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Design and applicability of the testing equipment for manufacturing micro parts from amorphous metal powder by using the hybrid contact laser sintering (HCLS) process

Tobias Montag[1], Jens Wulfsberg[1]

[1]Helmut-Schmidt-University, University of the Federal Armed Forces Hamburg, Germany

tobias.montag@hsu-hh.de

Abstract
The Hybrid Contact Laser Sintering Process is advantageous for manufacturing micro and small scale work pieces out of amorphous metal powder. Based on a specification sheet, a testing equipment is developed to identify and optimise the parameter ranges of the process. For net shaped parts it is necessary to have accurately manufactured cavity, stamps and pressing force measurement with lowest deformation effects, as well as a stiff machine frame. Furthermore, a cooling system and inert gas supply is provided.

Keywords: laser sintering, machine design, powder, amorphous metal

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].

For this case, the Hybrid Contact Laser Sintering Process was developed [3]. But until now, there is no applicable automated testing equipment to further develop this process and to gain the technology readiness level with the aim to bring it to maturity phase. This paper describes the design and the features of a fully automated testing equipment.

In a first step the methodology of designing the machine is pointed out. This is followed by describing the process fundamentals. In the main and final part functions and their meaning for the development and construction are analysed and requirements for machine construction are derived.

2. Methodology

The Systems Development Life Cycle (V-model) is used to develop the testing equipment. The planning phase is split into three tasks: problem definition, description of the process and development of a specification sheet. Main process functions are derived from the description of the process and are basis for elaborating the specification sheet. This step is attended by an FMEA-analysis to prevent malfunctions and inapplicability of the testing equipment in an early state.

3. Analysing the Hybrid Contact Laser Sintering Process

3.1. Description

The main characteristic of the HCLS-process is the concurrent powder pressing and sintering (see figure 1). The powder heating is done by a diode laser system with a wavelength of 1070 nm. Hereby the laser energy is transmitted through the lower stamp that is made out of sapphire to directly heat the amorphous metal powder. The powder pressing is typically done by the movement of both stamps to achieve a more uniform density distribution.

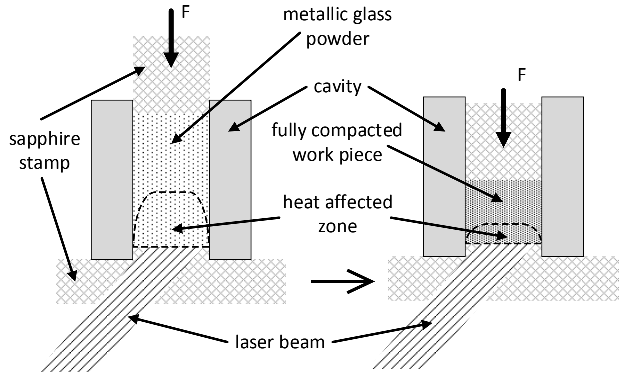

Figure 1. Sketch of the HCLS-process, left: initial situation, right: process done.

For accurate process control two process parameters have to be observed and measured. On the one hand the powder temperature is the most important parameter. If the temperature exceeds the crystallisation temperature of the material it is no longer amorphous and the part cannot be used anymore. For this, the best temperature measurement method is identified in [1] and is not discussed in this paper. On the other hand the pressing force has to be measured accurately.

Concluding, there are 6 main functions: filling in the powder, powder heating, powder pressing, removing the part, temperature measurement and measuring the pressing force. This is now the base for deviating requirements for the development of the testing equipment.

3.2. Analysing the Process and its Functions

For each function there are several requirements which are complemented by parameter ranges, if this is possible. In summary, all of them are representing the specification sheet.

Table 1 gives an extract of the requirements that are explained in this paper.

Table 1. Extract of specification sheet.

Short	Specification	Range [unit]
PH1	Provide cavity with inert gas	T <= 700°C
PH2	Install cooling system for cooling down the cavity	t_{cool} <= 5 min
PP1	Make fitting between cavity and upper and lower stamp	2 µm < s < 14 µm
MP1	Integrate piezo sensors for measurement of pressing forces	F <= 8.000 N
Gen1	Provide possibility to manufacture parts with different sizes	0.5 mm <= d,h <= 5 mm

3.2.1. Powder heating 1 (PH1)

Due to the high temperatures the cavity has to be filled with inert gas to prevent oxidation effects of the used material on the one hand and the material of the cavity and the upper stamp on the other hand. First, the powder is filled in and then the cavity is closed. This is followed by an evacuation process subsequently followed by inert gas filling.

3.2.2. Powder heating 2 (PH2)

As mentioned in [1] the amorphous material must not exceed crystallisation temperature. Besides the rapid and accurate laser power control, where the heat source can be deactivated directly, a supplementary cooling system is installed. Further tests have to show whether it has to run constantly or only if necessary. Additionally, this is advantageous for experimental procedure for cooling down the cavity to achieve same initial conditions immediately after one process sequence.

3.2.3. Powder pressing 1 (PP1)

The main influencing factor for the quality of the shape and the dimensional accuracy of the manufactured part is the processing of the two stamps and the cavity wall. Due to its high viscosity when exceeding glass transition temperature, the amorphous material is able to creep in smallest gaps lower than 20 µm [4]. For this case the fitting between the cavity and the stamps has to be manufactured accurately to achieve a small resulting gap in the range of 2 µm to 14 µm which correlates with the F6g6 fitting.

It is also obvious, that every small defect and element of the shape of the stamp is reproduced in the shape of the resulting part. So the edges of the sapphire stamp must be sharp without any bevel. Because of this sharp edge there may be large wear effects of the cavity caused by scratching of the sapphire and a higher risk of damaging the sapphire stamp due to undesired bending loads. This is prevented by three arrangements. Firstly, the lower sapphire stamp is split into two parts (see figure 2).

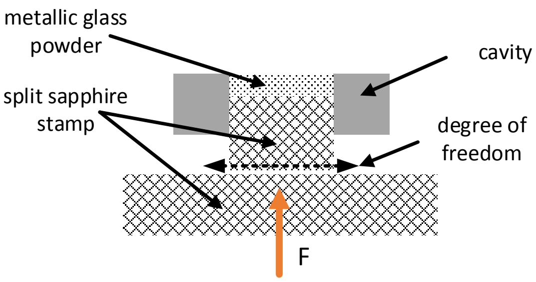

Figure 2. Sketch of split sapphire stamp.

But this splitting may result in a misrouted laser beam because of the small gap and not perfect match of both surfaces. Further tests and readjustment of the laser will show and eliminate this effect.

Secondly, accurate pressing in axial direction is required. For this, the parts involved (linear guides, carriages, transmission equipment and surfaces of sapphire stamp) must be aligned with lowest tolerances. If not, the error can be detected through pressing without powder and then be eliminated by realigning the equipment and therefore minimizing the initial pressing force. Thirdly, the cavity is hardened for minimized wear and can be replaced if it is worn out.

3.2.4. Measuring pressuring force 1 (MP1)

Due to their high resolution and low deformation, which is advantageous for size accuracy, piezo-electric sensors are used for the measurement of the pressing forces and the proportional pressures. For high indication accuracy the process related drift of the piezo sensors is measured and considered in the machine control. Additionally, the initial force (see subsection 3.2.3), that is basically depending on the frictional forces between stamps and cavity, and therefore depending on the ways of the stamps, must also be considered.

3.2.5. General 1 (Gen1)

As mentioned in subsection 3.2.3 the cavity is changeable. Therefore it is manufactured with a press fit and assembled to the base plate with integrated cooling system. The press fit is necessary to avoid undesired local buckling of the cavity if high pressing forces are applied. There are cavities to manufacture work pieces with diameters and heights from 0.5 to 5 mm. For changing diameters the laser focus is adjustable so the laser beam diameter changes. Additionally there are different focusing lenses to change the caustic of the laser beam to be more flexible.

4. Conclusion and Outlook

Concluding, the new testing equipment is basically applicable to manufacture small scale parts from amorphous metal powder. There are several risks that are evaluated by an FMEA and furthermore reduced or eliminated by mainly design features or further installing tests. Most critical is the accurate pressing process to achieve net shaped parts without the necessity of further processing steps combined with an accurate process temperature control that is evaluated in [1].

However, this testing equipment is only a first approach to provide the full flexibility for defining process boundaries and to optimise parameters. It also provides the opportunity to manufacture parts from conventional crystalline material to compare the results and parameter settings. Nevertheless, this testing equipment is not optimised to be used for production runs.

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