Correlation between process parameters and quality characteristics in aluminum high pressure die casting

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Aluminum high pressure die casting is one of the most productive manufacturing processes. The complexity of the parts rises and the quality requirements are increasing. The challenge in high pressure die casting is to reach the high quality standards in spite of the huge number of quality influencing process parameters. The interaction of all quality influencing parameters leads to extremely high scrap rates up to 10 - 25%. The European research project MUSIC (MUlti-layers control and cognitive System to drive metal and plastic production line for Injected Components) has the aim to decrease the scrap rates in high pressure die casting by developing an intelligent cognitive system taking all quality controlling parameters into account. In the frame of the project a special casting geometry has been developed, that allows the production of parts with several defects such as shrinkage porosity, cold shuts and distortion. The die is instrumented with many new and innovative sensors to monitor new process parameters, such as the sound of the shot, which have not been applied to date. The sensor data, the process parameters of the machine and the peripheral devices are stored together with the quality index of the castings in one common database. To find correlations the process parameters were varied with different DOEs. The database with the data of the cast trials is the basic information for the prediction of the cast part quality. In this paper two possible algorithms to calculate the cast part quality of future cast parts are presented.

KEYWORDS: CORRELATION – SENSORS – QUALITY PREDICTION – ALUMINUM HIGH PRESSURE DIE CASTING

INTRODUCTION: HIGH SCRAP RATES AS MOTIVATION FOR THE PROJECT

The high pressure die casting process is a productive manufacturing method to produce complex cast parts near net shape in a very short cycle time. Cast parts are characterized by a good surface quality, a high dimensional accuracy and a high tensile strength despite the low weight. The requirements concerning quality and mechanical properties and also the geometrical complexity of the components are rising. In the HPDC process an enormous number of parameters are influencing the cast part quality. The known and controlled parameters are the piston speed in the first and second phase, the switching point and the intensification pressure, that build together the shot profile of the injection process. These parameters and other parameters like the temperature of the heating oil, the furnace temperature and the parameters of the spraying unit are controlled and measureable parameters. They are controlled and measured by the units shown in Figure 1. Additional to this factors there are other quality influencing parameters, for example the remaining humidity in the die after spraying, the evacuated air quantity, the acceleration of the plunger and variations in the alloy composition that are not measured or stored to date. The interactions between all quality influencing parameters are leading to high scrap rates up to 10 – 25%. This value exceeds the scrap rates of other manufacturing processes by a factor of 10 or even 1000.

RESEARCH OBJECTIVE

The European research project MUSIC (MUlti-layers control and cognitive System to drive metal and plastic production line for Injected Components) has the aim to decrease the scrap rates in high pressure die casting by developing an intelligent cognitive system taking all quality controlling parameters into account.
As shown in Figure 2 the high pressure die casting machine and the peripheral devices are equipped with

sensors. All devices are attached to a network that is connected to one common data base. In this data base all sensor data and the controlled process parameters of the machine and the peripheral devices are stored. In the training phase the quality data of the casted parts is also entered in the data base. The correlation of the sensor data, the process parameters and the quality of the investigated cast parts allows training the cognitive system which is able to predict the quality of future cast parts during production. [1]

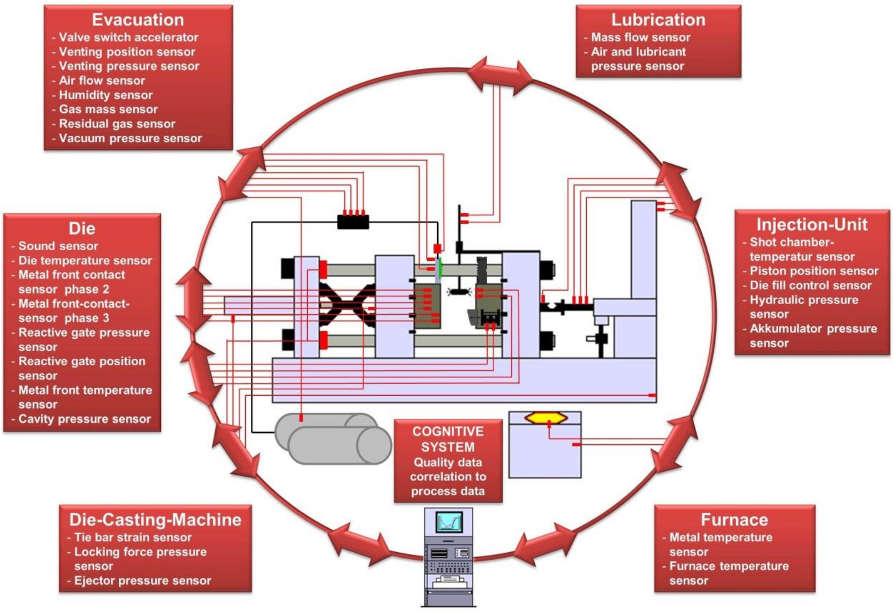

Figure 1: Innovative sensor network and cognitive system [2]

The training of the prediction model is the initial step for the prediction of the casting defects. Basis for this is the availability of process and quality data. The data are acquired during a design of experiments (DoE) varying the most important process parameters like the piston speed in the first and second phase, the switching point, the intensification pressure, the spraying time, the melt and die temperature etc. In contrast to the serial production the process parameters are not only controlled, but also stored for each cast part. Every casting has its identification number to relate the parts quality to the process data. The traceability can also be ensured with a RFID transponder that is inserted in the die and surrounded by aluminum after the shot. [3] In addition to the process parameters many sensors that are monitoring the injection process are placed at the casting unit, in the die and the vacuum unit. The positions of the sensors in the die are shown in Figure 2.

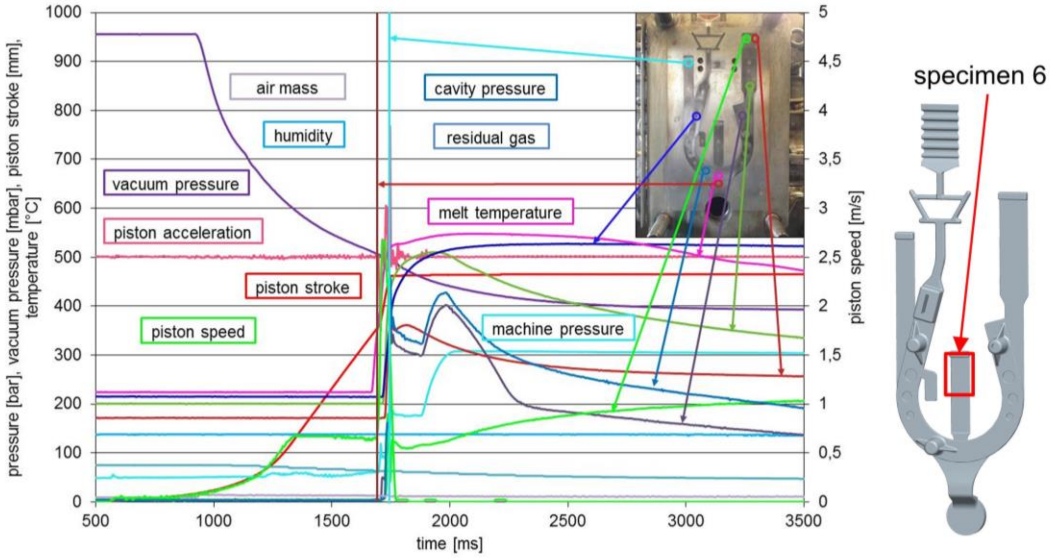

Figure 2: Shot curve with additional sensor signals

The sensors in the die are measuring the conditions directly at the surface of the die, which means that they are in contact with the aluminum alloy. Specific points of the sensor measurements were extracted and are part of the modeling for the quality prediction. Other novel parameters, that allow explaining and forecasting both the mechanical properties and the porosity are described by E. Fiorese and F. Bonollo. [5]

PREDICTION OF QUALITY CHARACTERISTICS

Partition model decision trees

Basis for the prediction of quality characteristics is the availability of process parameters that were varied in the DOE, data of the sensor measurements like temperatures and pressures in certain areas and the results of the quality investigations. The data were integrated in one common table. To predict the cast part quality the two modeling methods partitioning with decision trees and neural networks were used and compared. As partitioning model decision trees are useful for exploring relationships without having a good prior model. It can be used to handle large problems easily and the results are very interpretable. The model recursively partitions data according to a relationship between the process parameters and sensor data (X) and the quality characteristics (Y), creating a tree of partitions. It finds a set of cuts or groupings of X values that best predict a Y value. It does this by exhaustively searching all possible cuts or groupings. These splits (or partitions) of the data are done recursively forming a tree of decision rules until the desired fit is reached. [4] As example for the possibility to predict the cast part quality with a decision tree model the peak load in a bending test was selected as quality characteristic. The most influencing parameter and therefore the parameter that divides the measurement data in the first two groups is the piston speed in the second phase. The next groups are formed by the switch point and the spray time. As criterion for the quality of the prediction the coefficient of determination R^2 is indicates in Figure 3.

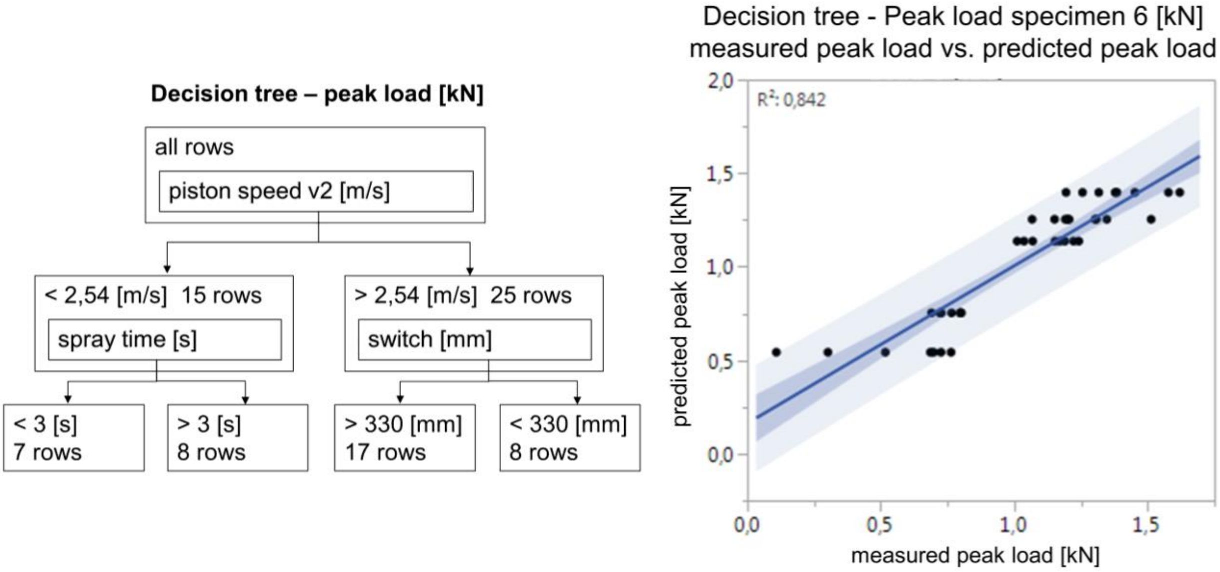

Figure 3: Decision tree model (left) and peak load predicted vs. measured values for decision trees (right) [6]

The range of R^2 is from 0 to 1. 1 indicates a perfect prediction and 0 means that the model is not able to predict the quality characteristic. The predicted vs. the measured values and the coefficient of determination are shown in Figure 3. For the prediction of the peak load of the bending force of specimen 6 the coefficient of determination R^2 is 0,842. The high value near 1 signifies a good model for the prediction. To validate the model a 5-fold cross-validation was implemented with R^2=0,794 as good validation result.

Neural network model

The second method that was used for the prediction of quality characteristics is the neural network model. Neural networks can be used to predict one or more response variables using a flexible function of the input variables. The main advantage of a neural network model is that it can efficiently model different response surfaces. Given enough hidden nodes and layers, any surface can be approximated to any accuracy. The main disadvantage of a neural network model is that the results are not easily interpretable, since there are intermediate layers rather than a direct path from the X variables to the Y variables, as in the case of regular regression. A neural network is a function of a set of derived inputs, called hidden nodes. The hidden nodes are nonlinear functions of the original inputs. [4] The neural network that was applied at the dataset of the casting trials could be specified by one layer of three hidden nodes. Figure 4 (left) shows the architecture of the one-layer neural network with 29 X variables and one Y variable. The predicted Y variable is a function of all nodes in the layer. The functions applied at the nodes of the hidden layer are called activation functions. In the example the hyperbolic tangent function was used as activation function. With the neural network model in the example a coefficient of determination of R^2=0,890 could be reached.

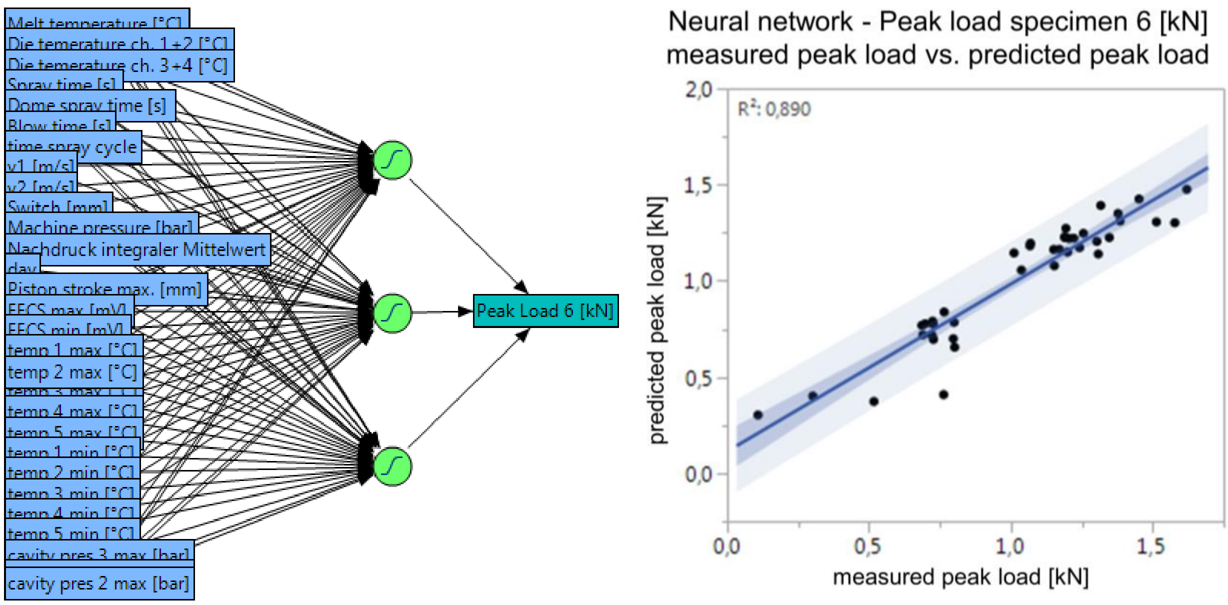

Figure 4: Model of neural network (left) and predicted peak load vs. measured values for neural networks (right) [6]

CONCLUSION

As example for the prediction of cast part quality the peak load in a bending test was chosen. The prediction was performed with two different models. Both models – decision trees and neural networks – indicate a good prediction quality what is shown in the diagrams in Figure 3 and Figure 4 and with the high coefficient of determination. The results that are achieved with decision trees are easier to interpret whereas the prediction with the neural network model lead to a better fit. The two models were also applied on other casting defects like the density and the distortion of aluminum high pressure die casting parts. The results of the prediction are very good. With a higher number of investigated cast parts, process parameters and sensor data the model can be improved and even better model fits can be expected. The Application of advanced models aims to improve the prediction of cast part quality and to decrease high scrap rates in high pressure die casting.

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