

**SYNTHESIS REPORT**  
**FOR PUBLICATION**

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**Title :** MODELLING OF COLD COMPACTION ("MC<sup>2</sup>")

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## 2 Summary

### 2.1 Keywords

Die, compaction, modeling, powder, software

### 2.2 Abstract of the results and benefits of the project

The principal innovation of the project concerns **the development of the simulation of the process of die compaction, the realization of a prototype software and the description of the specifications of an industrial modeling tool**. The numerical developments necessary for the development of the prototype software have been carried out. It has been demonstrated that the existing macromechanical models and the procedure for the determination of the input databases for the powder are suitable for the description of the process. **No further R&D programme for the development of new models is necessary** in order for the simulation to be widely used in industry.

The industrial partners have evaluated the technical impact of the results of the project, in particular for producing new complex parts with zero defects through the use of the prototype simulation tool. **It appears that the simulation can already be useful for some cases in order to increase the productivity of the PM part producers.**

For the development of the softwares, numerical developments have been carried out within the frame of the project. For instance, a new remesher has been developed and implemented within PreCAD®. **This remesher allows the automatic optimisation of the number of elements and their shape in order to optimize the quality of the simulation and to minimise the computing time.**

**New models suitable for the description of the behavior of the powder** during pressing and sintering have been implemented in the frame of the project.

In particular, a new thermoelastic anisotropic sintering model has been developed for the description of the sintering of ferrite pastes. This model has been implemented within the PreCAD prototype software.

**The packages have been validated through the simulation of several difficult compaction cases,** and several technical aspects have been considered:

- the computing time,
- the accuracy of the simulation,
- the robustness of the simulation.

The compaction and sintering of different parts have been simulated in the program.

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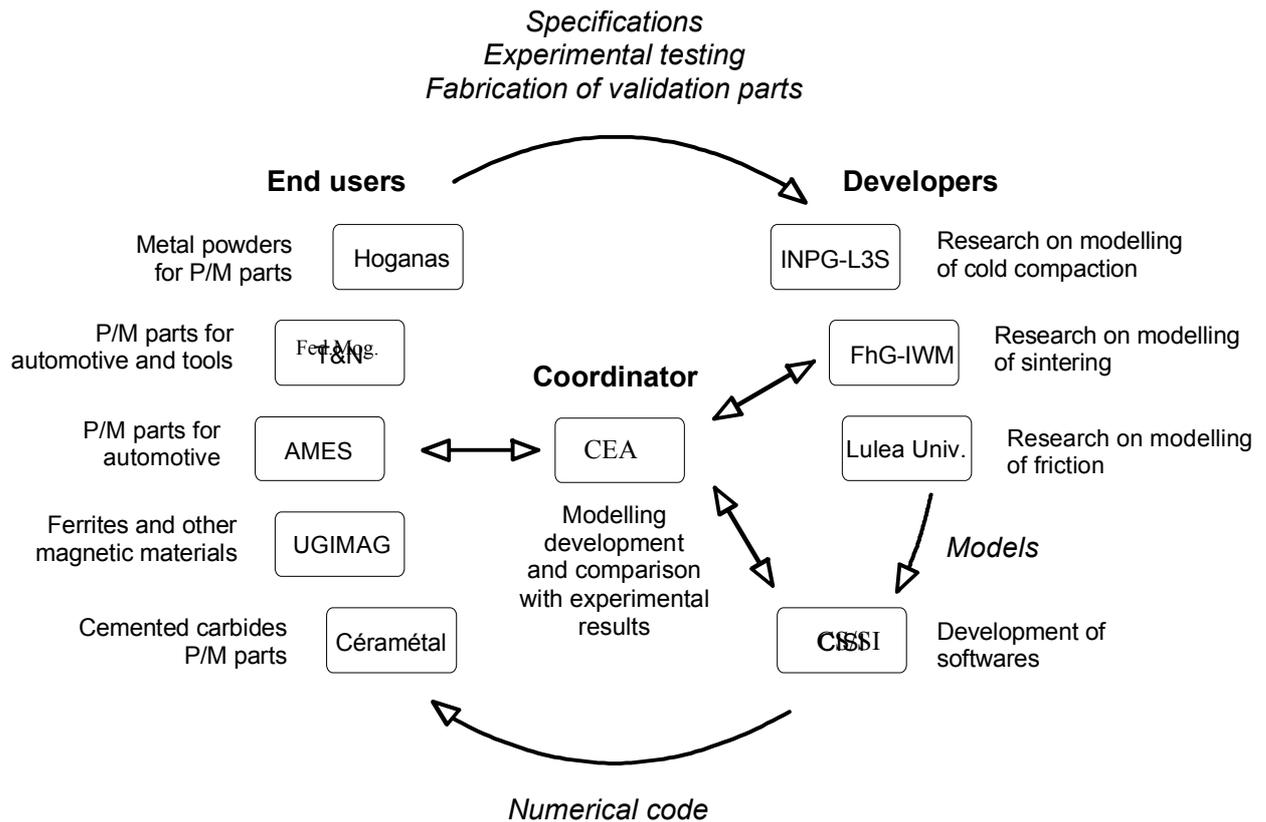
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**3.2 Consortium description**

A profile of the partnership, with the general activity and the role of each Partner in the MC<sup>2</sup> project is given in the figure below.



Organisation Name	Type	Size	Role	Country	Organisation's (business) activity	R&D function in the project
CEA/DTEN	ROR	600	C	FR	R&D in materials science and engineering. Modelling development and comparison with experimental results.	Project coordination. Development of remeshing for modelling of complex parts. Computation Analysis of computed and experimental results.
HÖGANÄS	IND	1000	P	SE	Producer of metals powders	Characterization of powders. Experimental determination of material data.
Federal Mogul	IND		P	US	Manufacturer of P/M structural metals parts, cutting tools,...	Experimental determination of materials data. Fabrication and characterization of reference P/M parts.
UGIMAG	IND	425	P	FR	Manufacturer of P/M ferrite permanent magnets for the automotive industry.	Experimental determination of material data. Fabrication and characterization of ferrite permanent magnets.
Cerametal	IND	500	P	LU	Manufacturer of hardmetal parts for metalcutting, wood and stone working industries	Experimental determination of material data. Fabrication and characterization of reference cemented carbides parts.
FhG IWM	ROR	90	P	DE	Research in P/M processes modelling.	Modelling of sintering. Computation.
Lulea University	U	50	P	SE	Research in P/M processes modelling.	Modelling of friction. Computation.
L3S	U	100	P	FR	Research in P/M processes modelling.	Experimental determination of material data.

						Modelling of cold compaction. Computation.
CS/SI	IND	2000	P	FR	Software house	Software development
AMES	IND	750	P	SP	Manufacturer of P/M structural metals parts	Experimental determination of material data. Characterization of cracks initiation, fabrication of reference P/M parts.

## 4 Technical achievement

### 4.1 Introduction

Powder metallurgy (P/M) is the **major manufacturing route** for a wide range of industrial parts such as transmission and gearbox steel parts for automotive, cemented carbides and high speed steels for metal-, wood- or stone-working, magnets and soft magnetic materials, fine ceramics, refractory metals, bearings...

All these parts are produced by **cold pressing** a powder in a die and **sintering** the resulting "green" body in a furnace. Although the problems are different in details, all these branches encounter the same practical difficulties:

- in most cases, a post-sintering operation (sizing or machining) is necessary to obtain the final geometry of the parts. This operation represents **10% to 25%** of the production costs.
- a tool set for die pressing costs between 1.000 and 100.000 ECU. The design of a tool set for a new product is made with a trial-and-error procedure that generates overcosts (**up to 50%** of the initial tooling costs) and delays (several weeks or months).
- about 2% (and far more for new fabrications) of the parts can be **defective** due to the presence of cracks. The need of a final control and the value of the rejected parts strongly increase the global production costs.

Savings for European industry estimated between **100 and 150 MECU** appear to be possible on development and production costs and time-to-market could be markedly improved :

- if the as-sintered parts could be more accurate,
- if the tool design could be based on reliable predictive methods,
- if the process could be well designed, so that no cracks occur.

This could be obtained by replacing the common trial-and-error procedure by a more efficient approach using predictive methods based on numerical simulation.

Consequently, the objective of the MC<sup>2</sup> Project was to develop the **industrial modeling of the whole P/M process for the wide range of materials concerned by this technique**. It was expected that crack-free parts with high geometrical accuracy (10 µm or 0.1%) and density homogeneity could routinely be produced, if the design of the parts, of the pressing tools and of the pressing schedule is based on a numerical simulation that integrates the knowledge generated experimentally and theoretically in this project.

### 4.2 Objectives

The main objective of the project was to develop the industrial modeling of die compaction and sintering. At the end of the project, it was expected to obtain a set of specifications allowing the realization by a

specialized software house of a commercial software based on the prototype software developed in the project.

The ultimate goal being the marketing of the modeling software with the goal of improving the competitiveness of the European PM industry.

For a wide use of the simulation by the industry, the program MC<sup>2</sup> has been intentionally oriented on models (for the description of compaction, friction, sintering...) as simple as possible in order to allow a rapid determination of the parameters for the models.

To achieve this goal, the technical programme has included:

- the selection and implementation of existing macromechanical models for cold compaction, friction and sintering in suitable finite element codes
- the experimental determination of materials data for several reference materials
- the validation and optimization of the numerical modelling, the simulation and the fabrication of reference parts
- the comparison between computed and experimental results in terms of geometry, density distribution, cracks, punch loads,....

The project ended with the definitions of the specification and the design of an industrial modelling tool usable in all powder industries.

### 4.3 Technical achievement

The main achievement of this research project is **the demonstration that the die compaction simulation has reached a good technical level for most cases**: simple 2D axisymmetric cases and more complex 2D or 3D cases. It has been demonstrated that the simulation can be useful for the prediction of geometry, density distribution and punch load for industrial parts. Moreover, it has been demonstrated that cracks can be predicted in some cases. The quality of the results of the simulation developed in the program is summarized in the following table:

<i>Item</i>	<i>Simple 2D parts</i>	<i>Complex or 3D parts</i>
<i>Density distribution</i>	Accuracy: <5% in all cases The qualitative evolutions on density are correctly described	accuracy: <5% in all cases The qualitative evolutions on density are correctly described
<i>Punch load prediction</i>	Accuracy: < 50% in most cases (at the maximum load). The qualitative evolutions are correctly described	The qualitative evolutions are correctly described
<i>Crack detection</i>	Not for all cases Only by comparison with a reference case.	Not realized
<i>Dimension after sintering</i>	<4% for ferrites	
<i>Numerical capabilities</i>	Enough to perform all the simulations including those involving long distance powder transfer	Enough to perform all the simulations including those involving long distance powder transfer

table 1: main results on simulation

The development of the simulation has been achieved on different platforms in order to insure the probability of success in the program. A prototype software based on the software PreCAD developed by the CEA, considered as the specific prototype software, has been developed in the frame of the programme. In parallel, **Abaqus /E** which is a commercial code has been evaluated and improved in order to give a reference. This code which is a generalist code, allows to perform the calculation of die compaction and sintering operations.

**Powcom** is another existing application developed by the University Polytechnic of Catalunya for internal use in AMES. This software is a specific tool dedicated to the die compaction simulation. It has been also developed and tested and improved in the frame of the MC2 program.

In order to measure the coefficient of friction during compaction at a range of low to relatively high green density, **a new device has been designed and constructed**. This device (**Error! Reference source not found.**) has been used to characterize the Distaloy powder and has permitted the determination of the friction coefficient law depending on the density of the powder even at low density.

During the project a **new device been designed and built for the characterization of the hard ferrite**. This device allows the compaction of ferrite slurry in a instrumented close die device with the evacuation and the measurement of the quantity of water during pressing.

During the project, **an extensive database for the simulation of die compaction and sintering by several model of different materials has been generated** (table 2).

<i>Material</i>	<i>CARBIDE</i>	<i>CERMET</i>	<i>Distaloy AE + 0,6 wax + 0.6 graphite</i>	<i>Hard ferrite grade A</i>	<i>Hard ferrite grade B</i>
<i>Database for the compaction</i>	X	X	X	X	
<i>Database for the sintering</i>	X	X		X	X

table 2: database available at the end of the program

Finally, the definition of the **specifications of a commercial modeling tool targeted at industry** has been achieved.

## 5 Exploitation plans and follow-up actions

### The numerical developments

Some numerical developments have contributed in large part to the success of the project: the adaptive remesher, improvements in the algorithms of resolution within the codes. Some of them can be exploited individually (such as the adaptative remesher) for other possible applications: simulations involving high deformations is considerably improved by the remeshing such as for stamping, forging, injection molding etc.

Cerametal considers that the most interesting numerical development within MC2 is the enhanced Drucker Prager Cap model developed by IWM (p-dependant parameters, crack prediction, ejection modelling, etc). Cerametal has an agreement with IWM that this model can be used when the project has finished.

Another item that could be interesting for Cerametal is the 2D-remeshing algorithm developed by the CEA on PreCAD. Unfortunately, most of their simulations are 3D-based and this algorithm will affect only a small percentage of their problems. Therefore they will have to evaluate how much additional work will be necessary in order to adapt the code to ABAQUS. On the basis of that evaluation they will decide whether they are going to implement this feature or not.

### **The improvement of knowledge of the die compaction process**

The project has led to an important improvement of the knowledge of the die compaction process. This output is clearly directly exploited by all the partners, particularly by the industry. No exploitation plan is needed for that.

The project has deepened Cerametal's knowledge of the compaction process, in particular

- the influence of DPC-model parameters on density distribution,
- crack formation indicators.

Cerametal will be used to help to improve the accuracy of future simulations.

### **The demonstration of the interest of the simulation**

This output will be considered either internally or externally by some of the partnership.

Federal Mogul sees the use of the prototype software being on specific customer problems to demonstrate the usefulness to current customers and as sales tool in attracting new customers.

This aspect is interesting to AMES to the extent that it will help them to gain acceptance for modelling as a design tool within AMES.

For the academic partners, the dissemination of the output will be made through communication and publications.

Céramétal has already implemented the use of simulation software. The results of MC<sup>2</sup> will serve as a basis to enlarge the number of possible applications as well as to streamline the calculations (set-up, calculation time, etc)

### **The material database**

In the project, 5 different powders have been characterized (2 ferrites, 1 cermet, 1 carbide and 1 Fe-based). An extensive data base is available on the compaction, friction and sintering behaviour of the powders. The Partners have agreed on the dissemination of the database :

- Cermet and Carbide results are not publishable,
- Fe- based base is publishable (and has already been published),
- Ferrite base is publishable (and has also been published).

No partner intends to exploit the database except through communications, and direct use for further internal simulation.

The material properties that were determined within the project are already being used by Cerametal. With the use of the IWM DPC material model they will be able to use all measured properties for the simulations.

## **Methodology/experimental procedures / new characterization means**

The project has allowed experimental procedures to be evaluated. The methodologies used in the project have not been developed specifically for the project. However, new devices have been developed in the project :

- the new device for the determination of friction coefficients by torque measurement,
- a new device for the characterization of the compaction of the ferrite paste allowing the filtration of water during pressing.

No partner has stated an intention to exploit the new devices.

The methodologies/experimental procedures used in the project will be used by most of the partners for further characterization of new powders. However, no exploitation is envisaged on this output (standards or patents). For instance, currently Cerametal don't plan to establish their own characterization means to determine the material properties necessary for the simulations.

As a first step Cerametal will be able to use the properties measured within the project and adapt them to other powders.

If the need arises to characterize other materials, Cerametal can always cooperate bilaterally with one of the project partners specialized in measuring.

### **The prototype software:**

During the project the prototype software PreCAD®, developed by the CEA has been improved, tested and validated. Its capabilities help to ensure the possible success of the commercialization. All the remaining technical work has been clearly defined in on task of the project " Specification for the design of an integrated tool including CAD and CAM module, shape optimization " .

This output will be exploited by the CEA, The prototype software will be transferred to software house for the creation of the commercial software. Royalties will be paid to the CEA on the base of the number of licenses sold.

## **6 References**

J.C. Cante, J. Oliver, A numerical tool for the prediction of cracks, EURO PM 2001, Memorias del Congreso, EPMA, VOLUMEN 3

J.C. Cante, J. Oliver, Una Herramienta numérica para la predicción de grietas en el conformado de pulvimateriales, Métodos Numéricos en Ingeniería y Ciencias aplicadas, E. Oñate, F. Zárata, G. Ayala, S. Botello y M.A. Moreles (Editores) cimne

J.C. Cante, J. Oliver, R. Weyler, Numerical simulation of powder transfer and compaction phases of the uniaxial powder compaction processes, EUROPEAN CONGRESS ON COMPUTATIONAL METHODS IN APPLIED SCIENCES AND ENGINEERING ; Memorias del congreso, ECCOMAS, 2000.

N. Solimanjad and R. Larsson. Measurement of Friction during Metal Powder Compaction. Proceedings in PM98 Congress, Vol. 2, 120-125, Granada Spain, 1998

B. Wikman, N. Solimanjad, R. Larsson, M. Oldenburg and H.-Å. Häggblad. Wall Friction Coefficient Estimation by Modelling of Powder Die Pressing Experiment. Powder Metallurgy, Vol. 43, No. 2, 132-138, 2000.

N. Solimanjad and R. Larsson. Dependence of Friction on Various Parameters in the Metal Powder Compaction Process. Proceedings PM2TEC Conference, Part 2, 33-44, Vancouver, Canada, 1999.

N. Solimanjad, H. Wikström and R. Larsson. A New Device for Measurement of Friction during Metal Powder Compaction. Proceedings PM2TEC, Part 3, 56-63, New Orleans, USA, 2001.

F. Toussaint, P. Doremus, Ph Tenaud, E. Di Marcello, 'An experimental and numerical approach to ferrite slurry compaction', European Congress on Powder Metallurgy, Nice 22-24, October 2001.

F. Toussaint, P. Doremus, Ph. Tenaud, E. Di Marcello, 'Caractérisation expérimentale du comportement des pâtes de ferrite et simulation numérique du procédé de fabrication d'aimants permanents', Colloque national de Métallurgie des Poudres, SF2M, 3-5 Juillet, Poitiers, 2001.

D. Bouvard, F. Toussaint, P. Doremus, 'Modelling Powder Processing of Permanent Magnet', PM 2002, Orlando, 16-21. USA, 2001.

E. Ayax et al, industrial use of Finite Element Simulation as a Design Tool and its Experimental Verification for a Development of Iron Powder Part. PM2001 October 22-24, Nice (France), p 267 – 273 , 2001