REAL-TIME HPDC QUALITY PREDICTION AND OPTIMIZATION SUPPORTED BY TRAINED COGNITIVE MODEL

N. Gramegna, P. Donaggio, A. Bassi, G. Scarpa – Enginsoft SpA
E. Battaglia, E. Fiorese – University of Padova – DTG, Vicenza, Italy

Manufacturing current trends show an improvement in demand for light products considering the material substitution for complex structural parts, the design and technology innovation as well as the evolution in smart production. Due to the high number of process variables involved and to the non-synchronisation of all process parameters in a unique and integrated process control unit, HPDC is one of the most "defect-generating" and "energy-consumption" processes in EU industry showing less flexibility to any changes in products and in process evolution. In both, sustainability issue imposes that machines/systems are able to efficiently and ecologically support the production with higher quality, faster delivery times, and shorter times between successive generations of products. Starting from an intelligent monitor system of HPDC process, an advanced trained meta-model is the key factor to improve the manufacturing efficiency predicting the real-time quality and cost of the product. The offered training methods and virtual or real Cognitive models correlate the input and sensors data with the quality indexes, energy consumption cost function. The Machine Operator or Production Manager can react shot by shot, supported by Control & Cognitive system integrated in the foundry site, to improve the quality and the production rate of each production line.

KEYWORDS: HPDC, SMART PRODUCTION, PROCESS CONTROL, COGNITIVE META-MODEL, QUALITY PREDICTION, COST ESTIMATION, PRODUCTION EFFICIENCY, PROCESS OPTIMIZATION, AGILE MANUFACTURING

INTRODUCTION

High Pressure Die Casting (HPDC) is a foundry area significantly dominated by European SMEs, that are producing more of 50% of Al alloys castings. The global market scenario is forcing HPDC foundries towards more flexibility in alloys use and in production lots, with more demanding quality requirements for the various classes of HPDC products, in view of their in-service performance [1]. Among quality requirements, a prominent role is played by the definition of acceptable defects/imperfections levels. The kind of information to be collected and a well-assessed methodology for quantitative evaluation of defects/imperfections are strategic issues, with specific peculiarities for each of the main classes of diecast Al components: Housing and covers; Thin wall components; Safety components; Engine blocks and Others [2-4]. The process, from which the product is generated, has to be correctly designed, tracked and improved as well. As for the product, the process guidelines and procedures must be defined in order to comprehend the various amount of aspects that characterize and bind the Injection Processes.

An completely new Control & Cognitive system, called *Smart Prod ACTIVE tool* and developed in the frame of the EU-FP7 MUSIC project, allows the real-time, quantitative and predictive evaluation of the fulfillment of product quality requirements in HPDC process. The application of this tool to the production cycle operated at RDS Moulding Technology SpA (an Italian SME HPDC foundry) is demonstrated in the present paper.

THE INTELLIGENT SENSOR NETWORK AND TRAINING OF COGNITIVE MODEL

The multi-stages HPDC production line at RDS has been the place to implement the innovative intelligent sensor network (ISN) [5] and the Cognitive system [6] from the design to the validation. As test-product on which evaluate the new technology, a diecast Gear Box Housing has been individuated, as well as the priority list of defects/imperfections to be minimized/avoided: Lamination, Cold shots, Flash, Blister and Incomplete casting [3]. A new die has been designed and built (fitting the requirements of the Colosio HPDC machine, on which the production was scheduled), introducing various sensors [7] in positions sensitive to process parameters variations. The Electronics GmbH acquisition system adopted allows connection with conventional HPDC machine, to monitor the injection curve as well as the achievement of data from sensors implemented in the die. The challenge is the positioning of proper and sufficient number of sensors where it's necessary to individuate the risk of defect generation. If the metal contact sensor or different sensor are invasive and complex to be applied, an external I.R. Thermo camera (the dual TTV system from Motul-Baraldi) can be applied to monitor the temperature evolution on the die surface before and after the lubrication phase, taking measurements from 10 different Region of Interest (ROI). The ROIs are often defined closed to the area of interest for quality prediction.

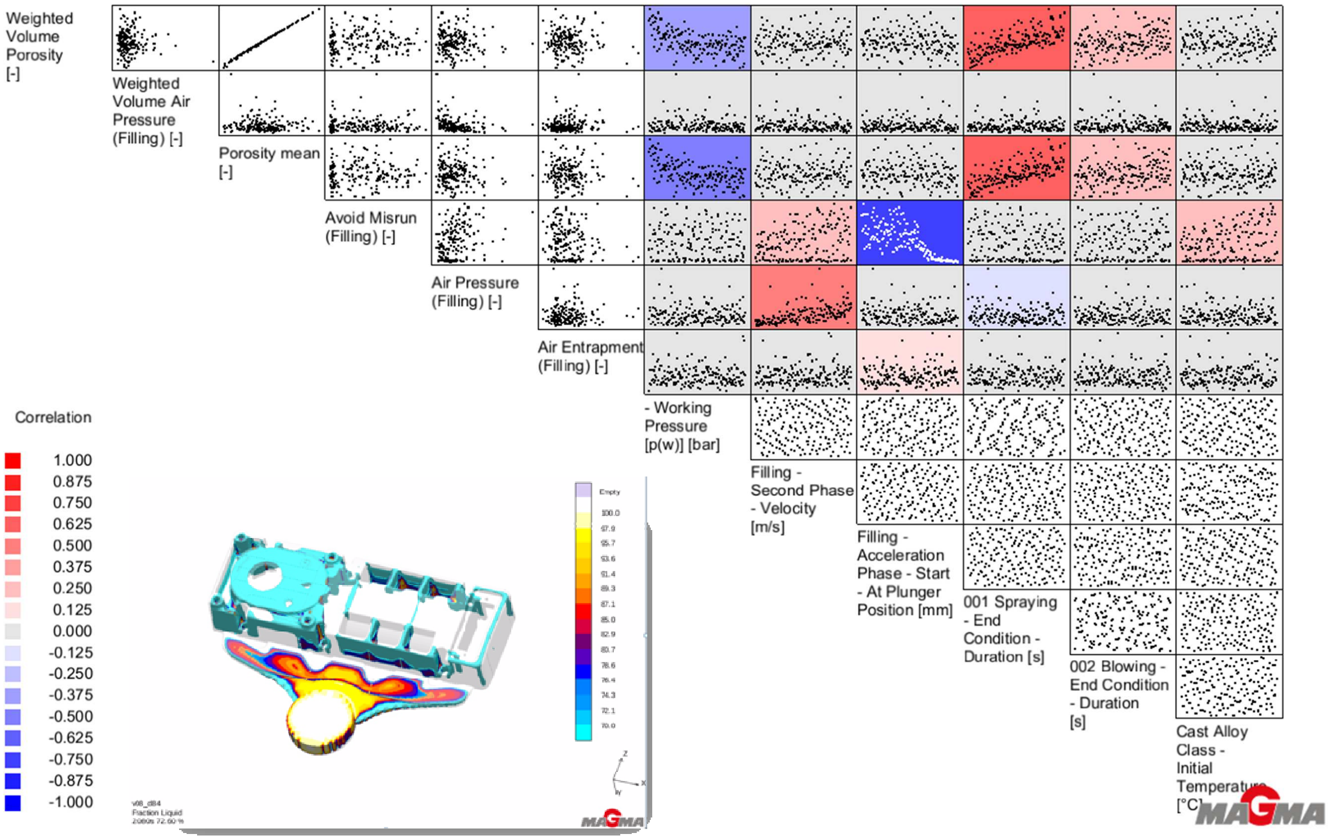

Fig. 1 - Correlation matrix based on 185 designs simulated by MAGMA5

All process parameters possibly affecting the quality of Gear Box Housing have been taken into account, and used in the training stage of a meta-model, both virtual and real, correlating input process variables and data from sensors with quality indexes in the areas of interest. Of course, the virtual design of experiment (DOE) adopted to train the virtual meta-model is at "low cost" in term of time and resources; it typically constitutes the first model to be applied in production. The correlation matrix, based on 185 evaluated designs (Fig. 1), is one method to visualize the dependency of quality indexes from process parameters and virtual sensor measurements (e.g. temperature, pressure, velocity). As expected, defects such as misruns are strongly affected by the plunger position, when switching from first phase velocity to second fast velocity – the quantitative correlation is now available – but there are small opposite effect due to second phase velocity of the plunger and initial temperature of the alloy. Similar comments are possible for shrinkage porosities depending from overpressure and spray time, or blister correlated with second phase velocity. The model needs to be trained with reference to a specific product and process, because the quantification of correlations are unique and not generalized.

Similar approach has been applied to train a model based on really produced and investigated castings. The same DOE has been performed, to validate the virtual meta-model and compare the effort and cost of it. A strong effort is needed for quality investigations and defects classification in cast products. The number of necessary castings to train the model, about 200, is similar to the conventional sampling used to tune the process at the start of the whole production. With this new approach, the sampling stages is used to train the model in understanding the genesis of all possible defects. The traceability of the castings, during the training or during the production id a mandatory task. The marking operation allow the Operator to separate the bad castings form the other in any time.
The decision of the meta-model to indicate scraps or good castings is based on the accuracy of the trained regression model, supported by 5 different RBF algorithms and 3 Classifiers, that are automatically elaborated and selected minimizing the error of the approximation; the decision is affected also by the fixed thresholds of acceptability by area and by defect category.

HPDC OPTIMIZATION USING SMART PROD ACTIVE IN PRODUCTION

The introduction of the *Smart Prod ACTIVE* tool in the factory floor needs a simple installation of LAN network connecting all devices in the production line: machine, die, thermo-regulation unit and I.R. thermo camera. The user interface was completely developed in HTML5 and Javascript Technologies. Thanks to the adoption of these technologies, it is possible to display, create and update the meta-model in real time (in production), within a common Internet browser. The system provides a wizard for assisting the user to create a new project. The wizard streamlines the following steps:

- Definition of base project parameters (project name, number of parts to be produced, injection duration, solidification duration)
- Part definition (either selected from a drop down menu, or by defining a name, part number and uploading one or more STL file for the part geometry)
- Die-mould definition (either selected from a drop down menu, or by defining a name, mould number and uploading a STL file for the die geometry)
- Connection with device (name of device, IP and port number, protocol): this step can be iterated to add a list of devices as needed
- Update of the sensors catalogue (allows to create new sensors entries as needed)
- List of active sensors (either on the machine or die; the sensors on the die can be associated also to a position relative to the die geometry)
- Upload of the initial meta-model for the project.

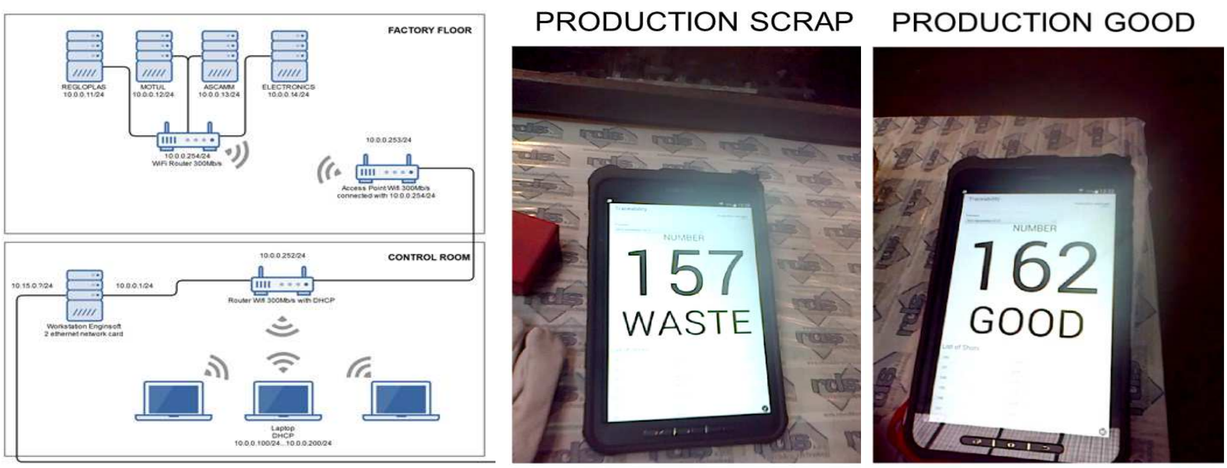

Fig. 2 – LAN network connection and real time prediction of Waste and Good castings

The production starts normally, using the best process setup. The stability and repeatability of the best shot is monitored with real time comparison of reference curve previously selected and the instantaneous verification of thresholds satisfactions to quality prediction. The scraps or good castings are visualized in PC, Tablet (Fig. 2) or smart-phone with available web connection to the system. The example shown in Fig. 2 is the results of the optimization procedure applied during the production: the scraps were expected during the warm-up of the die and good quality achieved at thermal steady state; a 30 minutes break generated some scraps at re-start (e.g. casting number 157) and good production after 5 castings (e.g. casting number 162) has been recovered.

CONCLUSIONS

The application of Control and Cognitive system at SME foundry has been demonstrated and validated. In the frame of HPDC production process, Operator and Process manager take advantage by adopting a centralized control system supporting process monitoring and quality prediction in real time. The innovation is evident, thanks to new smart devices supporting each decision on the basis of cause-effect correlations, and proper reactions suggested by a continuously updated meta-model. Re-usability and flexibility of the Smart Prod ACTIVE tool also allow agile re-start in case of small batches production.

The "zero defect" target is always the first priority of the approach, to minimize the defects with real-time retrofit suggested by the tool. The scrap rate reduction is focused on those defect factors mainly contributing the overall quality requirements of the product. Being the energy consumption connected to the production rate, the cycle time optimization (more pieces per hour) and the improved management of energy-demanding devices (furnace, thermo units, etc) lead to cost reduction.

A properly developed cost model is translating the effect of process setup and optimization in economic benefit calculate in real-time too.

The repository of process data, quality results, process efficiency and cost can be visualized with different statistical tools by the web application accessible by Operator, Process Manager, Quality Manager and Plant Director. The flexibility and extendibility of *Smart Prod ACTIVE* tool allow remote connections with all single production line, in a specific plant, located in all countries all around the world.

ACKNOWLEDGMENTS

This work was developed inside "MUSIC" Project (MUlti-layers control & cognitive System to drive metal and plastic production line for Injected Components), supported by European Union - [FP7-2012-NMP-ICT-FoF] under grant agreement number n°3141. The authors would like to thank the MUSIC consortium (www.music.eucoord.com), and particularly RDS Moulding Technology SpA.

REFERENCES

1. F. BONOLLO, N. GRAMEGNA, G. TIMELLI: F. BONOLLO, N. GRAMEGNA and G. TIMELLI, Journal of Metals, 67 (5) (2015), p 901.
2. F. BONOLLO, N. GRAMEGNA: The MUSIC guide to key-parameters in High Pressure Die casting, Assomet, Milano (2014).
3. E. GARIBOLDI, F. BONOLLO, P. PARONA: Handbook of defects in HPDC. AIM, Milano (2010).
4. CEN T/R 16749: Aluminium and aluminium alloys — Classification of Defects and Imperfections in High Pressure, Low Pressure and Gravity Die Cast Products, CEN, Brussels (2014).
5. U. GAUERMANN, A. MAZZAMUTO, N. GRAMEGNA: Proc. 6th Int. Cong. High Tech Die Casting, Venice (2016), AIM, Milan, paper n. 69.
6. N. GRAMEGNA, F. BONOLLO: Proc. 6th Int. Cong. High Tech Die Casting, Venice (2016), AIM, Milan, paper n. 68.
7. E. BATTAGLIA, F. BONOLLO, A. BROTTO, G. KRAL, A. MAZZAMUTO: Proc. 6th Int. Cong. High Tech Die Casting, Venice (2016), AIM, Milan, paper n. 66.