EUROPEAN COOPERATION IN THE FIELD OF SCIENTIFIC AND TECHNICAL RESEARCH - COST

COST 526
Automatic Process Optimization in Materials Technology
(APOMAT)

Title:

From final properties of components to mould and process design in metal injection moulding

Keywords: Metal injection molding, Metallic powders, plastic binders, optimization, FEM simulation

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1. Duration / run time of the project
48 months from September 2001 to August 2005

2. Overall cost
- 1600 Keuros

3. Funding situation
- Part of already assured funding : 600 KEuros
- Funding applied for a EC project (Growth, 15 May 2001): 500 KEuros
- Thinking about funding by INTERREG Program with Switzerland: 300 KEuros
- Funding by contracts with european companies: 200 Keuros

4. Project partners indicated to participate
The partnership is the following

- LMA – Applied Mechanics Laboratory (ENSMM Besançon) acts as the project coordinator and the main group implied in development of the optimization loop
- ARBURG GMBH (D) acts as a main partner in the development of the technology as a machine tool supplier and a technology supplier
- INETI - LISBOA (PO) is a technological research and development center interesting in promoting the use of PIM technologies in SME's.
- SOUTHWEST JIATONG UNIVERSITY (SJU) – CHENDGU (PR CHINA) is interested in the development of computational methods and computational tools for the simulation and optimization in PIM processing. Professor B. LIU has established strong collaboration and links with LMA that permit to strongly increase the efficiency of the partnership.

The collaboration in the partnership is strongly based on the fact that the use of powder injection molding technology in European industries is still well below the level in other developed regions, such as North America. To remedy this gap it is necessary to develop better ways to optimize injection-molding conditions and the mould designs, so as to avoid the expensive and time consuming trial and error procedures. As this strong reason, the Arburg company and INETI will mainly translate the needs from european industries and suppliers in that field, while LMA and SJU will provide efficient solutions based on a closed optimization loop. So, LMA and SJU are the main developers, INETI has the role to contribute to the diffusion of the PIM technology and possibility of virtual processing, whereas Arburg could provide part of the technology to interested companies.

5. Project partners to be found
The actual partnership group could be improved by participation of the other companies, such as component suppliers and the companies working in the same field. The component suppliers for automotive industry, as well as the watch and jewelry components, could be also interested.

6. Short description of the material process to be optimized
Powder injection molding of both ceramic and metallic materials is an adequate technology for production of the small, high accuracy and complex shaped components in large series. Its applications may extend in a broad range of production. PIM part production is a three-step process, which begins with the injection of a mixture of the metallic or ceramic powder with an organic binder in a mould; the green parts are then debinded, using appropriate techniques, and sintered in an

furnace to reach almost 100% pure density. Part quality is strongly dependent on the quality of the green parts obtained in the first step. So the design of the mould and an adequate control of the injection-molding phase are essential to get the desired quality for final products. The use of powder injection molding technology by the European industry is still well below the level known to exist in other developed regions, such as in North America. To remedy this gap it is required to develop better ways to design the moulds and to optimize injection-molding conditions. So as to avoid the expensive and time consuming trial and error procedures.

7. Material(s) involved:

Powder Injection Molding can use very large range of materials various types, such stainless steels, carbides, titanium alloys, tungsten, zirconia, silicon carbide, iron-carbide, copper, alumina, cemented carbide, etc. The associated plastic binders used to provide the required viscosity in injection can be also chosen in a very large range, such as polypropylene, polyethylene, polyvinyl chloride, paraffin wax, polyethylene glycol, microcristalline wax, etc. The feedstock composition greatly influences the injection stage and also the way to remove the plastic binder during the debinding stage. The optimal feedstock's composition should be optimized to render the process feasible and to get the components with required mechanical properties after all processing stages.

8. Optimization potential of the process or process step

The optimization potential in Powder Injection Molding is very high as the input material (feedstock) is in multiple phases. The chemical and physical composition can be easily changed. The multi-steps associated to complete process are involved by a lot of parameters that can be considered as candidate for optimization variables. So the optimization loop starts from feedstock compositions, such as the powder size, powder materials, powder volume fraction, plastic binder composition, adjuvant composition. In injection stage it is involved by the injection mould design and the choice of injection parameters, such as the mould design in order to avoid the segregation. Certainly, the debinding and sintering cycles have also to be controlled to get the final desired shape and required mechanical properties, microstructures and physical properties.

9. Specified material properties to be achieved

In Powder Injection Molding, the size and geometry of the parts should be controlled carefully because of the shrinkage during debinding and sintering. It depends strongly on the feedstock composition and processing conditions. The mechanical property is another criterion in PIM. It depends strongly on the powder material's mechanical properties and particularly on the sintering conditions, such as the temperature cycle, atmosphere.

The main defects to be avoided are the following:
Geometrical inaccuracy associated to heterogeneous shrinkage
Insufficient mechanical properties associated to sintering
Bubbles and/or cracks occurrence during debinding that result in defects after sintering
Undesired final microstructure due to sintering conditions

10. Process parameters to be optimized

Beside the feedstock preparation, all the processing parameters concerned in three main stages could be theoretically optimized. In injection stage, the mould geometry and injection parameters such as the temperature, injection pressure, as well as the packing pressure and cooling time, are most important.

In debinding stage, the temperature cycle and atmosphere are the most important parameters. Sintering is the most critical stage. The main parameters for sintering cycle and the sintering atmosphere should be correctly chosen to protect the component from oxidation and other defects, so that the perfect mechanical properties can be obtained.

10.2 Restraints for optimization parameters

It is necessary to account for the constraints limited by injection machine, such as the maximum values of pressure, clamping force, injection volume and packing pressure. In component design, some constraints have to be respected to avoid the segregation problem. During debinding and sintering stage, the constraints are mainly imposed by the capacity of debinding oven and sintering furnace, as well as the nature and quantity of binder and powder. The optimization on temperature cycles and atmosphere effects is important to obtain the good mechanical properties and size precision.

11. Material laws including material dependent coefficients

The flow of powder/binder mixtures in injection depends strongly on the intrinsic viscosities of such mixtures, process and interface conditions. The developments on material properties are aimed to the measurement and identification strategies, including the measures, inverse modeling and simulation of the mixture flow. The following tasks are scheduled:

1. Development of the viscosity models for powder/binder mixtures in taking its compressibility characteristic into account.
. Development of such models in numerical implementation of the simulation tools to account for the

behaviors of powder/binder mixtures in real injection conditions. An inverse modelling will also be performed to help the identification of such new models.

. Demonstration of the ability about the virtual prediction of component properties after injection with the proposed and validated models and simulation tools.

12. Simulator

MimForm is a software specially developed for metal injection molding simulation. This software works on a bi-phasic model on the basis of mixture theory. This modeling pattern is proven to be very convenient for high concentration powder charged mixed flow. The polymer binder and metallic powder are supposed to have the distinct flows, which named respectively the flows of fluid phase and solid phase. The variations of the volume fractions for each phase, which considered being the key variables, represent explicitly the segregation effects. A new developed explicit algorithm provides the high efficiency for computational operations. This algorithm is based on a dynamic model to perform locally the calculation in fractional steps manner by virtue of the lumped mass and pseudo mass matrices. A special scheme is precisely designed to maintain the mixture's incompressibility without any iteration.

13. Optimizer

The modelling of Material Processing research group in LMA has the long experience in development and utilization of the optimization algorithms in material processing simulation. The gradient based optimizers, stochastic optimizers based on genetic algorithms, or surface response based optimizers have been developed and used by this group. It proved by detailed analyses that the gradient based optimizers based on Levenberg Marquardt and Conjugate Gradient methods are more suitable for material parameters identification, and the Conjugate Gradient with Asymptotic Method based algorithms are suitable for geometry optimization. For process parameters, it has been proved that SQP based methods could give faster and more accurate results in certain cases. The research group possess numerous optimization algorithms and software as iSight software. In this project, development of the optimization algorithms is not planed, we need just to use the standard ones.

14. Competence / activities of proposer:

The Modelling of Material Processing research group (20 researchers) in LMA has many research and development experience in powder injection molding, both in experiments and simulation cases. Actually, five full time researchers are affected in this research field. The links with industrial companies are largely developed. This group has many experiences in European projects about the optimization in stamping and deep drawing processes. This group's competence in optimization, definition of quality functions, as well as the process control is well proved in various materials processing fields. The research efforts in Metal Injection Molding have been concentrated on three main themes:

Setting up of an experimental center in our laboratory. This center possesses an injection press for MIM feedstock, a thermal debinding oven and a sintering furnace. Different measure equipment are used to control the quality and the dispersion of molded parts. Multi-cavity moulds had been realized to study the various influencing parameters.

Development of the analysis, modelling and simulation for injection, debinding and sintering stages. For injection stage, we had developed a simulation tool that allow the accurate prediction of filling states, pressure, powder volume fraction, segregation in mold filling. This finite element software is capable for simulation of the industrial 3D injections. For sintering stage, we had developed the models and finite element software capable to predict the final density field and shrinkage. These simulation tools are powerful to help the process designer to obtain component with desired quality.

15. International state of the art and references

Numerous publications and conference papers are published during six years of your research. The total number can up to 20 international papers.

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T. Barriere, D. Renault, M. Dutilly, J.C. Gelin, Moulage par injection de poudres. Expérimentation, modélisation et simulation, Mécaniques et Industries, Vol. 1, 2000, pp. 201-212.

T. Barriere, B. Liu, J.C. Gelin, Recent Advances in the modelling of the molding stage in Metal Injection Molding, 2nd European Symposium on Powder Injection Molding, Munich, Germany, October 18-20 2000, Ed. by E.P.M.A., pp. 129-136.