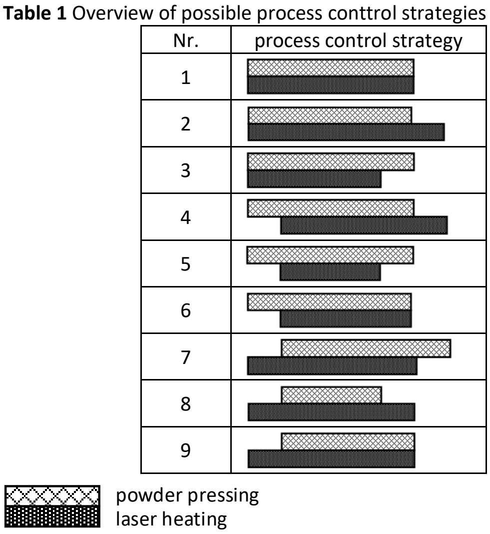
To evaluate the most promising process control strategy a first theoretical comparison of all possible ones is made. Within this some strategies are excluded from further analysis due to expectable bad results. The retaining control strategies are analysed more detailed to identify one or two most promising control strategies.

The criteria for assessing are: impact on the process time and effects of powder heating as there are exceeding glass transition temperature and heat conduction.

3. Process control strategies – first evaluation

Table 1 shows all possible process control strategies. The length of the bars displays the duration of the function and the position displays the kind of delay.

Table 1 Overview of possible process conttrol strategies



3.1.Excluding strategies due to waste of time

Process strategies where the powder pressing starts earlier than laser heating are excluded. The (pressure dependend) powder compaction is done fastly within less than one second and there is no benefit of pressure maintenance without laser heating. So strategies Nr. 4,5 and 6 are excluded.

3.2.Excluding strategies due to low heat conduction of amorphous powder with low density

Due to a low powder density the heat conduction is poor because the contact area of adjacent grains is small. If there is initial pressure attended by laser radiation the heat is transmitted deeply and more uniformly. So the strategies Nr. 7, 8 and 9 are excluded.

3.3.Retaining control strategies for further investigation

Strategies Nr. 1, 2 and 3 are recommended to be investigated more detailed. They are offering a good heat conduction and small process times.

4. Evaluation of most promising process control strategy

4.1. Defining laser radiation time and energy input

The main task of the HCLS-Process is to produce amorphous bulk material with high density. For this the material must exceed glass transition temperature T_g to achieve best flow characteristics with a significantly reduced viscosity. If the energy is too low the grains are kept in its original shape. Therefore two strategies of interaction of laser radiation time and energy input are compared: a) long laser radiation time and low energy input and b) short laser radiation time and high energy input (see figure 2).

In case of strategy a) the grains keep their shape due to temperatures lower than T_g = 400 °C. Diffusion effects in the contact areas of the single grains are detected so that there is a significant mechanical strength. For higher laser energy the sapphire stamp breaks over time.

In case of strategy b) the materials flows due to temperatures above T_g. The pores between powder grains with a temperature lower than T_g are closed and there is full density (observed plane: contact area of lower sapphire stamp and powder, see figure 1). The sapphire stamp is slightly broken and some of the powder material adheres to it. For further tests this strategy is used to identify the most promising strategy out of Nr. 1-3 (see table 1).

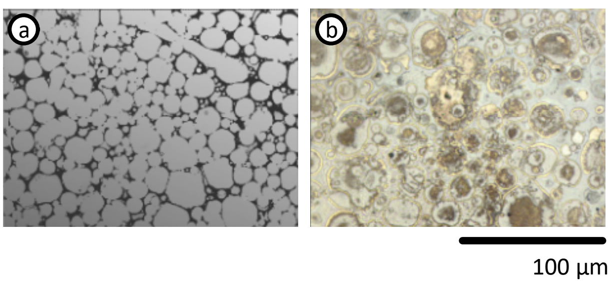


Figure 2. Comparison of interaction of time and energy: area of highest energy input with a) t_{Laser} = 7200 s, P = 50 W and b) t_{Laser} = 60 s, P = 90 W

4.2. Evaluation of the most promising process control strategy

The strategies Nr. 1-3 differ in the process end. Nr. 1 describes a concurrent end of laser radiation and powder pressing, Nr. 2 has got a late finish of laser radiation for energy input without pressing force and for Nr. 3 the pressing force ist applied when the energy input has finished.

Strategy Nr. 3 seems to have no additional advantage for there is a fast cooling of the powder bed. So the temperature falls below T_g within half a second that comes along with a rapid increase in viscosity and therefore reduced flow characteristics. Additionally there may be no positive impact in mechanical strength and the cycle time is longer so the economic benefit of this process decreases.

Strategy 2 may be advantageous for having lower viscosity of the material above T_g. But in this case there would be no driving force for an easier flow of the material to enhance the density of the powder bed and the risk of crystallization would increase. Therefore the pressure has to be applied the hole time when the material exceeds T_g.

So strategy 1 is identified as most advantageous for the HCLS-process. It will be used for operating the full test plan for process development. But for further optimization steps strategy 2 may be advantageous by adapting the energy input over time. If for example the mechanical strength is poor the energy can be reduced to a level where crystallization is avoided and further diffusion effects are achieved (see figure 3). But for long time energy input the risk of a broken sapphire stamp increases as can be seen in figure 4.

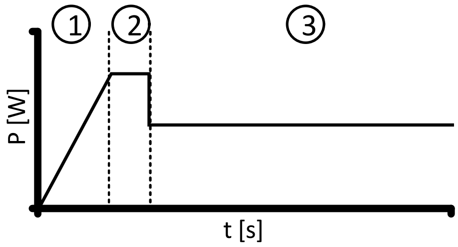


Figure 3. Examplary laser power input: 1) ramp up until material temperature exceeds T_g; 2) short dwell time with P_{max}; 3) long dwell time for diffusion effects with reduced laser power

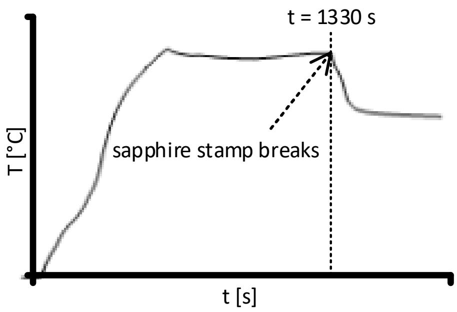


Figure 4. Chart of temperature trend for the detection of a sapphire break, t_{Laser} = 1800 s, P_{max} = 50 W

5. Summary

In this study the most promising process control strategy of the HCLS-process is defined. It is characterized by a concurrent start and end of laser radiation and powder pressing. Any possible delays are not advantageous to be operated within the full test plan for process development. Further optimization steps might use adapted control strategies.

References

[1] Montag T and Wulfsberg J 2015 Proceedings of the 15th euspen International Conference, Leuven, 2015, 197-198

[2] Quin Y 2010 Micro-manufacturing engineering and technology (Oxford, Elsevier) 115-118

[3] Wulfsberg J, Terzi M, Kuhn A, Bruhns F 2008 Verfahren zum strahlungsgeschützten Urformen, Umformen, Fügen und Trennen mittels aufgesetzter, kraftübertragender Kontaktoptik Patent DE102006051333A1