INCLUSIONS

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Here is one more presentation by Staf Henderieckx, the foundry expert from Belgium, presently residing in The Netherlands. In earlier three presentations which appeared in FOUNDRY in past, the focus was on (i) Iron Chemistry, (ii) Carbides in Ductile Iron, and (iii) Quality. In this presentation he focuses on ***Inclusions*** *– metallic, non-metallic and gaseous. He shares with foundrymen the world over, through such presentations, his long and rich experience as well as deep insight about various aspects of foundry technology and business.*

1. INTRODUCTION

Presence of inclusions in castings, whatever the type of material, is one of the most common problems in foundries. An average, quality conscious foundry, which has mostly solved the porosity problem to a very large extent, experiences the presence of the following non-conformities (repairable or not) :

Inclusions	50 - 55 %
Sand penetration	10 - 15 %
Shrinkage	10 - 15 %
Cracks / Tearing / Cold-shut	10 - 12 %
Others	6 - 8 %

To evaluate the problem, it is necessary to look at the type of inclusions and the cause or location or origin.

2. TYPES OF INCLUSIONS

There are mainly **three** types of inclusions: metallic, non-metallic and gas inclusions.

2.1 Metallic Inclusions

Metallic inclusions can also be of **three** different types:

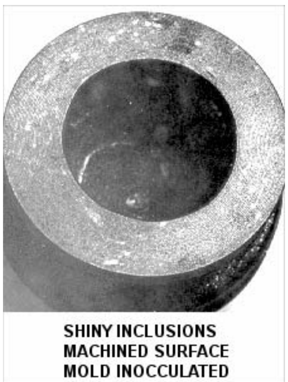
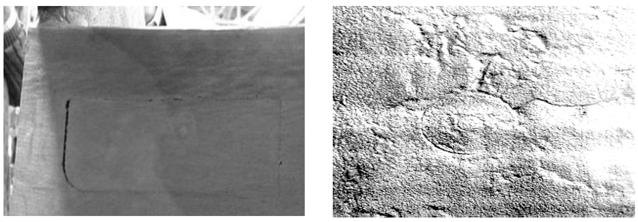


Fig. 1 : *Fe-Si inclusions in Grey Iron.*

(i) Non-dissolved Ferro-Alloys : This is mainly the case with **ferro-silicon** used as an inoculant in case of iron. When it is added at a very late stage, it has little or no time to get dissolved in molten metal, or when it is added in molten metal having very low temperature, it cannot get dissolved anymore.

(ii) Excessive Addition of an Alloying Element : When the added quantity of an alloying element is higher than the dissolving capacity of the base metal, based on its temperature, part of it will not get dissolved. A typical example is a very high and late addition of copper to iron (resulting in a brown to red coloured surface of the casting).

(iii) Foreign Material : Besides tools (e.g. a hammer), which can fall in the mould cavity before metal pouring, it is possible that chills will come loose from the mould and enter the liquid metal of the casting. Another possibility is the presence of non melted internal chills (cooling nails) or chaplets.



Chill **Chaplet**

Fig. 2 : *Unfused Chill and Chaplet in the solidified metal*

2.2 Non-Metallic Inclusions

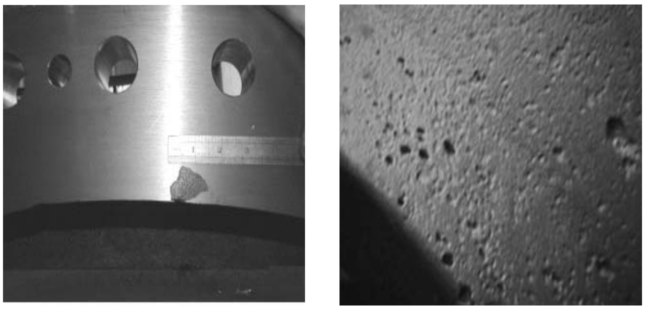
There are **two** main types of non-metallic inclusions: those formed outside the mould cavity and those inside the mould cavity. This difference is important as there will be different solutions to solve these problems.

(i) Formed Outside the Mould Cavity : This can be:

- Slag or furnace refractory (lining): slag from previous melt, re-dissolving in the metal, lining coming loose etc.
- Slag or ladle refractory: slag from previous melt, re-dissolving in the metal, lining coming loose etc.
- Slag from desulphurization products (in case of ductile iron)
- Slag due to nodularising and/or inoculation
- Slag from coagulant (i.e. from deslagging agent)
- Oxidation products (e.g. Cr-oxide, Al-oxide etc.)
- Contaminants, foreign objects (e.g. riser sleeve material etc.)

(ii) Formed Inside the Mould Cavity : This can be:

- Loose sand in pouring system or mould cavity
- Mould and core erosion material
- Oxidation due to turbulence in pouring box-sprue-runner system
- Oxidation due to turbulence in gating system
- Coating particles coming loose from the mould
- Mould treatment alloy reaction products (in-mould nodularising and/or inoculation)
- Not-reacted mould treatment alloys (nodulariser, inoculant)
- Contaminants (from mould, like riser sleeve material)
- Ceramic inclusions (refractory pipe, filter etc.)
- Reaction-products of organic nature in the mould (metal-mould reaction)
- Non-metallic materials rejected out of the metal (e.g. slag)



Sand **Slag, fine sand particles**

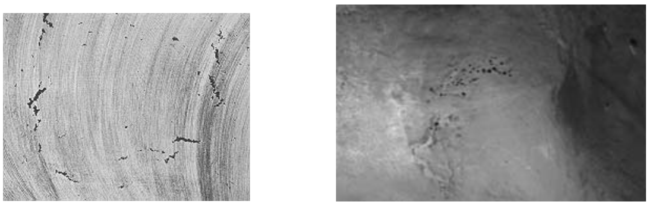
Fig. 3 : *Sand and Slag Inclusions*

2.3 Gas Inclusions

There are **two** types of gas inclusions: single element gases and complex gases.

(i) Single Element Gases like**:**

- Hydrogen (from water, humidity…)
- Nitrogen (from mould material, alloying elements…)



Gas inside metal section **Surface gas inclusions**

Fig. 4 : *Gas Inclusions*

- Oxygen, which is mostly present as oxides, and not as gas.

(ii) Complex Gases like**:**

- CO being formed above the equilibrium temperature of the metal present in the furnace
- Air, which could not escape from the mould cavity
- Gases from mould and core material, entering the liquid metal.

Presence of single element Gases and CO is due to the fact that it exceeds the solubility of that element in the liquid metal because the solubility of these gases decreases as the temperature of the liquid metal decreases.

The presence of gas depends on the temperatures (in furnace, pouring temperature…), type of mould material, coating condition (dry or not, water or alcohol liquefied…), the environment (humidity, monsoon season…) and the location and section of the vents.

Sometimes slag inclusions are combined with gas inclusions, due to the exothermic nature of the slag.

3. SOLVING THE PROBLEM

To discuss the solutions, it is necessary to start from the location of the inclusion where it is formed: (i) outside the mould, (ii) in the pouring system, or (iii) in the mould cavity.

3.1 Inclusions formed Outside the Mould

All inclusions formed in the metal before pouring should be removed and not poured into the pouring box. This means that **slag removing is very critical**. Because it is not an easy job, many times it is performed in a bad way. For this reason, provide good tools and personal protection and deslagging agent to assure a good result.

It involves:

- good removal of slag from the metal in the furnace, before the metal is tapped
- melting only one type of metal in one furnace to avoid formation of complex reaction products
- making lining of melting furnace and that of ladle from refractory of the similar nature

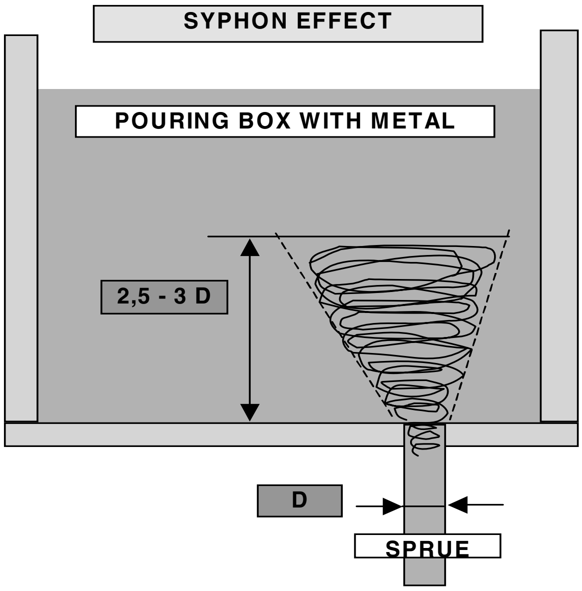


Fig. 5 : *Siphon effect related to the sprue diameter*

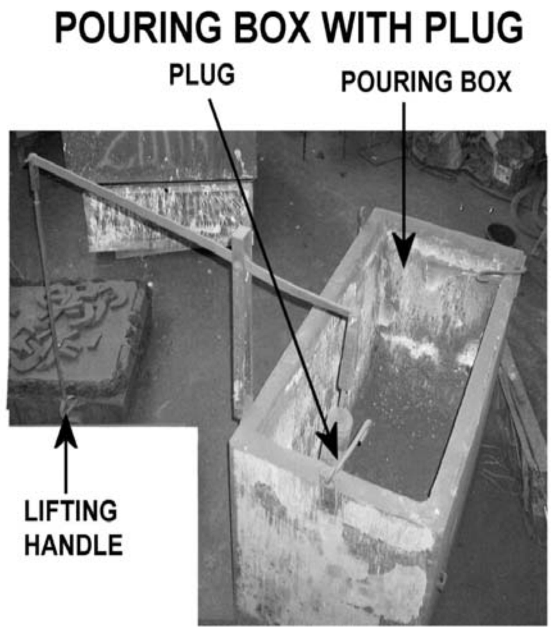


Fig. 7: *Example of pouring box for large castings (up to 10 to15 tonnes)*

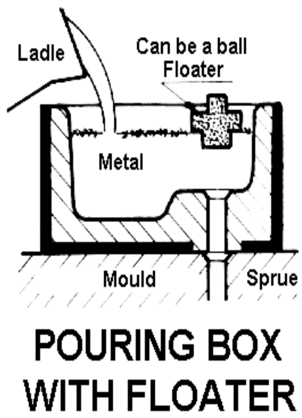


Fig. 6: *Design rules of pouring boxes for castings up to 100 to 200 kg*

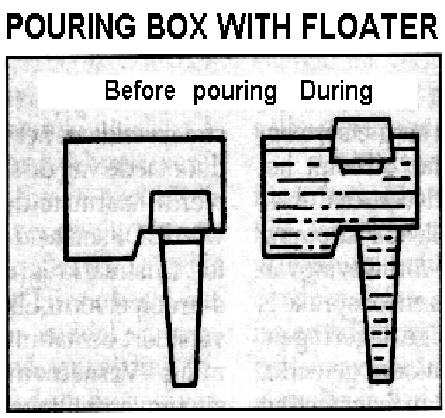


Fig. 8 : *Use of a Floater Plug*

- use of clean ladles
- removing slag from ladle after metallurgical treatments (viz. desulphurising, nodularising…).

It is also possible that during metal pouring in the pouring box new slag is formed, due to decreasing solubility of gases and other elements with decreasing temperature of the molten metal. Amount of such slag can be decreased by:

- keeping the melt as long as possible at **low** temperature
- removing slag in the furnace at **high** temperature, which will increase slag formation as well as gas content, and it can decrease metallurgical quality level of iron.

The amount of new slag formation can be minimised if the distance between the ladle and the pouring box is kept to a minimum. This requires a skilled and experienced pouring operator and a skilled team working in pouring and crane operation.

Whatever the result, the **pouring system** should be able to hold the inclusions poured into the pouring box.

The **pouring system** consists of pouring box, sprue, runner(s), ingate(s) and vents (sometimes risers are also taken into account). If filters are used, they are also part of the pouring system.

The first and very important element is the **pouring box**. Many foundries use incorrect box or box incapable of retaining inclusions. As in every container with a bottom outlet, there will be a syphon effect, which sucks air and inclusions in the metal stream and entering in our case the sprue and mould cavity. The pouring box should be designed to minimise this effect, which indicates a minimum height. Figures here give some examples of good systems.

3.2 Inclusions formed in the Pouring System

There are several causes:

- sand and dirt left in the pouring system during closing the mould
- incorrect material used in pouring system: bad sand condition, soft and/or brittle refractory pipes…
- incorrect design of pouring system, promoting formation of inclusions (slag)
- too high turbulence, due to too high metal velocity (slag, sand erosion…).

There are **two** types of pouring systems: pressurised and non-pressurised. Both are capable to hold inclusions if they are properly designed and used.

The elements that are necessary, independent of the type of pouring system, are:

- **Sprue pit**, in which quickly falling molten metal falls on the molten metal just previously entered. This is less dangerous than the poured metal directly touching the runner bottom at a high speed.
- **Slag pit**, which must hold the first metal, which is cold and dirty because it cleaned the pouring system.

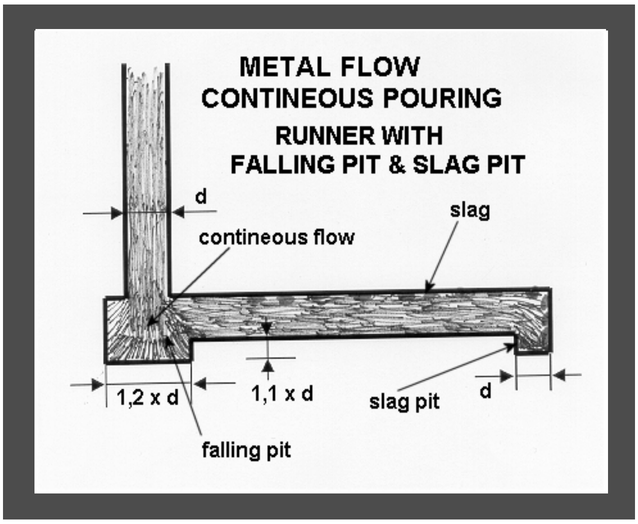


Fig. 9

Pressurised system : The pressurised system is preferred for low height moulds (up to maximum 1 m). The smallest section (choke section) is the ingate section.

The **section ratio** is:

$$S_{sprue} : S_{runner} : S_{ingates} = 1 : 2 : 0.75 - 0.85$$

The design is indicated in *Fig. 10.*

Non-Pressurised system : The non-pressurised pouring system is mostly used for high moulds, for moulds with more than 2 castings in one mould and when a filter is used. The smallest section (choke section) is the sprue section.

The **section ratio** is:

$$S_{sprue} : S_{runner} : S_{ingates} = 1 : 2 : 2 - 2.1$$

The design is indicated in *Fig. 11.*

3.3 Inclusions formed in the Mould Cavity

The formation is mostly due to a too high entering speed of the metal, which leads to turbulence, which, in turn, can promote slag reactions (Mg-slag in ductile iron), and/or sand and coating erosion in the mould and core.

If the mould material has too low strength and/or the coating is incorrectly applied, it will erode and go as inclusion in the liquid metal.

Another cause is the sand and/or any other material left inside the mould cavity during mould closing. It is also possible that this will lead to mould material-metal reactions that result in slag as also gas.

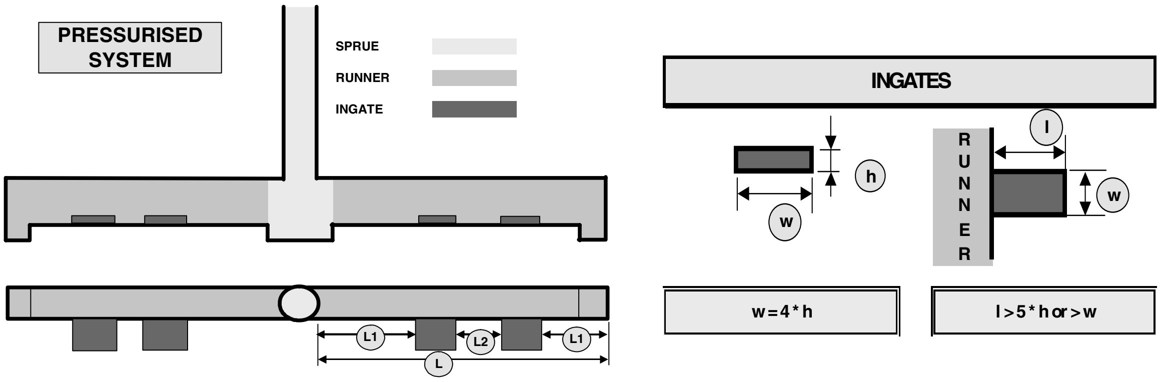


***Fig. 10 :** Schematic View of a Pressurised Gating System*

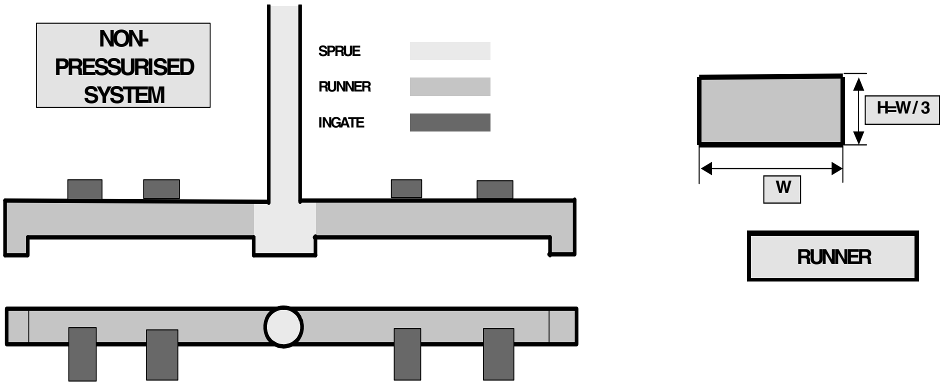


***Fig. 11 :** Schematic View of a Non-pressurised Gating System*

The last possibility is that gas is leaving the metal due to decreasing solubility at the time of solidification. This is especially the case for single gases like hydrogen, nitrogen and, to a lesser degree, oxygen.

Fig.12 shows the result in pure iron (Fe).

This indicates that, if there is a high gas content, especially nitrogen and hydrogen, after melting, there will most probably be a problem.

The problem for hydrogen is a little less as compared to nitrogen because of the high diffusivity of hydrogen (100 times higher) in iron alloys as compared to nitrogen.

Nitrogen solubility also depends on the chemical composition, which can be adapted, staying within the standard required limits, to increase it to the maximum. Gas that is soluble will not appear as a gas inclusion.

The following formula is mentioned for unalloyed iron alloys (T is temperature in °K) and if not correct, it indicates the influence of each element:

$$\mathbf{lg\,(\%N) = -\,(1000/T) - 0.86 - 0.06(\%Si + \%S) - 0.24(\%C) - 0.15(\%P) + 0.015(\%Mn) + 0.03(\%Cr)}$$

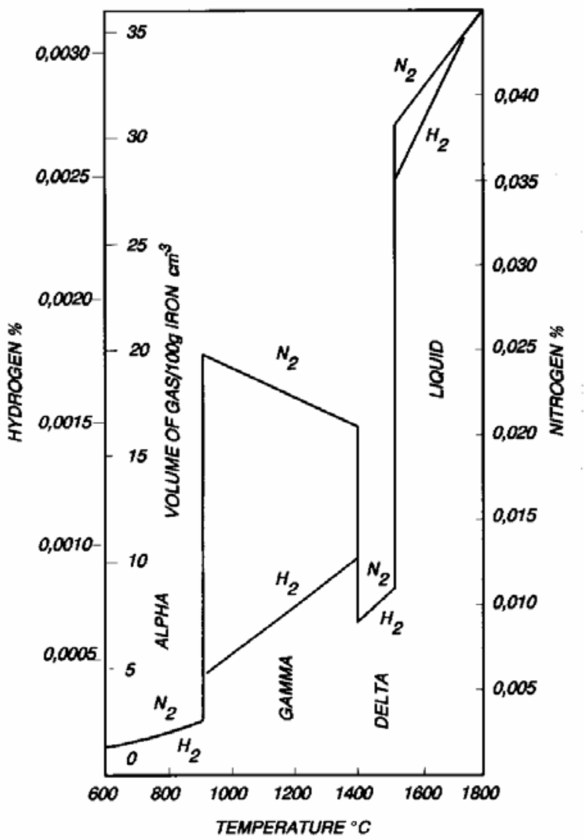


***Fig. 12 :** Nitrogen and Hydrogen solubility in Iron*

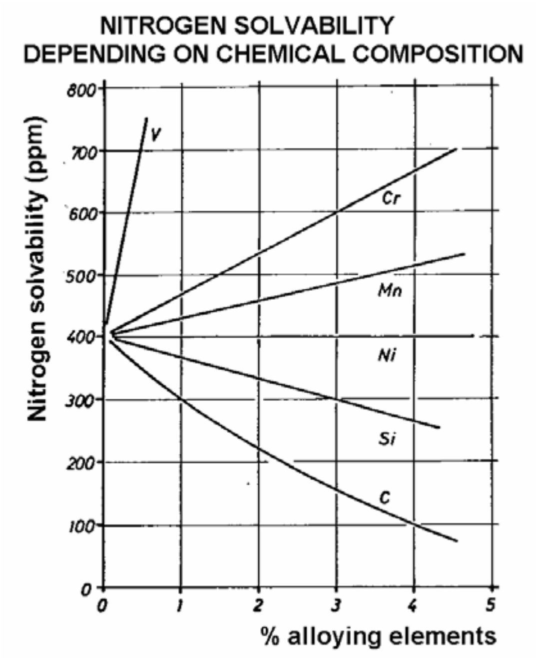


Fig. 13 : *Effect of Alloying elements on Nitrogen Solubility in Iron*

Another source is referring to the next figure, indicating that Mn, Cr and V are increasing the solubility, whereas silicon and carbon do have a decreasing influence (which is similar to the formula above).

Another possible gas source is from the mould material. If the LOI (Loss of Ignition) is high, there is a chance that the gas formed during heating of the mould material, will enter the liquid metal.

These inclusions (slag, sand…) can only be removed into the risers and or vents. The gas can easily be removed through the risers and vents and a little less through the mould material if the permeability is sufficient and/or small vent piercing is performed. It is dangerous to count on the permeability, especially for chemically-bonded sand, but it is safe to count on the venting.

For this reason the following is important:

- To have clean (deslagging) and low gas (degassing) containing metal because risers with a lot of inclusions will be less active.
- To adapt chemical composition for maximum gas solubility.
- To have vents on all high and/or separate high locations (in the mould) of the casting.
- To assure that the section of the venting is equal or larger than the choke section of the pouring system.

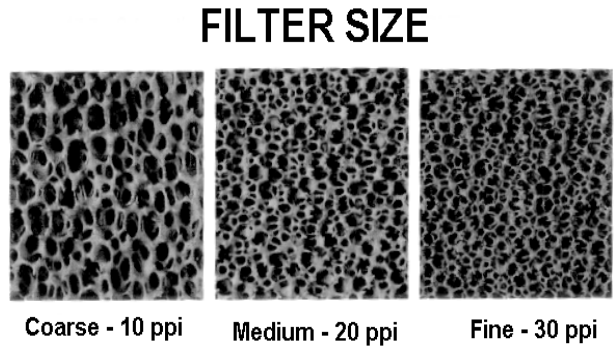


Fig. 14 : *Different Pore sizes in Filters*

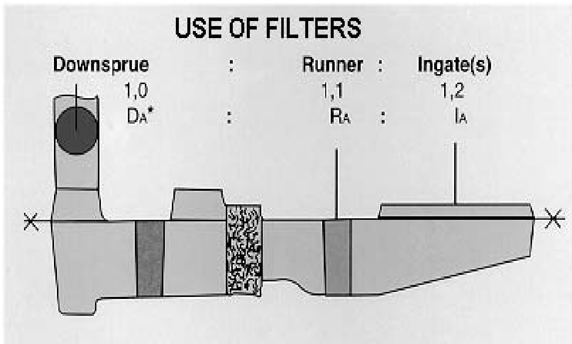


Fig. 15 : *Schematic view of placing a filter in a gating system*

4. CONCLUDING REMARKS

It is important to avoid inclusions entering the mould. This calls for proper melting, especially temperature control, and proper removal of the slag and gas. Please also pay attention that the pouring ladle (for low height metal fall) is very close to the pouring box during pouring.

The pouring system must be designed and calculated such that it will not promote new inclusion formation and that it can retain the inclusions and prevent them to enter the mould cavity.

The inclusions that are formed in the mould cavity are the most dangerous. The main reason is the high entering speed (and turbulence) of the metal and a high gas content. The best possibility to get the inclusions out is removing them through risers and vents. Counting on the permeability for the mould material "can" help for gases, not for solid and liquid state inclusions.

But it is certain that the foundry is in charge and can solve this problem to a very great extent, even without the use of filters, which may sometimes cause more trouble (if incorrectly used).