Tool design and materials for electro sinter forging (ESF)

Cannella, Emanuele; Nielsen, Chris Valentin

Publication date:
2018

Document Version
Peer reviewed version

TOOL DESIGN AND MATERIALS FOR ELECTRO SINTER FORGING (ESF)

Emanuele Cannella[1,2], Chris Valentin Nielsen[2]

[1]*IPU Innovation Factory, Denmark*
[2]*Department of Mechanical Engineering, Technical University of Denmark, Denmark*

Summary

A near net-shape forming process represents a suitable solution to obtain the final product by avoiding secondary machining processes. In this field, electro sinter forging is capable of accomplishing the advantages of sintering in a reduced amount of time. Classified as a high field mode (HFM) process, the main requirement is the electrical current passing through the electrical conducting powder. To obtain this, a closed-die setup with electrical insulating properties was used. Furthermore, the alignment between the compacting punch and die needed to be ensured by pre-aligning or alternatively by using an alignment system. The present work is focused on the designing phase of a tool for the electro sinter forging of a disc, made from titanium powder. By applying a pre-alignment system, the setup resulted suitable for this application. A tool design for sintering rings is also showed.

1. Introduction

Sintering processes enable the manufacturing of components starting from metal or ceramic powder. A sintering die is designed with the final shape of the sample, making possible the manufacturing of a near-net shape component. Complex geometries can be manufactured without machining processes. Secondary processes, like polishing, may be used to improve the surface roughness. A conventional sintering process is divided in two main steps [1], i.e. i) feeding, compacting of the metal/ceramic powder into a die and ejection of the compacted sample called green, and ii) sintering of the green in a temperature controlled oven. Grain growth, creep and large sintering time are the main disadvantages associated with conventional sintering. Electro current assisted sintering (ECAS) was developed to improve the conventional sintering process by reducing the process time and risks related to such long time at high temperature [2]. The component and/or the die is/are heated from the generated Joule heat [3]. The two aforementioned main steps are taking place simultaneously in ECAS. After pre-compaction of the green, the sample is sintered while being further compacted. The component is ejected from the die as sintered. Electro sinter forging (ESF) is one of the processes based on ECAS [4]. In this case, the principle is inspired from electrical resistance welding (ERW). The die has to be electrically insulating to concentrate the electrical current into the green compact.

Literature shows several examples of sintering dies used for ECAS processes. Graphite is commonly used for its electrical and thermal properties [5]-[6], especially in the case where both the die and component are heated. This is a solution in case of non-conductive powder. ESF requires electrically insulating tools. The most common solution is based on using a cylindrical insert as die and a container for strengthening [7]-[8]. The insert is typically made of ceramic because of its insulating property. Furthermore, literature also focused on the design of the punch/die alignment system, based e.g. on pre-alignment and guide-alignment, [8]-[9].

This paper presents a tooling system for electro sinter forging performed in a resistance welding machine. The insert-container approach was applied together with pre-alignment. Tooling systems for both disc- and ring-shaped parts are presented.

2. Case study

The tested material is commercially pure titanium powder grade 2. The average particle size was 150 µm and powder purity was 99.5%. The two sintered shapes were a disc and a ring, **Fig.1**. Titanium powder is suitable for this process because of its electrical conductivity.

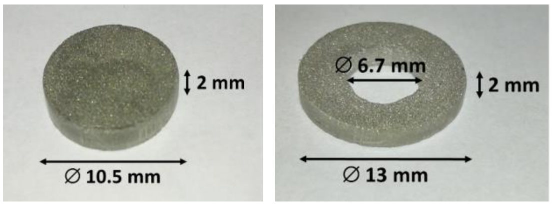

Fig.1 Disc- and ring-shape samples.

The samples were sintered by using an electrical resistance machine by Expert Maschinenbau GmbH, **Fig.2**. The press is mechanically operated by hydraulics and has disc springs for follow-up of the force. The electrical control unit is by Harms+Wende GmbH, **Fig.2**. The compacting load and electrical current were measured in-process by using a load cell and a Rogowski coil, respectively, **Fig.2**.

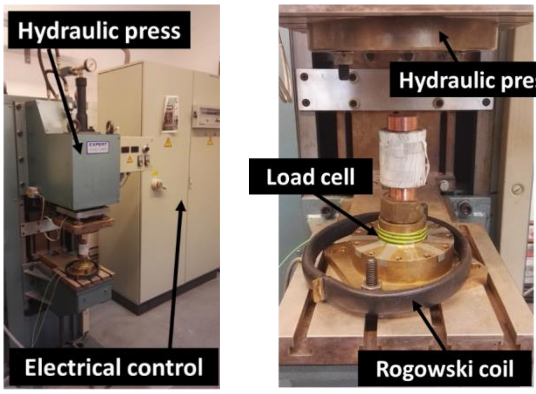

Fig.2 Electro sinter forging equipment: electrical resistance welding machine (left) and tool setup (right).

2.1 Process parameters

The process was carried out by setting the main process parameters, which are compacting pressure, sintering time and electrical current density. Typical parameter ranges for titanium are shown in **Table 1**.

Table 1 Process parameter range.

Compacting pressure	**Sintering time**	**Electrical current density**
70 - 100 MPa	100 - 200 ms	55 - 100 A/mm^2

The process parameters were in-process monitored by using a LabView interface. Typical graphs are shown in **Fig.3** and **Fig.4**.

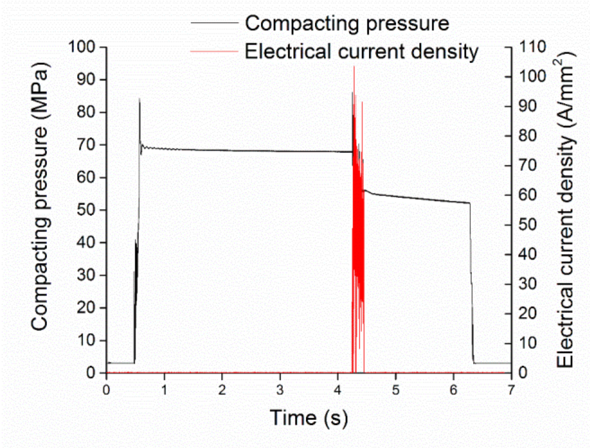

Fig.3 Example of measured process parameter profiles during a sintering process.

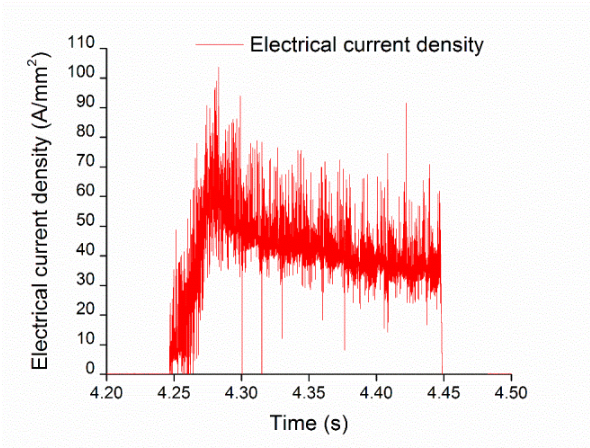

Fig.4 Detail of the electrical current density profile shown in **Fig.3**.

The in-process variations of the process parameter values are due to the changes in mechanical and electrical properties of the sample during the process.

3. Tool design

Both for the discs and rings, the design for ESF tools consisted of a ceramic die insert and an external steel container to support the insert. No pre-stress was applied at the interference. A clearance fit H7/h6 was applied. The use of ceramic material for the die insert concentrated the electrical current in the compacted titanium powder. The chosen material for the insert was aluminium oxide (Al_2O_3) for its electrical and thermal insulating properties. The drawback is the brittles, which resulted in several broken inserts. The container was made of structural steel, and the electrodes were made of electrolytic copper. The use of a Teflon tape surrounding the steel die made possible to avoid electrical contact between the die and the electrodes, as seen on the tool setup in **Fig.2**.

3.1 Disc-shape

The tooling for making discs consisted of a cylindrical alumina insert with a circular shape, **Fig.5** and **Fig.6**.

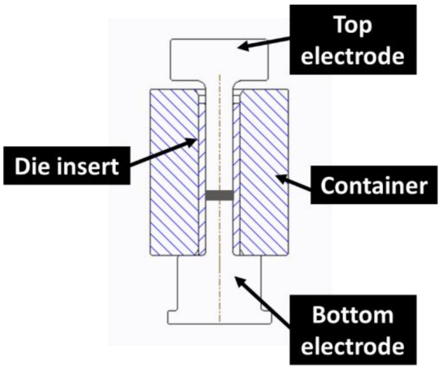

Fig.5 Cross-section of the tool setup used for discs.

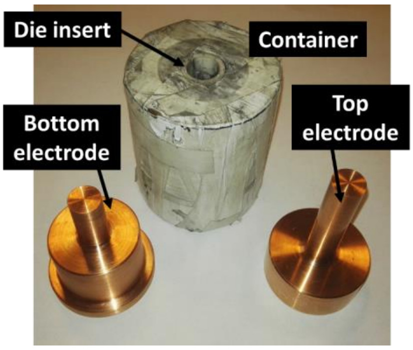

Fig.6 Tools for making discs.

A monoblock solution was tested by machining a sintering die of a 6000 series aluminium alloy. The die was hard anodised after machining to generate a 25 µm aluminium oxide layer, **Fig.7**. The solution worked for a few cycles before the anodised layer was damaged and generated electrical contact between the green compact and the lateral surface of the die.

Fig.7 Anodised die for ESF.

3.2 Ring-shape

The same design principles and materials were used for making rings. To manufacture the hole into the sample without any secondary machining, an alumina rod was used as mandrel in the tool setup, **Fig.8** and **Fig.9**. The ejection of the sample was operated with a double action, i.e. i) ejection of the ring and rod from the die and ii) ejection of the internal rod from the ring.

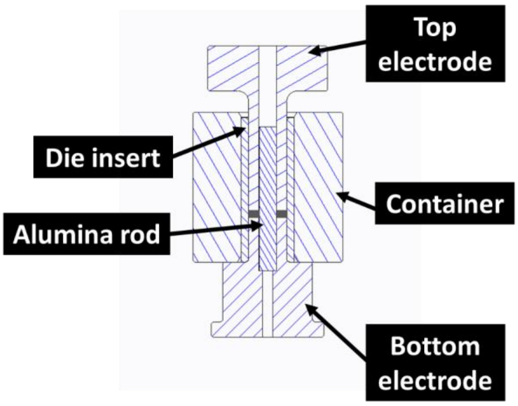

Fig.8 Cross-section of the tool setup used for rings.

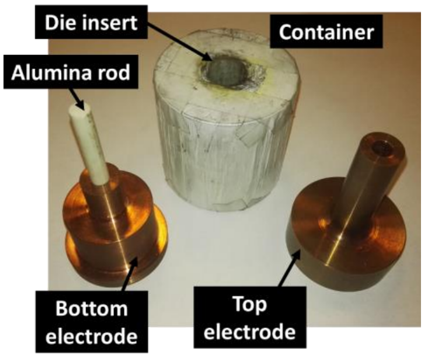

Fig.9 Tools for making rings.

4 Electrode-die alignment

The tool system design took into account the alignment of the electrodes to the die. Because of the high compaction load, a good alignment had to be ensured. Poor alignment of the electrodes might affect the part quality in terms of planeness and a non-uniform pressure and current density, **Fig.10**, which will lead to non-uniform sintering. Furthermore, bending of electrodes and die damage were avoided. Pre-alignment of the electrodes and application of a sub-press were considered. Pre-alignment was ensured by placing the top electrode in the die after the powder was feed inside, **Fig.2**. This allowed to have the top electrode in position and axially aligned by letting it start at about three diameters into the die. Application of a sub-press is illustrated in **Fig.11**. This principle will be advantageous for automated processing, but was not chosen for the preliminary experimental testing.

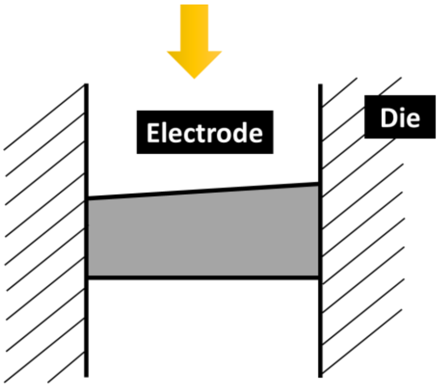

Fig.10 Effect of a misalignment on the sample planeness.

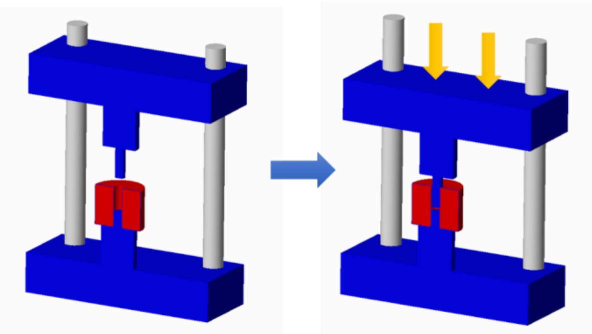

Fig.11 Sub-press system for alignment.

5. Conclusions

Tooling for making discs and rings by ESF has been successfully tested. Both tooling systems were based on an alumina insert acting as a die and surrounded by a steel container to strengthen the brittle ceramic die. The choice of a ceramic die was due to its good electrical insulating properties. Electrical insulation of the die was important for this ESF application to make the electrical current flowing only into the green compact and not through the die.

Two alignment solutions were considered. For the preliminary experimental purpose of the work, the pre-aligned solution was tested. Application of a sub-press was considered worth applying in the industrial context, where process automation is required.

Acknowledgments

This research work was undertaken in the context of MICROMAN project (“Process Fingerprint for Zerodefect Net-shape MICROMANufacturing”, http://www.microman.mek.dtu.dk/). MICROMAN is a European Training Network supported by Horizon 2020, the EU Framework Programme for Research and Innovation (Project ID: 674801).

References

[1] R. H. R. Castro: *Sintering*, vol. 35, R. H. R. Castro and K. van Benthem, Eds. Springer, 2013, pp. 1–16.
[2] S. Grasso, Y. Sakka, and G. Maizza: *Sci. Technol. Adv. Mater.*, vol. 10, no. 5, p. 53001, 2009.
[3] O. Guillon, J. Gonzalez-Julian, B. Dargatz, T. Kessel, G. Schierning, J. Rathel, and M. Herrmann: *Adv. Eng. Mater.*, vol. 16, no. 7, pp. 830–849, 2014.
[4] A. Fais: *J. Mater. Process. Technol.*, vol. 210, no. 15, pp. 2223–2230, 2010.
[5] D. Tiwari, B. Basu, and K. Biswas: *Ceram. Int.*, vol. 35, no. 2, pp. 699–708, 2009.
[6] D. Giuntini, J. Raethel, M. Herrmann, A. Michaelis, and E. A. Olevsky: *J. Am. Ceram. Soc.*, vol. 98, no. 11, pp. 3529–3537, 2015.
[7] F. V Lenel: *J. Met.*, vol. 7, pp. 158–167, 1955.
[8] J. M. Montes, F. G. Cuevas, J. Cintas, and P. Urban: *Metall. Mater. Trans. A*, vol. 46, no. 2, pp. 963–980, 2014.
[9] G. Maizza and a. Tassinari: *COMSOL Conf. 2009*, 2009.