EPMA European Structural Parts Group

Design for Sintering – Dealing with the anisotropy of dimensional changes: "DfS" - Demonstrator Project

Consortium Agreement

Issued February 2016

The Project – "DfS" 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
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.

Heads

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. Each Member agrees for a fee of **EUR 3390 for measurement and data processing of one component** - cost has been calculated including fixed costs and EPMA management fee of 13%. In case the partners will be interested in evaluating more than one component, the cost will be **EUR 1695 for each additional part** (including EPMA management fee of 13%).
   Special Case: In acknowledgement of their former contribution to prior “DfS like” projects with UNITN and their agreement to the present Project, Höganäs AB is allowed to participate in the Project free of charge. The required minimum number of Members is **three** (excluding Höganäs).
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. 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 (except Höganäs AB who will not be charged) to cover the cost plus an administrative fee of 13%.
7. **Payment Schedule:**
   - **50% at the start** of the “DfS” Project,
   - **50% after completion** of the “DfS” Project and delivery of the final report of the Part.
8. No new members may be admitted during the Project.
9. **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.

10. **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.
11. **Liability**. The Contractor is liable for negligence. The liability covers the proven damage.

All the terms of this agreement may be changed by UV, except for 2, 4, 9 & 10.

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 – Dealing with the anisotropy of dimensional changes: "DfS" - Demonstrator project

Project description

State of the Art

In the conventional press and sinter process the formation and growth of the interparticle neck during sintering is accompanied by either volumetric contraction (shrinkage) or expansion (swelling), depending on the material, the green density and the sintering parameters. Such a dimensional change has to be taken into account in designing the compaction tools and strategy in order to obtain, at least within certain limits, the precision required by the final products.

Dimensional change on sintering of cold compacted green parts is anisotropic, and anisotropy depends on several parameters, related to the material, the process and the geometry of the parts, so that the complexity of the phenomenon is definitely high. This subject has been systematically investigated in some recent works at Trento University, along two directions: 1) analysis of the mechanisms responsible for anisotropy of dimensional change; 2) study of the effect of geometry of the parts on the anisotropy of dimensional change [1-18].

The study of the effect of geometry of the parts led to the definition of an "anisotropy parameter K" depending on the geometry of the part and on densification. Such a parameter has been defined for pure iron and for axialsymmetric parts, even if some work has been made on Fe-Cu and Fe-P alloys. A design methodology accounting for anisotropy of shrinkage has been proposed, based on the anisotropy parameter K and validated through some case studies on three level industrial parts. A quite wide range of dimensions has been considered (from 3 to 70 mm) and a wide range of sintering temperatures, from conventional to high temperature. A very good agreement between the predicted and measured dimensional changes has been observed.

Further systematic work is needed to investigate different materials combined with different geometries and different green densities.

1. I. Cristofolini, C. Menapace, M. Cazzolli, A. Rao, W. Pahl, A. Molinari
The effect of anisotropic dimensional change on the precision of steel parts produced by powder metallurgy
Journal of Materials and Processing Technologies 7(212)(2012)1513-1519

2. I. Cristofolini, M. Pilla, A. Molinari, C. Menapace, M. Larsson
DOE Investigation of anisotropic dimensional change during sintering of iron-copper-carbon
The International Journal of Powder Metallurgy 48(4)(2012)37-43

3. I. Cristofolini, F. Selber, C. Menapace, M. Pilla, A. Molinari, S. Libardi
Anisotropy of Dimensional Variation and its Effect on Precision of Sintered Parts
Proceedings EURO PM2012 Congress & Exhibition, Basel 16-19 September 2012, ed. EPMA, Shrewsbury (UK), vol. 1, pp. 519-524

4. C.Menapace, M.Larsson, E.Torresani, I.Cristofolini, A.Molinari
Study of Anisotropy during Sintering of Ferrous Alloys
Proceedings PM2012, 2012 Powder Metallurgy World Congress & Exhibition, Yokohama (Japan) 14-18 October 2012, CD-room, Japan Society of Powder and Powder Metallurgy, ISBN: 978-4-9900214-9-8

5. I Cristofolini, M. Pilla, M. Larsson, A. Molinari
A DOE analysis of dimensional change on sintering of a 3%Cr-0.5%Mo-x%C steel and its effect on dimensional and geometrical precision
Powder Metallurgy Progress 3(12)(2012)127-143

6. A. Molinari, C. Menapace, E. Torresani, I. Cristofolini, M. Larsson
Working hypothesis for origin of anisotropic sintering shrinkage caused by prior uniaxial cold compaction
Powder Metallurgy, 56(3)(2013)189-195

7. A. Molinari, E. Torresani, C. Menapace, I. Cristofolini, M. Larsson
A study of sintering shrinkage kinetics of cold compacted ferrous green parts
Advances in Powder Metallurgy and Particulate Materials 5(2013)25-32

8. I. Cristofolini, N. Corsentino, M. Pilla, A. Molinari, M. Larsson
Influence of geometry on the anisotropic dimensional change on sintering of PM parts
Advances in Powder Metallurgy and Particulate Materials 11(2013)49-61

9. I. Cristofolini, M. Pilla, A. Rao, S. Libardi, A. Molinari
Dimensional and geometrical precision of powder metallurgy parts sintered and sinterhardened at high temperature
International Journal of Precision Engineering and Manufacturing 14(10)(2013)1735-1742

10. G. Cipolloni, C. Menapace, I. Cristofolini, A. Molinari
A quantitative characterisation of porosity in a Cr-Mo sintered steel using image analysis
Materials Characterization 94(2014)58-68

11. N. Corsentino, C. Menapace, I. Cristofolini, M. Pilla, M., Larsson, A. Molinari
"A dilatometry study of the influence of the liquid phase on anisotropy of dimensional change of iron alloys"
The International Journal of Powder Metallurgy (2014) in press

12. 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

13. I. Cristofolini, N. Corsentino, A. Molinari, M. Larsson
"A design procedure accounting for the anisotropic dimensional change on sintering of ferrous PM parts"
Advances in Powder Metallurgy and Particulate Materials 2014, 1(2014)115-127

14. L. Emanuelli, C. Menapace, I. Cristofolini, A. Molinari, M. Larsson
"Influence of sintering temperature on shrinkage anisotropy in Cr-Mo low alloy steel green compacts"
Advances in Powder Metallurgy and Particulate Materials 2014, 5(2014)99-107

15. N. Corsentino, I. Cristofolini, Libardi, S., A. Molinari
"Effect of high sintering temperature on the dimensional and geometrical precision of PM Cr-Mo steel parts"
Proceedings EURO PM2014 Congress & Exhibition, Salzburg 21-24 September 2014, ed. EPMA, Shrewsbury (UK), 13_P2_EP140145

16. I. Cristofolini, N. Corsentino, A. Molinari, M. Larsson
"Influence of geometry and process variables on the anisotropy parameter *K*"
Advances in Powder Metallurgy and Particulate Materials 2015, 1(2015)31-40

17. I. Cristofolini, N. Corsentino, A. Molinari, M. Larsson
"Study of the anisotropic microstructure of the uniaxially cold compacted green parts"
Advances in Powder Metallurgy and Particulate Materials 2015, 3(2015)9-18

18. I. Cristofolini, N. Corsentino, M. Larsson, S. Libardi, A. Molinari
"Anisotropy of the dimensional variation of sintered parts: a predictive model and a statistical evaluation of its reliability"
Proceedings EURO PM2015 Congress & Exhibition, Reims 4-7 October 2015, ed. EPMA, Shrewsbury (UK), 3213322

Objectives

The project aims at demonstrating the possibility to predict dimensional changes of real parts using the design methodology developed at UNITN.
The project also aims at stimulating the interest of partners at continuing the activity, in the frame of a further Club Project to explore the variables affecting the anisotropy of dimensional changes by investigating the influence of the geometry of the parts, of the material, and of process conditions.

The project (demonstrator project) will last one year (12 months).

The parts will be selected from the partners among the ones of their current industrial production, having an axialsymmetric geometry. The materials will be preferably shrinking materials; **just as an example**, the following materials might be selected:
1) Cu steel;
2) Prealloyed Mo/ Cr-Mo steels;
3) Diffusion bonded Ni-Cu-Mo steel;
4) Austenitic stainless steel.

The green parts will be measured by UNITN by the CMM (Coordinate Measuring Machine), then will be shipped 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 five parts will be measured. The measured dimensional changes will be compared to the predicted ones, to validate the model and the design procedure, and, in case, to provide further improvement.

<u>Benefits for the industrial partners</u>

The expected benefits for the partners can be summarised as follows:

- A rational (not empirical) design tool accounting for anisotropic dimensional change
- Avoiding "try and error" may help saving time and obtaining more precise results, for example designing the dies
- The design procedure may help meeting the requested tolerances on all the dimensions at the first time, also considering that often small and large dimensions show unexpectedly different dimensional changes
- A knowledge base to apply the design procedure to different materials, different geometries and different process conditions
- High and very high sintering temperature, often regarded risky for dimensional control, can be considered, thus exploiting the resulting improvement of mechanical properties

Work Packages

The project is subdivided into 6 Work Packages (WP)

<u>**WP1**</u> **(partners)**

Selection of the parts with axialsymmetric geometry, individuation of the component for each partner.

Deliverables WP1:

5 green samples each part from the production line to UNITN

<u>**WP2**</u> **(UNITN)**

Measurement of the green parts at UNITN.

Deliverables WP 2:

Dimensions of the green parts. Green parts back to partners for sintering.

<u>**WP3**</u> **(partners)**

Sintering of parts by the partners with the industrial cycle

Deliverables WP 3:

Sintered parts delivered to UNITN

<u>**WP4**</u> **(UNITN)**

Measurement of the sintered parts at UNITN.

Deliverables WP 4:

Dimensions of the sintered parts.

<u>**WP5**</u> **(UNITN)**

Data process and application of the design procedure

Deliverables WP 5:

Predicted vs. measured dimensional changes

<u>**WP6 Project Management and Reporting**</u> **(UNITN + EPMA)**

The Project Management will be supported by EPMA. The final report will be written by UNITN and EPMA.

Deliverables WP6:

Final report

Work Package time planning
Two or three meetings with all participants would be held, a kick-off meeting, one approximately half way through to report on progress (if necessary) and one wind-up meeting at project completion.
Duration of the project: 12 months

Work Package	1	2	3	4	5	6	7	8	9	10	11	12
WP 1	X											
WP 2		X	X	X								
WP 3					X	X						
WP 4							X	X				
WP 5									X	X	X	
WP 6	X	X	X	X	X	X	X	X	X	X	X	X

Costs

UNITN EUR 3000 each partner for measurement and data processing of one component

cost has been calculated including fixed costs.

In case the partners will be interested in evaluating more than one component, the cost will be EUR 1500 for each additional part

EPMA Management Fee (13%)