Capabilities of new multi-objective Casting Process Optimisation tool

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SUMMARY

The aim of the Growth Project GRD2-2001-50042 “IDEAL” is the definition of integrated design methodology to optimise the cast aluminium components, in order to satisfy some societal needs: reduce car emissions of pollutants, improve safety and reliability of vehicles, and cut down requirements of raw aluminium. Four technological packages share theories and software development results in two horizontal main project outputs: a software tool that integrate methodologies to link design needs with process demands, and a software package for optimisation of casting processes.
The numerical simulation can play a key role with respect to the design of a mechanical component as well as of the corresponding casting system. The objectives which drive the designer are generally well defined: improving the component quality, achieving homogeneous mechanical characteristics, maximising the die life, increasing the production rates, and the like. In reality it is very difficult to achieve all such objectives at the same time due to high number of variables involved. In the past, the only possible optimality approach was based on the experience, and hence on trial and error sequences from prototypes to a reasonable final design of the processes [1-5].
More recently, one result of IDEAL project is a novel optimisation technology that replaces the mentioned approach with much faster and low cost design and process methods, combining the foundry-man experience and the power of computer simulation [6]. A multi-objective optimisation can be performed by MAGMAfrontier that, sitting on the simulation codes, drive the virtual prototyping sequence to find the best compromise of optimal designs, taking into account various design and process variables and constraints, as well as different (and sometimes subjective and/or conflicting) technical, marketing and product metrics.

KEYWORDS
Optimisation, casting simulation, inverse problem

THE OPTIMISATION FOR FOUNDRY PROCESSES

The multi-objectives approach is clearly the only one consistent, whenever there is the need for a search for a "best compromise" solution among different and maybe conflicting objectives [3], under different constraints, or more precisely a complex process has to be faced, including:

- a number of objectives (requirements, or fitness), which should be satisfied "at best";
- several combinations of available choices;
- different constraints to be satisfied, sometimes precisely (i.e. those laid down by regulations), while sometimes they may be relaxed if necessary;
- different perception, or weight, for each objective, according to the user, without the possibility to clearly distinguish what is more important from what is not.

The key-problems in foundry scenario (fig. 1a) are related to castings quality, to productivity and process yield and to tools duration [4-5]. Such problems can be formalised as a set of numerical parameters:

- the quality of the casting is related to the absence of defects (valuable by solidification criteria available from numerical simulation) and to the final mechanical properties (also valuable by micro-modelling approaches);
- the productivity can be estimated by the computation of the solidification times and after the set up of the process in terms of cycle times;
- the duration of tools can be correlated to the temperature fields induced during processes, with particular regard to maximum service temperatures and to (maximum – minimum cycle temperature).

The final version of MAGMAfrontier has been implemented by integrating existing technologies such as MAGMASOFT and modeFRONTIER; it can be considered an expert system applied to casting, so that products quality can improve, human and economical resources can be better managed, project development and personnel training times can be minimised. The theoretical background of this approach is already well established and based on Genetic Algorithms or on Neural Networks. The support of specific algorithms and proper software permits to define the correlation between variables and targets of the optimal working conditions and to obtain, automatically and rapidly, a Pareto set of casting solutions (fig. 1b).

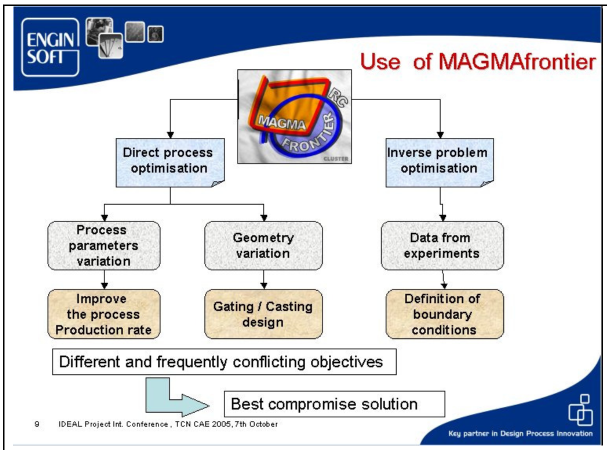

Fig. 1a – MAGMAfrontier: application sphere of casting optimisation tool

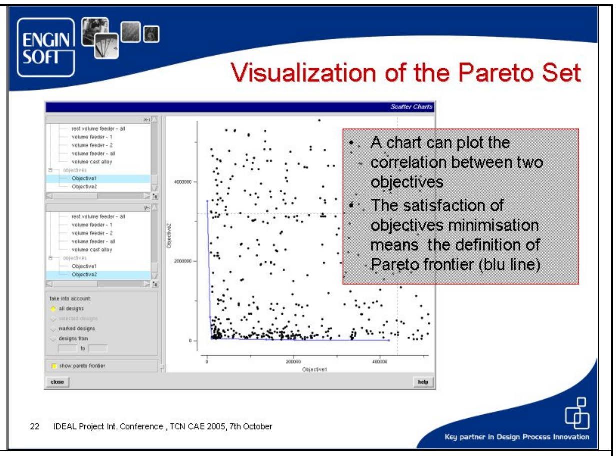

Fig. 1b – Visualization of Pareto set for two objectives

A sensitivity analysis or an inverse problem solution can be another applications of such tool and sometimes this aspect can be more interesting of the direct optimisation approach. A measurement of the foundry experience could be the ability to recognize which parameters can significantly influence the objectives and to research a solution considering the variation of some of them. The foundry practical time limits the investigation of the necessary design of experiments (DOE) to perform an accurate sensitivity analysis; today, the knowledge in this sense can be achieved by numerical approach for large and complex design space.

Expensive experimental investigations can reproduce some phenomena correlated to the casting process in order to measure the evolution of thermo-physical variables, e.g. the temperature vs time curve obtained from a thermocouple, but it is impossible to evaluate directly the heat transfer coefficient (HTC) at the interface of two materials with different thermal histories that generate heat flux. In this case, the objectives of inverse problem are the definition of HTCs for each material couples to fit simultaneously real and virtual thermocouple curves. Generally, the correspondence between simulation and real results can be converted in a inverse problem to tweak the casting simulation software.

MAGMAfrontier APPLICATIONS

Some of "traditional" templates have been tested by the involved partners to evaluate the efficiency of the tool in terms of set-up, calculation control and post-processing. The above mentioned "traditional" templates are described as highlights of development way.

In particular, the "Feeder optimisation" template can use a discrete list of standard/commercial feeders that link automatically the input variables into the DOE window definition, but shape, position and number of feeders can be free input variables without predefined relations derived from a list (fig. 2a). Other feeder optimisation examples have been developed taking into account a large number of solidification input variables, e.g. feeder neck dimension and riser volume, as well as filling effects on solidification path.

The "Gating optimisation design" template is more complex from the parametric point of view due to the large number of possible geometrical input variables. Moreover, the gating optimisation assures a perfect filling path into the runners while the soundness of casting is not guaranteed; although it seems an incomplete optimisation, the gating design is first more important task of the filling phase. Anyway, it means that casting evaluation area should be taken into account during the gating optimisation.

The "HTC calculation from measurements" template is a specific "Inverse Problem", dedicated to the definition of Heat Transfer Coefficients between the casting and the cooling medium (fig. 2b). In particular, a high interest has been declared for quenching process because the heat treatment is probably one of the processes requiring deeper knowledge. The casting geometry and the applied quenching method can drastically influence the time evolution of HTC due to cooling medium path and possible boiling effect.
MAGMAfrontier provides a procedure to evaluate quenching HTCs vs temperature starting from cooling curve measurements. Then, the objectives of optimisation problem are the error reduction between the virtual and real thermocouples located at the same positions. The quenching process can be simulated with some assumptions to simplify the numerical model.

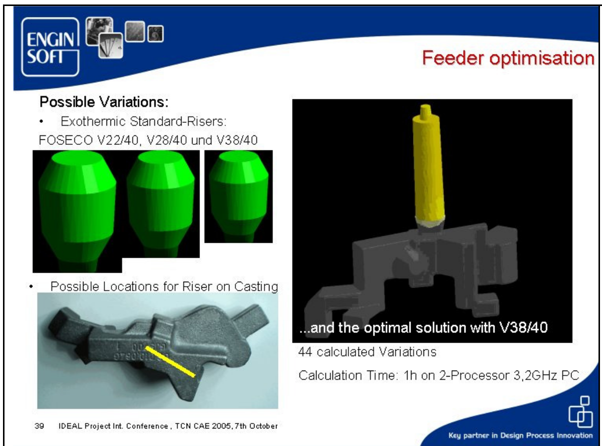

Fig. 2a – Feeder optimisation considering the variation of dimension and location

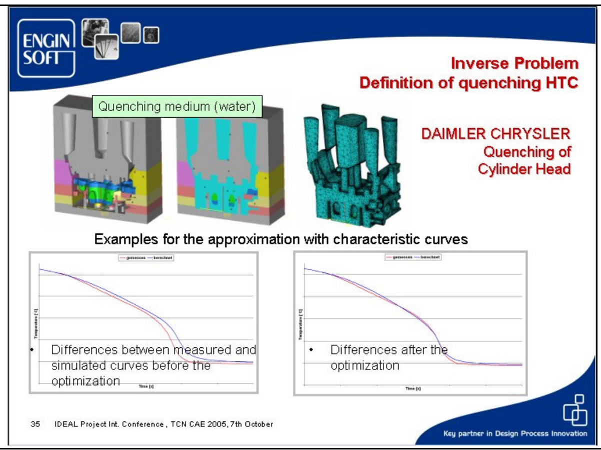

Fig. 2b – Definition of quenching heat transfer coefficient by inverse optimisation problem

CONCLUSIONS

The future competitiveness of the foundry industry is maintainable only if the foundries will be part of the design routines of new components, to improve both performance and reliability of Aluminium castings. For this purpose the concurrent engineering has achieved advantage by implementation of the software integration tools and methodologies that can play a considerable role for innovation and optimisation of cast aluminium components.

Clearly, the calculation performance of the computer can restrict the complexity of the project or the number of designs to evaluate in a reasonable time. During the software development, all the specification of system requirements has been satisfied and actually the Linux operating system has been chosen in order to compile the Linux cluster version.

MAGMAfrontier is actually a robust optimisation tool devoted to the casting processes and heat treatments that can change the design approach, support the process parameters control [7] as well as substitute the traditional trial and error mould validation.
The designer is fully free to personify the optimisation problem considering all casting simulation results that, obtained by MAGMASOFT, can be the sensible output variables to define the objectives of the problem.

The aim of the IDEAL project is the development of new simulation tools for advanced automotive materials that will lead to lighter and safer cars. The new design methodology forces the co-operation between designer and foundry-man to seek a common scope:

- improve the reliable performance of the component
- design of lighter component
- reduce the lead-time
- substitute the expensive rig-test
- reduce the cost of the component

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