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THE SIMULATION OF A LIQUID CAST IRON FLOW THROUGH THE GATING SYSTEM WITH FILTER

SYMULACJA PRZEPŁYWU CIEKŁEGO ŻELIWA W UKŁADZIE WLEWOWYM Z FILTREM

The need to improve the castings' mechanical properties and decreasing their defects is the reason why almost all foundries use ceramic filters. It is generally accepted that filters decrease the number of non-metallic inclusions and in the end improve the quality of the casting. The use of computer foundry process simulation makes casting technology design and the selection of the gating system easier. The main practical problem is the way of placing the filter inside the gating system, especially in the proper distance from the casting.

The main goal of this paper is to analyze and explain the foam ceramic filter placement on the efficiency of liquid gray cast iron filtration process. The results obtained from technological tests were compared with those obtained from computer simulation prepared in MagmaSoft®. We presented the benefits of using computer foundry process simulation software during gating system design at the stage of predicting and eliminating technological errors. We also assessed the possibility of computer simulation programs to predict the design of proper gating systems with ceramic filters.

Keywords: foam ceramic filters, gray iron, gating systems, casting mechanical properties, filter placement, computer foundry process simulations

Dążenie do poprawy właściwości mechanicznych oraz zmniejszania ilości braków odlewów spowodowało, że prawie we wszystkich odlewniach w części produkcji stosuje się filtry ceramiczne. Powszechnie uważa się, że filtry zmniejszają ilość wtrąceń niemetalowych w przepływającym metalu i tym samym poprawiają jakość gotowych odlewów. Posługiwanie się komputerowymi programami do symulacji procesów odlewniczych ułatwia projektowanie technologii odlewu oraz dobór optymalnego układu wlewowego. Problemem praktycznym, zależnym od decyzji technologa, pozostaje jednak określenie sposobu umiejscowienia filtra w układzie wlewowym, szczególnie odpowiedniej odległości filtra od odlewu.

Celem artykułu jest wyjaśnienie wpływu umiejscowienia ceramicznego filtra piankowego na efektywność procesu filtracji odlewów z żeliwa szarego. Wyniki otrzymane z prób technologicznych porównano z wynikami symulacji komputerowej MagmaSoft®. Przedstawiono korzyści używania programu na etapie projektowania układów wlewowych do przewidywania i eliminacji błędów technologicznych. Oceniono możliwości programu do przewidywania poprawnego projektowania układów wlewowych z filtrami ceramicznymi.

1. Introduction

It is a serious problem to design a proper gating system without a good knowledge of fluid mechanics laws and without computer software that support foundry simulation processes, especially those based on Computational Fluid Dynamics (CFD) [17, 18]. The constant need for decreasing costs and reducing defects leads to the situation where process engineers analyse with more care liquid metal flow in mould cavity. The use of computer foundry process simulation software makes prediction of the mould cavity filling possible. The way of liquid metal flow influences casting defects and its final properties. Proper mould filling can be achieved by suitable construction of gating system, which should obey several technological rules, such as [1 - 3]:

- providing continuous pour and avoiding turbulent flow of liquid metal;
- counteracting choking air and gases during pouring from pouring basin or mould walls;
- feeding mould cavity slowly and with determinated flow rate;
- holding back the slag and other non-metallic impurities.

Melting, modification, spheroidization and pouring of liquid cast iron can cause a great number of

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non-metallic inclusions. The majority of those inclusions is flushed during deslagging. Metal oxides and magnesium silicates cause discontinuity of structure, surface defects, decreasing of mechanical properties, workability and casting's quality. The use of ceramic filters is one of the ways of eliminating those inclusions. It is generally assumed that slag films with silicates and sulphides, moving with liquid cast iron are stopped at the filters inlet. Stopped slag develops a new, additional filter where next inclusions are stopped and start coagulation. Very small inclusions are also stopped on inner walls of filter cells.

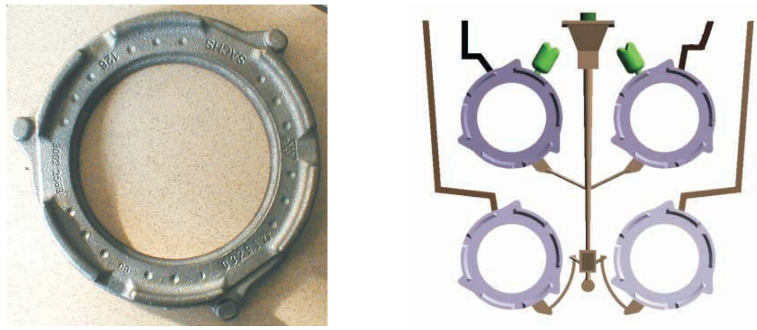
Foundries, in their efforts to achieve the best and repeatable quality of castings very often use ceramic filters in gating systems. Filter types, their properties, selection principles, rules of designing gating system with filters, the positive influence of filters on castings quality and the attempts of explaining filtration mechanisms are widely discussed in scientific literature and commercial instructions [4 ÷ 17]. One of the main aims of gating systems with ceramic filters is at least partial stabilization of turbulent flow of metal. Every change of gating system intersection, metal flow direction, metal flow roadblock or any other obstacle results in flow character change – steady flow becomes turbulent. After a few seconds of pouring metal into mould, starts the deformation of the superficial layer of moulding sand in gating system and mould cavity. Improper hydrodynamic conditions lead to sand erosion and sanding the cast. This problem occurs very often during producing a large size casting. Applying ceramic filters in gating system makes metal flow steady and reduces metal stream negative effect on mould cavity walls and in result reduces the amount of inclusions and oxides [12, 17, 18].

Only proper placement of filters in gating system leads to benefits of their usage when improper placement may cause reduction of their positive influence. Badly used filter does not bring improvement in casting quality but makes casting's production more expensive. Moreover, use of filters extends the time of one cycle in forming.

During cast technology and gating system with filters design, there should be taken into account the distance between filter and a mould cavity. A very common mistake is making this distance to long. Sometimes in parting plane casting technology ceramic filters are placed right next to the pouring basin, so this distance can be 60 cm or even more. Earlier investigations [14 ÷ 17, 19] show that flowing metal slows and calms the flow next to the ceramic filter changes into faster, strongly turbulent flow which result in secondary oxidation and mould erosion. In this paper we show and explain the filter placement influence on mechanical properties of the casting. Our conclusions are based on data analysis prepared during studies in one of Polish Foundries and results obtained from foundry processes simulation programs.

2. Research method

Technological performance tests were done on the clumping ring of the coupling (Fig.1) that was made of grey cast iron (EN – GJL – 250) [17]. Castings were made on the Disamatic production line with vertical parting plane. Alloys were melt using induction furnace. Inoculant was added to the liquid alloy stream during casting process. To keep the same process conditions all tests were performed during one melt. On account of casting defects appearing in casting part close to the gating system there were prepared series of mould of similar geometry with various filters placement. The foam ceramic filters of 20ppi 60x20x20 [mm] were used. In this moulds foam ceramic filters 20ppi 60x20x20 [mm] sizes were used. Ceramic filters placement are marked with red colour (Figure 2). Some samples of test castings were prepared, to determinate mechanical properties, hardness, fraction of oxides inclusions and metallographic specimens.



a) b)

Fig. 1. Ring casting: a) detail picture; b) feeding system with castings 3D model

a) b)

Fig. 2. Ring pattern plate with ceramic filter placement in gating system: a) filter settled under pouring basin; b) filter settled close to casting

To show flow phenomena and turbulences in liquid metal there were prepared cast iron ring casting computer simulation at MagmaSoft® software. Chosen research method allowed to obtain three-dimensional visualisation casting processes, mainly fluid mechanics of mould cavity filling. The simulation software were used to verify the influence of foam ceramic filters placement in gating system on flow pattern and effects of liquid alloy filtration. Three-dimensional model of proposed casting and sand mould were prepared in CAD system. After loading solid geometry into simulation software there were generated finite different mesh. Then using program data base there were inputted the process parameters: types of foam ceramic filters and thermophysical parameters of mould and alloy [19]. Matching it with industrial tests there were prepared three simulations for different filter placement in mould: without filter, with filter near to pouring basin and with filter near to mould cavity. Results obtained in different filter placement were compared with real casting analyse results. There were taken into account the way of metal filling mould cavity by metal, liquid metal speed distribution, temperature distribution and mould erosion.

3. Results

Oxide inclusion fraction

Investigations of oxide fraction show that in rings casted without ceramic filters oxide fraction is the highest.

Towards to low solubility of gaseous oxygen (few ppm) it was mainly oxides in non-metallic inclusions. To analyze total oxide content in alloy during the flow, samples were taken from various places in gating system, as in paper [17]. Figure 3 presents influence of gating system longitude and ceramic filters applying on metal oxidation during flow.

High number of oxide inclusions in casting obtained in the case of technology without applying ceramic filters appears to be obvious there can be observed lower content in the case of applying filter under pouring basin. The lowest content were found in elements casted in mould when ceramic filters were situated nearby mould cavity. Comparing oxides inclusions in pouring basin (as in initial alloy) with inclusions in casting, in the case without filter, it can be observed strong secondary oxidation of cast iron during stream flow through gating system (Fig. 2, footnote 4 and 1). During flow through very complicated gating system alloy flow becomes turbulent, mainly in initial stage of filling. In this stage secondary oxidation starts and inclusion of oxide increase even several times to the value about 2000 ppm. Similar effect of secondary oxidation of alloy can be observed for ceramic filter applied under pouring basin. Right after filter metal is pure, but after flow through another part of gating system started secondary oxidation (Fig. 3, footnote 5 and 2). Results of oxide inclusion fraction investigations shows that applying filters in distance about 10 cm from mould cavity has best influence on laminar flow of clear alloy.

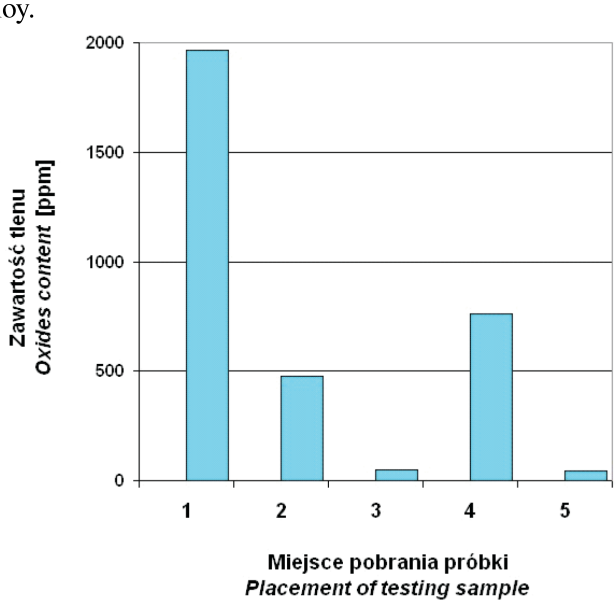


Fig. 3. Oxides content in samples: 1) from casting – ingate without filter; 2) from casting – filter in the basin; 3) from casting – filter close to the casting; 4) from pouring basin; 5) after the filter in basin [17]

Mechanical properties of the castings

Cast iron ring mechanical properties examinations show that strength of the casting grows as a result of ceramic filters applying [17]. It is caused by impurity decreasing in examined castings. Best parameters were obtained through placement of the filter in lower part of gating system, near to mould cavity (Fig. 4). Worse results were obtained in every other filter placement. This proves thesis that during flow after filter alloy is a subject of secondary oxidation and in aftermath its properties gets worse. Ring hardness after filtration is better because of lower level of impurities. Yield strength for examined samples gets lower what is connected with strength and hardness of gray cast iron increase.

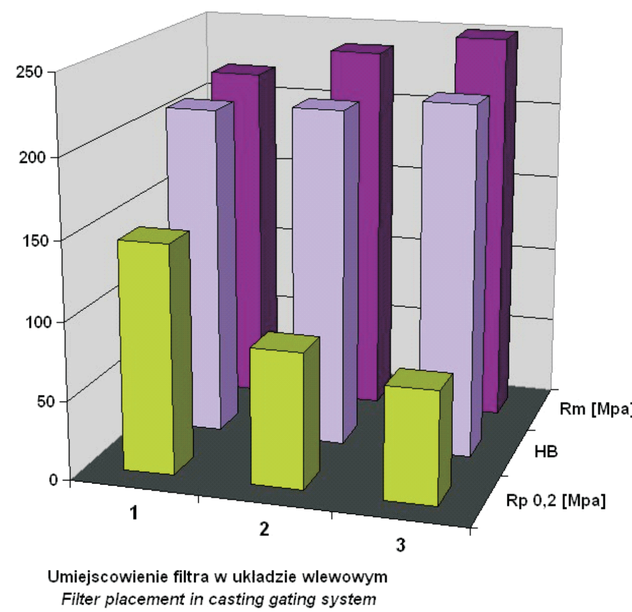


Fig. 4. Casting mechanical properties according different filters placement: 1) ingate without filter; 2) filter in the basin; 3) filter close to the casting [17]

Foundry processes computer simulation results

There were proceeded numerical simulation of filling mould cavity and crystallization using MagmaSoft® software. The way in which alloy fills gating system and mould cavity was analyzed using flow markers – named: "tracers". Simulation results showed how turbulent flow during filling mould cavity, especially until gating system channels are not fully filled with alloy. Figure 5 presents spread changes of liquid stream of cast iron in different cases of filters placement and in different stages of filling. When filters were not mounted bottom part of mould cavity started to be filled even when the gating system still was not fully filled. Applying filters in gating system slowed down cast iron flow and for some distance after filter flow became subcritical. Results of numerical calculations proceed with use of MagmaSoft® concerning influence of foam ceramic filters on liquid metal flow were confirmed in industrial tests.

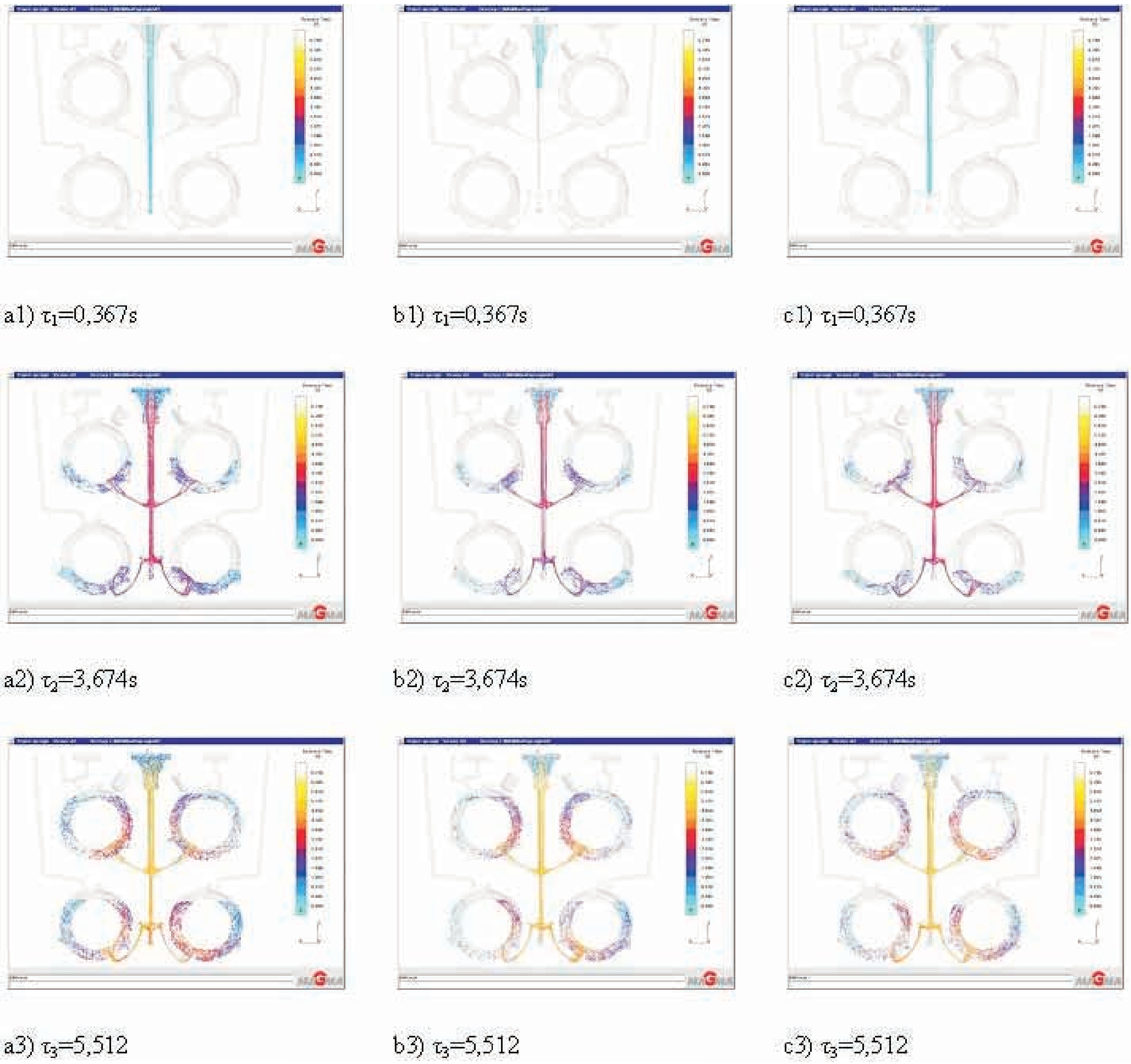


Fig. 5. Simulations results from tracers flow after time τ_1=0,367s, τ_2=3,674s and τ_3=5,512s in different filter placement: a) without filters; b) filter under pouring basin; 3) filter close to the casting

To complete observations of flow markers there were also analyzed liquid metal flow distribution (Figure 6). In the case of technology without filter metal flowed into the bottom part of mould cavity with high speed and its flow was turbulent. It could be reason of oxidation and high mould erosion. In the second version of simulation, with filter placed near the pouring basin, speed of liquid metal stream were restrained only the starting part of gating system. After flow through the filter alloy had long enough distance to accelerate and its speed again was high near to the mould cavity. Filter placement near to the casting, in the lower part of gating system showed the best results. Metal was restrained near to the bottom ingates and flow in the mould cavity was subcritical and slow. Such filter placement caused restrain of liquid metal stream at all the gating system longitude (Fig. 6, footnote c3)

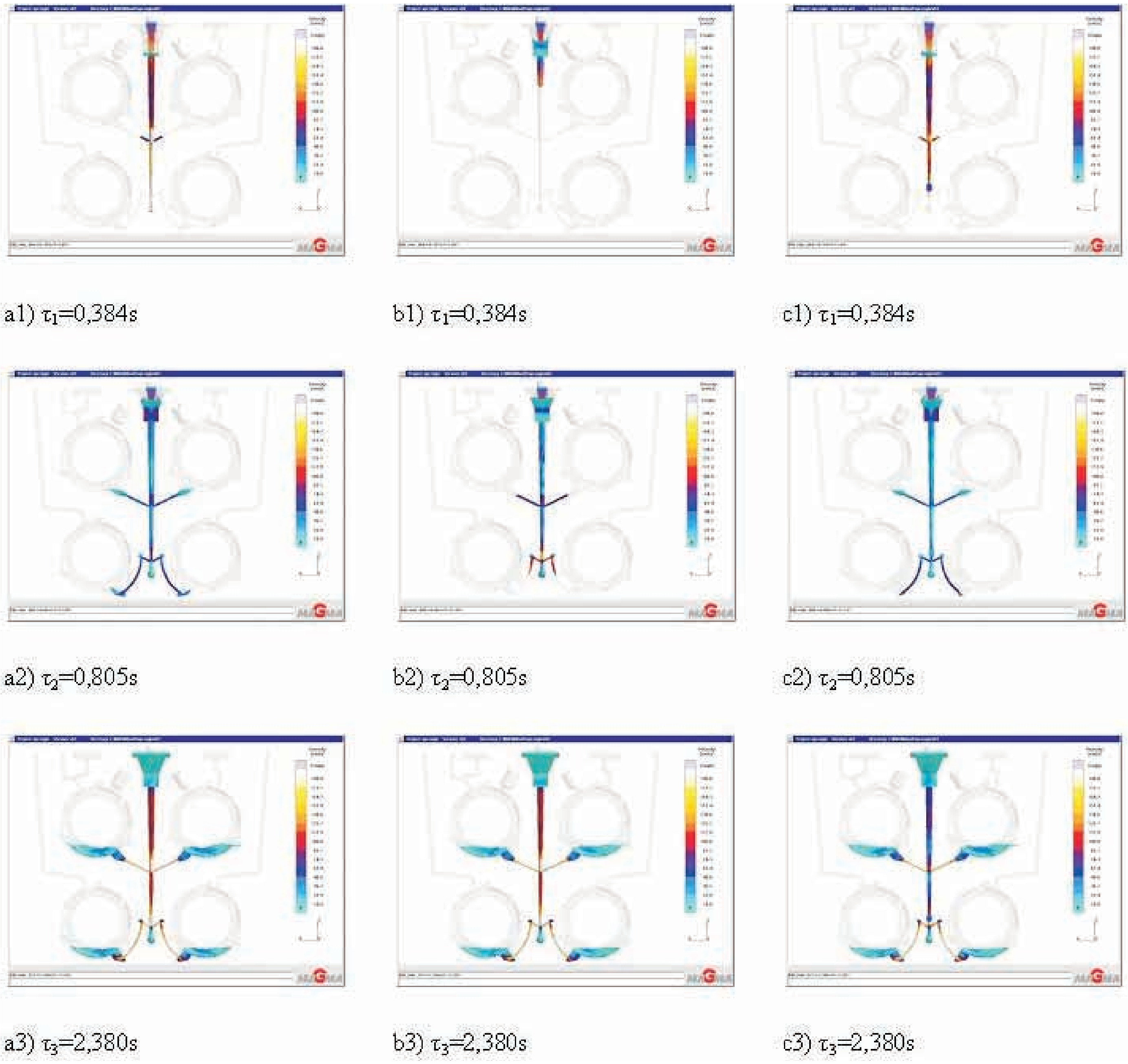
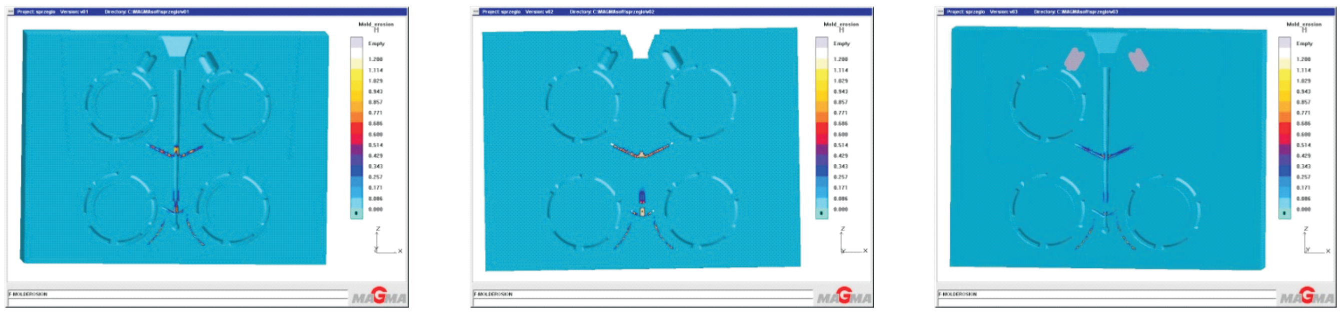


Fig. 6. Liquid metal pouring velocity distribution after time τ_1=0,384s, τ_2=0,805s and τ_3=2,380s in different filter placement: a) without filters; b) filter under pouring basin; 3) filter close to the casting

Long filling time of the mould cavity and very complicated gating system caused increase of danger of mould erosion. Results of investigations showed that then high speed of a stream for a long time caused erosion of the mould and this disadvantage regarded especially ingates (Fig. 7). Filter placement in the pouring basin did not guarantee less turbulent flow or decreasing the metal influence on gating system walls force for the bottom casting ingates. Applying the filters near to analyzed casting caused change of cast iron flow into subcritical one, reduction of the risk of mould erosion and consequently reduction of the risk of appearing new oxides and inclusions.



a) b) c)

Fig. 7. Results of mould erosion and gating system canals in different filter placement: a) without filters; b) filter under pouring basin; 3) filter close to the casting

Using the filters in the gating system, although partial restrain of the stream speed did not affect significantly on appearing and localisation of hot spots and casting crystallization process. This was evidenced by metallographic investigations results, which did not show any influence of filtration and decreasing number of impurities in alloy on cast iron structure and distribution of graphite in casting [17].

4. Summarize

Analysis of technological tests and results of computer simulations showed influence of distance between filter and mould cavity on impurities level in casting and the way of filling the mould. With metal casting without filters can cause mould erosion and worse properties of caste elements.

Applying filters in gating system restrain cast iron flow and makes it subcritical. However the filter placement is also very important. Fact of using filters does not guarantee expected quality improvement. Investigations showed that in the case of using filter near to pouring basin metal flow through the rest of channel accelerates and in effect turns into turbulent. This kind of flow can result in secondary oxidation of alloy and mould erosion. Wrong placement of ceramic filter provides only purifying of poured alloy from inclusions and oxides. It does not guarantee good effect of filtration till the moment of completely filling mould cavity.

The best effect of filtration is obtained for moulds with filter placed near the casting. After liquid metal reached the filter its stream becomes subcritical and possibility of mould erosion is insensible. Because of low number of inclusions casting has the best hardness and strength properties. The examinations showed that depending on the gating system construction most beneficial is applying filters in distance of 10 up to 20 cm from the casting and gating system should be as short as possible. Because of construction difficulties it can be hard to fulfil this rule and sometimes we need to place some filters in the mould. Moulds improved in that way are rather expensive but proper applying of filters is very important to keep filtration effect of cast iron. It provides repeatability of obtaining good quality elements what is very important nowadays for client satisfaction and keeping foundry reliability.

REFERENCES

[1] P. Januszewicz, J. Jabłoński, Modelarstwo i formierstwo. Część 2, Zeszyt 1. Skrypty uczelniane AGH nr 41, Kraków 1961.

[2] Cz. Podrzucki, Żeliwo – struktura, właściwości, zastosowanie. Tom pierwszy. Wydawnictwo ZG STOP, Kraków 1991.

[3] J. Braszczyński, Teoria procesów odlewniczych. PWN, Warszawa 1989.

[4] R. P. Pischel, A Filter is more than just a filter. Foundry Management & Technology, s. 24-33, April 2003.

[5] L. S. Aubrey, J. R. Schmahl, Application of reticulated silicon carbide foam filters for iron castings applications. Foundry Trade Journal **165**, 3440 & 3441 (1991).

[6] H.-J. Wojtas, O. Kurutas, Beitrag zu den Wirkmechnismen der Filtration metallischer Schmelzen – Einsatz von Schaumkeramikfilter im Stahlgu". Giesserei **85**, 7, 74-80 (1998).

[7] U. S. Sievers, "Filtration de grosses pieces en acier moule. Fonderie – Foudeur, 165, 16-36, (1997).

[8] L. Bechny, S. Vrabel, Filtracia materialov na odliatky". EDIS Zilinska Univerzita, Żilina 2000.

[9] D. V. Neff, "Filtry dla odlewnictwa ciśnieniowego". Biuletyn Metals Minerals 2/2001.

[10] M. Asłanowicz, L. Ościłowski, S. Pysz, J. Stachańczyk, P. Wieliczko, Zastosowanie fil-

trów ceramicznych do układów wlewowych dla staliwa. Przegląd Odlewnictwa **55**, 10/2005, 652-659.
[11] I. A n d r e w s, W. K a l l i s c h, Automatic Sedex filter setting on vertically parted moulds. Foseco Foundry Practice, Issue 224, December 2005.
[12] A. B a i e r, G. S t r a u c h, The influence of filter type and gating system design on the machinability of vertically parted grey iron castings. Foundry TJI **181**, 3656, 192-195, July/August (2008).
[13] Instrukcje technologiczne firm zajmujących się produkcją i wdrażaniem filtrów ceramicznych.
[14] A. C h o j e c k i, R. H a w r a n e k, Przepływ żeliwa przez filtry ceramiczne. 29 Konferencja Naukowa z okazji Święta Odlewnika 2005, s. 173-180, Wydział Odlewnictwa AGH, Kraków 2005.
[15] A. C h o j e c k i, R. H a w r a n e k Przepływ metalu przez filtry ceramiczne. Archives of Foundry **5** 17, 37-44, Łódź (2005).
[16] A. C h o j e c k i, R. H a w r a n e k, Przepływ ciekłego metalu przez filtry ceramiczne. 28 Konferencja Naukowa z okazji Święta Odlewnika 2004, s. 69-75, Wydział Odlewnictwa AGH, Kraków 2004.
[17] R. H a w r a n e k, T. S t a s i c a, Wpływ umiejscowienia filtra w układzie wlewowym na efektywność filtracji ciekłego żeliwa. Odlewnictwo – Nauka i Praktyka, Rocznik 8, Nr 1/2006, str. 15 20, Instytut Odlewnictwa, Kraków 2006.
[18] Materiały badawcze własne oraz materiały opracowane przy wykorzystaniu systemów symulacji komputerowych Magmasoft® oraz Fluent®, niepublikowane.
[19] Instrukcja obsługi MAGMASOFT® 4.2, Aachen, 2002.

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