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**Rafał Dojka PhD Thesis Review**
**«Investigation on the gating system: Reoxidation in the mould»**

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The thesis was submitted by Rafał Dojka titled as «Investigation on the gating system: Reoxidation in the mould» supervised by Prof. Jan Jezierski to Silesian University of Technology, Faculty of Mechanical Engineering in 2020. In accordance with the email I received on 30 April 2020, it was stated that I have been officially appointed as the reviewer position. I have downloaded the thesis and you may find my review and comments in seven categories below:

## 1. The topic and the contents:

The thesis concept is based on casting operations and defects that may be formed during filling operations. It aims to provide a solution to rejection rates which is one of the major problems in foundry applications. Therefore, starting from the title of the thesis and the contents included in the chapters with the experimental approach carried out in the tests, I find the thesis to be noteworthy and quite interesting.

The author discusses these issues with simulation studies first and their comparison and validation with the experimental findings. Therefore, the thesis is quite valuable. Particularly, since the concept is quite popular, and the literature is new to the bifilm concept, this thesis has the great potential to provide new insights to the subject; and contribute positively to the society.

I would like to also point out that I am quite thrilled to read the thesis, because in many foundries, it is very surprising to see that none of the concentration has been focused on the runner and sprue systems. Particularly, the idea of "as long as I can melt it, it can be cast" approach is quite wrong and the difficulties and challenges faced in such practices are quite valuable. Therefore, I am quite happy to see that this work is focused on this issue and sheds a light to one of the critical unseen and uncovered problems.

## 2. Thesis layout and literature survey:

The thesis consists of 212 pages with 11 contents. Chapter 2 presents a very interesting and extensive literature review with 153 references dating between the years of 2000-2020 which are up-to-date and all relevant papers. I have used ithenticate software to check plagiarism, and the result was 1%. Therefore, I can conclude that the author has not used any sentences directly from the references. The whole text in extreme acceptable limit in terms of ethics.

The author provides evidence to challenge the importance of runner designs and carries out a well-established experimental work to evaluate the issues. The thesis is covered in two main hypotheses. First work involves the effect of entrained surface oxide defects on the plasticity of cast parts. Second work focuses on the gating systems and air entrapment during mould filling.

In order to evaluate these hypotheses, initially, casting simulation was run with three different commercially available software namely: MagmaSoft, ProCast and Flow 3D.

Five different sprue designs were investigated. The geometry was chosen with different cross-section (rectangular and circle) with different tapered sprues in order to check the entrapment of surface oxide. The parameters chosen were not inappropriate. These are typical potential designs that could be used in foundry floor. The material and experimental parameters were provided in detail so that anyone who wants to repeat these tests could easily carry out them without any mis-information. In Figures 62 to 66, the absolute velocity of the liquid metal was given at different time intervals. This is important because (as discussed in the literature review) the critical velocity determines whether the liquid is subjected to turbulence or not. Later in the text, air evacuation and tracer results of simulation were also provided. The findings were then consolidated with Reynold, Weber and Froude Numbers. The results are justified with many different approaches. However, I would have like to see a discussion on the effect of surface tension. Most of the analytical approaches where Re, We and Fr are used, the surface tension is included in the equations as a parameter. However, I am always sceptical to the fact that these equations assume no friction and the effect of surface tension is included as the force holding the liquid meniscus. Actually, in casting operations, there are few other parameters that need to be included. For example, there is a critical radii value where surface tension no longer plays an important role which depends on the cross-section of the fluid that is flowing in the mould cavity. I am quite happy to see in Section 4.1.3 (Summary of Sprue examination) that the author has spotted this issue and concluded that these number might have a possible limitation.

Finally, it has been concluded that sprue has to be tapered in order to eliminate turbulence, bubble entrapment, bifilm entrainment etc. I was wondering if the authors could have come up with some mathematical formulation such that if the height of the sprue is X, the initial diameter is Y; then the bottom diameter should be Z. Has the author ever considered such approach?

In Section 4.2, runner design has been investigated. Similar to the sprue design, 7 different runner geometry have first been simulated and various parameters were analysed through casting simulation results. The reoxidation of the liquid during mould filling is an important parameter in castings. If it is not foreseen or considered, the final cast part may become filled with these hidden defects. This can be eliminated by the proper runner designs. The author had successfully considered different geometries and show evidences with simulation tools. My main question here is the missing discussion about the size or length of the runner bar. How many ingates should be selected based on the size of the casting? The author has looked into the use of 4 ingates. What would happen if only one or two ingates were used? What would be the taper ratio? Would we still need a choke?

In Section 4.3, ingate design has been investigated. Two main parameters were checked: the height and taper angle of the ingates. Again, the casting simulation tool was used to evaluate the effect of different parameters on the cas part quality. Absolute velocity has been taken into account to estimate the turbulence and how turbulence can be eliminated. The use of filter, vortex gate geometry, flush and trident gates were investigated by means of absolute velocity and how the design could be changed (geometrically) to achieve a quiescent filling where the critical velocity is not exceeded. As a result of the findings, the performance of the different designs was considered. However, I am curious about the shrinkage and the heat distribution that could affect the cooling of the cast part with regard to the various designs tested. The filling could be controlled to have a velocity below 0.5 m/s, however, the solidification of the cast part needs to be considered in terms of feedability and heat extraction. I would have like to see some discussion about such other possible effects that these designs might have on the final part quality.

Section 5.1 is one of the sections that I liked the most because it contains a new mould design to test the fluidity of castings which I was fascinated by a lot. Particularly when it comes to such PhD studies, I would expect to see new approaches, new ideas, new insights; and this new fluidity mould had attracted my attention significantly. Two designs were tested: vertical and horizontal. L500 steel was used to check the fluidity characteristics and temperature was set to five different levels: 1475, 1486, 1502, 1516 and 1527°C.

In Section 5.2, based on the simulation results, a series of casting trials were conducted and the simulation findings were compared with thermocouples placed inside the mould. For the characterization, non-destructive tests were carried out by initially checking the visual observations and confirmed by die penetrant and radiographic analysis. Additionally, mechanical test samples were collected to correlate the effect of mould filling with tensile properties. The mechanical test results were analyzed by means of Weibull analysis which is quite good approach because the statistical evaluation of findings is always important. Since this is a PhD thesis, arithmetic averages were not used which I find to be unsuitable. The Weibull analysis shown in Figures 188-191 are quite remarkable. The difference between the systems can be clearly seen which discussed by the author thoroughly. The findings were also justified by metallographic and SEM analysis. This is almost always important, because the author did not just speculate (in accordance with the literature review) but shown evidences to prove the findings. I am happy to see such methodology.

Section 5.6 is also one of my favorite type of tests. It contains the comparison of simulation and experimental findings. Simulation is a good tool that eliminated the trial-error (i.e. more economical and fast way to optimize) however, it is well known that simulations are not perfect. Therefore, I am amazed by the method where the author placed electrodes and recorded all the data sensitively to validate the simulation. I must congratulate the author for such efforts.

**3. Points in favor:**

The author has covered one of the most important issues in casting operations. Therefore, the starting point of the thesis, the hypothesis, the experimental setup, the analysis chosen are all in good methodology to cover up the problems and find a remedy to the defects. The text is properly organized with a good continuous read and in an understandable level. From the scientific point of view, I am happy to see that the results and conclusion have been justified with proper examinations. The general conclusion of the thesis has been defined solidly. As I have mentioned before, the goal of the thesis plays an important role particularly for the foundry applications. There are quite a lot of mis-applications in the industry. I am happy to see that this thesis is not based on hypothetical approaches with theoretical results. It demonstrates a valuable input for the industry. It is directly related with the industry and could provide and have the potential to be used by the industry. Therefore, I am positive and satisfied with the findings reported in this thesis.

**4. Methodology, experimental work, results and discussion:**

The thesis is inspired from both of the theoretical and methodological point of view. Aims and methods are clearly described, author represents the ideas and knowledge with sufficient theoretical background. The aims were fulfilled, methods of research work are appropriate to the aims and hypothesis formulated in the thesis.

The methodology chosen in the thesis was initially simulation studies and then its comparison with experimental works. Although there was no direct validation of the simulation, yet the author used these findings to evaluate the goal. Microstructural examination is an important way to characterize casting properties which has been carried out thoroughly in this thesis. It was supported with SEM and EDS analysis. Some of the casting trials were evaluated by means of mechanical testing and hardness measurements. The results were statistically analyzed by Weibull approach. Most of the experimental data was plotted as bar charts and the discussion was based on the graphical findings. It would have been extreme but I would have like to see some analytical formulations to correlate some of the findings.

**5. The grammar and quality of work:**

The language and the level of English might require a little bit improvement. However, it is not in such a state that this thesis is not acceptable. This is quite common particularly when the author's native language is not English. I find the text to be ok and easily understandable. Personally, I do not like long sentences that is connected with too many junctions. I am happy to see that this was not the case for this thesis. It has short and clear sentences. Simple and understandable. Few grammatical errors but overall ok.

The figures and tables are all clear with high resolutions. I did not find any image to be blur or non-clear.

**6. Questions:**

I was wondering if the author could come up with an analytical formulation as to how one can select the sprue type, size and geometry? For example, if the height of the sprue is X; initial diameter is Y, then the bottom runner diameter should be Z. Same scenario applies to the number of ingates that need to be selected for a cast part? Is there a critical length of the cast part to determine how many ingates should one apply?

Many simulation analyses were based on the assessment of critical velocity. And the resultant conclusion was analyzed by air entrapment and so on. Has the author looked into the solidification? Feeding criteria? Temperature distribution? Critical solid fraction? Feedability? Because, in the end, the author might have solved the problem of turbulent filling, but the actual cast part may end up having a problem of shrinkage.

In Section 5.6, electrodes were used to compare the simulation with experimental findings. I was wondering if the author ever faced difficulties during the recording of such data? What was the sensitivity of the wires?

Cast iron and steel are known to be "self-cleaning" alloys because the difference in density of liquid and its oxide is too high. Therefore, the dross is always on the surface and it can easily float to the surface rapidly. During mould filling, any entrapped air would try to float to the surface as well. How would you elaborate this issue (the issue of bubbles in mould cavity).

How confident and how sure are you about the data provided by Magma?
If the data was not existing in Magma, how would you extract the required data? Which tests would you do?

What is the confidence level of Magma and Flow? Have you compared the simulation with experimental findings? How would you elaborate the difference? What are the potential parameters that influence the difference between simulation and real experiments?

Can you talk about oxidation? What is oxidation? What are the mechanisms? What type of oxides would be seen? FeO? Fe2O3? Fe3O4? What about C? or graphite? Would it oxidize? What is the effect of alloying elements on the oxidation?

When casting grey iron, which parameters play a significant role? Which elements (or modifiers) are used for spheridizing of graphite? How does it work? What is the effect of temperature on spheridizing?

Can you define viscosity?

In fluidity tests, different cross-section thicknesses were used? What is the minimum thickness a liquid metal cannot flow? Can you measure or calculate it? Can you discuss the effect of surface tension?

My final question is: if you were given time, what would you change in your thesis? Which part would you like to focus more on? Which part was the hardest? Which part was the easiest? In future, which part of your thesis would you prefer to extend the work on?

**7. General comments and conclusion:**

The results of the thesis are relevant to current needs of the scientific community and of industry practice and are important for the further development of the runner and gating system that would aid the foundrymen to eliminate the formation of defects and obtain defect-free casting with minimum rejection rates.

I believe that the main objectives of the work have been fulfilled, as shown through the chapters.

The methodology used in the thesis is appropriate. In particular, the combination, evaluation and justification of simulation with real experimental practices. The thesis satisfies the conditions of a creative scientific work, as is shown through the publications of some of its results in peer-reviewed conferences.

The author of the thesis proved his ability to perform research and to achieve solid scientific results. I recommend the thesis for presentation with the aim of receiving the Degree of PhD. I also believe that the thesis should be nominated for the distinction for the valuable contribution to the society.

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