STUDY OF METAL FLOW THROUGH CERAMIC FOAM FILTERS

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SUMMARY

The paper treats of establishing the instantaneous flow rate, flow capacity of ceramic foam filters of 10 and 20 ppi porosity, and hydraulic resistance of filters when pouring ductile iron. The filters have been found to extend the pouring time.

Key words: foam filter, filter capacity, pouring time, pouring rate, hydraulic resistance

1. SUBJECT

A filter positioned in the gating system of the mould represents a hydraulic resistance that increases the overall resistance of the gating system to the flow of metal. In this way it reduces the flow capacity of the ingate and extends the pouring time. When considering the introduction of filtration, a number of foundries find the extension of pouring time to be a factor that poses technical difficulties. Not many data are available on the actual effect of filters on the pouring rate. Let us have a look at what the actual effect of filter is.

The filter is an element that captures in the gating system the impurities borne by the flowing metal. These impurities are mainly non-metallic inclusions formed by slag or moulding mixture particles, oxide films or also metallic inclusions – usually non-dissolved inoculant particles. These particles get captured on the filter input side or in the whole of its volume. According to thickness, there are flat filters (e.g. metallic

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screens or cloth filters) and volume filters (pressed, extruded and foam filters). On the filter input side the inclusions form a so-called filter cake. In the case of volume filters the inclusions get more or less captured also in the channels inside the filter. This process is referred to as in-depth filtration. The captured inclusions gradually clog the filter until it is blocked completely. For individual filters their flow capacity is therefore given and it is the amount of metal that should flow through the filter without any problem. The more effective the filter is, the more inclusions it captures and the lower its flow capacity is. In the literature and in manufacturers’ handbooks the flow capacity of filters is usually given as the weight of metal per 1 cm² of filter area or per filter of a certain size. The flow capacity of filters is given in dependence on the kind of metal, and the type and porosity of the filter.

The nature of the metal flow through a gating system with a filter is somewhat different from the flow through a system without a filter. The pouring begins with so-called “priming”. This is a stage in which the metal has flown up to the filter and has ceased flowing until it attains the required pressure and then it flows through the filter. From then onwards, pouring proceeds fluently but due to filter clogging it gets gradually slower. If the filter is properly dimensioned with respect to the size of the cast piece (and if the number of inclusions is not extraordinarily great), only the area with a low degree of filter clogging is practically used, where the reduction in pouring rate is not very significant.

The magnitude of hydraulic resistance due to the filter depends on numerous effects, the most important of which are:
- ratio of filter flow cross-section and the gating system choke
- filter thickness
- metal viscosity (given in particular by its composition, temperature and the amount of inclusions)
- rate of metal flow
- metal wettability of the filter (capillary forces play an important role in filters)

Due to hydraulic resistance, the metal does not flow at the theoretical rate of flow corresponding to the metallostatic (pouring) height $h$ according to the Torricelli relation

$$v_{\text{teor}} = \sqrt{2gh}$$  \hspace{1cm} (1)

but more slowly, at the rate

$$v_{\text{skut}} = \mu \sqrt{2gh}$$  \hspace{1cm} (2)

Coefficient $\mu$ is referred to as the rate coefficient and it is the ratio of the actual and the theoretical rate of metal flow. Its value lies in the interval $(0; 1)$. 
The rate coefficient is given by the sum of individual hydraulic losses $\zeta$ occurring in the gating system, according to the relation

$$\mu = \frac{1}{\sqrt{1 + \sum \zeta_i}}$$  \hspace{1cm} (3)$$

Hydraulic losses result from the friction of metal in the channels, internal friction (viscosity) of the metal, local losses due to changes in flow direction and changes in the channel cross-section size, etc. In the case of simple, short gating systems with large cross-sections these losses are small and the value of coefficient $\mu$ approximates 1 (in reality it is up to 0.8). However, with long gating systems of complex shapes and with small channel cross-sections and many changes in direction the sum of all resistances is large and the value of rate coefficient $\mu$ decreases (in complicated systems it can be even less than 0.2 – 0.3).

The filter resistance thus represents just another item of hydraulic resistance, due to which relation (3) changes to

$$\mu = \frac{1}{\sqrt{1 + \sum (\zeta_i + \zeta_{\text{filter}})}}$$  \hspace{1cm} (4)$$

The effect of the filter on the pouring rate depends on the magnitude of filter resistance $\zeta_{\text{filter}}$ with respect to all the other resistances in the gating system. In a complicated system the filter effect will therefore be small, in a simple system it will be relatively large.

Hydraulic losses in the channels depend very strongly on the rate of flow. The size of losses, expressed as the pressure loss $dp$ per unit length of channel $dL$, is rendered by the Forchheimer equation

$$\frac{dp}{dL} = a \cdot v + b \cdot v^2$$  \hspace{1cm} (5)$$

where $v$ - is the rate of metal flow in the respective channel section, $a$, $b$ - are constants.

It follows from the nature of this dependence that in the sections of gating system with a high rate of flow there are large resistances and, vice versa, in channels where the metal flows slowly, the resistances are relatively small. The greatest possible ratios of the filter cross-section and the choke area ($S_f : S_c = 4:1$ to $6:1$) are recommended not only in order to ensure sufficient filter flow capacity but also because
in an excessively dimensioned filter the metal flows at a low rate and hydraulic resistance of the filter is therefore smaller.

The effect of ceramic filters on metal flow and the clogging of filters with time were investigated on experimental gating systems when pouring ductile iron. The mould only consisted of the gating system, from which the metal flowed freely into another open mould, which had the function of a measuring vessel. This measuring mould was positioned on a rocker-lever system and its weight was continually measured using a strain gauge.

The cast iron poured was ductile iron, modification by the Sandwich method, with the content of Mg ranging between 0.04 and 0.045% and the pouring temperatures within 1360 to 1420°C. A tilting ladle was used when pouring. The foam filters used were of 10 and 20 ppi porosity, dimensions 35 x 35 mm, thickness 22 mm, made of SiC. To prevent large particles of slag from penetrating into the gating system a ceramic strainer was placed in the pouring basin. The metallostatic height of metal was 205 mm, the choke diameter was 20 mm. The ratio of filter area and choke area was $S_f : S_{ch} = 3.8 : 1$.

A typical plot of the weight of metal flow vs time is given in Fig.1. The differentiation of the weight curve with respect to time $\frac{dm}{dt} = f(t)$ gives the instantaneous weight pouring rate. The differentiation curve is formed by the rise section from the start of pouring to the maximum pouring rate, and by the descending section, which acquires zero value when the filter is totally clogged.

![Fig. 1. Example of the time-dependence of metal flow through a gating system with a foam filter of 10 ppi porosity](image)

Rys. 1. Przykład zależności czasowej przepływu metalu przez układ zalewania z filtrem pianowym o porowatości 10 ppi
The rise section of the curve is given by the process of filling the pouring basin and the gating system to a stable state. The duration of this stage depends particularly on the rate of filling the basin and on the volume of the system – in the course of our experiments it ranged from 4 to 7 s, exceptionally it was more.

The shape of the curve after reaching the maximum disproves the long-held idea of the existence of a stage of quasi-constant rate of flow followed by rapid filter clogging. Actually, when the maximum pouring rate has been reached, it starts to decrease continuously until the metal ceases to flow. According to available data, in the case of ductile iron it is recommended to consider a filter flow capacity of 2 kg/cm² for filters of 10 ppi porosity. It follows from the differentiation curve that with the 2 kg/cm² flow capacity (i.e. with a filter of 12 cm² in cross-section the weight of metal is 24 kg) we are in the descending section of the differentiation curve, in an area where the instantaneous rate of metal flow reaches about 55% of the maximum value.

The flow capacity of filters and their effect on pouring rate depend relatively strongly on filter porosity – see Fig.2. With filters of 20 ppi porosity the maximum pouring rate decreases by about 15% compared with 10 ppi filters but they get clogged more quickly. If we choose as the limit of filter flow capacity the amount of metal that has flowed through the filter by the time the pouring rate has dropped to half the maximum value, we find that the flow capacity of the 20 ppi filter is about 1.6 kg/cm² and that of the 10 ppi filter is about 2.3 kg/cm². These values are in good agreement with published data.

For comparison, moulds without the use of filter were also cast. Here, too, a rise section can be witnessed in the mould filling (again ca 4 – 5 s) after which the increase in metal weight is linear, i.e. the pouring rate is constant. At this stage the pouring rate is only given by the pouring height and by the hydraulic relations in the gating system. This situation is shown in Fig.2 (where the metal weight and the pouring rate are relative to 1 cm² of filter area).

The ratio of the pouring rate of a system without filter and the instantaneous pouring rate of a system with filter (given by the differentiation curve)

\[ \mu_f = \frac{V_{\text{with filter}}}{V_{\text{without filter}}} \]

corresponds to the instantaneous resistance of the filter and it is a function of the amount of metal that has flowed through the system – see Fig.3.
Fig. 2. Comparison of metal flow through a system with 10/20 ppi filters and without filter
Rys. 2. Porównanie przepływu metalu przez układ z filtrymi 10 i 20 ppi oraz bez filtra

Fig. 3. Rate coefficient of filters with 10 and 20 ppi porosity
Rys. 3. Wielkość współczynnika μ filtrów o porowatości 10 i 20 ppi
The type of filters and their gradual clogging do not affect the total amount of metal flow so markedly as the pouring rate does. If we consider the ratio of the pouring time with filter $t_f$ and the pouring time without filter $t_{wf}$ – i.e. the extension of pouring time due to the filter as a function of the weight of metal, see Fig. 4, we can see that at the start of pouring the extension of pouring time is not very significant but as the filter gets gradually clogged the extension is growing. For example, in the case of the 10 ppi filter, the pouring time increases by about 35% when the flow is 2 kg/cm$^2$ but then the increase grows considerably.

Let us now establish the reduction in the actual rate of metal flow with respect to the theoretical rate in a system without hydraulic resistance. With the metallostatic height of the pouring basin level 205 mm and with the narrowest cross-section of the gating system 3.1 cm$^2$ the theoretical flow of metal is 4.3 kg/s. The actual pouring rate in a system without filter was 1.85 kg/s (established by measuring). The gating system of a mould without filter has thus the rate coefficient

$$\mu_{\text{without filter}} = \frac{m_{\text{sec without filter}}}{m_{\text{sec theoretic}}} = \frac{1.85}{4.3} = 0.43$$

The rate coefficient of a system with filter $\mu_{\text{with filter}}$ varies with time. For a 10 ppi filter it is at the time of maximum pouring rate roughly equal to $\mu_{\text{with filter max}} = 0.38$, at the time of 2 kg/cm$^2$ flow it is ca $\mu_{\text{with filter}} = 0.32$.
From equation (4) the sum of all resistances \( \Sigma \xi \) of a gating system without filter (for \( \mu_{\text{with filter}} = 0.43 \)) equals 4.4. The resistance of the filter alone \( \xi \) when \( \mu_{\text{with filter}} = 0.38 \) is \( \xi = 1.5 \); towards the end of the declared flow capacity (\( \mu_{\text{with filter}} = 0.32 \)) it is \( \xi = 4.4 \) (that is to say it is comparable with the resistance of only the gating system without filter). The way in which inclusions get captured in the filter, which then leads to the metal flow through the filter getting blocked, is evident from the Baumann impression in the filter cross-section – see Fig.5. At this stage the metal flow was completely blocked.

![Direction of metal flow](image)

**Fig. 5. Inclusions captured in the filter**

Rys. 5. Wtrącenia wychwycone przez filtr

### 2. CONCLUSIONS

The tests carried out while pouring ductile iron revealed the time-dependence of the amount of metal and the progress of weight pouring rate during the flow through the gating system with ceramic foam filters.

At the start of pouring the filter does not present any significant hydraulic resistance. However, due to gradual clogging the filter resistance increases relatively quickly and when a flow of 2 kg/cm² is reached (this is the value usually given as the flow capacity of ceramic foam filters of 10 ppi porosity), the instantaneous rate of metal flow drops to about half the maximum rate of flow.

The extension of pouring time due to filter application is not very significant in the case of small flow capacities but with large flow capacities it is considerable. For a flow of 2 kg/cm² through a 10 ppi filter the pouring time increased by about 35%. We therefore do not recommend making full use of the declared filter capacity when dimensioning the size of filters.

Employing denser filters (for ductile iron a maximum porosity of 20 ppi can be considered) results in a considerable reduction of the pouring rate and a smaller flow capacity of the filters must be reckoned with.
The results given above relate to a concrete situation in the process of experimenting (metal composition, filter manufacturer, pouring height, metal temperature, etc.) and under different conditions the individual values will differ. The overall trend in the shape of curves can, however, be expected to be identical.

**BADANIA PŁYNIĘCIA METALU PRZEZ FILTRY CERAMICZNE PIANOWE**

**STRESZCZENIE**

Artykuł dotyczy ustalania chwilowej prędkości przepływu i wydajności przepływu ceramicznych filtrów pianowych o porowatości 10 i 20 ppi oraz odporności hydraulicznej filtrów w trakcie zalewania żeliwa sferoidalnego. Zauważono, że filtry wydłużają czas zalewania.

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