euspen's 15th International Conference & Exhibition, Leuven, Belgium, June 2015

www.euspen.eu

Concept for identifying the temperature conditions and distribution in amorphous metal micro parts manufactured by a hybrid contact laser sintering process

Tobias Montag[1], Jens-P. 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 (HCLS) Process is advantageous for manufacturing micro sized work pieces out of amorphous metal powder. Due to the small dimensions of the work piece the temperature measurement that is important for a robust process control is demanding. Comparing the tactile and the contact free temperature measurement method the tactile method was identified as most suitable to manage the challenges. Furthermore the need of accompanying temperature simulations is mentioned to get reliable maximum temperature data for a robust process control to avoid recrystallization of the structure.

Keywords: Micro Machining, Laser Sintering, Amorphous Metal

1. Introduction

The occurrence of size effects with ongoing miniaturization of work pieces leads to a decreasing accuracy and reliability of manufacturing processes [1]. One significant size effect for the quality of forming processes is the grain size / thickness ratio. It increases due to the rising influence of the grain size that is not scalable in the same range like the dimensions of the work piece especially when they reach the size of a few grains [1].

Due to the absence of grains the use of amorphous metals or so called metallic glasses is advantageous for manufacturing micro parts. But when heating metallic glasses for forming processes like sintering the time and temperature dependent recrystallization and grain building of the structure have to be avoided. It occurs slightly above its glass transition temperature [2]. Laser radiation seems to be the most suitable source for heating the metallic glass powder as it offers easy control of energy input. For this case the Hybrid Contact Laser Sintering Process was developed [3, 4]. One challenge is to accurately measure the powder temperature which is the key indicator for heat control. If this is not done properly the process temperature may exceed the recrystallization temperature.

The aim of this paper is to present a concept of a small testing machine to identify the most suitable way of temperature measurement within the sintering process. At first the effects of combining powder pressing and sintering process steps are outlined. This is followed by showing the concept of the testing machine that is planned considering those characteristics to accurately measure the powder temperature. Finally two ways for temperature measurement, the tactile and contact free method, are compared to identify the most suitable one.

2. The Hybrid Contact Laser Sintering (HCLS) Process

The main characteristic of the HCLS Process is the concurrent powder pressing and sintering. The laser energy is transmitted through the lower stamp that is made out of sapphire to directly heat the metallic glass powder. One challenge is to identify the influence of temperature distribution. It can be assumed that the bottom is heated faster than the top and as the dimensions are very small and the powder is porous the inner parts of the powder are heated with lower intensity (figure 1). The second challenge is the changing geometry while powder pressing. Two ways of pressing are possible: One-sided and two-sided pressing. For conventional powder pressing the two-sided version is advantageous because of the lower density difference within the work piece that is caused by wall friction [5]. For temperature measurement both versions must be considered to identify differences and to decide whether two-sided pressing is needed or the one-sided version is adequate. The main focus of temperature measurement is the position where the fully compacted work piece is located at (figure 1, right) because the main compaction of the powder takes place at a short time in the very beginning of the process.

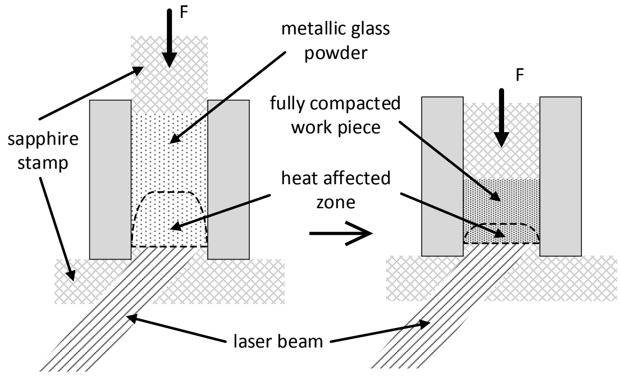

Figure 1. Setup of HCLS-Process and its effects.

Combining both challenges a third one is obvious: the density distribution dependent heating of the powder vs. the changing thermal flow. With increasing density the heat affected zone might be smaller (figure 1) but the thermal flow would be greater. To identify the significance of those effects powder with different densities has to be heated. Simultaneously the parameters for energy input have to be adjusted.

3. Concept for identifying temperature conditions

The concept of a testing machine for identifying the temperature conditions and the most suitable way for temperature measurement is shown in figure 2. The cavity for the metallic glass powder is cylindrical with three millimetres in diameter and height. The contact free measurement is done with a pyrometer by transmitting its measurement laser beam through another sapphire stamp that is placed at the top. The measurement range is 150°C to 550°C and the measurement spot is 0.8 mm^2. The tactile measurement is done by three thermocouples placed radial around the cylinder at different heights. The measurement range is -200°C to 1200°C and the measurement spot is about one millimetre. The used laser for powder heating is a diode laser with a maximum output power of twenty watts per fibre in continuous mode. Four fibres are attached to the laser so the maximum output power is eighty watts with a beam diameter of about 2.24 mm.

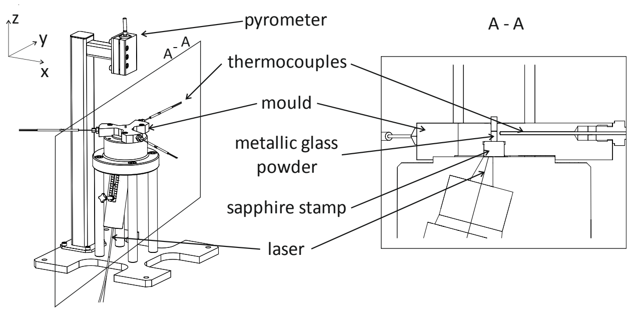

Figure 2. Concept for identifying temperature conditions.

4. Comparing contact free and tactile measurement

The assessment criterion for comparing both ways of temperature measurement is how they manage the challenges that are named in chapter 2. In the following the best way of measurement is identified. The aim is to achieve reliable data as basis for a robust process control.

4.1. General comparison of both ways of measurement

In general both ways of temperature measurement are advantageous. The contact free method offers smaller measurement spots down to 0.2 mm and lower responding times. The tactile method offers a larger measurement range especially for temperatures near room temperature and is more independent from disturbance variables like heat radiation and material properties like the emission factor.

4.2. Suitability for identifying temperature distribution:

As explained the temperature within the powder is not distributed equally. The area of the largest temperature is at the bottom, where the laser beam is aiming on. For this case three thermocouples were placed at different heights to discover the height dependent temperature distribution. Furthermore the mould and its integrated thermocouples can be rotated in steps of sixty degree. This leads to eighteen measurement points on the surface shell of the work piece. Due to the non-transparent cavity this is not possible for the contact free measurement method. If there was a cavity made out of sapphire it would be gradually scratched by the metal powder and become non-transparent. But neither the tactile nor the contact free measurement method gives the maximum temperature, which is important for process control. For this case temperature distribution simulations have to be performed. The input data are the thermocouple measurement data, the laser energy input and the thermal conductivity of the material. The output is a characteristic map for the maximum temperature that is the basis for process control.

4.3. Suitability for changing geometry

In case of one-sided pressing (top stamp moves down) the pyrometer has to change its position simultaneously in the same range for still having the smallest measurement point. Another disadvantage is the rising influence of disturbance variables. At first the influence of wall heat radiation increases due to the lower position of the sapphire stamp (figure 3a). At second there is a lower flexibility in case of manufacturing smaller parts. If the diameter decreases, the temperature of the wall influences the result due to the optical path of the measurement beam (see figure 3b). The tactile method is more advantageous due to shifted placement of several sensors along the height of the work piece. In case of changing diameters the mould is different but the placement of the thermocouples is similar. One disadvantage of tactile measurement can be seen in the influence of wall heat conduction due to the large mould and the space of one millimetre between cavity and measurement point.

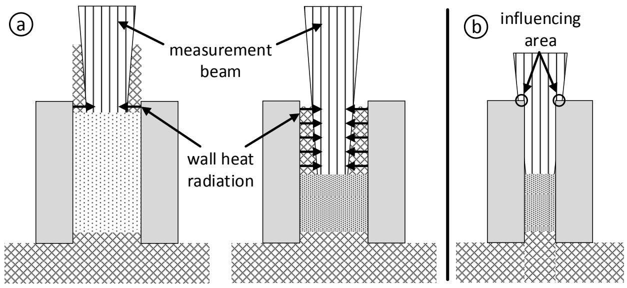

Figure 3. Effects of changing geometry while powder pressing (a) and reduced work piece diameter (b).

5. Conclusion

Based on challenges like non-equal temperature distribution and changing work piece geometry for temperature measurement, that occur within the HCLS process, a testing machine is developed to identify which measurement method is most suitable to achieve reliable data for a robust process control. As a first result the tactile measurement method is identified as most suitable for managing those challenges. But nevertheless additional simulations have to be performed to identify the maximum temperature that is important for a robust process control to avoid recrystallization effects. Future tests with the developed concept will validate the theoretical comparison of both methods. They also may indicate new effects that are not known at present.

Acknowledgements

This research is funded by the German Research Foundation.

References

[1] Vollertsen F 2009 Größeneinflüsse bei Fertigungsprozessen (Bremen BIAS Verlag) preface and 6-7

[2] Basu J and Ranganathan S (2003) Bulk metallic glasses: A new class of engineering materials *Sadhana* **3-4** 783-798

[3] Wulfsberg J P, Terzi M, Kuhn A and Bruhns F L (2008) Verfahren zum strahlungsgeschützten Urformen, Umfomen, Fügen und Trennen mittels aufgesetzter, kraftübertragender Kontaktoptik *Patent DE102006051333A1*

[4] Redlich T and Wulfsberg J P 2014 Consideration of Size Effects in Micro Forming Processes *Proceedings of the 4th International Conference on Nanomanufacturing Bremen, Germany*

[5] Schatt W, Wieters K P and Kieback B (2007) Pulvermetallurgie (Berlin Springer) 116f