Former theories of filtration when compared with new cognitions

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ABSTRACT

This paper gives a short insight into the theme, why former theories of working with filters are not useful to explain all phenomenon's in the field of modern gating. One part of the paper shows the former three mechanisms, its explanation and the consequential critical questions. These questions could not be answered by the former theories and require the new theories. The other part shows the theoretical consideration of how the filters really work instead of the former theories. There are also some practical examples shown where the new theories are supported and which are against the former theories. The paper demonstrates that filters can hold back inclusions and can prevent the forming of inclusions during the pouring process but in a way which is different from the previous knowledge.

Keywords: Filtration, Ceramic Filters, Gating, Filtration Effect

1. INTRODUCTION

The following lecture contains a simple summary of a few important problems which are often sources of errors in foundries. The intention is to present the most important special features of this topic to the reader in a simple and comprehensible manner. In the past we were often faced with some problems which were connected with the field of the filtration of molten metals that we were not able to explain properly, or solve, with the background of the former theories and the believed mechanisms of how filters work.

Because of these unsatisfied situations, the author starts to think about some new ideas of how filters work in an in gate system and to create some new theories.

2. BACKGROUND

Today we are forced to manufacture our castings economically and with a very high standard of quality. Apart from that, specifically in the automotive industry, the designer demand of weight reduction is to be met by reducing the wall thickness of the castings. The high cutting speeds during machining also require increasingly higher casting quality. This means that customer requirements, especially those directed at casting suppliers, with respect to surface quality and the absence of non-metallic inclusions in the casting, have increased greatly and become much more demanding. It is exactly these casting defects, which can occur due to an unsuitable gating system that can lead to dangerous weak spots in highly stressed components.

3. FORMER MECHANISMS OF FILTRATION

Up until now, the functioning of all ceramic filters was divided into three mechanisms that not only intercept the coarse particles on the surface but also the fine particles inside the filtration media. These particles can be much smaller than the pores, the cells or the holes of the ceramic filters. But two of these three mechanisms pose some questions when we look at our long lasting practical experience in the field of filtration. The three filtration mechanisms (Fig. 1) are:

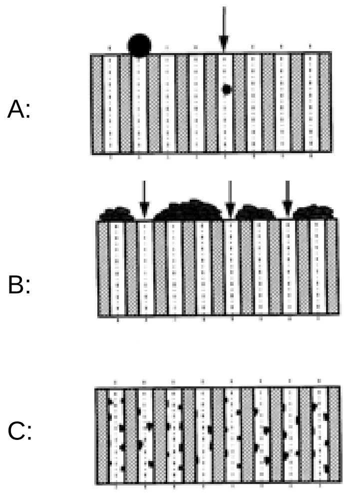


Figure 1 : Three filtration mechanisms.

A. Sifting out of large particles.

This mechanism intercepts particles that are larger than the pores of the filter. This is a pure physical effect and of course it works in this way.

B. Interception on the filter surface by filter cake.

A so called filter cake forms on the feed side of the filter due to the gradual accumulation of impurities there. This filter cake, in a certain way, leads to a narrowing of the cross sections and to undercuts, through which the molten metal has to flow.
Due to this, particles, which are smaller than the pores of the filter, can be intercepted here. But this mechanism poses the following questions.

- It is definite, that an extruded filter works well and can improve the casting quality. But how can it happen that a filter cake will "grow" on the small cell walls under the condition of high pouring rates? These small cell walls are not able to give such a support that the slag can create or grow to become a filter cake. Under real pouring conditions such a pulpy slag conglomerate would be pressed through the filter in cause of the dynamic pressure of the melt.
- How we can ensure, that the same open area of the filter will always be guaranteed and that the filter cake will always have the same "size"? If there is a real filter

cake it would have in every casting a different shape and respectable size. This causes, in every case, a different covered area on the filter front that would change in every casting and give a different open area of the filter.

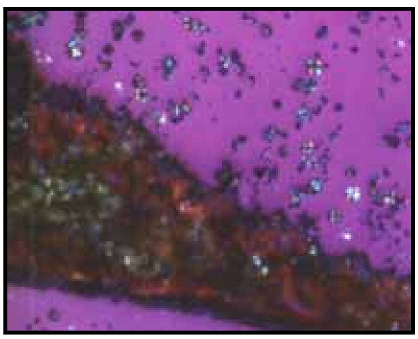
- Does the filter cake have a high enough mechanical stability, that it will not change its shape during the pouring process? Does the narrow thorough fair stay alive throughout the pouring time? A lot of the publications about the filter mechanisms show particles which appear to be solid slag particles. But in reality slag "particles" in the iron melt are not solid. They are more or less liquid, or at best doughy. With these conditions it is not possible to create a solid filter cake.
- Why should the molten metal flow through narrow thorough fair, when there is still enough open area? The iron flow always takes the path of the least resistance. That means that the iron would run through the open filter cells instead though small thorough fair if given the possibility.

C. Particle Bonding on the Inner Surface of the Filter Cavities.

This so called deep bed filtration intercepts those particles, like sand grains or small particles of refractory material which are smaller than the pores of the filter, and also liquid slag. It is important that we remember that the slag or dross in iron melts is more or less liquid and not solid.

The turbulence of the molten mass while it is flowing through the filter often results in inclusions coming into contact with the inner walls of the filter. Here the particles adhere to the filter ceramic and are therefore prevented from getting into the casting. Also this mechanism poses the following questions.

- That liquid and doughy slag adheres very well on ceramic material is a fact that we know. But is the inner surface area of a filter really high enough to keep out all slag or dross?
- The thickness of the adhered inclusions on the internal filter walls becomes thinner with higher pouring rates. Higher pouring rates cause a higher dynamic pressure and all particles which are not bonded very strong with the ceramic material would be washed out again. Is the remaining amount of bonded slag really enough to ensure the quality of our castings? The typical thickness of a slag layer inside of the filter is shown in Figure 2. This figure shows a part of a foam ceramic filter and a part from an extruded filter. Both slag layers are very thin and nobody knows exactly if this slag was bonded during the pouring process, or after the pouring process and during the solidification of the ingate system. Nevertheless the amount of slag in these thin layers is not important.



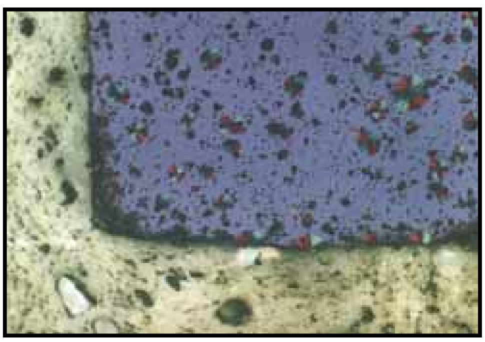


Figure 2 : Slag layer – foam ceramic filter and extruded filter.

- Why does a filter, which is made from a graphite material work? Graphite is used in the slag zone of steel ladles to avoid adhered slag. The adhesion between both materials is as low as possible and is this not the reason we get a little higher flow rates with these filters? These filters can not work with the "Deep Bed Filtration Effect". There must be another effect.
- Why does a filter give the same good result when its thickness is reduced because of economical reasons? When we reduce the filter thickness we reduce the inner filter surface area too. Would it not mean that the deep bed filtration effect would be reduced too?

Especially that deep bed filtration effect was often connected with the real and most important effect of a ceramic filter. And because of this the filtration effect was pictured in a relation with the inner surface of a filter. Diagram 1 shows that relation.

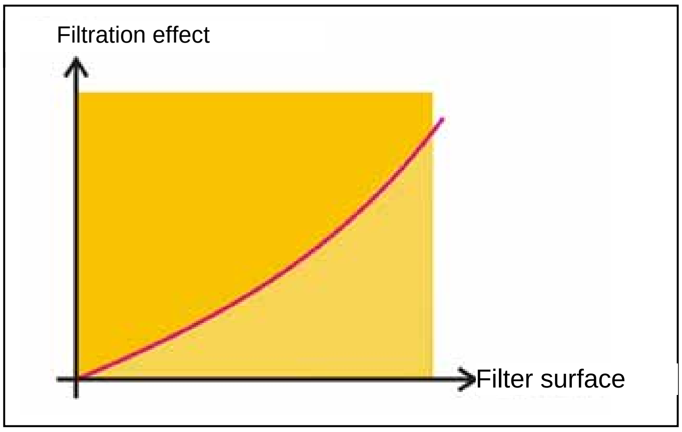


Diagram 1 : Relation filtersurface / filtration effect.

4. PRACTICAL FUNDAMENTALS FOR THE NEW THEORIES OF FILTRATION

Why does a filter get "blocked" by dusty melts when these three mechanisms are not

working as we thought? Of course when; for example, the level of the melt is lowered down to the filter surface while the pouring basin is not kept full. Then the floating slag in the melt will suddenly adhere to the surface of the filter and the filter will be blocked. In this way the pouring process is stopped.
But we think that in every regular case when the pouring basin or the funnel is kept full then the slag will not block the filter. Now we think, and we found out, that in nearly every case the viscosity of the melt is responsible for such effects (Fig. 3).

Figure 3 : “Blocked Filter”. View from below and ide view.

In this case the pouring process was stopped some seconds after the start of the pouring and the foundrymen thought that slag was blocking the foam ceramic filter. After we cut the solidified runner with the filters we saw that there is no slag in the filter or on the filter surface. What we can see is that the liquid iron (ductile iron) was not able to flow through the filter. The reason for this phenomenon is the high viscosity of the melt because of; for example, lower pouring temperatures or a variation of the metal analysis. An additional parameter is that the metal front that came in contact with the filter material, because of the thermal conductivity of the SiC-material, the foam ceramic filter reduced the temperature of the metal. The viscosity was thus increased so that the metal front was frozen inside of the foam ceramic filter.
This foundry uses a pore size of 10ppi (pores per inch) for the castings. We solved the problem with filters of a bigger pore size of 8ppi but without increasing the size of the filter which was 100x100mm!
One other practical example of the relation between open area and pore size was tested in a foundry where they used extruded filters with a cell size of 50csi (50 cells per square inch). One of the biggest disadvantages of these filters types are the low mechanical stability because of their very thin cell walls. The extruded filters also have the most open area of all filter types. As a result, customers who wanted to replace these filters because of the problems with filter breakage, with either foam ceramic filters or pressed round hole filters thought that they had to take a bigger filter size. The reason for this would be to get a filter with the same open area. The reasoning for this was the belief in the theory of the filter cake, which covers the filter, and that they had to keep enough open area. This foundry used two filter sizes, 100x100mm and 100x75mm. Because of the small amount of space on their patterns they were not able to place bigger filters in their in gate systems.

All trials with foam ceramic filters failed and they thought that the reasons were the less open area even when they used 8ppi foam ceramic filters. Because of the maximum porosity of 8ppi, we decided to make a test with pressed round hole filter.
In figure 4 it can also be seen that this filter type has a smaller open area than the extruded filters (square cells). In table 1 the data of both types of filters are shown in order to give a better overview.

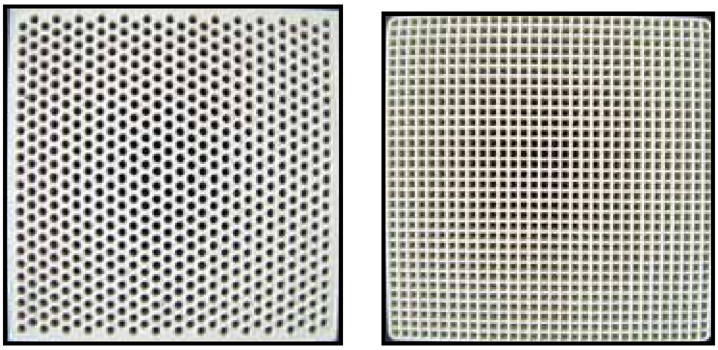


Figure 4 : Open areas of a pressed and extruded filter.

Table 1

Comparison of the geometries of extruded filters (cellfilters) and pressed round hole filters				
Filter type	**Dimension**	**Cell- / holesize**	**Open Area**	**% of open Area**
Cellfilter, 50csi	100 x 75mm	2,95 x 2,95mm	5056mm²	67%
Round hole filter	100 x 75mm	Ø 2,17mm	3142mm²	42%
Cellfilter, 50csi	100 x 100mm	2,95 x 2,95mm	6752mm²	67%
Round hole filter	100 x 100mm	Ø 2,81mm	4165mm²	42%

A pressed filter with a hole diameter of 2,17mm was not able to fill the mould because of the filters “blocked” and they thought that the small holes filtered to much slag. A filter with a 2,81mm hole was then used and we received 8 out of 10 good castings even though the amount of open area was only 42%. After this result we designed new filters for the sizes 100x100mm and 100x75mm with 3,5mm and 3,3mm diameter holes respectively. The data of these new filters are shown in table 2.

Table 2

Comparison of the geometries of extruded filters (cellfilters) with the new designed pressed round hole filters				
Filter type	**Dimension**	**Cell- / holesize**	**Open Area**	**% of open Area**
Cellfilter, 50csi	100 x 75mm	2,95 x 2,95mm	5056mm²	67%
Round hole filter	100 x 75mm	Ø 3,30mm	3650mm²	49%
Cellfilter, 50csi	100 x 100mm	2,95 x 2,95mm	6752mm²	67%
Round hole filter	100 x 100mm	Ø 3,50mm	5164mm²	52%

With these new geometries we have never had a problem with "blocked" or broken filters in the last four years, with over 200.000 castings poured, even though the open area of the new designed pressed filter is less than with the original extruded filter. The reason for the good result is only the good relation between the hole diameter and the viscosity of the ductile iron melt. Also an interesting paradigm was the solution of a problem with a big foam ceramic filter.

The pouring weights are over 9 tons. Because of the narrow space for the in gate funnel they were only able to use a filter size of a diameter of around 200 – 240mm. They used one foam ceramic filter with a dimension of Ø 200x30mm in 10 ppi in a steel quality. Unfortunately time after time they faced problems with "blocked" or broken filters.

When they had some blocked filters they thought that their iron was overloaded with impurities. As a result of these problems they asked for a single filter which would be able to handle this high pouring weight. Unsuccessfully, they started to drill 10mm holes into the foam ceramic filters to avoid the blockages. Because of these holes the stability of the filters were reduced more, which lead to more broken filters.

The question was would the liquid iron flow through the pores of a foam ceramic filter when there were some holes drilled through the filter where the melt could flow much easier. So we gave them a strainer core with a dimension of Ø 230x30mm with 49 holes Ø15mm which is shown in figure 5 and was developed 20 years earlier. To see the real dimensions, reference figure 5, which shows also a pressed filter with a dimension of 100x100mm.

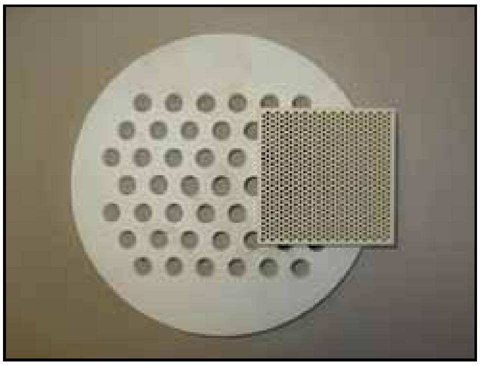


Figure 5 : Strainer core Ø 230x30mm and 100x100mm filter.

Until this day, with this solution, we produced around 220 heavy castings without any problems. All castings are “clean”. The question was, how could a strainer core “filter” a casting? We solved a lot of these phenomenons in the last years where customers always thought in the same way about a higher amount of slag and filter cakes. We never had to increase the filter sizes, which would be necessary if we still believed only in the three old theories of the mechanisms of filtration.

5. THE NEW TEHORIES OF FILTRATION

This means that it is not the amount of open area or the amount of inner surface of a filter that is important. The hole-, cell- or pore size in relationship with the viscosity of the molten metal is what is important in order to allow the melt to flow through a filter so it can successfully work! Of course the filter should not become the bottle neck in the in gate system, so the open area is nevertheless important to pay attention to. We expect the main effect to be the fixed resistance to the flow in our in gate system that the filter gives us. It is this resistance to the flow that is the most important parameter for the filtration effect. This causes a tailback in front of the filter, so that there is a possibility to separate liquid slag and sand grains (Fig. 6) in front of the filter because of the density difference of the slag, sand and metal.

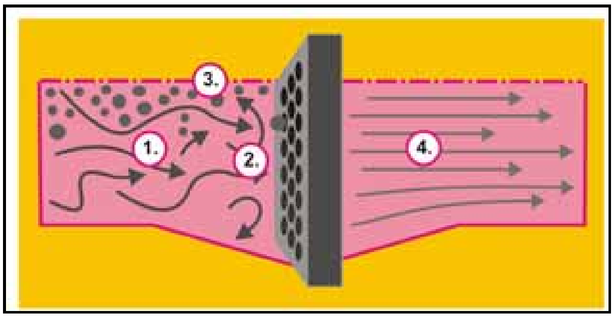


Figure 6 : Flow in front and after a filter.
Area (1) is an area of turbulent flow. When the melt is reaching the filter there is a tailback (area 2) so that the inclusions can be separated (area 3). After the filter we find an area of laminar flow (area 4).

If the resistance of the flow is to low then the speed of the melt is not slowed down enough to create a proper tailback and to reduce turbulences. In this case the inclusions could be carried with the metal stream and could pass through the filter. If the resistance to the flow is too high the slow moving molten metal could solidify inside of the filter, or the pouring time could become too long if the open area is great enough to handle the slow moving iron. We saw this effect in one of our investigations.

We simulated the flow in a filter chamber (Fig. 7) where we added some colored inspection particles, which have had the same density as water so that there would not be any false separation effects. During the pouring process there was also a tailback which captured some particles in front of the filter. The other very important effect is that the filter avoids creating turbulence after itself. Because of this laminar flow, the danger of reoxidation of the liquid metal is reduced. Especially in ductile iron we reduce the amount of dross because of that reduced turbulences. Another important effect is that the dynamic energy of the metal stream is reduced after the filter.

Figure 7 : Flow simulation with water.

6. SUMMARY

This laminar flow and reduced dynamic energy effectively avoids the creation of slag and sand erosions in our down stream in gate system. The little adhered layer of slag on the internal filter walls helps a little bit too. But we expect that this effect was absolutely overvalued in the past. During some examinations of graphite filters it was viewable that directly on the filter walls were no adhered inclusions, but the casting quality was good.

The next figures clearly show that the filter holds back a lot of inclusions without the “Deep Bed Filtration Effect”. The inner structure of the filter is “clean” and a “filter cake” was not found. All inclusions and impurities were found in front of the filter. We have inspected many filter seats after solidification in last years and we have found in nearly all cases pictures to be the same. It was obvious that the type of filter used was not relevant.

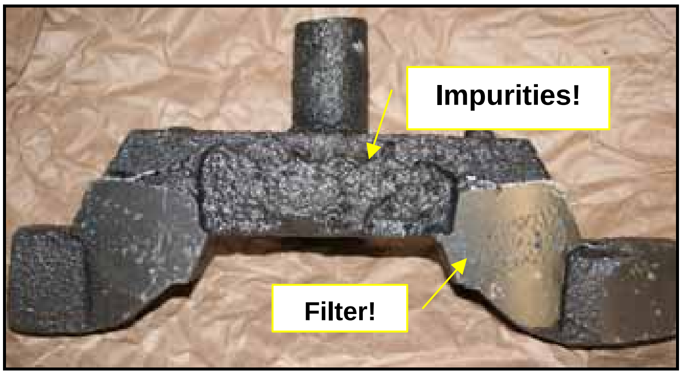


Figure 8 : Inclusions in front of the filters.

Figure 9 : “Clean” filterstructure.

In figure 10, some inclusions are visible which have been separated in front of a pressed round hole filter. This filter was installed in a vertical position in an in gate system.

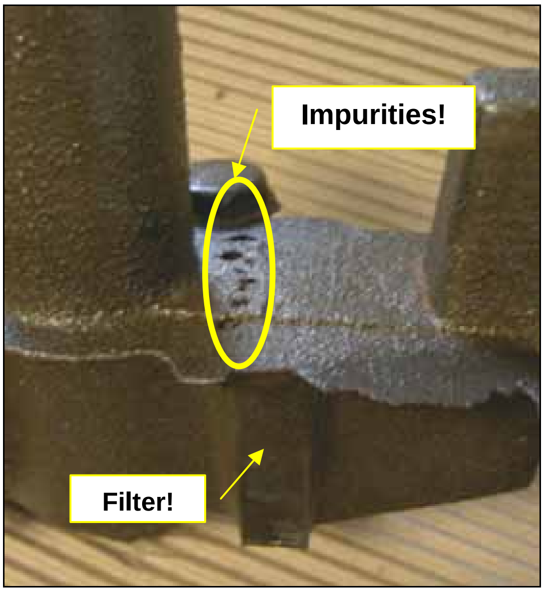


Figure 10 : Impurities <u>in front</u> of a pressed round hole filter, vertical position.

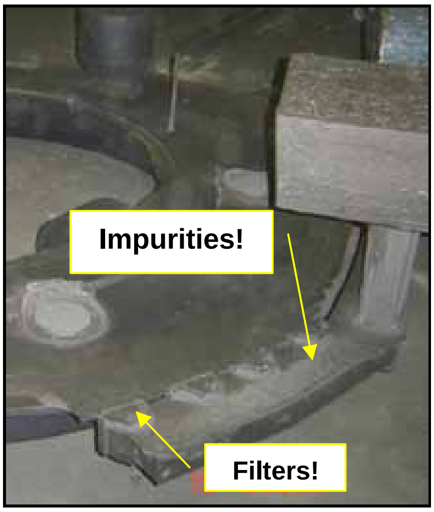


Figure 11 : Impurities in front of the filters and on top of the pouring basin.

The good results which we have found when using the heavy strainer core (see Fig. 5) is agreeable with the new theories too. Here the strainer configuration in the correct relation to the low viscosity of the melt allows the opportunity to create the appropriate tailback in front of the strainer core. In this instance, the funnel can kept full during the pouring process. In this example the impurities can be separated in the pouring funnel and the dynamic energy of the iron flow is reduced. This avoids effective sand erosion and turbulence (dross!) in the following in gate system (Fig. 12).

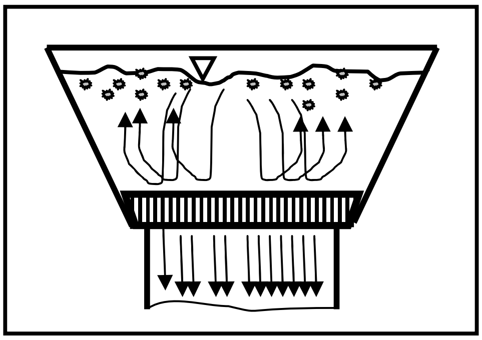


Figure 12 : Scheme of the function of a strainer core.

All of these practical examples show that we can get good results with all types of filters and that there is no reason to favor one type of filter because of its “Deep Bed Filtration Function” and we would change the diagram 1 in the following way to explain how the filtergeometry is connected to the filtration effect.

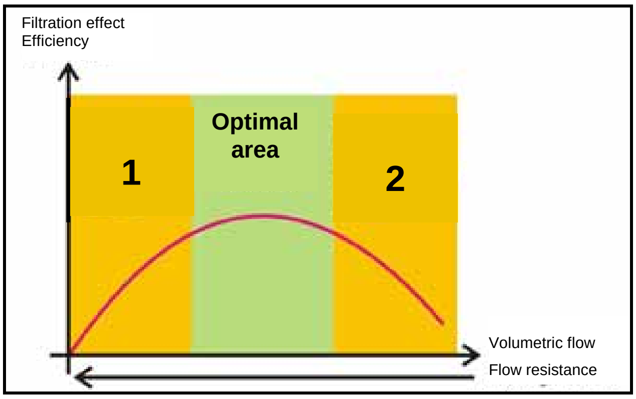


Diagram 2 : Ratio of volumetric flow and flow resistance to the filtering capacity

- **Zone 1:** Extremely low flow velocities and/or extremely high flow resistance lead to the danger of solidification (blocked filters)
- **Zone 2:** Extremely high flow velocities and/or extremely low flow resistance lead to the entrainment of impurities and extremely low backflow

There are other reasons why we have to focus on the different types of filters. These would be the mechanical resistance, the dimensional accuracy and the accuracy of the flow rates that each filter type would provide. We have generated some practical experiments to examine these effects more accurately than was reported in the past. We will present the findings of these latest experiments in the near future.

REFERENCES

1. “The influence of the ceramic filter on the flow in gate systems”, Lubomir Bechny, Petr Hajnik, Josef Burian, Hartmut Hofmann, Foundry magazine “Erfahrungsaustausch”, November 2000.

2. “Mode of action of the separation of non metallic inclusions in ductile iron with the help of ceramic filters“, Prof. Dr.-Ing. L. Bechný, Skript Metallurgie, University of traffic- and communication-siences of Zilina, Slovakei, 1999.