# Modelling Filters in Light Alloy Casting Processes (or "What Really Happens When Aluminium Flows Through a Filter")

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## ABSTRACT

A number of different types of so-called "filters" are used in the metalcasting industries with the aim of imparting some cleaning effect and flow control on the liquid metal as it passes through them. The filters range from simple planar meshes through extruded channels to reticulated foam structures and they are manufactured from a range of materials going from metals to glass or ceramics. It is most common that software packages used in the industry model the filters by a simple pressure drop associated with some area fraction and permeability parameters.

Recent experimental work at the IRC in Birmingham (Cox et al., 2000) has shown that filters of the same type can behave very differently depending upon the casting process in which they are employed. Modelling filter geometries for a range of different casting processes has indicated that the flow of metal and heat losses through the filters are rather complex and should be considered when using filters in the casting processes. This paper will present a number of cases of different types of filters modelled and different processes and indicate some of the sensitivities of the processes to boundary conditions imposed by the process.

## INTRODUCTION

Filters are commonly used in the foundry industry. The real action of the filters on the liquid metal is not really understood. Some filters are claimed to have a chemical action on the liquid metal or to be able to clean the metal by stopping the impurities or oxides that will result in inclusions in the cast part. However, some recent experiments carried out at the University of Birmingham in investment casting and results available on sand casting (Backman at al., 1999) have shown that the action of filters may be different in these two processes. As the main difference between these two processes is the mould temperature, the hypothesis of a partial solidification of the metal in the filter occurring in the sand casting process during the "priming" stage of the filling has been advanced, whereas there is no or less solidification in investment casting. In order to verify this hypothesis, and to reach a better understanding of how filters work, a numerical investigation of the flow and heat transfer in filters in both sand and investment casting has started at the University of Birmingham, in the framework of the FOCAST project. The FOCAST[1] project is an EPSRC project aimed to increase the understanding of the investment casting process.

Another issue is the way the simulation packages predict the influence of the filters on the metal flow. The filters are most of the time modelled as porous obstacles characterised by a pressure drop calculated from porosity and some surface ratios such as open porosity or proprietary coefficients. For example, for an extruded ceramic filter, with an open porosity of 0 in the directions normal to the extrusion direction (direction of the flow of the liquid in the filter as well) and an open porosity equal to $1-\frac{S_c}{S_f}$ in the direction of extrusion, where $S_c$ is the surface occupied by the ceramic in a section normal to the extrusion direction and $S_f$ is the total surface of the filter in the same section, the flow loss coefficient can be calculated from the permeability of the filter using the formula given in equation 1, where $K$ is the flow loss, $P$ is the permeability of the filter, m is the viscosity of the liquid metal, $r$ his density and $V_F$ the volumetric fraction of fluid which is equal to the open porosity in the direction ofd extrusion of the filter. The permeability can be estimated from equation 2 (Scott et al., 1986), where d is the hydraulic diameter of the canal through which the liquid is flowing, $V_F$ is the volumetric fraction of fluid, $b$ and $l$ are dimensionless parameters determined from the geometry of the porous media.

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[1] For more details http:\\irc.bham.ac.uk\epsrc\focast

$$K = \frac{\rho P}{\mu V_F}$$ Equation 1

$$P = \frac{d^2}{b}(V_F)^\lambda$$ Equation 2

This paper will present the preliminary results of this numerical investigation. First, the different models that have been used are presented, followed by the results obtained. A discussion of these results and their perspectives conclude the paper.

## MODELS

Three kinds of geometry of filters have been considered. Figure 1 shows the straight extruded filter (a), the shifted extruded filter (b) and the foam filter (c). Due to the complexity of the geometry of the foam filters, the resulting numerical model is huge in term of cells required to represent it. Therefore, very few results will be presented here for the foam filter. The shifted extruded filter does not exist in practice but is an intermediate model between the extruded and the foam filter, as it increases the tortuosity of the path that the liquid metal has to follow and keep the same volume or mass of ceramic material. It is still far from a foam filter as its thermal mass is very large compared to a foam filter. Three designs of filter print have been tried as well. Figure 2 shows them with the straight extruded ceramic filter.

Flow of liquid aluminium A356 [about 7% silicon and 0.6% magnesium] has been studied in sand and investment casting for the straight and shifted extruded filter. The thermo-physical data used for the aluminium alloy have been provided by the National Physical Laboratory (NPL, 2000). The liquid aluminium has been modelled as a Newtonian fluid. For the mushy zone, a variation of the viscosity as function of temperature described by equation 3 has been used.

$$\eta = K \exp\left(B f^s\right)$$ Equation 3

where $\eta$ is the viscosity of the metal, $K$ is the viscosity of the fully liquid metal, $B$ is the sensistivity of the viscosity to the solid fraction, and $f^s$ is the volumetric solid fraction.

For the filters, the heat capacity has been measured by Differential Scanning Calorimetry. The density has been measured. The heat conductivity has been estimated from the work of Hayashi et al. (Hayashi et al., 1998).

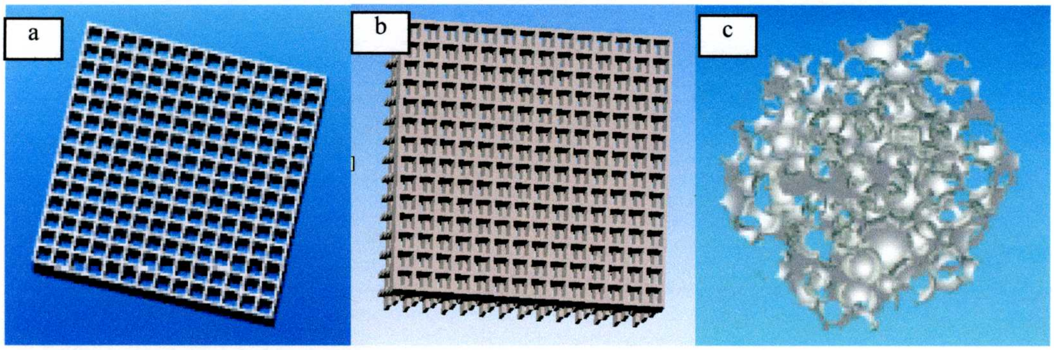

*Figure 1: Three kinds of filters, extruded ceramic filter (a), shifted extruded ceramic filter (b)*

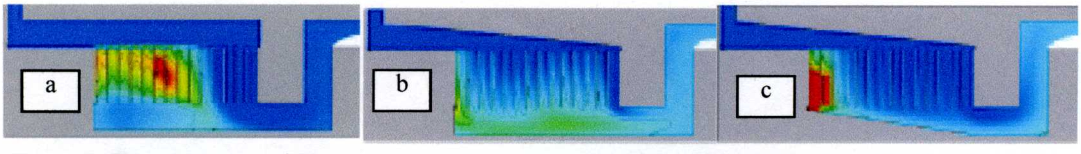

*Figure 2: Three designs of filter print, non tapered (a), top tapered (b) and top and bottom tapered (c).*

The heat transfer coefficient between the liquid metal and the filters has been estimated as a value of 20000 $Wm^{-2}K^{-1}$. The heat transfer coefficient between the liquid metal and the sand has been estimated as a value of 600 $Wm^{-2}K^{-1}$ (Woodbury et al., 2000). The heat transfer coefficient between the liquid metal and the ceramic shell has been estimated as a value of 10000 $Wm^{-2}K^{-1}$ (Stemmler et al., 2000).

## SIMULATION RESULTS

Simulation has been carried out using the three designs of filter print in sand casting. For the investment casting, only the non-tapered running system has been used. The simulations have been carried out using Flow-3D[2].

### MODELLING THE GEOMETRY OF THE EXTRUDED FILTER VERSUS USING A POROUS OBSTACLE.

Flow-3D is the package used for the simulation presented in this paper. One way to model a filter is to use a porous obstacle and define the parameters discussed in the introduction. This has been done for an extruded ceramic filter. In the same time, a simulation in which the filter is described as a obstacle by its geometry has been carried out. Figure 3 shows a comparison at a given time between the predictions of the two models. The prediction of the filling is in fact not very different with the two models, even if it can be seen on this pictures that the porous obstacle is less filled than the filter defined by its geometry. But there is a huge difference on the prediction of solidification, has shown on the figure. In the case of the porous obstacle, figure 3 left, the area where the maximum solidification occurs is at the bottom left of the filter, and there is only less than 10% solid. In the case of the filter defined by its geometry, the amount of the maximum solidification is in the centre of the filter, and the amount of solidified liquid is about 50%.

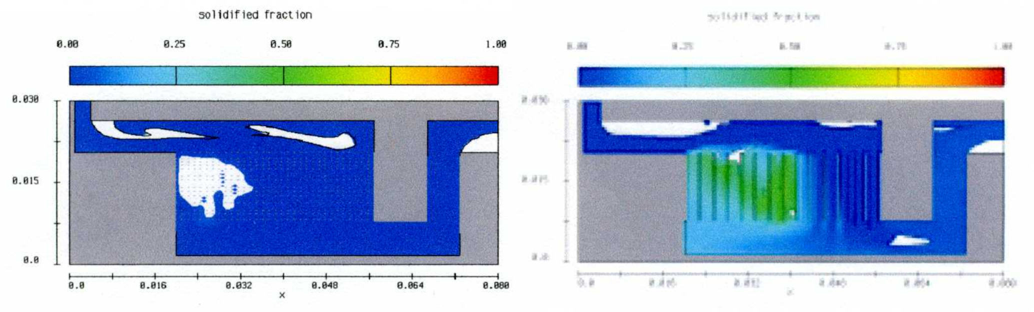

***Figure 3: Comparison of the filling and solidification predicted for an extruded ceramic filter modelled as a porous medium (left) and with its own geometry (right)***

### COMPARISON OF THE STRAIGHT AND SHIFTED EXTRUDED FILTERS.

In order to look at the influence of the geometry of the filter, comparisons have been made in the case of sand casting, with a non-tapered filter print.

Figure 4 shows the beginning of the filling for both straight and shifted extruded ceramic filters. Figure 4a and 4b show that the beginning of the filling is very similar with the two filters until the liquid metal start to enter the filter. Figure 4c and 4d show that in the case of the straight filter, the metal goes through it faster. They also show that the back filling of the runner above the filter is faster with the shifted filter. The filling of the filter is faster as well with the shifted filter. Figure 4e and 4f show that the position of the lowest temperature is affected as well by the flow of the metal in the filter. In these two figures, the red or dark color in the runner area corresponds to a temperature of about 650°C and the blue or dark color in the filter area corresponds to a temperature of about 570°C. With the straight filter, there is more re-circulation of liquid metal in the filter, and in fact, the lowest temperature area is in the middle of the filter, whereas with the shifted filter it is on the left side of the filter. In both cases, the lowest temperature is in the area where the velocity of the liquid metal is the lowest. For comparison, the exit temperature at 0.2 s. are about 611°C for the straight filter and 600°C for the shifted filter.

Figure 5 shows a comparison of filling time for the two kinds of filter. The volume of metal plotted corresponds to the volume

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[2] http:\\www.flow3d.com

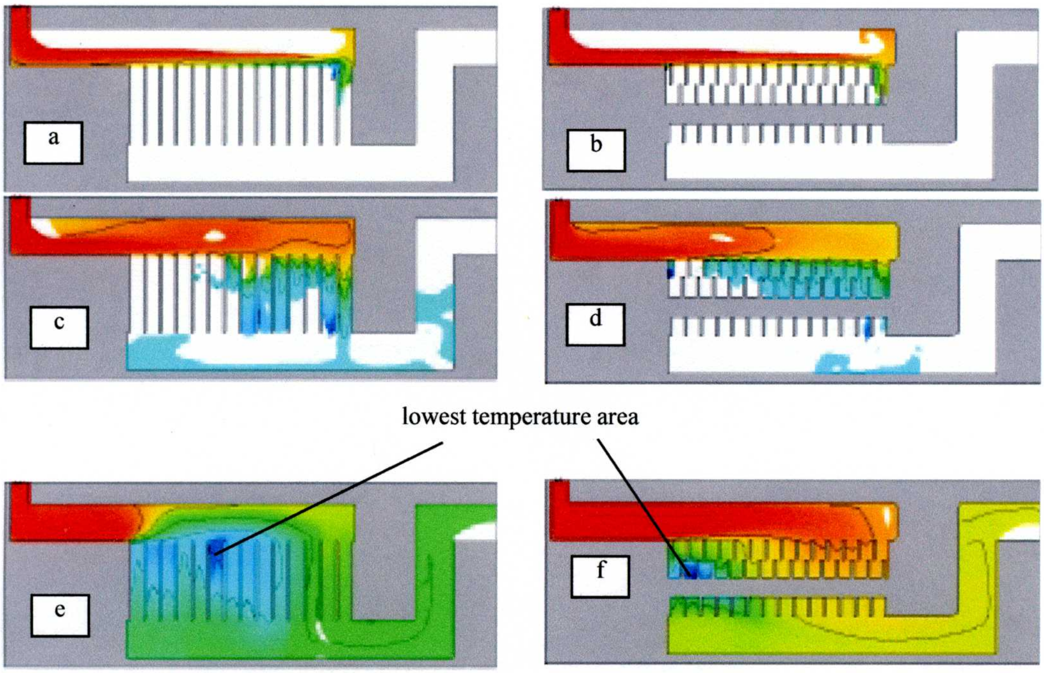

***Figure 4: Comparison of the filling with straight and extruded filter (coloured by temperature). a and b: 0.03s; c and d: 0.07 s; e and f: 0.2 s.***

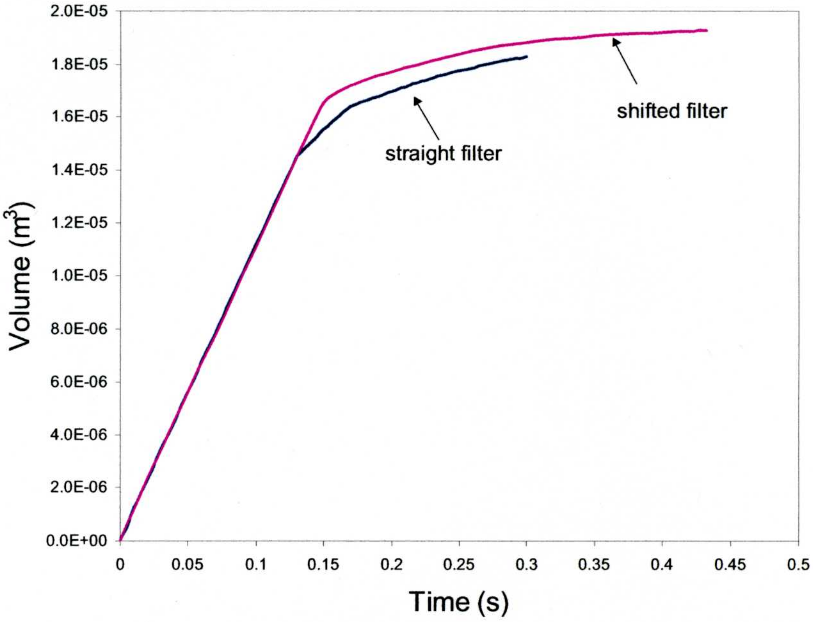

***Figure 5: Comparison of the filling time for the straight and shifted extruded filters.***

in the frame that is plotted in figure 4. The volume available for the liquid in the frame for the two types of filter are the same. Figure 5 shows that in the case of the shifted filter, after 0.13s, the volume increases faster than with the straight filter. After 0.15s, the evolution of the volume seems to be very similar, with an offset. The difference is explained by the back filling of the runner above the filter that is faster in the case of the shifted filter, as its permeability is lower due to the higher tortuosity of the metal path.

Another interesting parameter to investigate is the volume of solidified metal in our system. Figure 6 shows the comparison of the volume of solidified liquid, normalised by the total volume of metal. It appears that in the case of the shifted filter the