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The effect of filter type on filling during Low Pressure Die Casting: a numerical study

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ABSTRACT

Purpose: Purpose: Effect of filter types on filling during low pressure die casting researched to find optimal filtration design for wheel casting process.

Design/methodology/approach: Three types of filters, which are commonly used during low pressure die casting for light alloy aluminium wheel production, investigated with numerical simulation. In addition, numerical simulation for without filter is made for control variable. According to numerical simulation results, filling time, molten metal velocity results are used to define suitability of the molten metal for wheel casting. Thirteen Control points and two filtration areas generated to calculate the molten metal velocities before and after the filtration areas.

Findings: Three different filtration designs for aluminium wheel casting compared according to molten aluminium velocity results of numerical simulation in terms of flow of melt. Filtration design with flat filter is the optimal filtration design for aluminium wheels casting, according to numerical simulations. In addition, combination of other filters with flat filter is suggested to find optimal filtration design according to performance of filters during low pressure die casting.

Research limitations/implications: 0.5 m/s velocity for molten metal is accepted as a critical maximum limit for reliable casting according to literature search on aluminium casting. No field test was done in this study.

Originality/value: Effect of flow properties on casting quality is promising research field and the effect of filters is part of this research field.

Keywords: LPDC; Wheels; Simulation; Filtration; Aluminium

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ANALYSIS AND MODELLING

1. Introduction

Light alloy wheel is both an aesthetic part and safety equipment for passenger cars. Wheels must have sufficient mechanical properties and surface quality to meet these conditions. LPDC method is the main manufacturing method for light alloy wheels; this method has a low cost comparing with other permanent mould methods with reasonable mechanical properties and good surface quality. To make high-quality wheels, it's important to make production without any external or internal defects. The casting defects have relationship with mechanical properties and surface quality [1]. Metal purity is important because of this reason. Defects that are caused by melt purity are called inclusion. Inclusions vary according to the chemical composition of the melt. Filters are used to separate the inclusions from melt. Filters separate the inclusion, when molten metal flows through the filtration systems. So filters can't separate inclusions formed after filtration system. Previous reports specifying that "The filter cannot capture inclusions which are formed just behind the filter" [2].

There are three mechanisms of filtration; Filtration with straining, Filter cake formation, Depth filtration; shown in Figure 1. The inclusions that are larger than the filter holes can't pass through filter.

a)
b)
c)

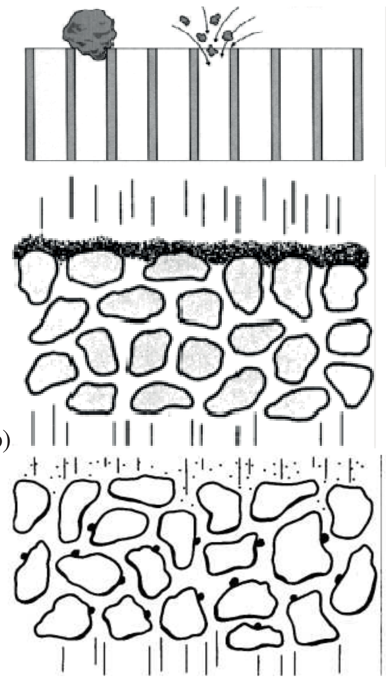

Fig. 1. Mechanisms of filtration a) filtration with straining, b) filter cake formation, c) depth filtration [3]

So the big inclusions are captured by filtration with straining mechanism (Fig. 1a). Filter cake formation capture inclusion on filter surface as the filtration with straining. But the larger inclusions which clogged the filter hole collect smaller inclusion on filter surface until filter totally clogged (Fig. 1b). Depth filtration is different from other filtration mechanisms. Depth filtration can be explained as a volume filtration. The Inclusions agglomerate the filter walls and stay separated from the melt (Fig. 1c) [2].

a)
b)
c)

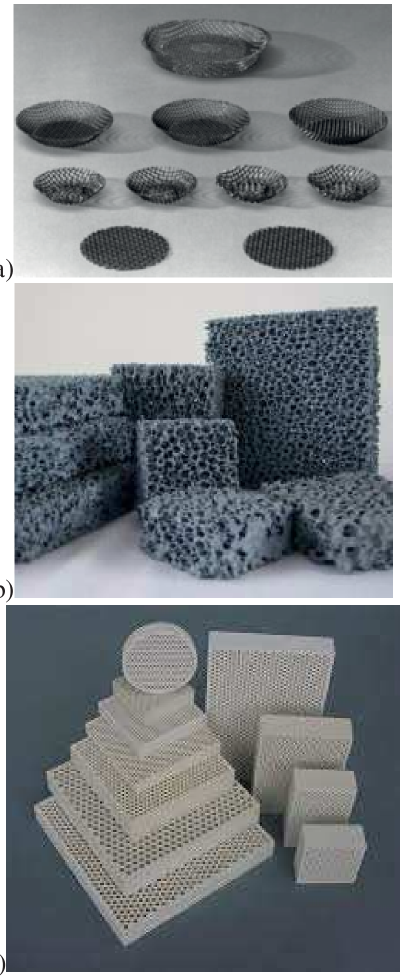

Fig. 2. Filter types a) flat filters, b) foam filters, c) extruded filters

Filter types are classified according their material or manufacturing method. For wheel casting 3 types of filter are most commonly used. These are; flat filters, foam filters, extruded filters, shown in Figure 2. The flat filter mesh size could be between 1.0-2.0 mm for aluminium casting (Fig. 2a). Foam filters are classified according to filter porosity (pores per inch) (ppi) and porosity changes between 20 and 40 ppi for aluminium casting. Extruded filters are classified according to density of filters (cell per square inches) (csi) and density changes between 50-300 csi for aluminium casting [2]. Filters regulate the flow of the molten metal by reducing the melt velocity (Fig. 3). If filter is clogged before the mould cavity, this would lead to a misrun. Because of this, the surface area of filter, the depth of filter, permeability of filter (mesh size, csi, ppi) and geometrical properties of filter are important for casting quality as if mentioned previous works [3-6].

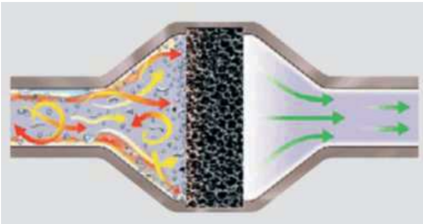

Fig. 3. Effect of filter on flow properties

Previous reports are specifying that, “The flow loss in the gate caused by filter can help calculation of filling parameters” [7]. These parameters are important for computer simulation of mould filling. The velocity of the melt after filter can be calculated as a function of pressure drop (ΔP). Geometry of filter and the effect of filter on flow can be estimated. The filling simulation of the wheel casting with different filter types is investigated using MagmaSoft V5.3. There are three types of filters; i.e., extruded filter (%65 porosity) with height of 100 mm, foam filter (10 ppi) with height of 100 mm and wire mesh filter with 2 mm mesh size (%55 porosity), are used for the filling simulations in MagmaSoft.

2. Material and method

In this study, numerical methods are used for the calculation the effect of filters on melt flow properties as previous works which studied [8-11]. MagmaSoft V5.3 software is used for the numerical calculations. The properties of the melt, mould parts and filters are chosen from MagmaSoft Database. In this study LPDC mould filling is made by counter gravity flow. At the beginning of the casting process, molten aluminium is held in the holding furnace at 720°C. Filling pressure is applied to airtight holding furnace according to filling process parameters with pressurising gases. As furnace, inner pressure increases, it pushes the melt up inside the riser tube. Therefore, molten metal starts to fill stalk and mould cavity due to pressure difference between furnace pressure and ambient atmosphere pressure.

Filing pressure parameters are held constant for all numerical calculations during this study. This condition assured filling parameters not to be effective on simulation results. Numerical calculations are made for melt velocity and vectors before and after the filtration areas. The filtration areas and measurement points summarized at Fig. 4. Filter area 1 is for extruded and foam filters, which cannot be used at casting gate due to the shape of the gate area. Filter area 2 is used for flat filter. The measurement points are used at the inflow and outflow zone of the filtration areas. X points are at the inflow zone of the filter area 1 and Y points are at the outflow zone of the filter area 1. Y points are important for the comparison of the stalk flow of the different filter types. Z points are for the measurement of the gate velocity of filters. Q points are for the measurement of the casting inlet area velocity. Q points are very effective on the casting quality.

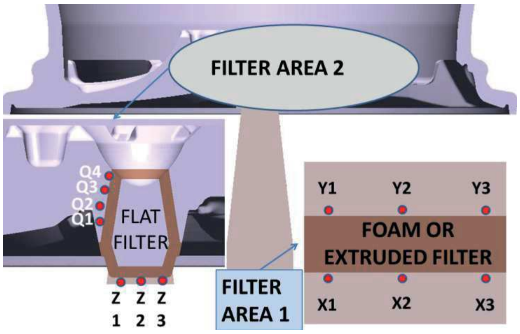

Fig. 4. Filter areas of simulation

Liu says, “The Mg/Al alloy emerging at the top of the inlet in an open space of bottom gating system, aluminium oxide film on the surface entrained into bulk aluminium melt at the velocity greater than 0.50 m/s” [12]. In this area, where the Q and Z points located, according to Liu, if the velocity of the melt velocity is greater than 0.50 m/s, this velocity will affect the quality of the casting.

In MagmaSoft equation 1 describe the pressure loss caused by a filter:

$$\Delta P = K_1 \cdot V + K_2 \cdot V \quad (1)$$

ΔP Pressure loss by the filter [Pa],
V Velocity of the melt [m/s],
K1 Coefficient [kg/(m^{2}s)],
K2 Coefficient [kg/m^3].

$$K_1 = L \cdot \eta / K_D \quad (2)$$

K1 Darcy's specific permeability,

L Length of the filter path (thickness) [m],
η Dynamic viscosity [kg/(m.s)],
KD Constant for structural properties.

The K1 and K2 coefficients account for laminar and turbulent pressure loss, respectively. The coefficients can be defined by experiment or theory. The K1 coefficient is related directly to the Darcy permeability (Equation 2).

Flow directions for the filter must be distinguished for two directions. The first direction is the main flow direction through the filter. The second direction is the cross flow direction. This can be considered as the anisotropy of the filter material. A sample filter configuration is shown in Fig. 5.

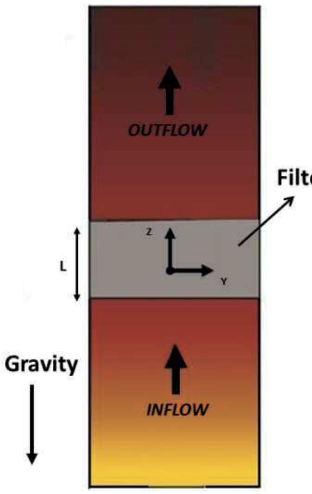

Fig. 5. Flow directions within a filter

The extruded filters have many channels that run parallel to main flow direction. So no cross flow exists for the extruded filters. Foam filters, on the other hand, allow flow in both directions. If the filter has isotropic properties, K1 and K2 are identical in main and cross flow direction. Therefore filter properties are determined as shown in Figure 6 [13].

The properties of filters as summarized on Fig. 6 are calculated with the experimental work on water or air by MagmaSoft. In this study, no experimental result is examined to calculate the properties of filters. So MagmaSoft database is used. If the two coefficients for the pressure loss calculation are known already, these values can be determined from the database.

Due to their geometry, foam and extruded filter are used in stalk. Flat filter is used at gating area. These areas are actual filter zones in casting practise. The geometry of the foam and extruded filter are not suitable for using at the gate. But flat filters could be formed to use at the gate area. Simulations are made considering these issues. Simulation mesh properties and the geometry are the same except for filter geometry, so the differences between simulations are filter geometries and the properties of the filters.

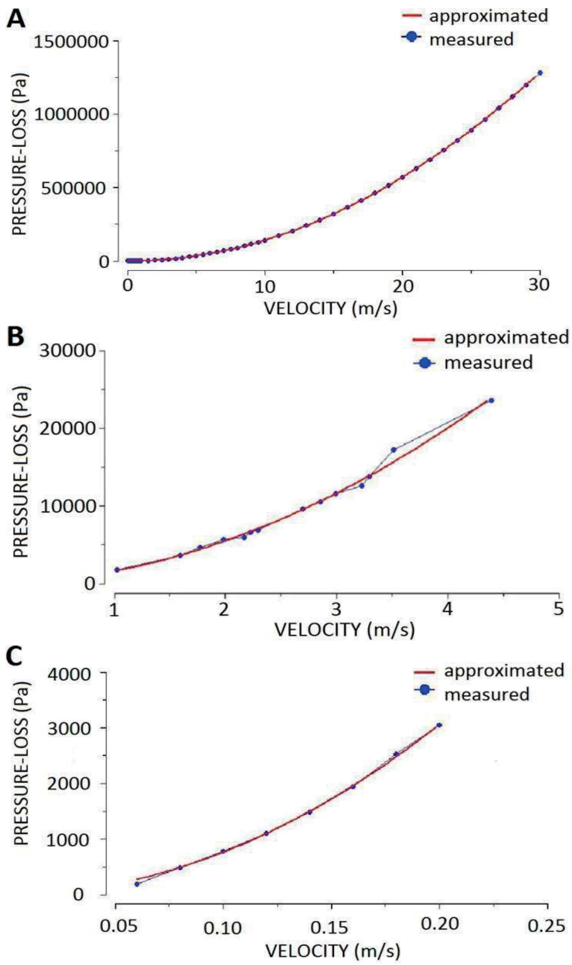

Fig. 6. The properties of the filters a) flat filter, b) extruded filter, c) foam filter

3. Results and discussions

As tabulated in Table 1 simulation results show that filter type has an effect on filling time. Without filter and extruded filter filling times are noticeably shorter than other filters. According to results, the longest filling time belongs to flat filter. The filling time of the foam filter is between the filling time of the extruded filter and the flat filter. The filling time differences show that filters are effective on casting filling time and flow properties.

Table 1.
Filling time results

Filter type	Filling time, s
No filter	18.045
Flat filter	28.966
Extruded filter	18.692
Foam filter	23.537

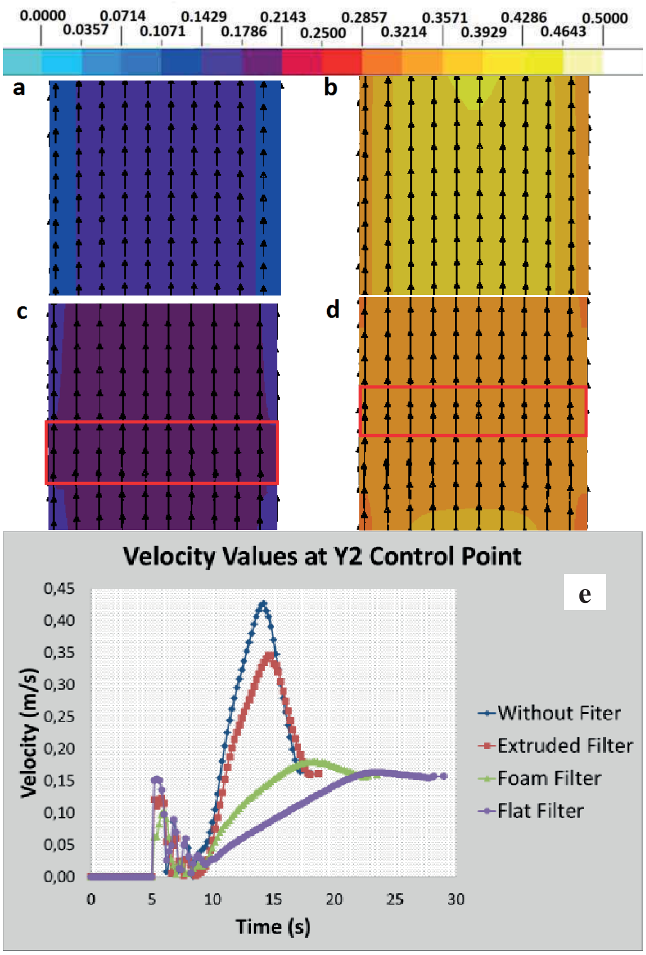

Fig. 7. The properties of stalk flow at the maximum velocity; a) flat filter, b) without filter, c) foam filter, d) extruded filter and e) velocity values at the control point Y2, (melt velocity at stalk)

Average values of the control point Y2 are shown in Figure 7e. Maximum filling velocity for the Y2 point is 0.43 m/s for the simulation without filter. With extruded filter, maximum filling velocity is 0.35 m/s. The velocity at the stalk with foam and flat filter are nearly the same and around 0.17 m/s. At maximum velocity, the flow properties of melt are shown at Figure 7. The vectors of the flow for all filter types show that there is no turbulence flow at the stalk. But velocity for the extruded filter (Fig. 7d) is more homogenous throughout the section of the stalk compared to other filter types. The velocity distribution of foam filter is nearly the same with extruded filter. For the rest of filter types examined, the flow velocity has a relatively high value on the centre line of the stalk. But as mentioned before, there is no turbulence flow and high melt velocity at the stalk. So the homogenous flow is not much effective on casting quality.

Level of melt velocity at the gate and casting inlet area is pretty effective on casting quality. The velocity values at the gate controlled by Z control points and at the casting inlet are controlled by control points Q. Control point Z2 velocity values summarized at Figure 8. Maximum velocity at the Z2 point is 1.10 m/s for without filter. With extruded filter, maximum velocity at Z2 point is 0.98 m/s. The velocity at the gate with foam filter is 0.52 m/s, and the velocity of flat filter at the gate is 0.32 m/s. Fig. 8 shows that the only acceptable flow properties are casting with foam and flat filter.

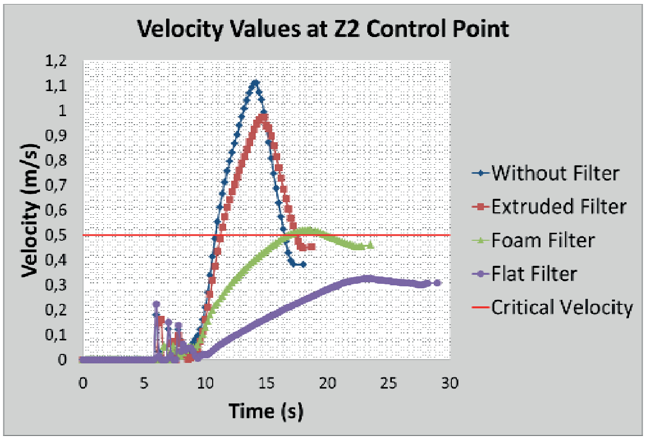

Fig. 8. Velocity values at the control point Z2, (melt velocity at gate)

When gate area is examined a noticeable velocity difference is examined throughout points Q1-Q4. Figure 9 represents the velocity values of control points Q and Z. Major velocity difference can be observed at control points Q1-Q4, regarding Z control points a slightly higher velocity is observed in the centre line (Z2) compared to the edge control points (Z1, Z3). This velocity deviation trough out sections represents a corresponding characteristic for X, Y and Z control points.

Because the highest velocity occurs at point Q4 so for a distinctive comparison of filter types Q4 point is evaluated. These results summarized at Fig. 10. Maximum velocity at the point Q4 is 1.0 m/s without filter, with extruded filter

0.9 m/s. Accordingly 0.48 for the foam filter and 0.32 m/s for the flat filter are attained. Flat filter simulation has resulted maximum velocity under 0.5 m/s pointing acceptable casting properties.

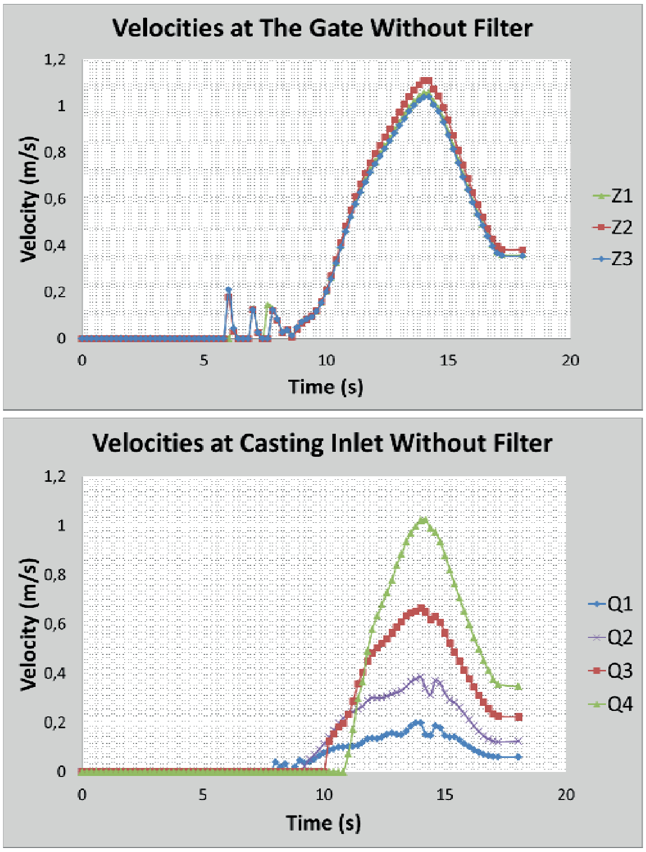

Fig. 9. Casting inlet and gate velocity values

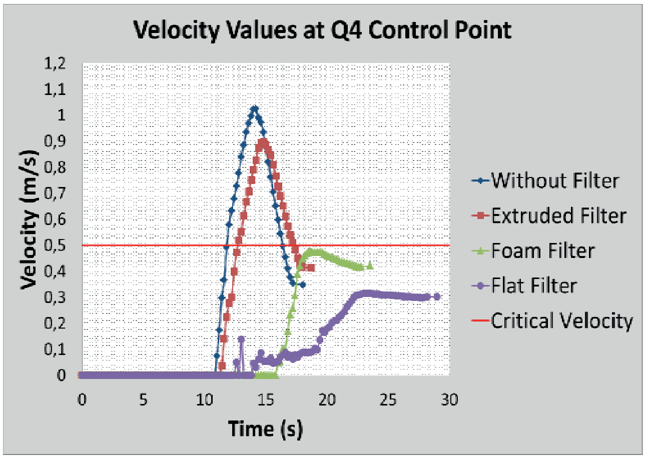

Fig. 10. Velocity values at the control point Q4, (Melt velocity at casting inlet)

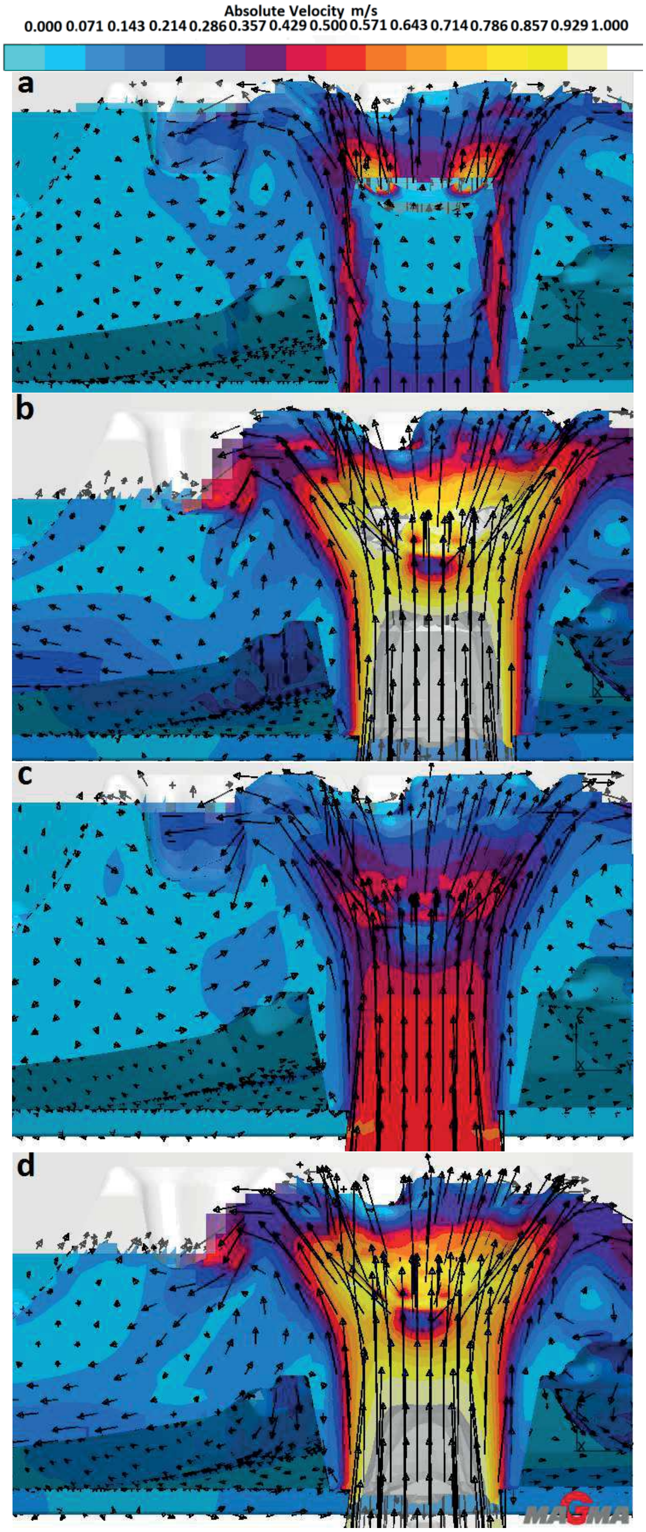

Fig. 11. The properties of the gate of the casting and casting inlet flow at the maximum velocity. a) flat filter, b) without filter, c) foam filter, d) extruded filter

Figure 11 represents simulation results at an instant time for maximum velocity for each filter type. According to these results, gate velocity values obtained with extruded filter and without filter are considerably high for quality casting. As shown in Figure 9 in advance, the simulation with foam filter results for the melt velocity at Z2 control point are negligibly higher than 0.50 m/s. As can be seen in Figure 11 the velocity is homogenously separated at the gate and velocity values are acceptable with foam filter. Turbulence can be observed at the casting inlet for all filter types. The turbulence area is considerably narrower for flat filter compared to other filters. Simulation results show over 0.50 m/s melt velocity areas are not commonly visible at flat filter casting according to simulation scale.

Simulation results show that filling time, melt velocity and turbulence area are altering with filter type. Filter type affects the melt velocity at the stalk, but being under 0.5 m/s resulting negligible effect on casting quality. At the gate of the casting and casting inlet, there is the turbulence flow. So melt velocity is important for casting quality at the casting gate and casting inlet.

4. Conclusions

In this study, the common filter types in LPDC are examined by numerical simulation. According to simulation results, filter type is effective on filling time, gate velocity and flow characteristics. The flat filter yields the best flow properties according to simulation results. Foam filter can be used, but it can lead to clogging in stalk. Since all inclusions that occur in the melt after filtration area will be poured into the casting, flat filters have an advantage according to the location of the filtration. The flat filter is the most economical filter. The extruded filter, which has depth filtration mechanism, can be used for cleaner melt and homogenous melt flow in combination with flat filters to improve casting quality for specific models that need more surface quality.

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