EPMA European Structural Parts Group

Design for Sintering – Improving the reliability of the design procedure accounting for anisotropic dimensional changes "DfS 2"

<u>Consortium Agreement</u>

Issued April 2018

The Project – "DfS 2" as defined in Annex 1
The **Contractor** –

- Department of Industrial Engineering, University of Trento, via Sommarive 9, 38123 Trento, Italy : **UNITN**

The **Coordinator** –

- The European Powder Metallurgy Association, Talbot House, 2nd Floor , Market St., Shrewsbury SY1 1LG, England: **EPMA**

The **Members** – Paid up corporate EPMA members funding the Project (Special Rules apply to Associate Members).
The **Participants** – The Contractors and the Members

The Coordinator and each of the Participants are individually referred to as a "**Party**" and jointly as the "**Parties**".

UV = unanimous vote of Members and Contractors.

<u>Heads</u>

1. The Members and Contractors agree to cooperate in order to complete the Project according to Annex 1.
2. The Parties undertakes for the duration of the Project and for a period of five years after the delivery of the final written report to the Members, to hold in confidence all Confidential Information (as defined below) disclosed by either Party to the other and to refrain from disclosing Confidential Information to any third party. Confidential Information shall only be disclosed when necessary for the performance of the Project and subject to UV.

   Confidential Information shall include all technical, financial and business information regarding the Parties and their subsidiaries as well as their products, processes, production methods and techniques (including metal powder samples), provided that Confidential Information shall not include:

   (i) information which was known by the receiving Party at the time of disclosure as shown by written record to this effect;

   (ii) information which at the time of disclosure is in the public domain or which is published after disclosure or otherwise becomes part of the public domain through no fault of the receiving Party;

   (iii) information which the receiving Party can show was received by it from a third party who did not to the best knowledge of the receiving Party acquire the information, directly or indirectly, from the other Party under an obligation of confidence.

For UNITN: Notwithstanding the foregoing, the Contractor is obliged to publish in the usual scientific form the results of studies undertaken during performance of the Project. The Members gives their fundamental consent to such publication. The Contractor will inform the Members beforehand of any planned publication and will give them the opportunity of commenting on it within a reasonable period, at latest four (4) weeks after submission of the text intended for publication. A Member is entitled to refuse their consent to a publication if it is intended to publish company related data or, in connection with the granting of patent rights, if it is intended to publish any anticipatory information likely to constitute a bar to novelty. In such cases, the Participants will, without delay, seek to reach a special agreement governing the form and timing of rapid publication and taking due account of the legitimate interests of both the Members and the Contractor.

In case of abstract submission to any Congress and Conference, the Contractor will circulate the text in due time to have the consensus from the Members within two (2) weeks.

3. The Contractor agree to not carry out a similar project on anisotropy of dimensional changes of sintered parts with organisations other than the Members until completion of the Project (delivery of the final report). The aforementioned obligation shall not apply to other entities of UNITN other than its performing entity (Mechanical design and Metallurgy group) research group, including Prof. Alberto Molinari and Prof. Ilaria Cristofolini. The Scientific Responsible of the Project for UNITN is Prof. Ilaria Cristofolini.
4. The Members agree to share equally a common Project fee of **38,307 Euros** plus a fixed cost per Members of **9,577 Euros** (costs of measurement and data processing). The required minimum number of Members is **four** for a maximal individual project fee of **19,154 Euros for the three years project** unless all the Members agree to exceed the maximum Individual project fee.
5. **VAT**: VAT will be added to the Project Fee as appropriate but may be reclaimed according to local arrangements (e.g. "Reverse Charge" mechanism). All VAT numbers are to be provided to the EPMA.
6. **New Members**, who did not participate in the "DfS" - Demonstrator Project may participate in the DfS 2 project by settling a "UTFH results access premium" of **EUR 2,300** at the start of the Project in addition to the DfS 2 project fee. Minimum number of members for the project is 4.
7. The Members also undertake to provide the Contractors with the necessary materials (powders, specimen etc...) for the Project. If no agreement on the in-kind contribution can be made between the Participants, each Member is free to withdraw from the Project. If the Consortium agrees to subcontract the in-kind internally or externally at additional costs, the EPMA will coordinate this task and charge equally each Member to cover the cost plus an administrative fee of 13%.
8. **Payment Schedule:**
    - **25% of the total fee at the start** of the "DfS2" Project,
    - **50% of the total fee after completion** of the activities forecasted for the **first part**, as presented to the partners in a dedicated meeting (after 18 months).
    - **25% of the total fee after completion** of the **project**, as presented to the partners in a dedicated meeting (after 36 months).
9. No new members may be admitted during the Project.
10. **IPR** means all results in the form of technical information, know-how and intellectual or industrial property rights, including but not limited to patents, models, designs, copyright, trade secrets and rights in unpatented know-how. "Foreground IPR" means any IPR arising or resulting from the Project. Foreground IPR shall be the property of the Party performing the work generating the Foreground IPR. Should several Parties have contributed to the results – then the IPR shall be the property of the Party who has predominantly contributed to such result. Each Member is granted a global, perpetual, royalty free license to freely use any and all Foreground IPR (including the right to

change, alter, amend and sub-license such Foreground IPR). Background IPR means any IPR owned or controlled by a Party at the date of signature of this agreement or developed and/or acquired independently of this agreement. Background IPR shall remain the exclusive property of the Party providing such information. For the avoidance of doubt, no license rights are granted regarding Background IPR through this agreement.

11. **Warranty**. The Contractor's warranty extends solely to the use of due scientific diligence and to compliance with accepted engineering practice. The Contractor does not guarantee that the desired objectives of the research and development project will be achieved.
12. **Liability**. The Contractor is liable for negligence. The liability covers the proven damage.

The terms 1 and 2 of this agreement may be changed by UV.

Coordination will be undertaken by the EPMA, who will have responsibility for invoicing, day to day liaison with the Contractors and keeping Members informed. The EPMA will operate under the same confidentiality agreement as Members and the EPMA President will arbitrate any unresolved disputes.

Signatures: signed individually by all Members and Contractors

ORGANISATION:

VAT NUMBER:

NAME:

DATE:

SIGNATURE:

Annex 1

Design for Sintering – Improving the reliability of the design procedure accounting for anisotropic dimensional changes "DfS 2"

Project description

State of the Art

In the previous project – DfS demonstrator project, 1 year lasting – the design procedure accounting for anisotropic dimensional change developed in previous work [1-3] has been applied to five industrial axi-symmetric parts, differing for geometry, material, green density, process conditions, aiming at verifying its reliability and effectiveness in predicting dimensional changes.

The design procedure is related to a single ring, the application on real parts implies the identification of coaxial rings in the real parts. Coaxial rings were identified by a "column based approach" (referring to the powder columns, which can be identified during uniaxial compaction) or by a "maximum section based approach" (referring to the maximum amount of shrinking/swelling material, which drags after the other rings). See 3 for explanation in depth. As observed in previous work, this project also confirmed the better effectiveness of maximum section based approach. Procedure application requires that complex geometries are reasonably reduced to rings, so that the influence of missing amount of materials when predicting gears as rings (base cylinder vs. top teeth), as well as the presence of cavities, have to be taken into account.
Parts were measured both in the green and in the sintered state using a measurement procedure specifically defined for each part, and measured dimensional changes were compared to predicted dimensional changes. Different geometrical parameters, as by previous experiments, were used in the design procedure when applied to parts showing a small change in volume (that is isotropic dimensional change from -0.0018 to 0.0012) and to parts showing a large change in volume (that is isotropic dimensional change -0.024, - 0.025).
The influence of compaction has been highlighted in some cases, mostly in parts with small isotropic dimensional change. Considering nominally same dimensions, the dimensional change was overestimated in the part close to upper punch, and underestimated in the part close to the lower punch. Explanation hypotheses concern the influence of filling, compaction, ejection, hold down…, while gravity and friction with sintering trays are likely negligible.

In parts almost not shrinking neither swelling the influence of the extremely small value of isotropic dimensional change (0.0005) on results has to be considered (large effect of extremely small values at denominator).
When predicting the dimensional changes of parts with large isotropic dimensional change, problem is that the reference data for large isotropic dimensional change are derived from parts subject to liquid phase sintering , while those studied are solid state sintered parts.

In all the cases a good agreement has been found between predicted and measured dimensional changes, the difference being always **lower than 1%** (specifically, lower than 0.2% for parts showing small change in volume and lower than 0.75% for parts showing large change in volume). In terms of ISO tolerance classes, the difference between predicted and measured dimensions corresponds to IT8-IT9 maximum, more frequently to values lower than IT6-IT7.

Moreover, interesting results have been obtained predicting a free form profile (oval), identifying a reliable corrective function which led to predict dimensional changes within the required tolerances. The method can be successfully applied to other elliptic-oval profiles.

Open points issued by the DfS demonstrator project

The results obtained by the previous project highlighted that dimensional changes can be predicted with good accuracy, and that further investigation on a wider sampling might improve it even more, aiming at enlarging and strengthening the database, from which the geometrical parameters describing the anisotropy parameter *K* derive, also investigating in depth the complex mechanisms responsible for anisotropic dimensional change.

In particular, open issues are:

- the influence of compaction strategy (filling-compaction-ejection-hold down) and consequent green density and density distribution
- the influence of solid state sintering in comparison to liquid phase sintering determining large change in volume
- the two different relationships (derived from the step by step development of previous work) describing the anisotropy parameter K in case of “small” and “large” isotropic dimensional change: what if “intermediate” isotropic dimensional change? Data related to “intermediate” change in volume, that is isotropic dimensional change between 0.002 and 0.025, might allow determining a unique relationship describing the anisotropy parameter *K*, only differing for the parameters related to geometry.

1) I. Cristofolini, N. Corsentino, A. Molinari, M. Larsson , “Study of the Influence of Material and Geometry on the Anisotropy of Dimensional Change on Sintering of Powder Metallurgy Parts”, International Journal of Precision Engineering and Manufacturing 15(9) (2014) 1865-1873

2) Cristofolini I., Corsentino N., Larsson M., “Analytical model of the anisotropic dimensional change on sintering of ferrous pm parts”, Powder Metallurgy Progress, 16 (1) (2016) pp.27-39

3) Cristofolini, I., Corsentino, N., Molinari, A., Larsson, M., “A design procedure accounting for the anisotropic dimensional change on sintering of ferrous PM parts”, Advances in Powder Metallurgy and Particulate Materials - 2014, Proceedings of the 2014 World Congress on Powder Metallurgy and Particulate Materials, PM 2014, vol. 1, pp. 115-127

Objectives

The project aims at improving the effectiveness and reliability of the design procedure, aiming at developing a tool, which actually can be used in the design step. The goal is reducing the difference between predicted and measured dimensions to about 1/5 of the dimensional tolerance. The mechanisms responsible for anisotropic dimensional change on sintering will be investigated in depth. This implies to enlarge the database, from which the effectiveness of the design procedure derives, investigating the behaviour of simple ring shaped parts, differing for dimensions.

On the basis of the open points issued by the previous project, the influence of geometry, material, and green density will be investigated.

The project is roughly split into two parts:

Part 1: effect of geometry and green density

Part 2: effect of compaction strategy

Aiming at exploiting the knowledge gained in the previous DfS demonstrator project, in **Part 1** the characteristics of the sampling will be as follows:

- Material: the same materials used in the previous project for each partner
- Geometry: rings characterized by 3-4 different $H/(D_{ext}-D_{int})$
- Green density: 3 different green densities
- Compaction strategy: standard industrial strategy
- Sintering temperature: the same considered in the previous project

In **Part 2** the characteristics of sampling will be as follows:

- Material: the same materials used in Part 1 for each partner
- Geometry: 2 of the geometries used in Part 1 for each partner
- Green density: maximum green density considered in Part 1
- Compaction strategy: 2 different hold down forces (10% and 20%), 2 different compaction speed
- Sintering temperature: the same considered in Part 1

The project will last three years (36 months), involving a collaborator at UNITN.

As in the previous project, the green parts produced by the partners will be sent to UNITN to be measured by the CMM (Coordinate Measuring Machine). The partners will also provide the measured dimensions of the die, so to estimate the spring-back. After measurement UNITN will be send green parts back to the partners to be sintered in the industrial conditions. The sintered parts will be measured and dimensional variations will be calculated for each single part. For each component ten parts will be measured. The change in volume will be derived from both the measured dimensional change and the water displacement method. The measured dimensional changes will be used to enlarge the database, from which parameters K and α in the design procedure are derived. The new relationships describing K and α will be used in the design procedure and predicted dimensional changes will be compared to the measured ones. One green and one sintered part for each condition will be used to investigate microstructure (LOM and SEM, hardness measurement…).

Work Packages and Time Planning

The project is subdivided into 12 Work Packages (WP)

Part 1: effect of geometry and green density

WP1.1 **(partners)**
Selection of the geometries (rings characterized by 3-4 different $H/(D_{ext}-D_{int})$ and of the 3 green densities for each partner.
Deliverables WP1.1:
15 green samples each geometry and green density from each partner to UNITN

WP1.2 **(UNITN)**
Measurement and characterization of the green parts at UNITN.
Deliverables WP1.2:
Dimensions and microstructural characterization of the green parts. Green parts back to partners for sintering.

WP1.3 **(partners)**
Sintering of parts by the partners with the industrial cycle
Deliverables WP1.3:
Sintered parts delivered to UNITN

WP1.4 **(UNITN)**
Measurement and characterization of the sintered parts at UNITN.
Deliverables WP1.4:
Dimensions and microstructural characterization of the sintered parts.

WP1.5 **(UNITN)**
Data process and analysis of the effect to K and α. Application of the design procedure and comparison predicted-measured dimensional changes
Deliverables WP1.5:
Enlargement of database and new relationships describing K and α in the design procedure. Predicted vs. measured dimensional changes

WP1.6 Project Management and Reporting **(UNITN + EPMA)**
The Project Management will be supported by EPMA. Regular Progress Reports and Meeting Minutes will be written by UNITN. The final report will be written by UNITN and EPMA.
Deliverables WP1.6:
Progress Reports, Meeting Presentations and Minutes
Mid-term report and Part 2 plan

Part 1: Time Planning
This project continues the activities performed in the previous one, so that one mid-term meeting with all participants in the end of the first part looks to be sufficient, providing that UNITN will be at disposal any time, when needed, for calls and, in case, individual meetings. The mid-term meeting will be aimed at sharing and discussing the results and planning the activities of the further part.

Duration of the Part 1: 18 months

Work packages	Months																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
WP1.1	X	X																
WP1.2			X	X	X	X	X											
WP1.3								X	X									
WP1.4										X	X	X	X					
WP1.5														X	X	X	X	
WP1.6	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Part 2: effect of compaction strategy

__WP2.1__ **(partners)**
Selection of the compaction strategy for each partner - 2 different hold down, 2 different compaction speed, 2 of the geometries selected for Part 1, maximum green density reached in Part 1.
Deliverables WP2.1:
15 green samples each geometry and compaction strategy from each partner to UNITN

__WP2.2__ **(UNITN)**
Measurement and characterization of the green parts at UNITN.
Deliverables WP2.2:
Dimensions and microstructural characterization of the green parts. Green parts back to partners for sintering.

__WP2.3__ **(partners)**
Sintering of parts by the partners with the industrial cycle
Deliverables WP2.3:
Sintered parts delivered to UNITN

__WP2.4__ **(UNITN)**
Measurement and characterization of the sintered parts at UNITN.
Deliverables WP2.4:
Dimensions and microstructural characterization of the sintered parts.

__WP2.5__ **(UNITN)**
Data process and analysis of the effect to K and α. Application of the design procedure and comparison predicted-measured dimensional changes
Deliverables WP2. 5:
Enlargement of database and new relationships describing K and α in the design procedure. Predicted vs. measured dimensional changes

__WP2.6 Project Management and Reporting__ **(UNITN + EPMA)**
The Project Management will be supported by EPMA. Regular Progress Reports and Meeting Minutes will be written by UNITN. The final report will be written by UNITN and EPMA.
Deliverables WP2.6:
Progress Reports, Meeting Presentations and Minutes, Final report

Part 2: Time Planning

This second part concerns compaction strategy, which is something new for the project, so that a mid-term meeting with all participants about in the middle of Part 2 will be organised to share first results, providing that UNITN will be at disposal any time, when needed, for calls and, in case individual meetings. The meeting will be aimed at sharing and discussing first results and planning the activities up to the end of the project. A final meeting is then foreseen at the end of the project.

Duration of the Part 2: 18 months

Work packages	Months																	
	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
WP2.1	X	X																
WP2.2			X	X	X	X	X											
WP2.3								X	X									
WP2.4										X	X	X	X					
WP2.5														X	X	X	X	
WP2.6	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Costs

		Cost to be divided by the number of members	**Fixed cost for each member**
UNITN	Unitn collaborator	30,000	
	Characterization, measurement, and data processing		7,500
	Overhead (13%)	3,900	975
EPMA	Management fee (13%)	4,407	1,102
Total		38,307	9,577

Total cost to be divided by the number of Members: 38,307 Euros
Fixed cost for each Member: 9,577 Euros

Total Costs Example:

4 Members: cost each Member 19,154 Euros

5 Members: cost each Member 17,238 Euros

Etc.