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Experimental Investigations on the Ejector Forces in the Die Casting Process

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Abstract

A measuring system was developed for the measurement of ejector forces in the die casting process. When selecting the sensor technology, particular care was taken to ensure that measurements can be taken with a high sampling rate so that the fast-running ejection process can be recorded. For this reason, the system uses piezoelectric force sensors which measure the forces directly at the individual ejector pins. In this way, depending on the number of sensors, it is possible to determine both the individual ejector forces and the total ejector force. The system is expandable and adaptable with regard to the number and position of the sensors and can also be applied to real HPDC components. Automatic triggering of the measurements is also possible. In addition to the measuring system, a device and a method for in-situ calibration of the sensors have also been developed. To test the measuring system, casting experiments were carried out with a real aluminium HPDC aluminium component. The experiments showed that it is possible to measure the ejector forces with sufficient sampling rate and also to observe the process steps of filling, intensification and die opening by means of ejector forces. Experimental setup serves as a basis for future investigations regarding the influencing parameters on the ejection process.

Keywords: Innovative Foundry Technologies and Materials, Application of Information Technology to the Foundry Industry, High Pressure Die Casting, Ejector Forces

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1. Introduction

The ejector system of the die casting tool has a high influence on the technological and economic performance of the die casting process as it influences the production reliability as well as the quality of the die cast components. Despite its high importance, the layout and the dimensioning of the ejector system today is usually based only on the experience of the designer. Especially in the case of new designs this can lead to insufficient part ejection and thus to component defects and production interruptions. On the other hand, too many ejectors have a negative effect on the surface quality of casted parts and are a source of mechanical errors in the casting process.

Despite the importance of this topic, the literature provides only limited information on the knowledge-based design of ejector systems. There are also only a few publications on the simulative or experimental determination of ejector forces. For instance, Köser et al. [1] carried out investigations for the simulative modelling and determination of ejector forces in the magnesium high-pressure die casting process. The simulation was split in two parts, the casting process simulation with ProCAST and the mechanical modelling of the ejection process and the stresses in the component using VPS. Investigations were done on a simplified casting component and multiple ejector system designs with regard to number and positioning were tested. In addition to the simplified casting component, a real industrial-used casting component was also simulated. Without experimental data, however, a validation of the simulations was not performed for any of the casting components.

Some investigations, such as those of Adam [2] and Terek et al. [3], dealt with the experimental determination of demoulding forces in relation to surface coatings. While for Adam [2] the aim of the investigations was to avoid spraying and thus the associated damage to the die, for Terek et al. [3] the aim was to generally reduce the demoulding forces by surface coating of the die. Both used a simplified aluminium die casting component and measured the tensile force necessary to pull coated pins from the cooled part. For the force measurements, the pins were pulled out of the casting component in tensile testing machines. Moreover, Adam also conducted experiments with an instrumented die casting tool.

Tosa and Urakami [4] measured the ejection forces in a parameter variation in order to determine influencing variables on ejection. The varied parameters were locking time of the die, release agents, intensification pressure and flow velocity in the ingates. In this case, the total ejector force was determined by measuring the hydraulic pressure of the cylinder actuating the ejector plate. Therefore, in this case, no measurement of the individual ejector forces was possible. In contrast, German and Klein [5] as well as German [6] measured the forces directly at individual ejectors. The aim of the investigations was the optimization of the spraying process during die casting.

However, none of the publications mentioned above allow a correlation to a simulation-based approach due to a lack of detailed information regarding individual ejector forces, process parameters, part geometry and surface conditions. Hence, further investigations on the experimental determination of ejector forces in the die-casting process appear to be reasonable in order to gain a deeper understanding of the HPDC process and to provide valid experimental data for a further development of simulation models.

2. Scientific Approach

Casting process simulation has the potential to be a powerful tool for the efficient, knowledge-based design of ejector systems. For the development of the required simulation models, a deeper understanding of the ejector forces as well as the component behavior during the ejection process is crucial. Therefore, the aim of this work was to establish a measuring system for the experimental determination of ejector forces and to evaluate the measuring system through casting experiments.

The selection of the test component was carried out based on two criteria. On the one hand, a typical aluminium die cast component was to be used in order to achieve a high comparability with industrial components. On the other hand, the component was supposed to be as symmetrical as possible in order to investigate possible symmetry effects of ejector forces. Based on these criteria, an existing casting tool for a nearly symmetrical aluminium structural component ("node element") was selected for the experiments (Fig. 1). The tool uses 35 ejector pins for the ejection of the casting component.

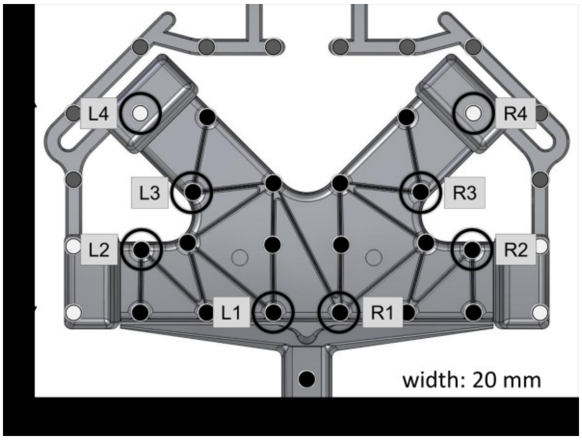

Fig. 1. Structural component with ejector positions and position of instrumented ejectors (marked with circle)

Due to the estimated high speed of the ejection process, the sampling rate was the main criterion in the selection of sensors and data acquisition technology. In the simulations of Köser et al. [1], it was shown that the actual detachment of the component from the die surface takes place within approximately 10 ms. It was therefore assumed that a sampling rate of at least 10 kHz is required. Further criteria for the selection were a high temperature resistance and a high load capacity of the sensors in order to avoid damage to the sensors in case of tool malfunctions, leading to a possible blocking of the ejectors. For these reasons, piezoelectric sensors (9103A) from Kistler with a maximum load of 100 kN and a maximum sampling rate of 62.5 kHz were selected. Kistler 5165A charge amplifiers were chosen for amplification, due to their ability to measure dynamic force changes as they occur during the ejection process. The voltage signals from the charge amplifiers were processed through a data acquisition platform (cDAQ-9184) from National Instruments to a computer. For the initial casting experiments, the sampling rate of the sensors was set to the maximum of 62.5 kHz. In the course of the experiments, it was reduced to 12.5 kHz as it became clear that this sample rate is still sufficient for a peak evaluation of ejector forces. In addition to data processing, the script of the data acquisition platform also contained a routine for automated triggering. The signal of the machine control for opening of the die was used to automatically start the force measurements for each casting cycle in order to reduce the amount of data due to the high sampling rate (Fig. 2).

The casting experiments were performed on a Bühler 53D cold chamber die casting machine. Eight of the force sensors were placed in a modified ejector plate under the ejector pins (Fig. 2).The ejector plate was modified in a way that 33 of the 35 ejector positions could be equipped with force sensors. This method allows to investigate different sensor positions and active ejector pin setups. In addition, an extension of the sensor array to more than eight sensors was made possible for future tests. By attaching the ejector plate to the ejector cover plate, a preload was applied to the sensors. Due to this preload, a gap formation between ejectors and sensors was avoided on the one hand. On the other hand, it was also possible to measure negative forces at the ejectors.

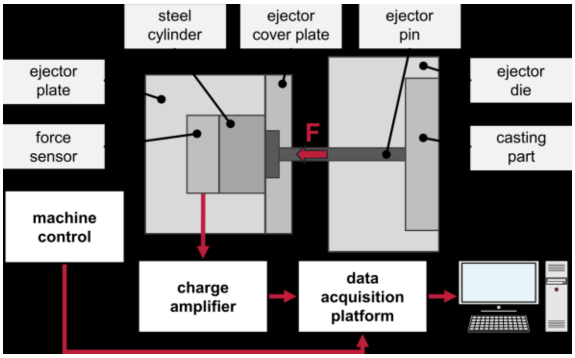

Fig. 2. Sensor configuration for the force measurements

Because of the undefined preload, the sensors had to be calibrated in-situ. A calibration device was designed for this purpose. In this calibration device, another piezoelectric sensor was fixed with an expansion screw and thus also subjected to a preload. The device was then calibrated in a compression testing machine by adjusting the sensitivity of the calibration sensor until the force values of both sensors were at the same level. To calibrate the sensors installed in the ejector plate, the calibration device was placed on the end of each of the extended ejectors and subjected to a sudden load with a hammer. The resulting force was measured with both sensors and the sensitivity of the sensor to be calibrated was adjusted until the measured force of both sensors was the same. In order to minimize the friction during ejector movement, a release agent was applied. Moreover, the calibration process was to be repeated before each casting series.

The casting experiments were performed with the alloy EN AC-AlSi10MnMg and the release agent SL-1697S from CHEM-TREND with a mixing ratio of 1:125. The first casting series were carried out without the automated triggering routine in order to do a basic testing of the sensors and to get an overview of the resulting forces during the entire casting process. In these cases, the measurements were started during the dosing of the melt into the shot sleeve. After initial testing of the measurement system multiple casting series with 40 cycles each were performed. The data analysis was done with MATLAB.

3. Results

The initial casting series for basic testing of the equipment showed that, in addition to the ejection process, the filling (2nd phase), the intensification (3rd phase) and die opening could also be observed through the force measurement at the ejector pins (Fig. 3). While filling and intensification were shown by an increase of the ejector forces, the opening of the die and thus the detachment of the casting from the ejectors could be observed by decreasing pressure forces at the ejectors.

In the initial casting experiments, it was also observed that the largest force gradients in the ejection process occurred in a period of less than 40 ms. Therefore it was possible to reduce the sampling rate of the measurement system to 12.5 kHz for the following casting series in order to reduce data sizes.

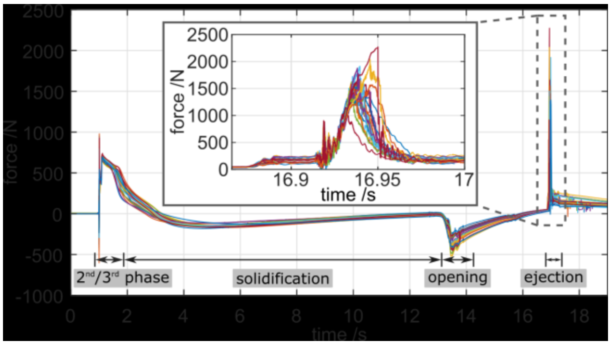

Fig. 3. Measured forces at one ejector for 22 cycles

Evaluation of the force peaks during ejection showed forces for the single ejectors ranging from 373.6 N at sensor R4 up to 2845.6 N at sensor R2. The average of the total ejector force for the eight instrumented ejectors was 10,138 N. In order to investigate the change of the maximum ejector forces over the course of the casting series, the values were plotted in bar diagrams over the casting cycles. Fig. 4 shows the stacked bar chart for all instrumented sensors. As illustrated, strong fluctuations of the maximum forces in the first half of the casting series (cycles 21–40) were observed. Since the fluctuations to this extent only occurred at the beginning of the casting series, it was assumed that the process had to be initialized over at least 20 cycles in order to carry out reliable measurements. For this reason, only the second half of the casting series was considered in the further evaluation. For the second half of the casting series the average of the total ejector force of all sensors was 10,309 N.

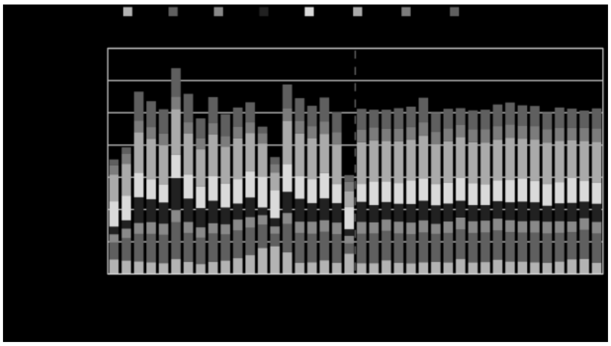
Fig. 4. Ejector force maxima for all sensors

In order to investigate the fluctuation of the ejector forces over the second half of the casting series, the values of the maximum forces were plotted in box plots (Fig. 5). On the one hand, it could be observed that the force levels of the different ejector positions showed clear differences. For example, the average ejector force for sensors L1, L3 and R3 was less than 1000 N, while sensor R2 reached more than 2400 N. On the other hand, the ejectors demonstrated different fluctuation behavior. While sensors L2, L3 and R3 showed little fluctuation in a range of less than 200 N, the force values for sensors L1 and R4 varied in a range of approximately 500 N.

In some cases, the evaluation of the boxplot also showed indications of symmetrical behavior of the ejector forces between the sensors on the left and on the right side of the die. In the cases of sensor pairs L3 and R3 as well as L4 and R4, similar ejector force levels were observed. In contrast, the ejector force levels for the sensor pairs L1 and R1 as well as L2 and R2 differed significantly.

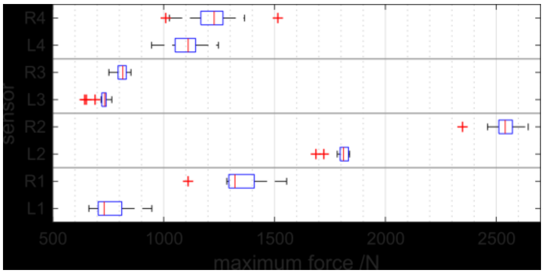

Fig. 5. Boxplot of the ejector force maxima of all sensors (second half of the casting series: cycles 21–40)

4. Conclusions

Within the scope of this work, a system for measuring the ejector forces during the aluminium die casting process was developed. The system uses piezoelectric force sensors, which are placed inside the ejector plate. The sensor arrangement can be adapted and extended with regard to the placement and number of sensors and is applicable to different dies. The casting experiments and the statistical evaluation of the results show that the system is suitable for measuring the ejector forces with regard to the sampling rate. The evaluation also showed that after an initialization phase of 20 casting cycles, reliable force measurements can be made. For the testing of the measuring system, casting experiments with a real structural component were carried out. Since not all of the ejectors were equipped with sensors, no statement could be made about the total ejector force for the whole casting component. Therefore, an improvement of the system could be achieved primarily by extending the number of sensors. For future experiments, an extension of at least four sensors should be aimed at.

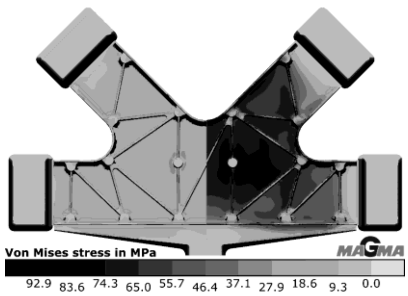

Fig. 6. Simulated von Mises stress depending on the alloy type (left: AlSi9Cu3, right: AlSi10Mg)

Using the developed measurement system, further investigations will deal with evaluating the influence of different parameters on the ejector forces. Through simulations (Fig. 6) and literature (Tosa et al. [4], German et al. [5], German [6]) the alloy, the type and mixing ratio of the release agent, the locking time, the intensification pressure as well as the pressure and the speed of the ejectors have been identified as possible influencing variables. Fig. 6 shows the simulated von Mises stress in the casting component "node element" for two different casting alloys. It is assumed that the von Mises stress is affecting the ejector forces. Further investigations will also focus on the influence of die surface degeneration on the ejection behavior. For this purpose, force measurements are to be carried out on a die in industrial use which is about to be phased out. For comparison purposes, the same tests will then be repeated with the identical replacement die casting die. A further subject of future investigations is the reduction of active ejectors and its influence on part quality. Enabled by a simulation based approach, the ejectors carrying the main load during ejection are to be identified. Simulations as well as casting experiments will deal with critical cases of significantly reduced ejectors, leading for example to part distortion or even surface defects. The ability of a simulation based approach to predict (and therefore avoid) those malfunctions will be then studied more in detail, paving the way for a sound, knowledge based setup of ejectors in die casting dies.

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References

[1] Köser, O., Rückert, J., Ubl, P. (2015). Modeling and Optimization of Part Ejection in Magnesium High Pressure Die Casting. In European Metallurgical Conference 2015, 14–17 June 2015 (pp. 371-382). Düsseldorf, Germany: GDMB

[2] Adam, M. (2016). *Development of a Surface Concept for Aluminium Die Casting Moulds using Wear Protection layers to reduce Release Agent Application and Spray Cooling to a Zero Level*. Dissertation. University Kassel, Germany. (in German).

[3] Terek, P., Kovacevic, L., Miletic, A., Kukuruzovic, D. Skoric, B., Drnovsek, A. & Panjan, P. (2017). Ejection Performance of Coated Core Pins Intended for Application on High Pressure Die Casting Tool for Aluminium Alloys Processing. *Tribology in Industry*. 39(3), 334-339.

[4] Tosa, H. & Urakami, A. (1973). Influencing Variables on the Die Casting Ejection. *Gießerei-Praxis*. 5, 79-84. (in German).

[5] German, A. & Klein, F. (1998). Optimization Potentials in Spraying water-miscible Mould Release Agents in Die Casting. *Gießereiforschung*. 3, 120-126. (in German).

[6] German, A. (1999). *Application and Effect of water-miscible Mould Release Agents during Die Casting*. Dissertation. Otto-von-Guericke-University Magdeburg, Germany. (in German).