CZECH FOUNDRY SOCIETY
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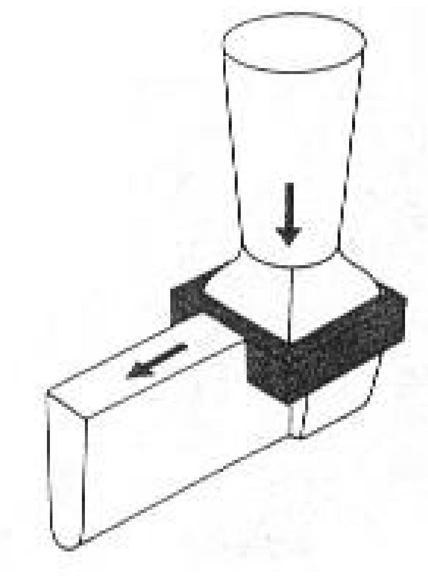
CASTING ALLOY FILTRATION

Jaromír Roučka et al.



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INTRODUCTION

Alloy filtration is now an integral part of casting technology. It helps to achieve high-quality castings, and, moreover, it is instrumental in removing defects and production difficulties. Filtration has mainly been applied to low-temperature casting alloys – especially to aluminium alloys, and this method is also often used for ductile cast irons. The goal of filtration is to capture both the non-metallic inclusions that penetrate into the gating system from the ladle and the inclusions that arise in the course of pouring. This "refining" of melts results in increased homogeneity of the metal, improved mechanical properties, removal of many metallurgical defects, improvement of casting surfaces and (which is sometimes surprising and often not fully appreciated) significantly improved machinability. Many foundries use filtration to increase surface quality and machinability. However, filtration is rarely used for steel. The main obstacle to a larger exploitation of filtration is mainly its high pouring temperature and other related problems. However, fast progress can be witnessed in this field. Filters are mainly used in sand moulds, and filtration plays an important role in investment casting.

The application of filters has brought some specific features and changes into standard production. Although the range of filter application in foundries is relatively high, we can come across many cases of improper filter positioning and errors in dimensioning the gating system. Sometimes, this results in that the expected effect is not achieved, and then it is claimed that filtration has no sense or even that many defects/rejects are produced that have not been observed beforehand. It is true that the basic principles of filtration must be respected and, in a sense, a stricter observance of the technological process must be secured.

The application of filters entails additional costs. This is an argument used by company economists, who can only see the current increase in costs without any relation to product quality, reduction of fettling costs, overall production economy and higher competitiveness. If the filtration effect is assessed in a wide range of the production process and improved saleability, it can be said that the price of filters is negligible compared to the effect achieved, and that filtration is very economic.

The handbook on filtration was produced within the activities of the Technology Committee of the Czech Foundrymen Society and with its financial support. The theoretical part brings a kind of summary, in which we try to present much information from different papers, handbooks or company publications. It is true that in many cases some pieces of information are at variance with each other, and it is difficult to find the best and unique solution. However, it is not our aim to find a unique solution. Many foundries do not use filters in compliance with the recommended procedures and still they achieve very positive results. The aim is not to offer a unique method for the design of gating systems but to explain how filters operate and to give the basic principles of their application.

The handbook is complemented with some examples from various technological branches – from "standard" casting with horizontal parting plane, pouring into moulds with vertical parting plane, steel casting and investment casting. All foundries that have made their data available for presentation in this handbook have had good experience of filtration, they use filtration as a standard method and have developed their own methods of applying filters in the gating system.

1 WHY FILTERING

To produce a high-quality product, it is necessary to produce a casting that has the prescribed shape and dimensions, without any external/internal defects, including all the required mechanical, technological, structural, and other properties. A number of properties are related to the presence of foreign particles in the casting. Metal purity is thus a significant criterion of quality. In practical terms, this means that in the casting there should be no foreign metallic or non-metallic particles that penetrated here with molten metal from the ladle or were formed during pouring or were present in the mould cavity, for example, due to negligent cleaning of the mould. Generally, these foreign particles are called inclusions. According to their composition, inclusions fall into two groups – **metallic inclusions** and **non-metallic inclusions**. Non-metallic inclusions are found in castings much more frequently, and their effect is more harmful than that of metallic inclusions.

The first attempts to reduce the quantity of inclusions in castings were made long ago – this idea is as old as foundry work itself. Over the centuries, founders have tried to produce castings of higher purity, with better-quality surface, and better properties. A systematic approach to the design and dimensioning of gating systems appeared in the 1930s, when the principles of flowing and empirical experience came to be applied. The efficiency of inclusion capture was one of the important viewpoints in the design of gating systems. The separation of inclusions was mainly achieved by their capture in special sections of the gating system – i.e. slag traps – mainly on the principle of different metal and inclusion densities. This principle can be used mainly for iron alloys where inclusions have significantly lower densities than metal. On the other hand, the mechanism cannot be employed with alloys that have densities similar to those of inclusions, e.g. aluminium alloys, where other principles must be used. For example, the fact that inclusions in the gating system get stuck to mould walls is made use of. Flat runners therefore capture inclusions very well, in particular oxide films. However, the efficiency of these separation methods is limited.

Ceramic "strainer cores" have been used in foundries since about the mid 1960s. These were placed in the pouring basins near the sprue, and their purpose was to capture coarse slag particles. Since the late 1970s, screens and filters have been used for the capture of inclusions in gating systems. At the beginning, their utilization was limited to casting aluminium alloys, mainly for the aircraft industry. The filtration of iron alloys is made difficult by the higher metal temperatures and higher demands on filter behaviour at high temperatures, especially high refractoriness, resistance to thermal shock, high temperature creep, etc. The wide-spread utilization of filters came primarily with the extension of the production of ductile cast iron during the 1980s, and especially in the1990s. Filtration of steel is difficult, mainly because of the required resistance of ceramics to high temperatures and the related higher prices of these filters. This is why filtration has been used in steel casting to a lesser extent, only for special and highly demanding castings. However, its use is on the increase.

The term filtration refers to the separation of inclusions that are present in the metal. The filter may be used, for example, when reladling the metal from the melting furnace to the holding furnace, and it can be positioned as a partition between the reservoir of molten metal and the furnace outlet, but the filter is most frequently inserted into the gating system of each mould. It should be noted that **the filter is able to capture only the particles which are already present in the metal during its passage through the filter** but other particles can appear during the metal flow between the filter and the mould cavity, or during solidification. From the viewpoint of efficiency, filtering **as close as possible to the mould cavity** is of advantage.

In the gating system the filter complements or even replaces the elements whose function was to capture slag particles. It replaces the function of runner, centrifugal skimmers, saw-tooth slag traps, or other tools that are used for this purpose. **In this way, the gating system can be simplified, and some parts can even be completely removed.** This method often leads to the parting plane of mould being made better use of, to savings in molten metal, and to reduced fettling.

Filters that are installed in the gating system can be used for a metallurgical intervention in metal quality. Thus in the case of cast iron, inoculation has recently come into much use, in which inoculation bodies are placed on filters or inoculants are applied to filter ceramics. In comparison with in-ladle inoculation, this method makes it possible to reduce significantly the quantity of inoculants.

1.1 HOW INCLUSIONS ARE HARMFUL IN A CASTING

Inclusions can be found on the casting surface or inside the casting. Some inclusions have the shape of compact particles, while other inclusions form thin films but of large surface dimensions. Some inclusions are separate particles, whereas other inclusions agglomerate into compact clusters. Some inclusions are not bonded to the alloy microstructure and others concentrate in intergranular spaces. Depending on all this, the negative effect of inclusions can manifest itself in various ways.

Deterioration of casting surface quality – Inclusions are detrimental in that they impair the appearance of the casting surface and in that large inclusions (particularly those formed in steel re-oxidation) reach deep into the casting. Removing such defects is expensive and, moreover, it requires considerable machining allowance. As a consequence of the inclusions reacting with the mould material, both the amount of burned-on sand and the surface roughness can increase.

Deterioration of mechanical properties – An inclusion is a foreign particle that interferes with the metal matrix. Inclusions make the mechanical properties deteriorate, in particular ductility and fatigue strength. Considerably reduced is mainly the low-cycle fatigue strength. Apart from the quantity of inclusions, the significance of this effect depends on the volume and the shape of inclusions. Inclusions that form films have an adverse effect. They damage large areas of the metal structure and they also cause the notch effect. Of very negative effect are inclusions that form a network along the grain boundaries, inclusions that are arranged in lines, and inclusions with sharp edges.

Deterioration of machinability – The majority of non-metallic inclusions have a higher hardness than the basic alloy. This is significant, especially in aluminium alloys, where the inclusions are formed mostly by very hard aluminium oxides. However, this effect is also observed in all other types of alloy. Poorer machinability results in a deterioration of the surface being machined, in reduced cutting performance and in markedly reduced service life of tools.

Casting leakage – Leakage arises if oxide film inclusions, typical of aluminium alloys, are present. In pressure-loaded castings in particular, the pressure medium penetrates through the wall of the casting along the inclusions. (Leakage is frequently caused by structural micro-porosity – very often in ductile cast iron - or by "faulty” joints between the molten metal and inserted metallic components. These causes, however, cannot be eliminated by any filtration.)

Gas bubbles – This defect is caused by the presence of inclusions either directly, if inclusions react chemically with metal while gas is generated (in the case of iron alloys it is CO in particular) or indirectly, when inclusions can serve as suitable nuclei for bubble nucleation during solidification. **The problem of gas bubbles gets very often solved if inclusions are removed.** This effect is very frequent in aluminium alloys but it is also important in other alloys.

1.2 ORIGIN OF INCLUSIONS

To increase metal purity, it is necessary to find the origin of inclusions and the moment when they arise. Inclusions are formed in a molten metal throughout the whole process of melting and when liquid metal is being poured. Depending on how they were formed, inclusions fall into **exogenous inclusions** – i.e. inclusions which penetrate into the metal from outside, e.g. by furnace and/or ladle lining erosion, from mould material or as primary slag particles that are formed due to air oxidation, and **endogenous inclusions** – i.e. internal inclusions that are formed in the metal as a consequence of metallurgical reactions during the period of casting/solidification. The type of inclusions and their chemical composition depend on the metal composition, mould material composition, refractory lining, types of inoculant and/or admixture, and other conditions. At pouring temperatures, **inclusions can be in the solid, liquid or semi-liquid (viscous) state.** According to their origin, the inclusions fall into metallic and non-metallic inclusions.

The main sources of inclusions are as follows:

- slag - metal oxidation products
- refractory materials
- refining agent residua
- mould materials and erosion products from moulds and cores
- eroded paints
- endogenous inclusions – formed in consequence of the metallurgical reactions in metal
- non-dissolved inoculant/alloying addition residua

Slag – This type of inclusion arises from slag-forming additions and is due to the effect of chemical reactions of molten metal during pouring and in the pouring ladle. This primary slag should be removed as thoroughly as possible prior to pouring or captured in the pouring equipment. Tiny particles often get into the mould together with the metal, especially at the beginning of the process. The primary slag is usually captured in the pouring basins, runners, or special slag skimmers. The slag capture capability is the most important criterion in designing the shape and size of these elements.

Refractory material – Inclusions are formed in consequence of the erosion of refractory lining in melting furnaces, ladles, teeming nozzles, and auxiliary refractory materials. The composition of inclusions corresponds to the composition of the respective refractory materials.

Mould material – Inclusions find their way into the metal via mould/core erosion as a consequence of the dynamic and thermal effect of the flow of metal in the gating system or in the mould cavity. Unsuitable lay-out, improper ingates, and the choice of unsuitable mould materials significantly contribute to the formation of inclusions. Erosion appears especially in places with high turbulence, at points of abrupt changes in flow direction, and at sites where the metal falls from a great height or which the metal flow strikes against. Another, and very frequent, inclusion source is the mould material that remains in the mould due to careless cleaning of the gating system or the mould cavity before the process. The origin of sand inclusions is very often related to the occurrence of sharp, non-rounded edges in the gating system (most frequently on the transition from the pouring basin to the sprue) which get easily entrained by the flow of metal.

Paints – Paints may be a source of inclusions in the case that they are eroded during pouring, or as a consequence of the coat cracking and peeling off.

Endogenous inclusions – arise due to liquid metal oxidation during pouring, or as a product of metallurgical reactions. These inclusions are, in particular, oxides and sulphides. Ductile iron forms "secondary slag", which is the result of magnesium reacting with oxygen, sulphur, and with oxides of other elements. The chemical composition and the shape of endogenous inclusions also depend upon the concentration of modifiers and inoculants, deoxiding agents, and the pouring temperature.

Metallic inclusions – appear less often. This group of inclusions is usually formed by non-dissolved metallic additions – most frequently they are poorly dissolved inoculants or alloying elements that are added into the metal flow. Imperfect dissolution very often occurs when a metallic addition is covered with a layer of slag. The origin of metallic inclusions is usually easy to identify.

Only such inclusions can be captured in the gating system that are already present in the metal at that moment. No matter how effective, filtration cannot capture inclusions that are formed, for example, due to turbulence just behind the filter or in the mould cavity, through erosion or, in the case of endogenous inclusions, during solidification.

1.3 INCLUSION TYPES IN PARTICULAR ALLOYS

The sources of exogenous inclusions are similar for all alloys. They include sand, eroded refractory materials, primary slag, or residua of refining salts or their products. What differs is the quantity of inclusions and their ratios. The higher the pouring temperature, the more extensive the erosion of refractory and mould materials. Especially for steel, a large number of non-metallic inclusions are caused by erosion. The types of endogenous inclusions mainly depend upon alloy types.

From the perspective of capturing inclusions by filtration, their liquidity (running property), particle size and shape are the most important criteria. Inclusions formed by individual particles are more difficult to capture than inclusions that form clusters. Filtration captures large inclusions relatively well, in particular oxide films. These clusters are usually captured reliably on the filter input side. Inclusions that are present in the liquid state are captured with much difficulty, and there is a high probability of such particles flowing through the filter.

1.3.1 ALUMINIUM ALLOYS

Al_2O_3 oxides are the prevailing types of inclusion in aluminium alloys. The inclusions are formed either by the ”old” inclusions that were present in charge materials or were formed during melting and were not removed during refining, or by the "new" inclusions that are formed due to the reaction between oxygen and aluminium during pouring. The problem of removing aluminium oxides lies in the almost identical density of inclusions and of the melt. For this reason, the inclusions do not rise to the surface and tend to remain inside the metal. The oxide inclusions originate in the reaction of aluminium with air oxygen in compliance with the following formula

$$4\ Al + 3\ O_2 = 2\ Al_2O_3$$

or in the reaction with humidity (airborne, from mould mixtures, salts, etc.) according to the formula

$$2\ Al + 3\ H_2O = Al_2O_3 + 6\ H$$

Aluminium oxide forms the inclusion, and hydrogen dissolves in the melt. **Inclusions of aluminium oxides mainly form films. In the melt they are always in the solid state.** Oxide inclusions are suitable sites for the nucleation of gas bubbles. **Removing the inclusions will often solve the problem of gas bubbles in castings.**

Spinels, in particular $MgAl_2O_4$ and $MnAl_2O_4$, which originate due to oxidation, and borides TiB_2 and VB_2 as products of inoculation, represent other frequent types of inclusion, which are present in aluminium alloys already during pouring. With higher Fe, Mn and Cr contents, inclusions can form in the melt that are based on these elements (so-called sludge).

The acicular phase of iron, the phase of the type of "Chinese script" and also inclusions based on aluminium alloyed with copper and magnesium are only formed during solidification, and thus they cannot be captured by any filtration.

Insufficiently removed refining slag is often a source of inclusions in aluminium alloys.

1.3.2 GREY IRON (ALSO WHITE CAST IRON)

Oxides of primary elements Fe, Mn, and Si present in cast irons are the prime sources of inclusions. A typical inclusion of endogenous origin in grey iron is the SiO_2-FeO-MnO or Al_2O_3-SiO_2-FeO-MnO particle. As regards crystallography, these are in particular spessartite (3MnO-Al_2O_3-3SiO_2) and rhodonite ($MnSiO_3$). Slag particles can also include BaO, CaO or other metallic oxides that are contained in inoculants.

The temperature of slag is dependent upon its chemical composition. At usual pouring temperatures, slag may be in the solid, viscous (i.e. semi-solid) or liquid state. Slag’s are mainly composed of a complex of FeO-MnO-SiO_2-CaO oxides, in which silicon oxide prevails. A slag with a high solidification temperature (as much as 1370°C or more) usually forms if the content of SiO_2 is above 50 percent. This slag forms a solid "crust" on the metal surface. Slags with a lower content of SiO_2 (< 35 % SiO_2) and a higher content of MnO can remain in the liquid state up to a temperature of about 1180 ^oC.

Slag may contain a small amount of Al_2O_3 and CaO oxides. Aluminium and calcium come primarily from the inoculants. The consistency of the slag formed by Al_2O_3-FeO-MnO-SiO_2 depends upon its specific composition and its temperature. The inclusions can remain liquid up to a temperature of about 1190^oC.

Inclusions that are in the solid state during pouring can be separated in the gating system by rising to the surface, in centrifugal slag-removing equipment or by filtration. Inclusions with a low solidification temperature that are in viscous (semi-solid) state at the usual pouring temperatures can be captured only by mechanical adhesion on the walls of the gating system or on filters. As revealed in metallurgical tests, the inclusions are mostly of a glass-like nature, and they form the envelopes of grains of mould material or of solid inclusions.

At temperatures higher than equilibrium temperatures, FeO, MnO, and SiO_2 oxides that form slag particles react with carbon in the cast iron, and carbon mono-oxide is generated according to the formulae:

$$FeO + C = Fe + CO \qquad (1)$$

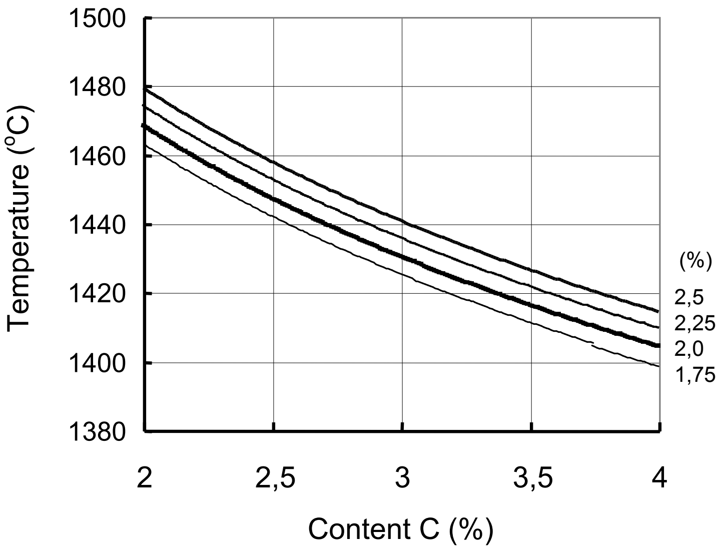
$$MnO + C = Mn + CO \qquad (2)$$

$$SiO_2 + 2C = Si + 2CO \qquad (3)$$

The carbon monoxide produced may cause bubbles and pinholes in the castings. Reactions (1) and (2) run already at temperatures above 1200^oC, while the significant reaction (3) at temperatures of about 1450^oC. The temperature at which silicon dioxide is reduced by carbon is called the inverse temperature; its value depends on the content of carbon and silicon, and it can be calculated according to the formula

$$T = \frac{27486}{15.47 - \log\frac{\%Si}{\%C^2}} - 273.15 \qquad \left[{}^oC\right]$$

The inverse temperature curves for the C content in the range from 2 to 4% and the Si content from 1.75 to 2.5 % are shown in Fig. 1. If the temperature of the melt is lower than the respective inverse temperature, silicon reacts with atmospheric oxygen and forms SiO_2 slag. For temperatures higher than the inverse temperature, carbon in the bath reacts with SiO_2 particles, thus giving rise to CO.



Due to this reaction, slag or silicate inclusions disappear from the melt. (This is known to happen during melting in induction furnaces when at sufficiently high temperatures the bath surface gets clear.) At the same time, this means that at high pouring temperatures of cast iron (approx. above 1 450°C) the danger of slag inclusions appearing in the castings is smaller. For this reason, it is recommended that cast iron be cast at high pouring temperatures.

Fig. 1: Inverse temperature in LLG as a function of C and Si content

1.3.3 DUCTILE IRON

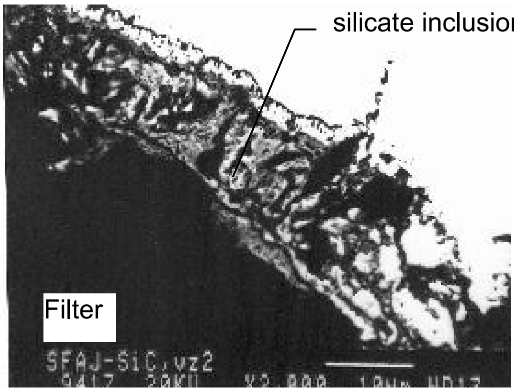
So-called **secondary slag**, which in the English literature is referred to as "dross", is the main source of non-metallic inclusions in ductile iron (this type of inclusions does not appear in grey iron). Dross represents typical endogenous inclusions that originate **in consequence of chemical reactions of modification magnesium with silicon, sulphur and other elements that are present here.** It is formed by a complex of magnesium silicates and MgS, or by oxides and sulphides of rare earth metals contained in modifiers and inoculants. Aluminium oxides, calcium oxides, and titanium oxides can be present, too.

Dross occurs in 2 morphological types in particular (Fig. 2):

- Type 1: Large particles formed by magnesium silicate – forsterite (Mg_2Si0_4) or enstatite ($MgSiO_3$), which usually contain iron, and, to a smaller extent, aluminium oxides, calcium oxides and titanium oxides. Sulphides and graphite particles are also present. In iron they form **films that are freely dispersed in the metal or envelopes on mould mixture grains and in filter walls** – see Fig. 2a.

- Type 2: Dispersed and chain-like inclusions that mainly contain MgS. Sulphide inclusions are **dispersed in the metal as single particles or are joined in clusters or chains** – Fig. 2b.

a)



b)

Fig. 2 Examples of inclusions in ductile iron
a) Magnesium silicate inclusion sticking to the filter
b) Dispersed MgS inclusions

Dross particles partly rise to the metal surface in castings, where they impair its surface quality and, in part, they remain inside the metal.

Sulphide inclusions originate as a product of iron desulphurization by magnesium during modification and during subsequent cooling of modified iron, according to the formula:

$$Mg + S = MgS$$

Because of their small size, sulphide inclusions have a low velocity when rising to the surface, and only a small part of them are able to rise to the metal surface in the pouring ladle. The quantity of inclusions is directly proportional to the content of sulphur in iron before modification. At modification temperatures, the inclusions are in the solid state. Sulphide inclusions arise also when the liquid metal is cooling in the mould. Hence they cannot be totally removed through filtration.

The formation of silicate inclusions depends on their chemical composition and metal temperature. They arise during modification, pouring and solidification. This means that the inclusions cannot be completely removed from the melt by filtration. Dross appears in iron especially at temperatures below 1450°C, and at temperatures below ca 1350°C it is usually in the solid state. According to the literature, the maximum rate of forsterite formation is at temperatures between 1400-1430°C.

Graphite inclusions that occur in the vicinity of silicate inclusions or as part of inclusion complexes are always of degenerated flake-like shape. The cause of graphite degeneration is the high local content of sulphur, and low magnesium activity in these locations. Graphite inclusions arise mainly in irons with a high carbon equivalent. The occurrence of graphite inclusions is related to the degree of pouring temperature, i.e. the inclusions may (but need not) be present in iron. In cast irons with a high carbon equivalent, primary graphite may form at the usual pouring temperatures. In such cases, the metal has a high viscosity, and it may be difficult to produce a casting at all. Such iron may easily "get frozen" on the filter.

During the capture of slag particles, capillary forces are seen to act intensively, fixing the inclusions to the mould or filter walls. Manganese-iron (III) and magnesium (II) silicates, which at the usual temperature are still liquid, participate in the formation of envelopes (which provide inclusion anchoring). Even solid inclusions are captured and fixed by the envelopes – Fig. 3.

1.3.4 INCLUSIONS IN STEEL CASTINGS

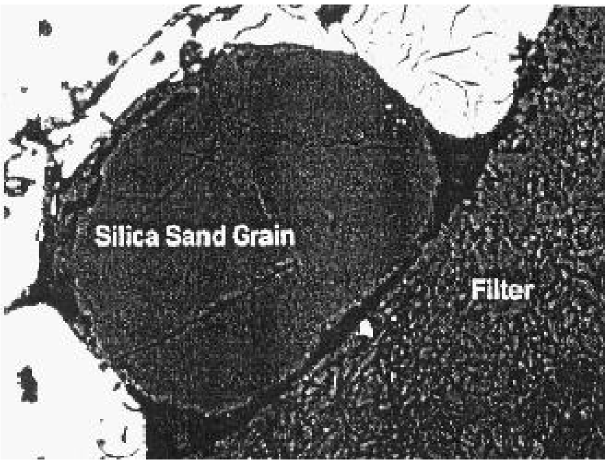


Fig. 3 Solid inclusion fixed to a filter wall

A large amount of steel inclusions come from the reaction of metal and slag with lining, or metal with air. MnO, FeO, SiO_2 and Al_2O_3 oxides prevail, the other oxides, such as Cr, Zr, Ti, etc., are found less often. It is believed that 20 – 90% of inclusions stem from the reactions of the metal with the lining(different authors give different values; however, it is evident that the lining is a significant source of inclusions, and steel purity also depends on the lining quality. The chemical composition and the type of inclusions that come from the reaction with the lining depend, of course, on the kind of lining material.

A great number of non-metallic inclusions come from steel re-oxidation with atmospheric oxygen. The re-oxidation occurs on the free melt surface as the metal is being poured out of the furnace, transported and then as it is flowing in the mould. In aluminium deoxidised steel, mostly aluminate inclusions are formed. Aluminate inclusions have a high solidification temperature, and they are in the solid state during pouring. These inclusions can be captured quite well by filtration, see Fig. 4.

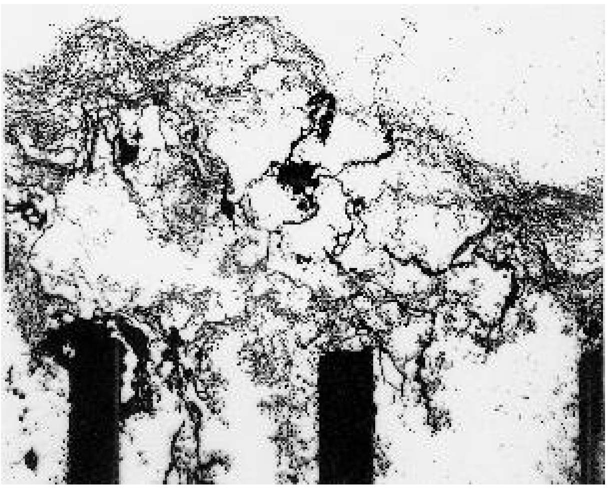


Fig. 4 Filters of aluminate inclusions in steel captured by pressed filter

With a low Al content, oxides of less reactive elements, e.g. Si, Mn and Fe, are formed. (It is known that in the direction away from the sprue to remote parts of the casting the content of Al in the metal is markedly reduced, while the number of other oxides increases proportionally.)

The amount of inclusions that can be captured in the gating system depends on their consistence at pouring temperatures.

Inclusions usually have a melting temperature that is close to the pouring temperature of the metal, during pouring they are in viscous state and thus they can be filtered, which takes the form of inclusions getting stuck to filter wall due to capillary forces. MnO inclusions are too liquid to be filtered, in particular at a higher Mn:Si ratio. These inclusions pass easily through a filter. Viscous inclusions can form the envelopes of solid inclusions, in particular SiO_2 particles, and this suspension gets stuck on mould walls or in filter channels.

2 WHAT FILTERS ARE AND HOW DO THEY WORK

2.1 MECHANISM OF FILTRATION

Filtration is the process of separating **solid particles** from the melt, with the solid particles being captured on the filter and the liquid phase passing through the filter. In addition to solid particles, there are also **semi-liquid phases** of high viscosity in molten metals; this fraction is captured by the adhesion mechanism, i.e. the particles "stick" to the filter walls.

Generally, there are three mechanisms of filtration:

- filtration by straining
- filter cake formation
- depth filtration

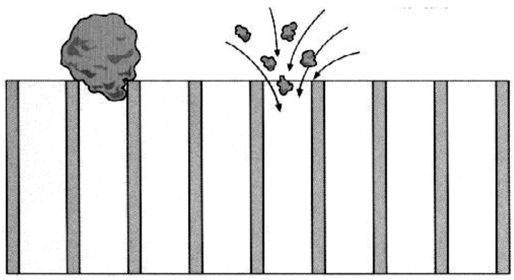


Fig. 5: Filtration by straining

Filtration by straining consists in the capture of inclusions that are larger than the holes in the front (i.e. inlet) part of the filter (Fig. 5). This is the same mechanism as in the case of strainer cores. However, this method can capture only big particles, in particular inclusions that form films.

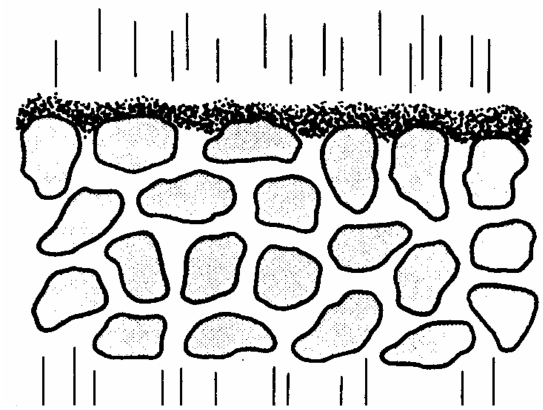


Fig. 6: Filter cake formation

Filter cake formation follows up on the capture of the first inclusions on the filter face. Smaller particles get captured on the big ones. The inclusion layer gradually increases, reduces the metal flow is reduced until the filter is completely clogged. The mechanism of filter cake formation makes it possible to capture even very small inclusions with dimensions of as little as 1 - 5 µm.

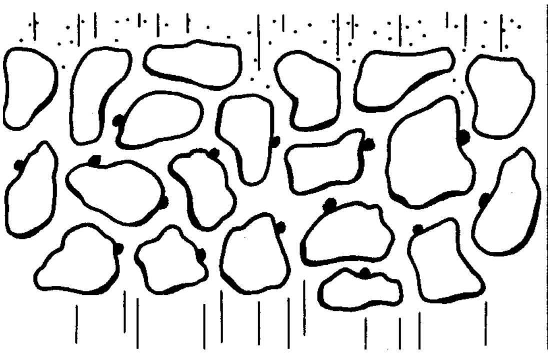


Fig. 7: Depth filtration

Depth filtration – is carried out in the whole filter volume. Its principle is based on the adhesion of inclusions (bonding) on the ceramic filter walls – see Fig. 7 - and the mutual bonding of individual inclusions. During depth filtration, the inclusions envelop the filter ceramics, and the individual particles of inclusions agglomerate and form "bridges" with their edges anchored on filter channels. The efficiency of depth filtration may be affected by the metal temperature, chemical composition of the filter material and inclusions (wettability), and the shape of filter channels.

If an inclusion moves along a smooth runner wall, the probability of its capture is lower than that when the inclusion is in contact with more than one wall (e.g. in a corner of a square runner). The smaller the runner cross section (and the more turbulent and direction-changing the metal), the higher the probability of inclusion capture during depth filtration.

Adhesive forces make the individual inclusions stick together and fix them on filter runner walls. If an inclusion is to be captured by depth filtration, it is necessary that adhesive forces be higher than the dynamic effect of metal, which attempts to entrain the inclusions in the flow. It is evident that the chance to capture inclusions will increase with higher adhesive forces and a lower rate of metal flow. The locations with a very low rate of flow are ideal for capturing such inclusions.

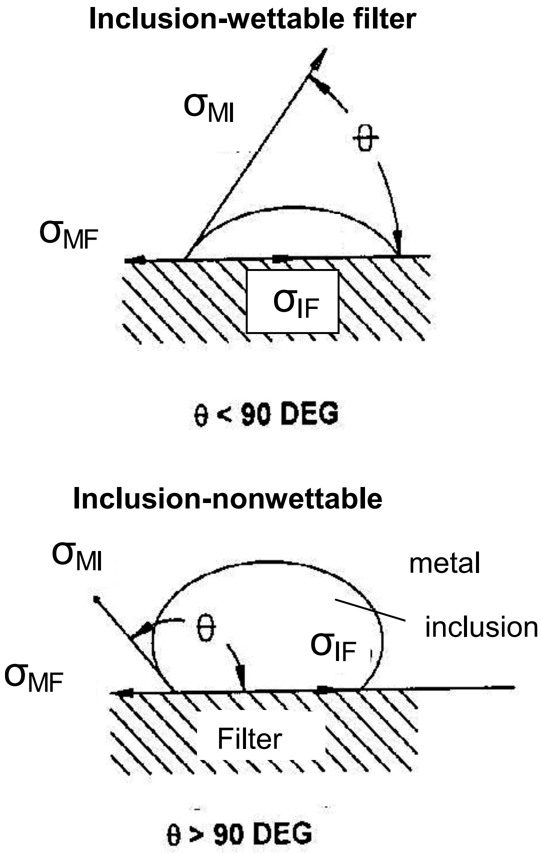


Fig. 8: Filter wetted by liquid inclusion

The adhesion of **liquid** (viscous) inclusions to a filter depends on the interfacial energy between liquid metal (M), inclusion (I), and filter (F).

$$\Delta G = \sigma_{IF} - \sigma_{MF} - \sigma_{MI}$$

where: ΔG – is the Gibs free energy
σ – is the interfacial energy

The inclusions will be fixed firmly to the filter surface if $\Delta G < 0$.

The ratio of interfacial tensions between the metal, the inclusion, and the filter is characterized by the mutual wettability or non-wettability of individual components. The wettability is given by wetting angle Θ, and this angle shows in the shape the liquid phase meniscus – see Fig. *8*. If a filter is wettable by a liquid inclusion, the angle is $\Theta < 90^{o}$. A non-wettable inclusion has the angle $\Theta > 90^{o}$.

The magnitude of adhesive force is given by the following equation:

$$(WA)_{IF} = \sigma_{MI} \ (1 + \cos \Theta_{FI\text{-}MI})$$

From this formula, it is evident that **the better the wettability between the filter and the liquid inclusion, the higher the adhesive forces.**This mechanism is also suitable for capturing **solid** inclusions. When neither the filter material nor the solid inclusion is wettable by a melt, the inclusion is pushed toward a filter wall by capillary forces, where it is retained by these forces. Fig. 9 illustrates a particle of solid inclusion retained to the filter wall.

Different filter materials and different inclusions have different liquid-metal wettability and thus different capability to capture solid inclusions. **The lower the metal wettability of solid inclusions and filter, the better the inclusion capture**. **For example, the ceramic made of SiC has the lowest wettability for ductile iron (and the best capability of depth filtration). The particles that are captured in this way are held on the walls by forces that can retain particles even in places with intensive metal flow.**

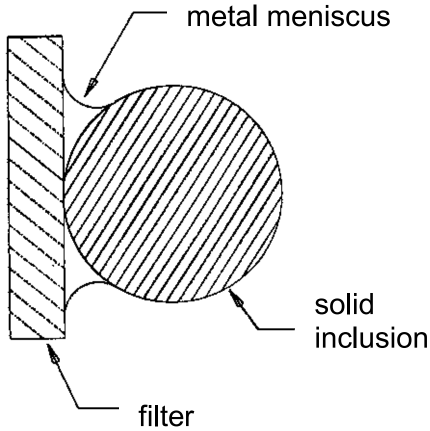


Fig. 9: Solid inclusion captured on filter wall

The above-described relations only refer to the physical bonding of inclusions in filters. For temperatures of flowing metal, it can be expected that chemical reactions and bonds between filter and inclusions will appear. In systems with chemical reactions, a chemical bond between the filter and the ceramic is gradually formed. For this reason, filters with the melting temperature (softening temperature) close to the pouring temperature may have a higher filter efficiency than those made of high-refractory ceramics.

2.2 FILTER TYPES

Ceramic elements that are designed to capture inclusions in the gating systems are usually divided into strainer cores and filters.

Strainer cores – (Fig. 10) are flat ceramic bodies with straight circular holes with diameters from 4 to 10 mm, and thickness values from 6 to 12 mm, which capture primary slag at the beginning of pouring, when the pouring basin is still unfilled. The strainer cores are usually placed on the bottom of the pouring basin at the foot of the sprue, exceptionally in another place of the gating system. In addition to capturing coarse impurities, they have further advantages, for example, they speed up the filling of the pouring basin, prevent the appearance of vortexes above the sprue and reduce metal turbulence. The inclusions are captured only by the straining mechanism.

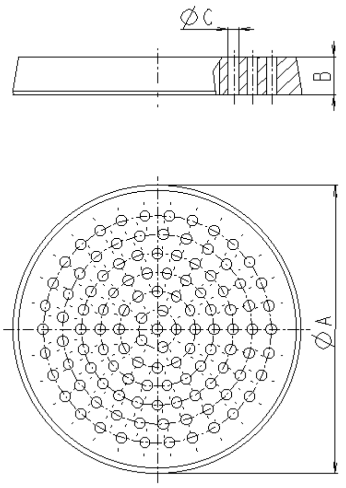


Fig. 10: Ceramic strainer cores

The total cross section of holes in a strainer core is often lower than that of the sprue. If the gating system is not dimensioned for high overpressure, the strainer core forms a "choke" in the gating system. A space may appear below the strainer core that is not completely filled with metal and where air is entrained. **The total hole cross-section in the strainer core should therefore be greater than that of the sprue.**

Strainer cores mainly capture coarse slag particles but they do not capture tiny inclusions.

Filters usually work in a different way. The size of filter pores is considerably lower than in strainer cores, ranging usually from 1 to 2.5 mm. The refining mechanism consists in blocking the large inclusions on the inlet filter side (similar to strainer cores) but, in addition, the mechanisms of "filter cake" and "depth filtration" play a role in capturing inclusions. In this way, considerably smaller inclusions than the size of filter holes can be captured, i.e. only a few micrometres in size.

The same as with strainer cores, the **ratio of flow area to total area** is an important characteristic of filters. The area formed by ceramics constrains the filter cross section - see Fig. 11. Unless the metal flow is to be reduced by passing through the filter, it is necessary to increase the filter cross section in comparison with the runner cross section so that the total cross section of all holes is identical to that of the choke in the gating system. The proportion of the flow cross section in the total area amounts to some 15 – 80%, depending on the type and arrangement of filters. This means that **the total filter area should be at least 1.25 - 7 times larger than that of the choke.** (A smaller filter might itself become the choke). The larger the flow cross section of filter holes, the lower the resistance to metal flow.

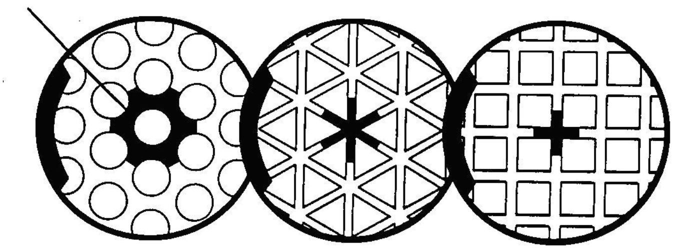


Fig. 11: Flow cross section of a filter

The filter separation efficiency is strongly dependent on the size of filter holes. The finer the filter, the better the filtration effect. However, it is necessary to bear in mind that the filter will soon clog. High-porosity filters and small-hole filters have a lower flow rate.

Many different filters are used for the filtration of melt that differ in their structure, active area and filter efficiency. They fall into 2 basic groups:

- flat filters
- volume filters

Both types significantly differ in their filtration mechanisms.

The area of flat filters is significantly larger than their thickness. Impurities are only captured on the filter inlet side by the straining mechanism and by forming the filter cake. The thickness of the filter has no effect on its efficiency.

In volume filters, both the filtration effect on the filter inlet side and the capability of depth filtration are exploited. The capability of depth filtration differs depending on the size of holes, their cross section, lay-out and also on filter material.

2.2.1 FLAT FILTERS

Due to their "two-dimensional" pores, flat filters act as strainer cores. All impurities larger than the dimensions of filter holes, sometimes also smaller particles, get captured on the filter inlet side, where a filter cake is formed. The depth filtration does not come into play here (or its share is very low). Metal gratings, but more often woven textiles produced from refractory fibres, are employed as flat filters.

Metal gratings can only be used for low-temperature alloys, mainly aluminium alloys. Steel wire screens with a mesh of about 2 - 3 mm are cut to a larger size than the flow profile at the point where the grating is applied. The gratings are usually placed in the extended profile in the runner – a kind of small chamber. If the grating is placed vertically, it is inserted into the groove of the chamber pattern prior to moulding. If the grating is positioned horizontally in the parting plane, it is laid loosely or locked in a print.

Since inclusions in aluminium alloys are in the nature of films, the efficiency of metal gratings is relatively good. A very favourable price is also an advantage. After solidification, however, the steel filter remains solidified in the gating system, with which it returns back into the melting furnace. This may lead to an undesirable increase in iron content in the melt.

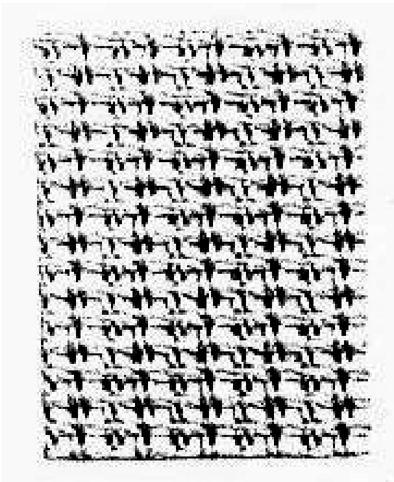


Fig. 12: Flat woven filter

Cloth filters are woven from refractory textiles into shapes roughly similar to metal gratings. The individual fibres that form the filter grating are twisted together from many fibres by a complicated method, the same as a rope – see Fig. 12. The filters differ in mesh, profile and thickness of individual strands.

Refractory cloth is produced from fibres of amorphous SiO_2 of 97-99 % purity. The woven filter is treated thermally and chemically, which increases the SiO_2 proportion, filter rigidity, and improves the properties at high temperatures. The maximum pouring temperature is 1620°C (applications of temperatures of up to 1700°C have also been reported).

To improve the efficiency of filtering, the filter textile can be activated by impregnation with a special resin. A fayalite film is formed by the reaction of inclusions containing iron oxides with the resin. This film reduces the surface tension between filter material and inclusions. The latter are fixed on the filter much more firmly (a certain form of depth filtration takes place). When pouring ductile iron, the capture of magnesium oxides (in particular forsterite Mg_2SiO_4) is improved by this method.

The textile filter mesh is selected with respect to the metal being poured. The flow area of filters depends on the type of cloth and the mesh size; it usually ranges from 10 to about 30 percent of the total filter area. (Fine-mesh filters have a relatively smaller flow area.) The recommended mesh size for individual alloy types is given in the following Table.

Alloy	Mesh (mm)
Grey iron	1.0 – 1.5
Ductile iron	1.5 – 2.0
Steel	1.0 – 1.5
Aluminium alloys	1.0 – 2.0

The cloth filters are inserted in the mould parting planes such that they overlap the flow profile on each side by at least 10 – 15 mm. The method of positioning is shown in Fig. 13. Due to their low thermal capacity, it is possible to place many filters in one mould at different sites. This allows impurities that have entered the mould with molten metal to be captured on the first filter, and to remove other, tiny inclusions that have been formed due to the flow in the gating system. The filters are used without a frame or with a reinforcing frame. The filter should be positioned horizontally in the gating system.

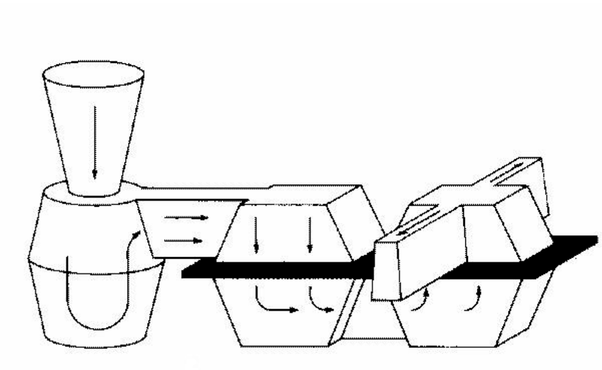


Fig. 13: Positioning filters in a mould

It is recommended that the print for installing the filter should be 1 - 1.5 mm larger than the filter surface dimensions. This makes it easy to insert the filter and enables its thermal dilatation.

If cloth filters are used, there are no problems with the flow of the first metal (priming), but it is recommended that the **pouring temperature** should be increased by **15-30°C compared to the moulds without filters.** Where possible, it is recommended that an "over-run arm" of the runner should be provided at the filter inlet side so that the filter gets pre-heated. Some problems may arise from the stress caused by the metal flow in that the cloth becomes curved and may be drawn out of its bedding in the mould. In any case, **it is necessary to take into account the possibility of curving** and place the filter at such a distance from the casting that, in case of curving, **it does not reach into the casting**. If the flat filters are suitably placed, they can serve as breaker cores and facilitate the breaking of gates and risers.

For gates with cloth filters, it is recommended to choose the following ratio of cross sections

$$S_{sprue} : S_{runner} : S_{filter} : S_{ingate} = 1 : 2 : 4 : 2$$

If steel (and similarly cast iron) is poured through a filter with 2 mm pores, a pouring rate of 0.25 kg/s.cm^2 can be expected.

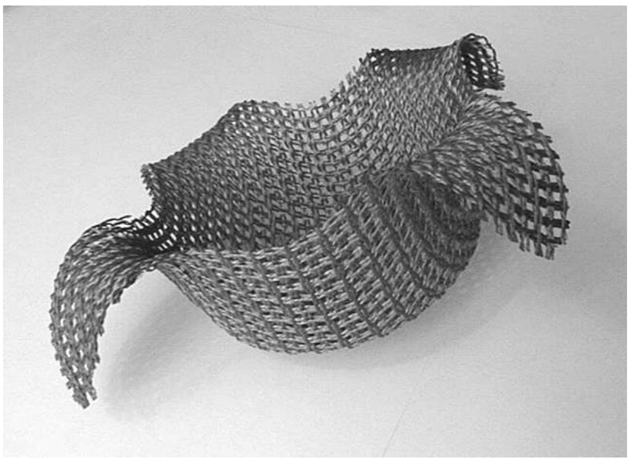


Fig.14: Cloth filter for the pouring basin

This type of filter is very suitable for precision casting by the method of lost wax pattern. Filters in the shape of baskets are used, they are easy to insert into the pouring basin funnel. However, the use of flat cloth filters is not very frequent in our country.

2.2.2 VOLUME FILTERS

In volume filters, use is made of the filtration effect on the filter inlet side (where the filter cake forms) and of the capability of depth filtration. The capability of depth filtration is different in different filters. Volume filters are divided into the following groups: **pressed filters, extruded filters and foam filters.**

Pressed filters – are similar to strainer cores – see Fig. 15. They are produced by pressing a semi-dry ceramic mixture in metal moulds, with straight flow-through holes being pressed at the same time. These holes are mainly of circular shape (other shapes are rather rare). After pressing, the filters are annealed. The filters are characterized by their dimensions, thickness, the diameter of holes and their density in the filter flow area. The hole diameters are usually from 1.8 to 2.5 mm, and thickness ranges from 12 to 22 mm. The flow area is 45 - 58 % of the total filter area. The material is selected according to the type of metal to be melted.

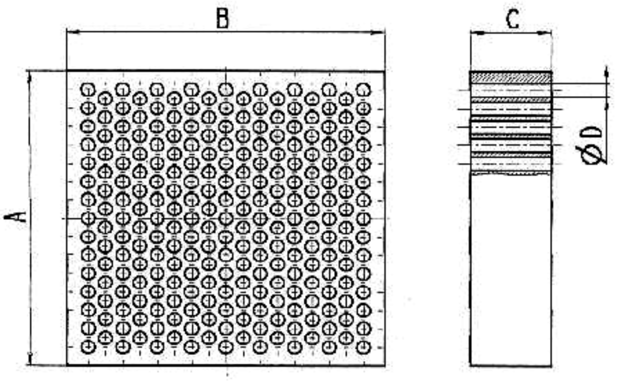


Fig. 15: Pressed filters

Extruded filters – are also filters with straight runners. They are produced by extruding plastic ceramic material through a die with rectangular/square holes – Fig.16. Compared to the previous type, the grating walls are markedly thinner, and hence they have a larger flow cross section (about 65 %) and lower heat capacity. The square cross section of filter channels is more suitable than that of circular shape, and the filters are of a relatively high depth filtration effectiveness.. In Fig. 17, a number of inclusions can be seen captured on an extruded filter.

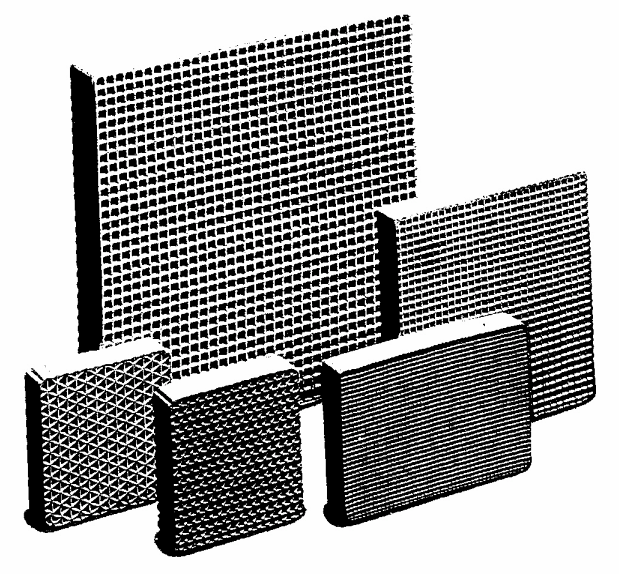


Fig. 16: Celcor extruded filters

The density of extruded filters is evaluated according to the number of holes per square inch (2.54x2.54 mm) and is referred to as csi (cells per square inch). Generally, filters with a density of 50-300 csi are used. (The greater the number, the denser the filter.) This type of filter is mainly used for the filtration of cast irons but it can also be used for steel. **A density of 50-100 csi is recommended for ductile iron and 200-300 csi for grey iron.**

The thickness of extruded filters is about 10-20 mm. The higher the thickness, the more effective the depth filtration and the higher the resistance to mechanical stress due to flowing metal. (Very thin filters break or bend). Thick filters have a higher heat capacity and they cool molten metal more intensively. The same holds for pressed and foam filters.

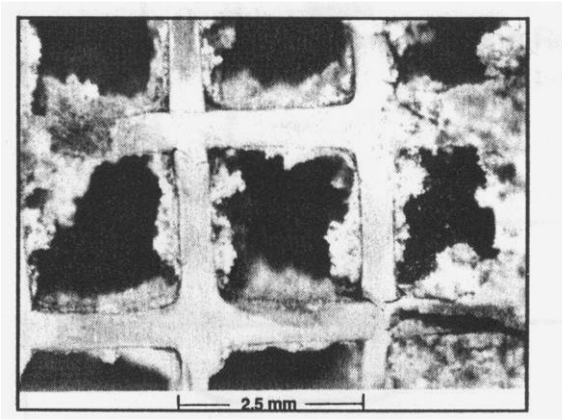


Fig. 17: Extruded filter with captured inclusions

Filters with triangular holes are considered to be the news in the group of extruded filters – see Fig. 11. An improvement of filtration efficiency due to more perfect depth filtration, an increase in filter strength and better hydraulic conditions of metal flow are ranked among their advantages. The higher efficiency of depth filtration is due to the fact that the probability of an inclusion contacting two walls is in filters with triangular holes greater than in channels of square cross section. For this reason, the triangular-hole filters with a density of 90 csi have the same filtration efficiency as the square-hole filters with a density of 150 csi.

Foam filters – are based on a system of mutually linked cells in the shape of pentahedron– Fig 18. Foam filters are produced by filling a polyurethane foam matrix with a suitable ceramic suspension. After firing the foam, a ceramic filter frame is created – Fig.19. The filters differ in their pore sizes, which are given by the porosity of the foam porosity used. **The porosity is evaluated by the number of pores per inch (25.4 mm) and is referred to as ppi** (pores per inch). Filters with **a porosity of 10, 20 and 30 ppi** are **usually** used for metal filtration in moulds while for aluminium alloys in melting plants and metallurgical plants porosities of up to 60 ppi are used. The higher the number, the higher the density of filter.

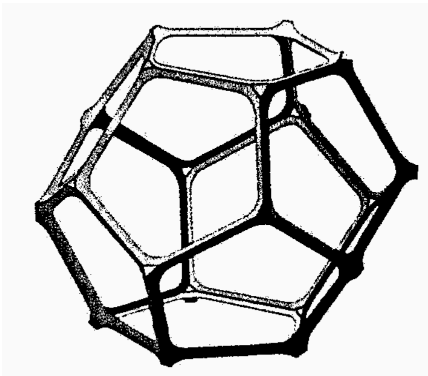


Fig. 18: Foam filter cell

The density of filters is chosen with respect to metal liquidity (running quality) and the rate of clogging. For alloys with low liquidity and alloys with a high quantity of inclusions, filters with larger pores (density 10 or 20 ppi) should be chosen, and for alloys with good liquidity, thicker filters (20-30 ppi) are suitable. The flow profile of foam filters depends on the robustness of ceramic frame, and it usually makes up to 80 % of the total filter area.

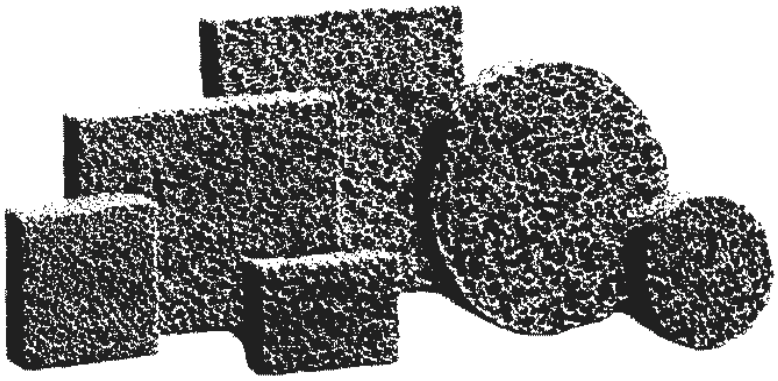


Fig. 19: Foam filters

The mode of metal flow in a foam filter in which local turbulences and frequent changes in flow direction occur, due to which inclusions come into contact with filter walls, is suitable for depth filtration - Fig. 20.

Fig. 20: Flowing in a foam filter

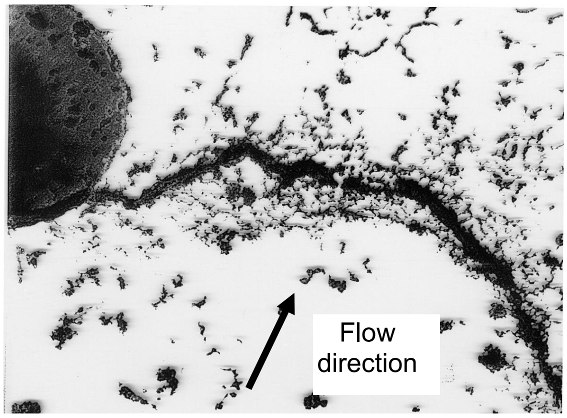
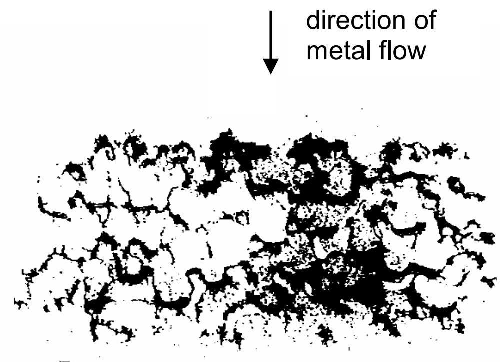


Fig. 21: Inclusions forming a bridge in foam filter

Inclusions whose dimensions are significantly lower than the pores are captured on walls, and additionally they get stuck to one another and form "bridges" anchored on filter walls –

Fig. 21. The mechanism of depth filtration removes effectively even very small inclusions up to 3-5 µm in size. With increasing amount of inclusions captured, the filter is gradually clogged, and it becomes closed for other inclusions. The flow capacity thus depends on the amount of inclusions, pore sizes and adhesive forces between individual inclusions nd the filter (i.e. it depends on filter material).

A high efficiency of depth filtration is the most important advantage of foam filters compared to all other types. With flat filters, depth filtration cannot, in fact, occur (even if a partial inclusion capture by the effect of surface tension does occur, the effect of filter depth is absent). With straight-hole filters, the mechanism of filter cake formation predominates, but depth filtration is also possible). Filter thickness has, however, no great effect on the total filtration efficiency. In foam filters, the whole filter thickness participates in depth filtration – the greater the filter depth, the more effective the filtration. This is evident from the distribution of sulphide inclusions in a filter after pouring ductile iron – see Fig. 22. **In general, the thickness of foam filters is in the range from 18 to 25 mm.**



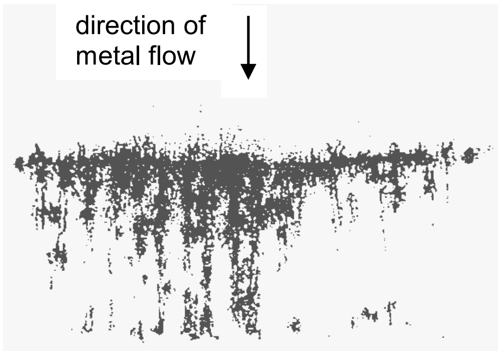


Fig.22: Sulphide inclusions captured in a foam filter and in a pressed filter with straight channels

The porosity of foam filters for individual alloy groups can be selected according to the following table:

Alloy		Filter porosity (ppi)
Cast iron:	grey iron	20 – 30
	ductile iron	10
	malleable iron	30
Steel:	low-carbon	10
	high – carbon	10 – 20
	stainless	10
Aluminium alloys		20 – 40
Magnesium alloys		10 – 20
Copper alloys		10 – 20

2.3 CERAMIC FILTER MATERIAL

The molten metal creates drastic conditions for the filter and these lead to a premature filter destruction. The main modes of filter stress are as follows:

- thermal shock caused by a sudden temperature increase during contact with molten metal
- stress due to a high temperature that may be close to the limit of ceramic refractoriness
- dynamic impact of metal flow at the beginning of pouring
- long-term mechanical stress at high temperatures which causes creep
- filter erosion due to hydraulic forces
- chemical corrosion of filters due to the action of slag

It is known from experience that if only some of the above properties are provided for, a proper filter operation will not be guaranteed. The quality of filters is very often assessed erroneously according to their refractoriness or static strength at normal temperature.

The high-temperature filter properties are specified by both refractory filler properties and bond properties. The material of filters must be stabilized, and no phase transformations, degradation of components, changes in volume, etc. must occur.

The properties that characterize the filters are as follows:

- bending strength at normal/high temperatures (1500^{o}C)
- creep resistance
- thermal shock resistance
- resistance to the chemical effect of slag

Experimental tests are the only reliable method for a complex assessment of filter quality. The principle of the tests consists in passing a certain volume of metal through the filter under defined conditions. The properties of the filter are evaluated according to the temperature at which the filter gets damaged. These tests are commonly used by some producers (e.g. impingement test).

Types of filter ceramics used

Pressed filters:

Pyrostat is used for alloys and metals with lower melting temperature – its composition consists of about 50 % SiO_2 and 40 % Al_2O_3. For the casting of steel, filters with a higher content of Al_2O_3, in particular mullite ($3 Al_2O_3 . 2 SiO_2$), are produced.

Extruded filters:

cordierite + mullite	- up to 1 450°C	- Al, Cu alloys, cast irons
mullite + corundum	- up to 1 500°C	- cast irons above 1 550°C and aggressive slags
zirconia + spinell	- up to 1 870°C	- super-alloys, steel – shell moulds

Foam filters:

Filter ceramics	Chemical composition	Max. operation temperature (°C)	Thermal shock resistance	Slag Resistance	Creep resistance	Relative cost	Applications - alloys
Alumina -chemical bond*	Al_2O_3	1200-1450	bad	good	middle	low	Al
Mullite	$3 Al_2O_3 . 2 SiO_2$	1650	good	bad	excellent	low	cast irons, non-ferrous super alloys
Alumina – zirconia	65% ZrO_2 +35% Al_2O_3	1600	excellent	good	middle	middle	ferrous/non-ferrous alloys, super alloys.
Zirconia PSZ **	97% ZrO_2 + 3% MgO (Y_2O_3)	1700	excellent	excellent	middle	high	steel, Ni
SiC - Al_2O_3		1600	excellent	middle	middle	low	cast irons, Cu alloys

* Depending on the type of bond ** Partially stabilised zirconia

Note: The above data are only informative, depending on a specific formula, annealing temperatures and other effects.

2.4 FILTER EFFECT ON FLOWING METAL

In addition to capturing inclusion, filters have an effect on the mode of metal flow in the gating system. The presence of filters shows particularly in:

- changing the pouring rate
- smoothing the flow of metal and limiting the turbulence

2.4.1 POURING RATE

The filter in the gating system makes pouring non- uniform. As can be seen from the curve of mass pouring rate (see Fig. 23), several stages of pouring time can be distinguished:

- time up to priming the filter
- time of uniform flow
- time of intensive reduction of filter flow

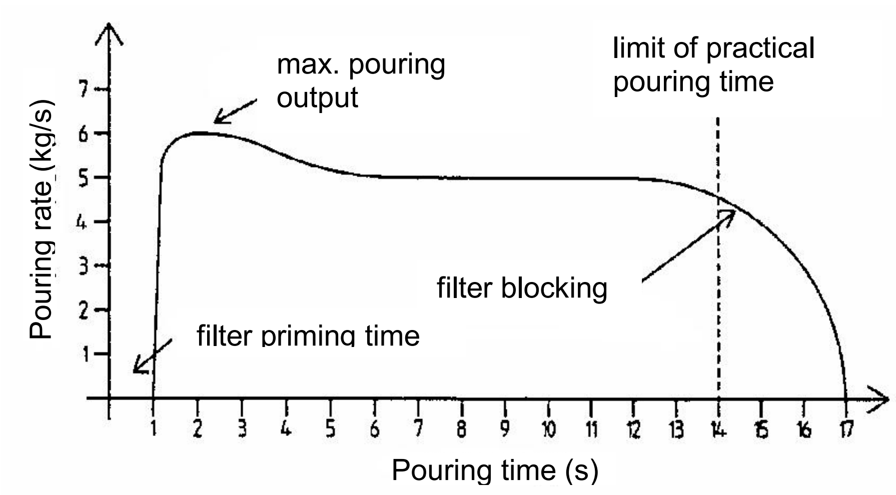


Fig. 23: Curve of filter flow rate

The process during which the filter pores are filled with metal and a continuous flow is achieved is called **priming.** Priming has two parts. In the first part, the metal that flows towards the filter enters the filter pores. In the case of flowing through channels of such small dimensions as are usual with filter, the effect of capillary forces comes to be strongly manifested. The resistance to filter priming is described by the formula given below. Because the filter is usually not wettable with metal, capillary depression appears (see Fig. 24), which prevents priming:

$$\textit{resistance to filter priming} \approx -\frac{\sigma_{MF} \cdot \cos\theta}{d \cdot \rho}$$

where: σ_{MF} - is the surface tension of metal
Θ - is the wetting angle
d - is the channel diameter
φ - is the metal density

The less wettable with metal the filter is (the greater the angle Θ) and the smaller the filter holes, the higher the resistance of capillary forces. This may cause **problems,** in particular in the case of **small-hole filters, small pouring heights or relatively low pouring temperatures of the metal.**

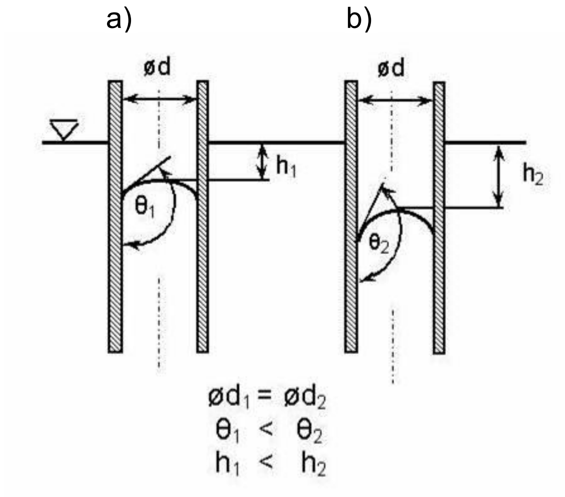


Fig. 24: Resistance to filter priming:
a) better wettability – lower resistance
b) poorer wettability – higher resistance

In the second stage of priming, molten metal fills the whole filter channel length. In this stage, much energy is needed to overcome the resistance to flow in filter channels.

Priming is made complicated by considerable temperature losses in the metal, due to which its viscosity increases or the metal can solidify in the filter. The higher the heat capacity of filter (i.e. the more robust the filter is) and the higher the cooling properties, the higher the thermal losses in the metal.

For this reason, **it is necessary to pour at a higher pouring temperature than without filter.** Priming is facilitated by pre-heating the filter, either before inserting it into the mould or simultaneously with preheating the mould (for example, when pouring into ceramic moulds) or with the first inflowing metal. In this case, a sort of "by-pass" is formed. This means that the first metal "runs" past the filter inlet side and flows into a chamber – a reservoir above / behind the filter without passing through the filter – see Fig. 27d. (In this metal, there is usually a large amount of impurities that can clog the filter.) This preheating greatly facilitates the passage of further metal.

A pressure potential proportional to the filter resistance is necessary for the metal to flow through during priming. After priming, the required pressure is reduced. It is evident that this resistance is also dependent on filter porosity and hydraulic losses in the channels. It has been reported that while pouring steel through a zirconia filter with a density of 120 csi the priming occurred at a metal-static pressure of 140 mm metal but a pressure of only 19 mm was sufficient for the subsequent flow. As a result of these circumstances, the gating system behaves rather differently compared to pouring without filter: This may bring problems at the beginning of pouring. After the beginning of pouring (until a pressure is reached that is necessary for priming), it seems that metal does not penetrate into the gate and the pourer slows down the pouring. But then the level suddenly drops and the pouring rate must immediately be increased. The pressure required for priming may acquire high values, hence the mould **must have a sufficient cope height.**

After priming, a nearly constant rate of metal flow is achieved for a certain period. During this stage, a filter cake is gradually formed, and the filter volume is clogged; at first without any significant effect on the pouring capacity. If the degree of filter clogging is high, the rate of flow will markedly decrease until the flow is blocked. **The filter size must be chosen such that pouring is finished in time while the flow is sufficient.**

2.4.2 LIMITATION OF TURBULENCE

The flow in the gating system, particularly in the sprue, is accompanied by very intensive whirling. This turbulence causes the erosion of mould walls and metal oxidation, which gives rise to inclusions and air entrainment. The mode of flowing depends on the type of metal, the shape of gating system, the changes in metal flow direction, and the rate of flow. The nature of flow is given by the Reynolds number

$$\mathrm{Re} = \frac{w \cdot D_h}{v}$$

where: w - is the rate of metal flow
D_h - is the hydraulic diameter of channel
v - is the kinematic viscosity of metal

The higher the Reynolds number Re, the higher the metal turbulence. With Re < 3000, the flow is laminar, with a minimum danger of erosion, with Re > 15000 – 20000 it is quite turbulent and whirling is present over the whole channel cross section. The higher the value of **Re**, the more intensive the turbulence. If no filter is used, the flow is almost always decisively turbulent. **The favourable effect of the filter consists in reducing the Reynolds number and thus also turbulence** due to the markedly smaller hydraulic diameter of filter channels compared to runners **–** Fig. 25. If the diameter of a sprue is 40 mm and the diameter of a filter hole is 2 mm, the value of Re is reduced 20times. During the passage through the filter, the flow becomes calm – the turbulent flow changes to laminar flow. (Of course, after a certain path, turbulence appears again but usually on a smaller scale than before the filter.)

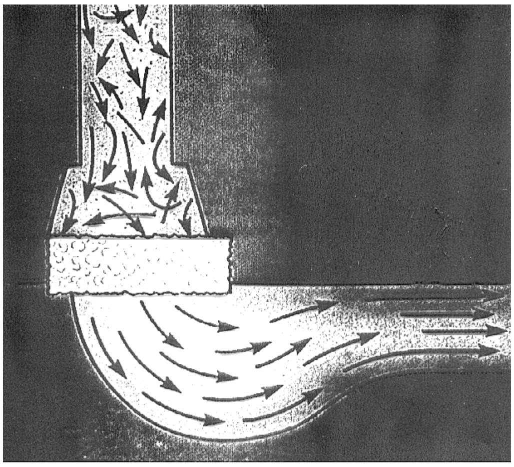


Fig. 25: Transition from turbulent to laminar flow of metal due to a filter

(The hydraulic diameter of channel is given by the following formula:

$D_h = 4.S/O$, where S is the cross section of channel and O is the circumference. For a circular cross section $D = D_h$. If rectangular, slot or triangular channels are used, the hydraulic diameter and thus also turbulence are reduced.)

3 DESIGN OF GATING SYSTEM

3.1 POSITIONING FILTERS IN GATING SYSTEM

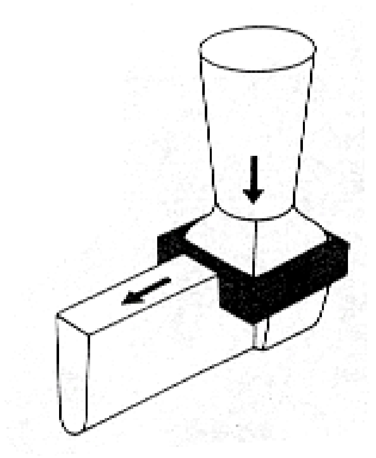


Fig. 26: Direct pouring on a filter

There are a number of possibilities of positioning the filter in the gating system. In principle, they can be divided into two groups:

Direct pouring – the filter is in horizontal position so that the metal flow impinges directly on the filter (Fig. 26). This method is used for the positioning of filters in the pouring cup or in moulds with vertical parting plane. **Positioning the filter in the parting plane below the sprue is used in practice very often but there is a danger of filter rupture due to the dynamic impact of the metal.** The danger of rupture exists particularly when the sprue is very high or when pouring from a ladle with bottom outlet.

If direct pouring is applied, only 1 filter can be employed in one mould.

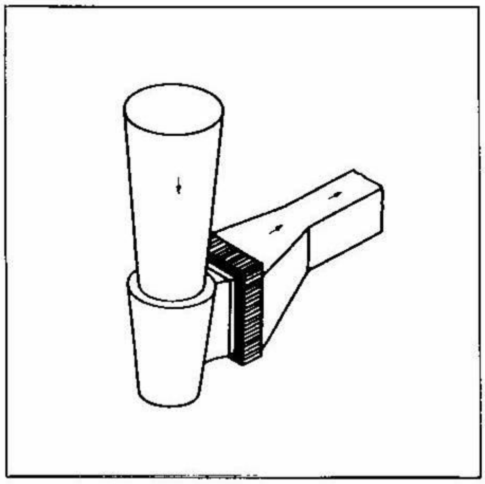
Indirect pouring – the filter is placed in a special chamber in the gating system so that it is not loaded directly by the stream of falling metal. Depending on their position with respect to the direction of metal flow the filters can be situated:

- perpendicular to flow direction – Fig. 27 a,b
- parallel with inflowing metal – Fig. 27 c
- slanting – Fig. 27 d

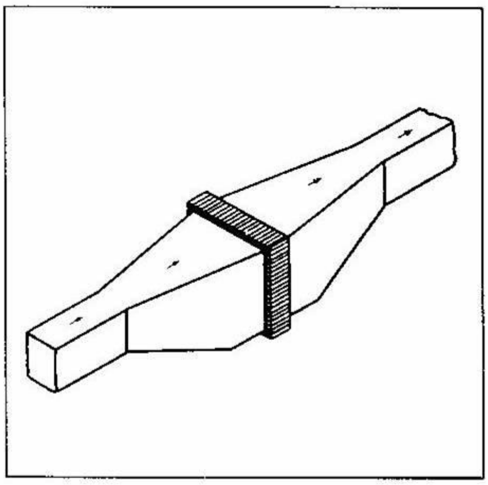
With indirect pouring, the gating system can be provided with several branches with separate filters.

Position perpendicular to flow direction – Fig. 27 a,b, The filter is positioned perpendicular to the path of metal. A relatively great dynamic impact occurs. The first (i.e. the coldest) metal that flows towards the filter must pass through the filter, and there is no chance of the filter being pre-heated.

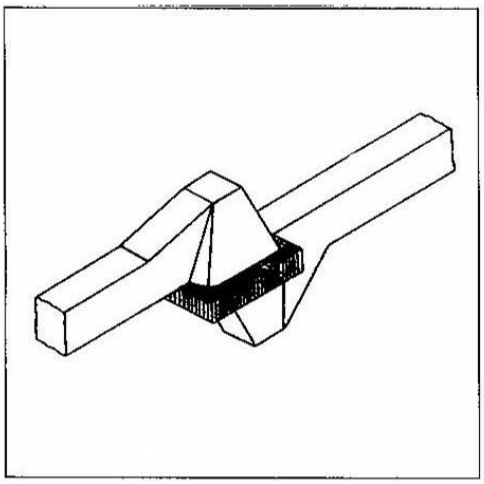
Advantages:	- relatively great dynamic impact of metal which, on the one hand, is advantageous from the viewpoint of priming while on the other hand the probability of filter rupture is greater - low demand for space
Disadvantages:	- the first ("cold ") metal must pass through the filter – the danger of metal "freezing" - impurities (in particular large slag particles) have no chance to rise to the surface - the danger of filter clogging



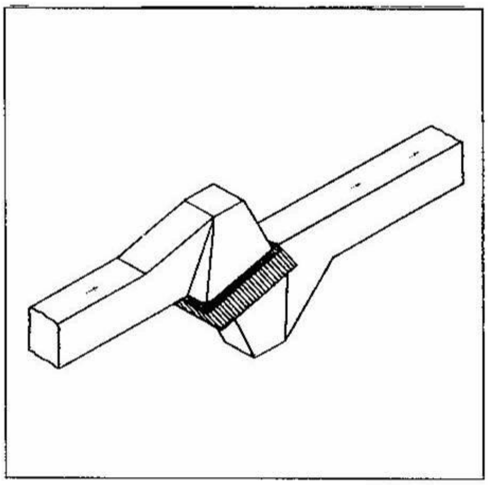
a) Vertical position of filter close to the sprue



b) Vertical position of filter in the distribution runner



c) Horizontal position of filter



d) Slanting position of filter

Fig.27: Filter positioning

The filter is usually situated in close vicinity of the sprue, or farther in the distribution runner. The position adjacent to the sprue is suitable from the viewpoint of priming, but the position farther from the sprue (as close as possible to the ingates) makes it possible to capture inclusions that have only been formed in the gating system.

The filter is usually inserted in the drag, only the upper filter print is in the cope. The prints should be along the whole circumference. It is absolutely wrong to insert the filter without the upper print. The gap between the filter and the mould represents the cross section with a much lower hydraulic resistance, through which a considerable volume of non-filtered metal can flow. Also, the danger of filter rupture is greater. The filter should lean on the whole print area. For this reason, it is suitable to have chamber patterns with the smallest draft.possible.

Filter position in the flow plane – see Fig. 27 c. The filter is placed in horizontal position in the drag. There is a metal reservoir above the filter. The reservoir is a chamber located directly above the filter or it is placed as an overflow just behind the filter. The first (cold) metal need not pass through the filter, it can be captured in the reservoir. At the same time, the filter is pre-heated, which makes the flow of incoming metal easy. In the reservoir, large slag particles can be captured that might cause filter clogging. From the viewpoint of pre-heating it is sufficient when the reservoir height is twice the filter thickness. The metal should always flow through the filter from top to bottom.

Slanting filter – see Fig. 27 d, This is probably the most suitable way of positioning the filter. It gives a uniform filter loading. It directs favourably the metal flow and helps to make large inclusions rise into the chamber above the filter.

Distribution runner and ingates

Since the inclusions are captured by means of a filter, the runner behind the filter does not work as a slag trap, but only as a distribution runner. It is suitable if the gating system behind the filter is as short as possible. The distribution runner should be filled with metal during pouring. If the filter is placed vertically, the distribution runner is in the drag, and the ingates are at its upper level – Fig. 28, or the distribution runner behind the filter is led into the cope. If it is of advantage, the gating system can form a number of branches with separate filters. In practical terms, the distribution runner and even the filter are very often placed in the cope. However, the runner cross sections must be chosen such that the space behind the filter is completely filled with metal.

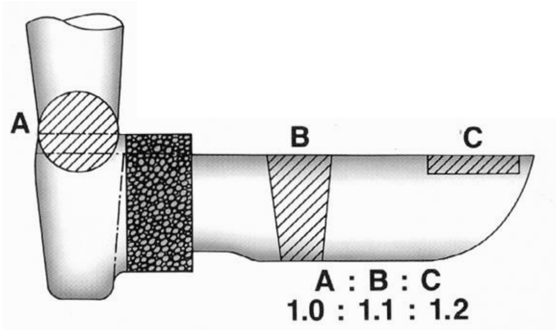


Fig. 28: Example of the gating system design with vertically placed filter

3.2 DIMENSIONING GATING SYSTEM WITH FILTERS

Gate systems with filters should always be designed **as system without overpressure – acting as the choke is the sprue or the narrowing where the sprue opens into the distribution runner.** It is recommended that the cross sections of the sprue, the distribution runner and the ingates should be in the following ratio:

$$S_{sprue} : S_{runner} : S_{ingate} = 1 : 1.1 : 1.2$$

3.2.1 FILTER SIZE

The filter size is determined from two viewpoints, with **the following two conditions having to be satisfied:**

- **the filter should not function as the choke of the gating system,**
- **the required metal volume must pass through the filter – the filter must not be clogged during pouring**

The filter in the gating system presents an obstacle to the flow of metal. The filter resistance depends on the ratio of its area to the choke, on filter thickness and on porosity. If the flow area is sufficiently large compared to the sprue cross section, the filter will not work as a choke. The larger the filter area, the smaller the filter effect on pouring time - Fig. 29.

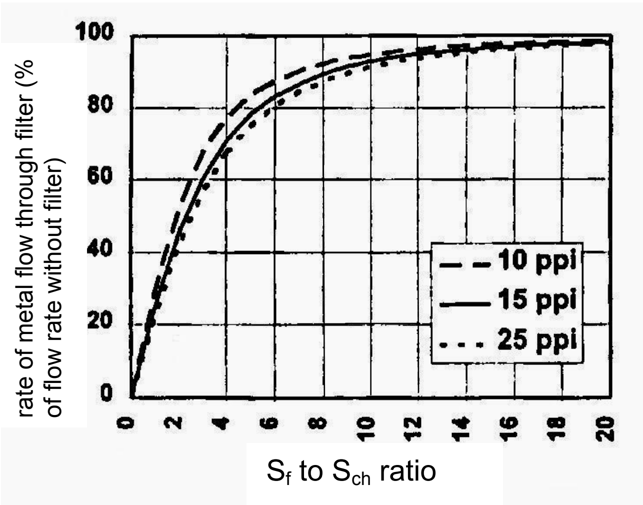


Fig. 29: The effect of filter size on pouring time extension

Regarded as the filter flow area is only an area through which the metal can flow, i.e. in the case of pressed or extruded filters it is the filter area reduced by the area of prints – see Fig.30. In the case of foam filters, where flow in the transverse direction is also possible, the whole filter area is regarded as effective.

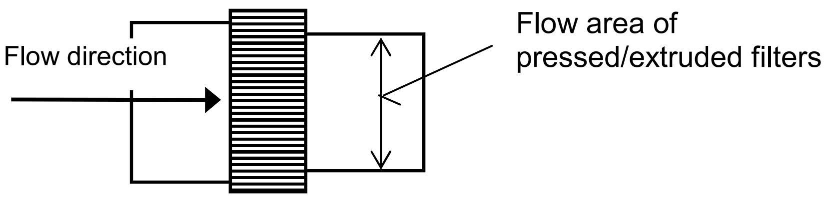


Fig. 30: Filter flow area

To avoid throttling the gating system by the filter cross section, it is recommended that **the minimum ratio of the filter flow area S_f to choke S_{ch}** is chosen as suggested in the following Table:

Alloy type	S_f:S_{ch}
Grey iron	3 - 4
Ductile iron	3 - 6
Steel	min. 4.5
Aluminium	4 - 8

The filter which captures the inclusions is gradually clogged until the metal flow stops completely – see Fig. 23. **The filter must be dimensioned such that it shall not be blocked.** Unless pouring from a ladle with bottom outlet, it is suitable to provide preliminary separation of coarse inclusions ahead of the filter, for example by means of strainer cores.

Only a certain metal volume can pass through the unit filter. **The flow rate of filter is given in kg per cm^2 of filter flow area.** For foam filters, the following flow rates m_f are given:

Alloy type	Filter porosity (ppi)	Flow rate (kg/cm^2)
grey iron	20	2 - 4
ductile iron	10	1 - 2
Carbon steel	10	1 - 1.2
Alloy steel	10	1.5
Niresist	10	0.8 - 1

For pressed and extruded filters, it is possible to use a higher flow rate – about 4-6 kg/cm^2 for grey iron and 2-3 kg/cm^2 for ductile iron.

The above values are only informative. The actual flow rate depends on metal purity, pouring height, filter position in the gating system, filter thickness and other effects. It depends very significantly on filter porosity of filters. If finer filters are used, their flow rate is significantly reduced. **The higher the number of inclusions in the alloy and the higher the filtration effect, the faster the clogging. The flow rate of filters depends on the method of pouring. If a ladle with bottom outlet is used, the flow rate is significantly higher than when pouring over a lip ladle.**

The relationship between the quantity of inclusions and the flow rate of filters shows very clearly **in ductile iron** above all. **The higher the content of residual magnesium Mg_{zb}, the higher the amount of non-metallic inclusions and the lower the filter flow rate.**

With respect to flow rate, the size of filter is given by the relation:

$$filter\ area = \frac{metal\ quantity}{filter\ \ flowrate}$$

where: filter area – cm^2
metal quantity – kg
flow rate – kg/cm^2

For example, to pour 100 kg of ductile iron through a filter with a porosity of 10 ppi, a flow rate of 2 kg/cm^2 may be expected. The minimum filter flow area must then be 100/2 = 50 cm^2. This corresponds to a square filter with dimensions of 75 x 75 mm.

3.2.2 DIMENSIONING THE GATING SYSTEM CHOKE

The size of the choke in a gating system is calculated similar to ingates without filters, using the following formula:

$$S_{\check{r}} = \frac{22{,}6\ .\ m_k}{\rho\,.\,\mu\,.\,t\,.\sqrt{h}}$$

where:
- S_{ch} - is the choke of the gating system (cm^2)
- m_k - is the weight of molten metal (kg)
- ρ - is the metal density (kg/dm^3)
- μ - is the rate coefficient
- t - is the pouring time (s)
- h - is the pressure height – usually the cope height (cm)

The rate coefficient includes all the resistance to flow that appears in the gating system. It is mainly the effect of a change in direction, metal friction on runner walls, the effect of viscosity, etc. **The higher the resistance, the lower the rate coefficient**. Its numerical values is given in various charts and tables. For practical use, it is suitable to find out the value experimentally and use it for moulds with a similar arrangement of the gating system. The dependence of pressure loss on metal flow rate and filter porosity is given in Fig. 31. With a properly dimensioned filter, the value of rate coefficient is reduced by only 10-20 %. This means that **the pouring time is extended by 10-20 % due to the filter effect. The larger the filter area (the S_f : $S_{\check{r}}$ ratio), the lower the filter effect on the pouring time. To maintain the original time, it is necessary to increase the choke area (in this case probably the sprue) by the value given above. The sprue diameter will then increase by 5 to 10 percent compared to the gating system without filter.**

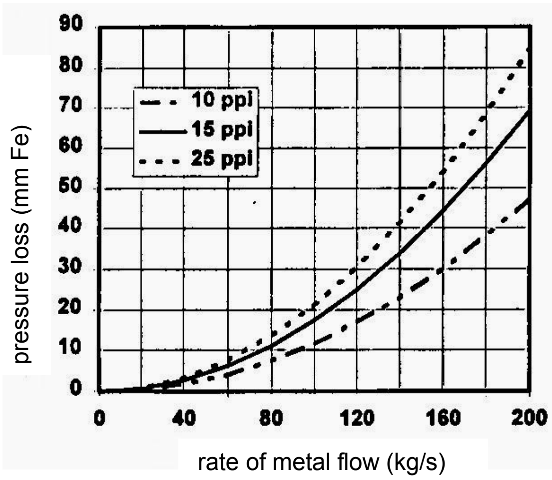


Fig. 31: Pressure loss caused by a filter

4 STEEL FILTRATION

Steel filtration is a new trend, and to a certain extent, also a technological speciality. The problem here is the high pouring temperature which can be withstood only by filters made of special ceramics. Another problem is the higher danger of metal "freezing" on the filter. The filters are made of ceramics based on mullite or partially stabilised zirconia (PSZ). Straight-hole filters and foam filters can be employed, and good experience has been obtained with cloth filters. Manufacturers give the maximum filter temperature for steel between 1680 and 1700 ^{o}C. The cost of the filters is, naturally, higher than the cost of filters for lower temperatures, and this fact is very often a limiting factor for their wider application. The importance of steel filtration in our foundries has not been appreciated so far.

Steel inclusions are mainly formed by reoxidation products, i.e. oxides that arise when molten alloy is poured and flows in both the gating system and the mould cavity. It is estimated that the reoxidation products form about 80 % of all macroscopic inclusions in steel castings. The inclusions have relatively large dimensions, of the order of millimetres. Other inclusions stem from moulding materials, primary slag, eroded lining and steel deoxidation products. The effect of filters consists in both capturing the inclusions and, above all, reducing the metal turbulence in the gating system, which results in reduced reoxidation. The reduction of turbulence is considered the main favourable filter effect.

4.1 POSITIONING FILTERS IN GATING SYSTEM FOR STEEL CASTING

The filters are placed in the horizontal or vertical plane. The location of filters directly under the sprue is not recommended, because they could get damaged. To facilitate priming, it is suitable to select the arrangement in which the filter can be pre-heated by flowing metal. Good experience has been obtained with the arrangement as shown in Fig. 32. With this lay-out, a "chamber" is located at the inlet side (above or behind the filter) that is used to capture the first (i.e. cold) metal. The first inflowing metal sweeps over the upper surface of the cold filter, the filter is preheated, and the first metal is captured in either the chamber or the overflow behind the filter. Further metal can pass through the pre-heated filter more easily. The methods in which the pre-heat is not possible and the first metal must pass through the filter are less suitable for steel casting.

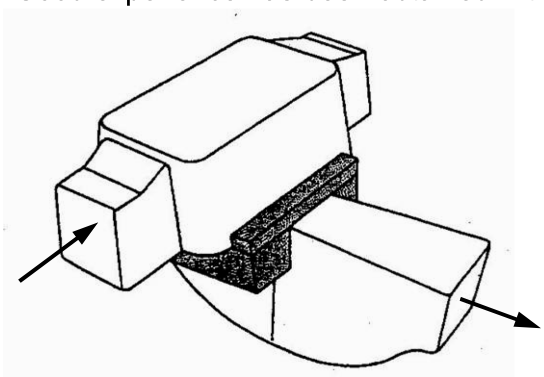


Fig. 32: Recommended method of filter positioning for steel casting

The positioning of filters must be secured along the whole circumference. The seating area should take 45 % of the total filter area. The unsupported area on the circumference should be as small as possible. The size of filter prints should not be smaller than the values given in the following table.

Filter size (mm)	Filter seating (mm)
50 x 50	5
75 x 75	8
100 x 100	10

4.2 SIZE OF CROSS SECTIONS IN GATING SYSTEM

The gating system should be a system without over-pressure, the choke is the sprue and the ratios of cross sections are:

Ssprue : ΣSfilter : ΣSrunner : ΣSingate

1 : 4.5 : 1.15 : 1.3

4.3 FILTER SIZES

The sizes are chosen according to the pouring rate and the quantity of metal to be poured. The porosity of foam filters is usually 10 ppi, only rarely is it higher. For foam filters with a porosity of 10 ppi, the following pouring rate is usually given (the data differ according to individual manufacturers):

	carbon steel	alloy steel
flow rate (kg/cm^2)	1.1	1.5
pouring rate (kg/cm^2.s)	0.1	0.15

For filters with the most frequent dimensions the respective values are given in the Table:

Filter dimensions (mm)	Max. metal quantity (kg)		Max. pouring rate (kg/sec)	
	carbon	alloy	carbon	alloy
50 x 50	30	40	2.5	4
75 x 75	65	85	5.5	8.5
100 x 100	110	150	10	15
diam. 50	25	30	2	3
diam. 75	509	65	4.5	7
diam. 100	90	120	8	12
diam. 150	200	270	18	27

The above values should not be exceeded.

4.4 POURING TEMPERATURES

It is recommended that pouring temperatures should be chosen 80°C above the liquidus temperature.

Typically, the pouring temperature for carbon steel with 0.25% C is 1600°C,

for Ni/Cr 18/8 it is 1520°C

The liquidus temperature for pure Fe–C alloys:

Carbon content (%)	Liquidus temperature (°C)
0.1	1528
0.2	1520
0.3	1511
0.4	1503
0.5	1495
0.6	1487
0.7	1480
0.8	1473

Liquidus temperature reduction due to the presence of 0.1 % of one of the following elements:

Element	Liquidus temperature reduction (°C/ 0.1 % of element)
Mn	0.5
Si	0.8
Cr	0.15
Ni	0.4
Cu	0.5

4.5 POURING HEIGHT

Due to the more difficult priming and the greater risk of metal freezing, a sufficient pouring height must be provided. (The lower the carbon content, the worse the liquidity.) For steel with poorer liquidity (e.g. low-carbon steel), the pouring height must be at least 150 mm above the filter to ensure complete filling of the casting.

4.6 USING FLAT CLOTH FILTERS FOR STEEL CASTING

If cloth filters are used, the problems related to "priming" are reduced in comparison with bulk filters. It is recommended that the following basic instructions for dimensioning the gating system should be observed:

- The optimum filter mesh is 2 mm
- It is necessary to avoid direct pouring onto the filter
- Filter flow area is 4 to 6 times larger than the choke (sprue cross section)
- pouring rate is up to 0.25 kg/cm2.sec.

5 TECHNOLOGICAL SPECIFICS OF FILTER APPLICATION

5.1 DIRECT POURING ONTO FILTER

As mentioned before, it is usually recommended that the filter should not be placed directly below the sprue in order that the melt should not be falling from a great height. Direct pouring can be used in cases when the dynamic effect of metal is not too high, especially in pouring cups, closed risers with/without filters which are situated in the pouring cup of ceramic moulds for precision casting.

Pouring cups

Pouring cups are provided with a filter in the bottom, which serves as the pouring basin, and when pouring is finished, as a riser. Metal from the pouring cup enters directly the casting, and using this method replaces the whole gating system.

Pouring cups are usually made of light-weight heat-insulating materials.

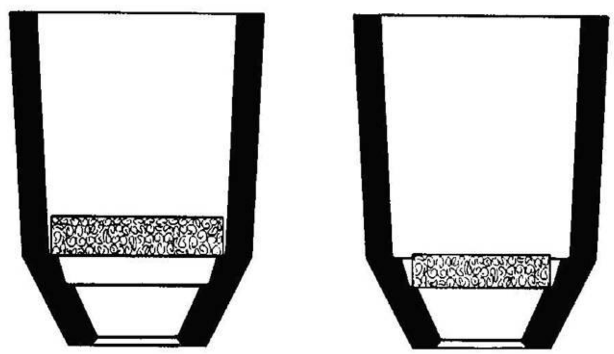


Fig. 33: Pouring cups with filters

Advantages:

- directional solidification
- high exploitation of molten metal
- high exploitation of frame area
- lower fettling costs

The filter is placed free in a seat on the cup bottom, and after the end of pouring it rises to the surface. The seating shown in Fig. 33 makes it possible to use filters of two sizes, depending on the flow rate required.

Similarly, cups can be used with cloth filters bonded to the cup bottom.

Pouring cups can be either mounted in the mould cope or installed as 'separate pouring basins' on the mould. If solidified metal does not remain in the cup, it can be used repeatedly.

Sleeves can also be closed. The filter is placed in the upper face of the sleeve below the sprue – Fig. 34. The sleeves are inserted either tightly in the print or pre-moulded in the mould cope or in the seat on the bottom (i.e. they are floating). In this case, the print in the cope must have a certain clearance that is given by the lifting force of metal during pouring.

The flow rates of filters that are installed in pouring cups can be 20 - 30 % higher than for those placed in the gating system.

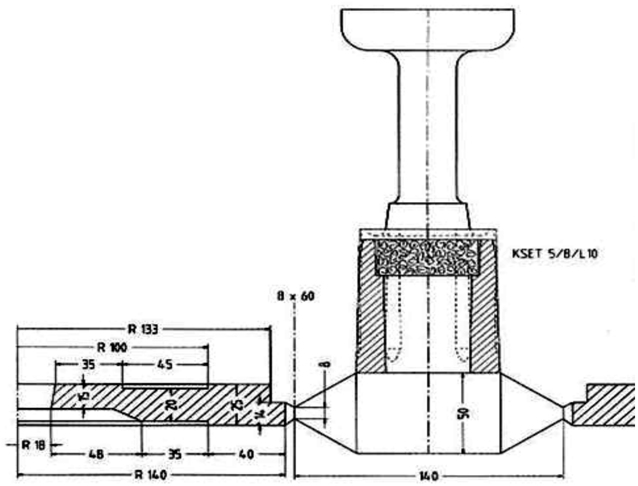


Fig. 34: Closed riser extension with filter

Pouring cup sizes must be chosen in keeping with the module rule:

- cast iron: $M_N = 1.0 \times M_O$
- steel: $M_N = 1.2 \times M_O$

5.2 FILTRATION IN MOULDS WITH VERTICAL PARTING PLANE

This type of filtration is mainly used in Disamatic machines, less frequently for the filtration during die casting. The problem with moulds with vertical parting plane is the insertion of filter and its fixation up to the moment the mould is assembled. There are two methods available – positioning the filter in either the pouring basin or the sprue.

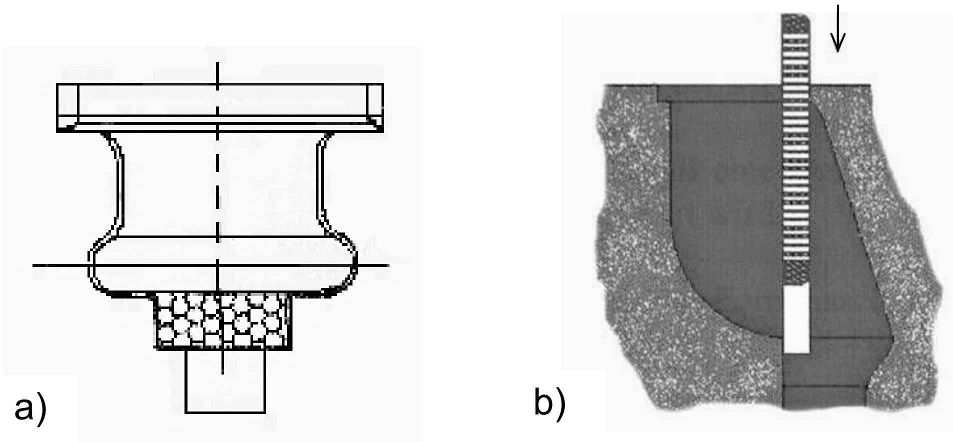


Fig. 35a,b: Filter insertion in the pouring basin of moulds with vertical parting plane

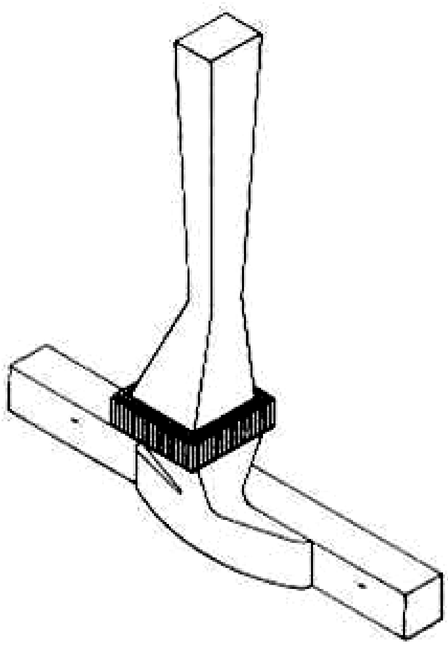


Fig.36 Filter in the gating system of a mould with vertical parting plane

The possibility of inserting the filter into the pouring basin is limited by the metallostatic pressure height necessary for priming. Because the depth of pouring basins is usually not great, it is possible to use such filters for which priming and subsequent metal flow will be no serious problem – mainly large-pore filters and straight-hole filters. The filters are inserted in the bottom of the pouring basin – Fig. 35a, or in the parting plane as shown in Fig. 35 b. From the viewpoint of filer flow rate, filtration in the pouring basin will be easier with grey iron than with ductile iron. Inserting the filter in the pouring basin is suitable because the filter can be inserted manually after the mould has been assembled. Thus the machine cycle is not made longer, as would be the case if filters were inserted with the aid of a mechanical device.

The filters are inserted into the sprue as shown in Fig. 36 – either in straight or in diagonal position. The filters can also be placed in distribution runners.

5.3 HEAVY CASTING FILTRATION

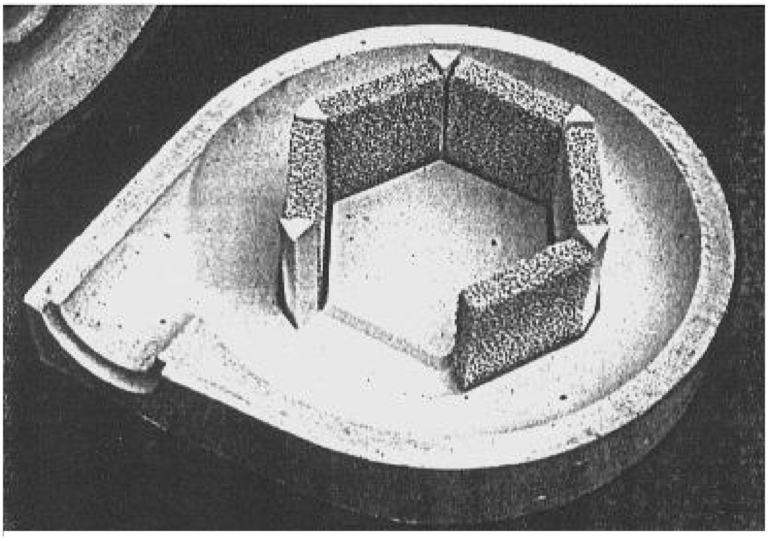


Fig. 37: Filter carousel

The metal quantity that can be filtered by current filters is limited by the flow rate. In the case of ferrous alloys, the magnitude of mechanical stress due to metal flow leads to filters being usually used that are 100 x 100 mm in size; exceptionally they may be as much as 150 x 150 mm. (However for light-metal alloys, filters of much larger dimensions can be used.) For castings with the weight greater than the flow rate of one filter, metal is distributed from the sprue into several branches with separate filters.

For heavy castings, filter carousels are used. The filter carousel consists of the following parts (Fig. 37):

- upper and lower carousel halves
- usually 6 foam filters
- fixing wedges

The metal flows in tangential direction to the circumferential runner, passes through the filters towards the inside from where it is removed in the axial direction of carousel. Metal is fed and drained via fire-clay pipes. The filtration rate is given by the total flow rate of all filters and the type and degree of metal contamination. It is usually given in the literature that the filtration power is 1.2 –1.5 times higher than that of the same area of filters located directly in the gating system.

The filter size is usually from 75x75 to 150x150 mm, but most frequently 100x100 mm. When pouring carbon steel, flow rates of about 1 to 1.5 tonnes can be expected (with alloy steel up to 2 tonnes) if the 6 times 100 x 100 mm carousel is used.

The carousel is made of a ceramic material based on Al_2O_3. It is inserted into the mould during moulding, and it can be placed at any site and in any position. Metal from one carousel can be distributed to more castings, while several carousels can be interconnected when filtering a larger volume of metal. The usual methods of positioning filter carousels are shown in Fig. 38.

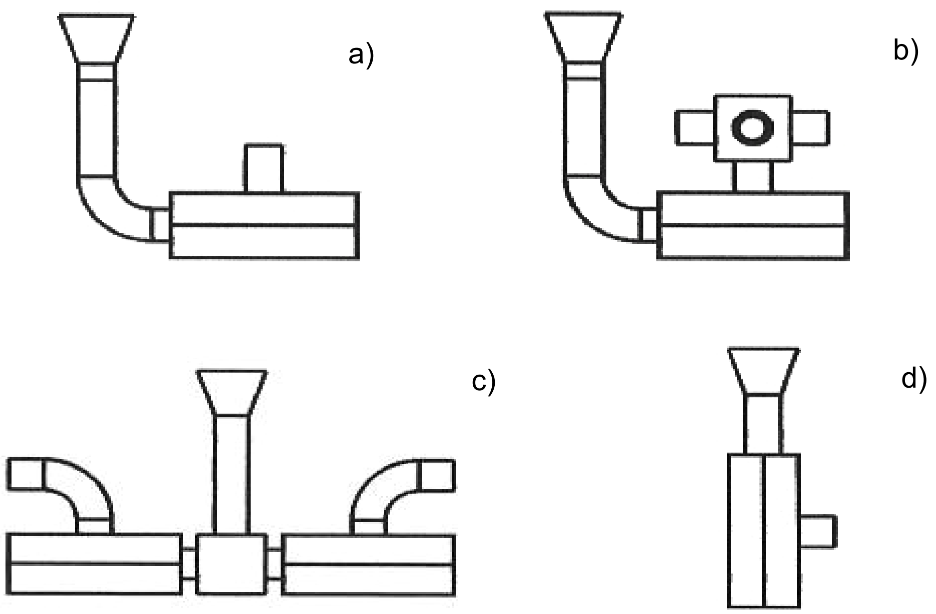


Fig: 38: Methods of fitting filter carousels
a) usual arrangement – bottom inlet
b) metal distribution to more branches or more castings
c) several carousels fitted to one sprue
d) vertical carousel position

5.4 INOCULATION OF METAL BY INOCULATION BODIES ON FILTER

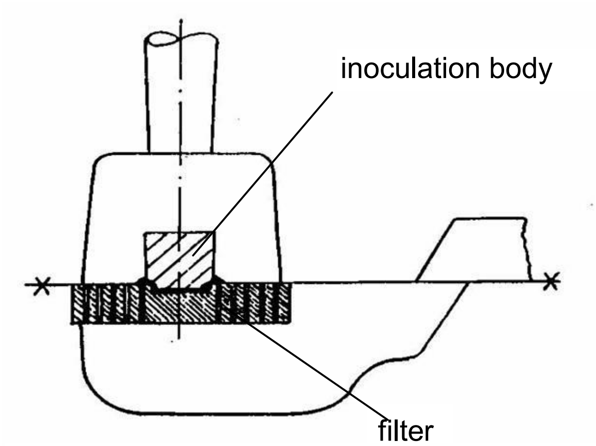


Fig. 39: Inoculation bodies on a filter

In the casting of iron, the method of graphite inoculation of metal by inoculation bodies has been spreading. FeSi-based bodies are placed in the pouring basin or gating system. This method combines the effects of inoculation and filtration. The bodies are bonded to the print on the filter inlet side. The filters are situated below the sprue so that the metal flow impinges on them - see Fig. 39. With this arrangement, the body is in an area of intensive metal turbulence, and it can be assumed that the inoculant will be dissolved properly. A sufficiently large chamber must be pre-moulded above the body.

The size of inoculant is chosen according to the volume of metal flow. To speed up the start of inoculation effect at the beginning of pouring, some producers deliver the filters with crushed inoculant applied on the filter inlet side. The amount of inoculant and the method of application must be chosen with respect to the metal temperatures and pouring times so that uniform inoculation is obtained during the whole pouring time.

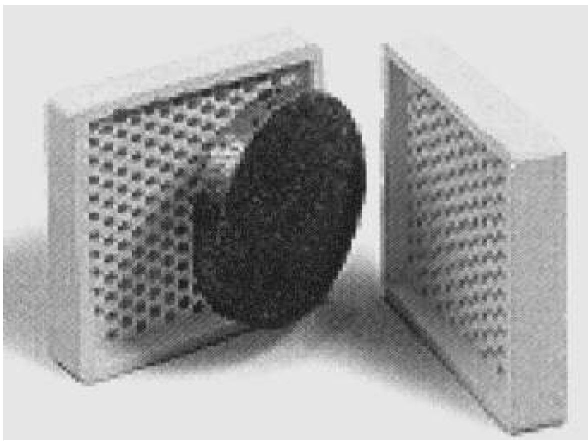


Fig. 40: Inoculant body in a split filter

Tablet-shaped inoculant bodies can also be placed in split ceramic filters. These are straight-hole pressed filters. Some producers combine filter halves with different hole sizes; the holes on the filter inlet side have a larger diameter and they capture coarser impurities in the inflowing metal, while the smaller holes in the outlet half capture finer inclusions and/or non-dissolved inoculant particles.

5.5 USING FILTERS IN DUCTILE IRON MODIFICATION BY IN-MOULD METHOD

When ductile iron is modified by the in-mould method, a huge number of inclusions are formed. These inclusions are either the product of the modification process or they are the

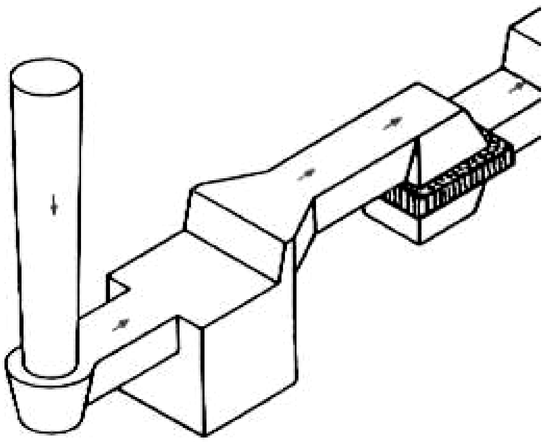


Fig. 41: Filter installation for in-mould modification

non-reacted particles of the modifier. Hence, it is necessary to install an effective filter behind the reaction chamber. In view of the great number of inclusions, it is of advantage to install the filter in horizontal or slanting position. In this case, some inclusions rise to the surface, and the filter flow rate is therefore higher than in the case of vertical position. A suitable method of filter installation is shown in Fig. 41.

When dimensioning the filter area, it is necessary to consider as maximum the cast iron flow rate of 1 kg/cm^2.

6 DIFFICULTIES RELATED TO FILTER APPLICATIONS

The application of filters brings certain changes in the design of gating systems and, above all, greater demands on satisfying the technological conditions of pouring. The main difficulties are usually the following:

- blocked filters
- premature clogging of filters
- peeling, cracking and erosion of filters

Blocked filters – this effect is caused by:

- low pouring temperature
- using too dense filters
- low pouring height
- unsuitable filter position without the possibility of pre-heating it (especially with steel)
- non-uniform filter porosity

Pouring temperature must be checked. The lower limit of pouring temperature is usually higher than it would be if pouring without filter. The minimum pre-heat temperature above the liquidus temperature is given by metal liquidity, filter density and pouring height.

Filter porosity is chosen according to metal liquidity and the rate of filter clogging. The filters with extremely small holes eliminate priming – the first metal does not at all flow through.

Pouring height is given by the filter height under the metal surface in the pouring basin. If a ladle with bottom outlet is used, the pouring height is given approximately by the height of metal level in the ladle, which is usually sufficient. A small pouring height does not provide sufficient pressure for metal priming.

Unsuitable filter position with respect to priming is such a position when very cold metal arrives at the filter. For high pouring-temperature alloys, it is suitable to pre-heat the filter by the first inflowing metal (see Fig.32).

Non-uniform porosity is a production defect that occurs only in foam filters. This defect is caused by structural non-uniformity of the foam used or by not respecting the technological conditions of filter production. In this case, the filters are either very thin (with a small ceramic wall thickness and large pores) or with a robust ceramic frame with clogged and, consequently, blocked pores. In the first case, there is a danger of mechanical damage and erosion, and in the second case, metal does not pass through the filter, the filter is clogged, and the pouring time is significantly prolonged. In the foundry, **it is recommended that the density of filters should be checked by weighing them. It is suitable to determine an optimum filter weight, and to reject filters outside the permissible limits.**

Premature clogging occurs:

- during the penetration of large slag particles (or other inclusions) towards the filter
- if inclusion contamination in the metal is higher than usual
- if the pouring temperature is low
- if too dense a filter or a filter with clogged pores is used

The capture of coarse inclusions must be ensured either in the pouring ladle (in that case a bottom outlet ladle or a tea-pot ladle is used for pouring) or in the pouring basin. Coarse particles that are not captured very often block the passage through the filter. **If pouring from tilted ladles is employed, it is recommended that pouring screens be used in the pouring basin. Increased metal contamination** can be due to different reasons, e.g. a very short time between metallurgical processing and pouring, with some alloys (especially aluminium alloys) it is improper refining. In hyper-eutectic ductile irons, liquidity can significantly deteriorate due to the elimination of primary graphite.

Filter density must be selected not only from the viewpoint of priming but also flow rate. When pouring a melt with a great number of inclusions (e.g. pouring ductile iron with a high initial content of sulphur), it is possible to achieve the required flow rate by either increasing the filter area or choosing less dense filters (at the cost of lower filtration efficiency at the beginning of pouring).

Damage to filter ceramics – cracking, bending and erosion

is caused by:

- defects in the production process at the manufacturer’s
- using an unsuitable filter type, e.g. with lower refractoriness than corresponds to the type of cast metal, very thin filters, etc.
- incorrect filter location in the gating system

Poor quality of the filters delivered can be recognized even by a layman from the peeling ceramics, breaking edges, low strength of filters, their unusual weight (too light or too heavy), sometimes evidently incorrect dimensions. Such filters should not be used.

The filter type must correspond to the type of metal. This holds in particular for high pouring-temperature metals where the application of filters with insufficient refractoriness results in filter cracking or erosion.

Erosion is not caused by mere ”dissolution” of filters due to very high temperatures but by chemical interaction between filter ceramics, slag particles and metal, and also by the action of hydrodynamic forces.

Hydrodynamic forces that arise in the filter are similar to those which damage the pump and water turbine vanes. As metal flows around individual filter profiles, turbulences and pressures appear that result in ceramic particles being torn out and the filter being eroded. This phenomenon is called WAKE and its principle is shown in Fig. 42. The origin of non-metallic inclusions that are found in a casting is not caused by poor filtration efficiency but by

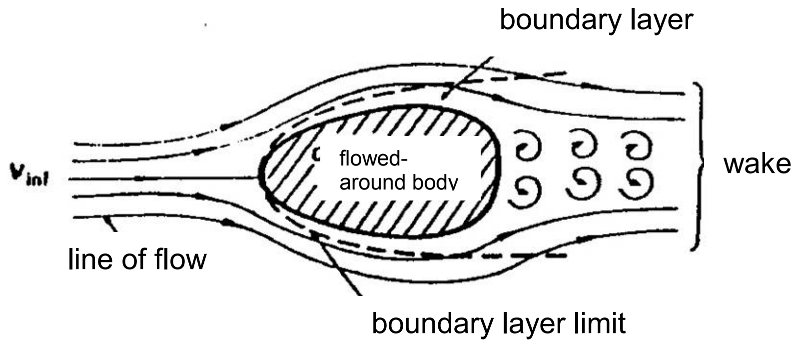


Fig. 42: Appearance of wake when metal is flowing through the filter

the erosion of the filter. Not only the properties of filter ceramics, but also any improper shapes and gating system profiles contribute to the erosion.

Filter thickness must correspond to surface area dimensions. (Mechanical stress of filters increases with the square power of dimension.) Hence the thickness of larger filters must be higher compared to small filters. Very thin filters will bend, crack or erode.

Filter insertion should be done in such a way that the filter is supported in the prints in as large a part of the circumference as possible. Seating the filter on only 3 sides of the circumference is not suitable because much higher bending stresses then appear in the filter.

Extremely high temperatures of metal and **pouring directly on the filter** are frequent causes of the defects produced in foundries**.**

The filters must be inserted into the mould with much care in order to avoid abrasion or breaking. There must be adequate clearance in the prints. To prevent the peeling of foam filters during handling, refractory paper is often applied to filter circumference

Before positioning the filter, it is suitable to blow it through with compressed air.