New theory on how casting filters work

The desire for optimised casting quality and the production costs to achieve this quality must be kept within a reasonable relationship. Today ceramic filters are used to stop non-metallic inclusions entering the mould cavity, improve the casting’s physical properties and enhance productivity. However, a new theory developed by highly experienced ceramic filter manufacturer Hofmann Ceramic provides a completely new understanding of how ceramic filters work. This in turn also influences the way the filters are used in practical operation. The following article explains this in detail.

Foundrymen use ceramic filters primarily with the objectives in mind to enhance the product quality and remove impurities such as non-metallic oxides and loosened refractory and moulding material particles from the molten metal. Perforated sand strainer cores, used until around 1960, were increasingly replaced by ceramic strainer cores developed by Hofmann Ceramic – with direct consequences for the quality of casting products.

A key benefit of the strainer cores was their ability to maintain the bath level in the pouring basin at a consistently high level thanks to the defined free cross-section of the strainer core. This solution also prevented reaction products from being entrained into the casting mould. Further development work brought about ceramic foam filters featuring a porous net-work structure. These filters became available on the market in the 1980s. The next step was the development of extruded or pressed ceramic filters with regularly shaped openings – triangular, rectangular or round.

Triumph of ceramic filters

Although ceramic filters have become very widely used, there is still no agreement on the pros and cons of the various filter philosophies. It was long assumed that ceramic foam filters were best at filtering out impurities. Nevertheless, it was clear to most foundrymen that a uniform flow pattern also has major influence on the quality level.

For over 20 years, Hofmann Ceramic has regularly conducted new studies into how the different filter systems, which are all part of Hofmann Ceramic’s product portfolio, actually work. When specimens produced with different filter systems were tested, the properties such as notch impact strength and machinability (tool wear) did not show any significant differences depending on the used filter systems. This was an unexpected result.

Well-known filter mechanisms called into question

Three generally accepted filtration mechanisms were derived from the numerous research activities and theories on the principle of ceramic filters.

Mechanism 1: Coarse impurities are held back because they do not fit through the pores, holes or cells of the filter (Figure 1).

Mechanism 2: A filter cake forms as a result of impurities gradually accumulating on the filter inlet side. It was presumed that this procedure reduces the open cross-sectional area and undercuts. When the molten metal flows through the apertures, increasingly smaller impurities, i.e. smaller than the pores of the filter, are held back. However, there is the risk that, as casting proceeds, the filter cake clogs up and blocks the filter (Figure 2).

Mechanism 3: The third theory is that of depth filtration, which also holds back particles that are smaller than the openings of the filter. Turbulence created by the molten metal flowing through the filter causes the particles to adhere to the inner filter
walls. However, as the flow speed increases, there is the risk that the impurities will be flushed away again (Figure 3).

Based on the two mechanisms 2 and 3, the generally accepted assumption has been that there is a direct link between filter performance and the available filter surface area (Figure 4).

However, first doubts about this theory arose when in casting practice increasingly thinner filters were being used to cut costs. The standard filter thickness fell from around ¾ to ½ inch. This amazing result is all the more reason to question the established theories. Feedback from users of Hofmann Ceramic filters revealed that the reduced filter thickness, and thus the reduced filter surface area, did not affect casting quality, except in cases where filters broke owing to their lower strength. This finding cannot be explained by the filter theories described above.

For quite some time now, a number of foundries have also been using graphite filters for metal filtration. Here the legitimate question is: why does a filter made of graphite filter at all? Graphite is used – for example in the slag zone of steel ladles – to actually prevent slag from sticking. According to previous filter theories (see theory 3), the property of ceramic material precisely is to react with the slag at the surface, binding the oxides (depth filtration). Exactly this effect is prevented by graphite filters, but they still do their job.

Ceramic strainer cores are the forerunners of modern ceramic filters. They are still used today despite the large hole diameter, even for products such as brake discs, which are highly sensitive to inclusions. At the strainer cores no useful filter cake forms, nor does depth filtration seem feasible as the surface area is too small for this. A new finding shows that the good results from the strainer cores can be attributed to their location in the gating system where they reduce the kinetic energy of the molten metal. The inclusions can float up as a result of the damming effect and the flow speed is reduced. In turn, this reduces/minimises turbulence and thus slag formation, thereby creating an “indirect” filtration mechanism.

New understanding for improved casting quality

For an explanation of the relationship, it is necessary to pursue further research. For this reason, Hofmann Ceramic has repeatedly examined real castings and their solidified gating systems. The areas to be examined were cut out and examined in the laboratory. The obtained micrographs were interpreted using the three main theories. Examples are shown in Figures 5 and 6, with the seemingly logical interpretations based on the existing theories.

However, Thorsten Reuther, the foundry engineer and technical manager and customer care officer at Hofmann Ceramic, believes that flow factors play a much more important role...
than previously assumed. Producing a good casting requires first and foremost sufficiently fluid, i.e. low viscosity, molten metal. The cross-sections of the gating systems are calculated on this basis, using fluid dynamics. Hofmann Ceramic is confident that a streamlined design of the gating systems is just as important as the flow rate calculation.

Also the issue of viscosity has given food for new thought. In recent years, problems repeatedly occurred with “blocked” filters. This was explained by slag blocking the filter pores. However, Hofmann Ceramic discovered that in almost all cases the problem was actually attributable to the high viscosity of the molten metal, in combination with the fluctuation range of the filter pores. Ceramic foam filters are more sensitive in this regard due to their wider production tolerances (fluctuations in porosity). If a highly viscous molten metal gets in contact with the filter material, the filter extracts heat from the metal. This causes the viscosity to increase even further, leading to the molten metal freezing in the filter (Figure 7).

Therefore in these cases slag or the mechanisms mentioned above are not the reason for the behaviour in the filter.

The most accurate calculation is useless if a poorly designed gating system generates turbulence leading to oxidation of the molten metal. Casting defects are very frequently misinterpreted in this regard. The resulting slag inclusions do not indicate whether they have arisen before or after the filter. Today gating systems are in most cases no longer developed using “best practices”, as they very often simply have to fit into the space available on the pattern plates. This fact very often leads to turbulent flow patterns. On the other hand the strength of ceramic filters is that they actually enable and promote laminar metal flows.

Also the newly detected filter effect – best casting results come from optimum flow conditions

According to findings by Hofmann Ceramic, this is the main reason for the success of the filters. The avoidance of turbulence and stabilisation of the metal flow in the mould filling process therefore needs to be viewed as a “fourth filter mechanism”. The effect was simulated with water in flow analysis tests – with highly impressive results. The general fluid dynamics in water are absolutely comparable with those in a “genuine” molten metal, as documented in earlier studies conducted by various research institutions. Coloured particles make the laminar flow behind the filter visible (Figure 8). This figure clearly shows turbulence ahead of the filter – direction of flow from left to right – and a laminar flow free of turbulence after the filter. Another surprising finding is that the turbulence ahead of the filter binds the inclusions and prevents them from proceeding further.

These studies suggest that filtering “inside the filter” is only minimal and that the area around the filter can be classified into four zones (Figure 9). Zone 1 is dominated by turbulent flow. The much more important effect occurs ahead of the filter, where the inclusions are separated in the back flow due to the damming effect.
Influence of the filter on the flow in the gating system

Figure 9

Even the phenomena shown in Figures 5 and 6 can be explained by this. The flow resistance of the filter reduces the flow speed and creates a back pressure. The density difference between metal and slag causes physical separation, leading to the non-metallic inclusions depositing ahead of the filter (Zone 3). This also holds true for vertical moulds where the filters are usually fitted in a horizontal position. Here, the deposits “float” up to the upper section of the gating system or in the pouring basin and get caught ahead of the filter. At the same time, inclusions larger than the filter openings are also filtered out.

After the filter, a laminar flow prevails over a specific, still to be investigated length. This prevents renewed slag formation and lowers the risk of sand erosion in the mould. In other words, “more stable” filling is possible in the mould system after the filter.

Summary

In studies conducted with heavy castings, specialists at Hofmann Ceramic have observed that filtration can be “fine tuned” through specific changes to the hole configuration in filters (number and diameter of the openings). The hole diameter and pore size need to be correctly proportioned in relation to the viscosity of the molten metal to achieve the desired braking effect and avoid filter freezing. The available free filter area is of secondary importance as long as the filter does not become a bottleneck. “According to our latest findings, filter performance therefore depends primarily on whether the flow resistance is set correctly,” says Reuther, summarising the results of the research activities illustrated in Figure 10.

“The correct location of the filter and optimum design of the gating system also have significant influence on filter performance. The latter increases considerably if the filter is placed as far as possible from the sprue and as close as possible to the gate. Setting all (Zones 2 and 3) and after the filter, where the flow is laminar (Zone 4).
these parameters correctly is almost half the battle as filtration actually takes place before and not in the filter, as can clearly be seen in Figure 11.

The design of the filter – random network structure or periodic cylindrical pores – impacts less on filter performance than flow resistance. Yet the quality of the filters cannot be neglected. Dry-pressed filters from Hofmann Ceramic, for example, boast much greater stability to filter fracture, a problem repeatedly occurring with other filters. Uniform filter geometries also have the positive effect that casting time fluctuations and the risk of freezing are minimized. This in turn reduces the rejection rate, quality problems and complaints.”

Specialists from Hofmann Ceramic provide advice on the optimum installation position and the correct design of gating systems and offer a wide-ranging portfolio of foundry products enhancing the control of the solidification process, e.g. patented feeders, SiC chills, pouring bricks, stoppers and ceramic components for investment casting.