

# Production experiences with improved filtration of ductile iron castings

## Abstract

New ferrous materials and competitive material forming processes are creating pressures on iron foundries to produce thin-section ductile iron castings, to improve quality and to reduce costs through improved performance and machinability. The introduction and/or formation of non-metallic inclusions is a significant factor affecting the quality and machinability of ductile iron castings.

A number of steps can be taken to prevent or remove non-metallic inclusions, including monitoring the quality, use and application of raw materials, consumables and supplies. In recent years, foundries have discovered that the use of extruded cellular filters incorporated in correctly designed gating systems will complement good melting and molding practices and will reduce scrap and improve the machinability of ductile iron castings.

A new extruded ceramic filter with triangular-shaped cells has been developed by an international supplier of foundry consumables in conjunction with a recognized producer of high-temperature fluid-flow products.

This new filter has been subjected to actual production conditions by ductile iron foundries and critically examined in university laboratory tests to determine its filtering efficiency and its practicality for use in high-volume automatic molding operations. Findings show that, compared to other ceramic filters with similar open frontal area, there has been no change in flow rate and the triangular-cell filter traps inclusions better by virtue of its unique geometry.

This paper briefly reviews the factors affecting scrap reduction and machinability improvements and discusses the theory of the new triangular-cell filter design. It summarizes the results of production trials of the new filter by a major producer of critical automotive castings and presents results of laboratory examinations.

## Background

Wagner Castings, an Internet Company, is a major producer of ductile iron castings, including automotive and truck safety critical components. Wagner operates two foundries, one in Decatur, Illinois, and one in Havana, Illinois. In addition to induction furnace melting and automatic molding operations, Wagner provides casting design assistance, with extensive product development activities.

Foseco, Inc. is an international manufacturer of consumables and supplies for ferrous and non-ferrous foundries. In conjunction with Corning, Inc., specialists in manufacturing ceramic products for high-temperature fluid flow applications, Foseco has worked to adapt catalytic converter substrate extrusion technology to the filtration of molten metals. The first extruded ceramic filters for ductile iron were introduced in 1982. The triangular-cell ceramic filter described below is the most recent product of this continuing collaboration.

## Market forces affecting ductile iron foundries

As automotive and other manufacturers seek new ways to improve performance of critical safety-related components, while simultaneously reducing weight and cost, ductile iron foundries are facing competition from other forming processes and new materials. Forgings, stampings and weldments, although lacking the forming versatility of castings, offer a variety of metallurgical benefits and reduced machining requirements which make them attractive alternatives. In addition, free-machining steels and other high-performance ferrous materials are being developed which offer machinability characteristics previously only available in leaded steels and cast iron.

Ductile iron foundries must make significant material and process modifications to lower scrap rates and improve casting consistency, machinability and strength to assure the survival of the industry.

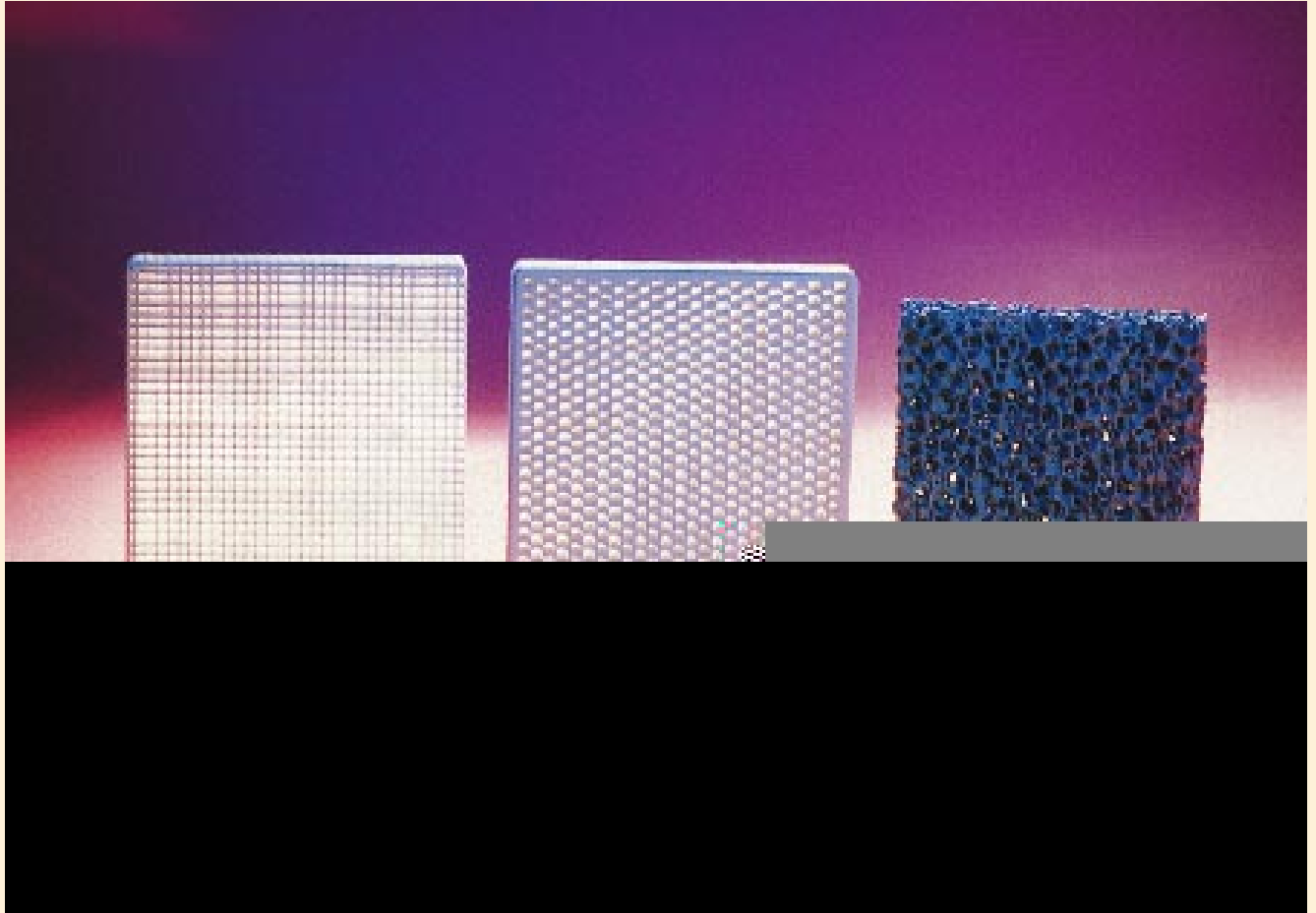


Figure 1:

### Factors affecting casting quality and machinability

While chemistry, metallurgy, internal voids and dimensional accuracy are major factors affecting the quality and machinability of ductile iron castings, it is the occurrence of non-metallic inclusions which is the greatest cause of foundry scrap, customer returns and customer complaints about machine tool consumption and machining problems.

The cost of the raw casting is often just a fraction of the total cost of a machined part, due to the costs of machining and labor. When the discovery of non-metallic inclusions forces scrapping of a partially or fully machined casting, the manufacturer has already incurred substantial costs which cannot be recovered by returning the casting to the foundry for credit.

Recognizing the sources and causes of inconsistent metallurgy, microstructure defects and non-metallic inclusions is an obvious first step to eliminating them and improving ductile iron casting machinability.

Both raw material issues and process issues must be examined. The quality and consistency of scrap, consumables and molding media must be assured and treatment times, holding times, pouring practice and shakeout procedures must be carefully monitored.

### External and internal sources of inclusions

Tramp elements and foreign objects in ferrous scrap, furnace and ladle slags, ladle refractory materials, magnesium reaction products, melting slags, desulfurization and inoculation slags, and reoxidation products are all causes of non-metallic inclusions which arise outside the mold.

Molding sand, foreign material within the sand, mold or core products and reoxidation products resulting from turbulence within the gating system and mold cavity, are all causes of non-metallic inclusions which arise inside the mold.

Each of these issues requires foundry attention as part of a total quality control program to eliminate or prevent sources of inclusions. This article focuses on one aspect of total quality control, the use of in-mold filtration. While filtration is an ideal way to trap external inclusions and trap or prevent internal inclusions from forming after other quality control measures have been implemented, it must be accompanied by good ductile iron foundry practices.

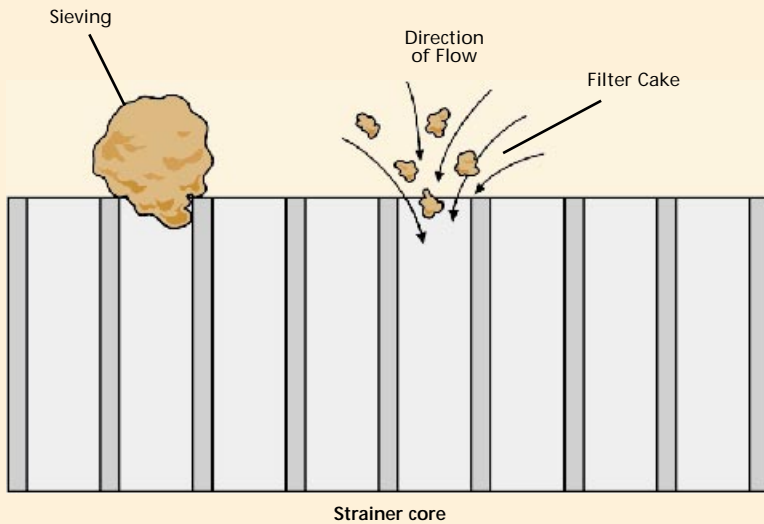


Figure 2: Square blockage

### Basic types of ceramic filters

A variety of ceramic materials and shapes, produced through various methods, have been used to filter molten metal with varying degrees of effectiveness. These include cloth, reticulated foam, pressed clay strainer cores and extruded cellular filters. For purposes of this discussion, we have eliminated cloth which, because of its "two-dimensionality," has no deep-bed filtering capacity (See "Filtration mechanisms" discussed below). Figure 1 shows examples of extruded cellular, pressed clay and reticulated foam filters used for in-mold filtration of ductile iron.

Selection of a suitable filter for a given ductile iron application is determined by molding method, nodularizing practice, inoculation practice, desired filtration effectiveness, pouring temperature and desired metal flow rate. While the cost of filtration is also a consideration, the benefits of foundry scrap reduction, improved yield, improved alloy recovery, better appearance, fewer customer returns and improved machinability readily justify the use of filters in critical castings.

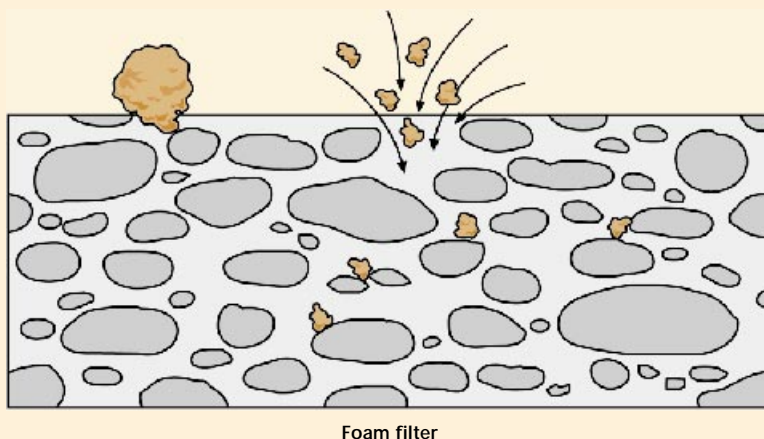


Figure 3: Foam blockage

### Filtration mechanisms

An understanding of basic filtration mechanisms is needed to evaluate the differences between various types of "three-dimensional" ceramic filters and appreciate the benefits of the new extruded cellular ceramic filter discussed below (see figure 2).

**Sieving** is the mechanical prevention of a particle from passing through a filter passage which is smaller than the particle. In ductile iron, particles encountered are not necessarily spherical in shape. Many of the particles are in the shape of strings which drape over some number of passage openings. Filter passage entries must be small enough to trap the desired particle size, but with enough passages available for adequate flow to achieve desired pouring times.

**Cake Filtration** begins as the first particles are trapped on the entry face of the filter and subsequent slag and dross accumulate on these particles. The resulting "cake" becomes a filter itself, restricting the passage of further inclusions into the mold cavity. Using a filter with smaller channel entrances will not only affect sieving as described above, but it will accelerate the onset of cake filtration.

**Deep-Bed Filtration.** The surface energy of oxide particles which are small enough to pass through the filter cake and enter the passages of the filter is very high. These particles are attracted to the oxide surfaces of the inner passage wall by a natural tendency to reduce the overall energy of the system. Once these particles make contact with the inner surfaces, a sintering action occurs which permanently bonds the inclusions to the passage walls.

The chemical composition and temperature of the passage wall affect both the amount of attraction and the rate of sintering. Compositions of cordierite, mullite and alumina most closely match the composition of ductile iron inclusions, and, since their melting temperatures are close to the pouring temperature of ductile iron, extruded filters high in these materials have been proven to be more effective than those which are high in crystalline silica.

The cross-sectional shape of the passages through the filter is also a factor. A particle coming into contact with two walls of a passage (as in a corner of an extruded cell) instead of one (as in a round or spherical passage) experiences greater reduction in surface energy (more attraction to the passage walls). Flow calculations have also revealed lower pressures in cell corners, increasing the likelihood of attracting slag.

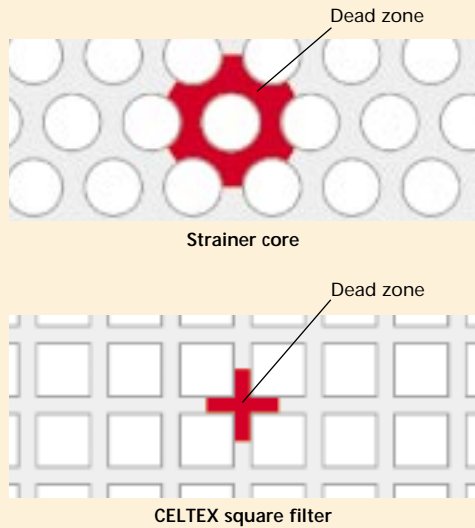


Figure 4: Dead zone comparison; pressed strainer cores versus extruded ceramic filters

Foam filters also employ three filtration mechanisms. (see figure 3). Sieving and cake filtration are similar to that seen in extruded cellular filters and pressed strainer cores, relying on the average pore sizes on the entry faces. Deep filtration results not from attraction and sintering, but from direct interception by the foam filter walls as the metal passes through the tortuous path inside the filter. Foam filters rely upon specific density differences between inclusions and the metal as well as hydrodynamic effects such as eddy currents to increase the likelihood of particles smaller than the pore size remaining in the filter. Little sintering occurs because of differences in chemical composition between the filter material and the inclusions.

Depending upon the composition and configuration of the filter, each of the three mechanisms may have a greater or lesser effect on the filtration effectiveness, flow rate and capacity (amount of metal which may be filtered prior to blockage).

### Flow considerations

Consistency of flow rate and flow capacity are important considerations in understanding and evaluating filtration. From back pressure equations developed to model fluid flow through a channeled or honeycomb cellular structure, it has been determined that flow rate is a direct function of the hydraulic diameter (the ratio of the cell cross-sectional area to its perimeter), the number of cells per unit filter frontal area (cells per sq. in. or cpsi) and a constant which is related to cell shape and other fixed parameters. It is inversely related to the filter depth or length of the filter through-channels. (Flow rates of ceramic foam filters are more difficult to predict because of the difficulty in producing consistent pore sizes and controlling the number of pores per unit volume of foam.)



Figure 5: New triangular-cell extruded ceramic filter prior to pour

Passage size, shape, density and wall thickness determine the open frontal area of a filter. "Dead zones" on the entry face of the filter obstruct and reduce the flow of molten metal. As seen in fig. 4, the dead zones in strainer cores with round passages are considerably greater than those with extruded cells having flat sides. Not only do increased dead zones reduce the flow rate, but they create a more turbulent flow as the metal exits the strainer core. This mixes air with the molten metal and creates oxide inclusions downstream of the strainer core, inclusions which are formed too late to intercept them.

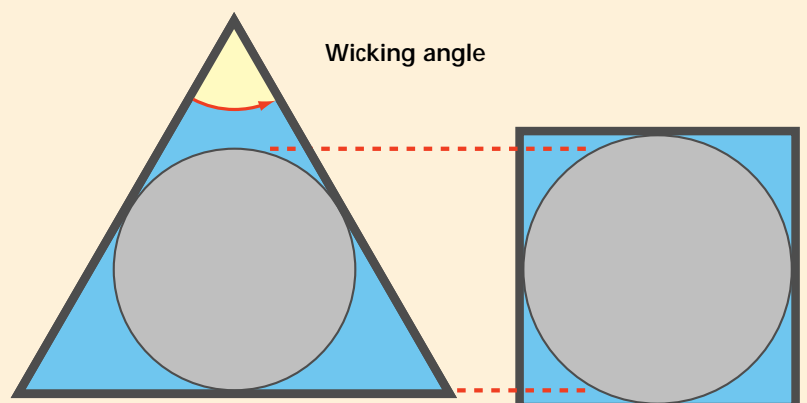


Figure 6: Reduced hydraulic diameter, triangular-cell vs square-cell extruded ceramic filters

Pore density and dead zones also affect total flow before blockage. When open frontal area is reduced by dead zones, it is generally necessary to use a larger (total frontal area) filter to get equivalent capacity. (Increasing hole size will improve flow, but reduce filtering efficiency.)

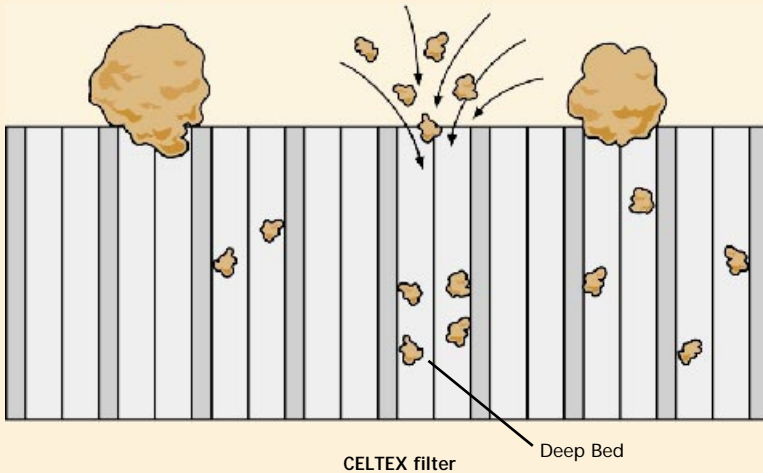


Figure 7: Slag attracted to corners of triangular-cell extruded ceramic filters

### Development of triangular-cell extruded ceramic filters

Square-cell extruded ceramic filters, first introduced to ductile iron casting in 1984, have helped foundries effect major scrap reductions over non-filtered castings. However, continuously increasing quality demands from casting users have made it clear that additional improvements in scrap reduction and machinability are needed.

While continuous refinements in square-cell filter design and application have been made since 1984, it became obvious that further modifications of existing technology would not produce the desired improvements. Thus, again working with Corning, Inc., Foseco developed a new triangular-cell, extruded ceramic filter which has resulted in substantial improvements in filtration performance, with substantial scrap reductions and machinability improvements, compared to traditional square-cell filters (see figure 5). Of equal importance, this new filtration capability was attained without sacrificing the superior flow and capacity characteristics of cellular ceramic filters.

**Improved Sieving and Cake Filtration.** The improved filtration performance of the new triangular-cell filters results from a reduction in the hydraulic diameter of the cells (compared to square cells), brought about by the more restrictive area of the equilateral-triangle shape of the cells (see figure 6). This smaller opening is able to sieve (mechanically prevent passage of) smaller inclusions. In addition, this reduced opening accelerates the activation of the cake filtering mechanism previously described in "Filtration mechanisms."

**Maintained Flow Rate.** While the new cell geometry reduces the hydraulic diameter of the cells, the open frontal area of filters having the same cell density (cps) remains consistent and essentially the same. This is a critical issue in the use filters in automatic molding and pouring operations.

**Improved Deep Filtration.** Improved deep filtration is attributed to the increased amount of active internal surface area (the combined surface area of the filter channel walls) and the smaller corner angle (referred to as "wicking angle") of the cells. As also anticipated in "Filtration mechanisms" above, the possibility of an inclusion coming into contact with two walls instead of one is further increased by smaller angles (60° instead of 90°). (see figure 7). Because of these performance improvements, calculations indicate, for example, that a 90 cps triangular-cell filter will have the same filtration efficiency as a 150 cps square-cell filter, while maintaining a higher flow rate under similar casting conditions.

**Improved Cold Strength.** In addition to improved filter efficiency, the naturally greater strength of the triangular shape has resulted in 15% greater cold strength compared to square-cell filters of similar density, for increased ease of handling and automatic insertion.

**Balance of Parameters.** In the process of developing these new triangular-cell filters, it was discovered that the effectiveness of the design is achieved when filter parameters including cell density, filter depth (thickness), open frontal area, wall thickness, hydraulic diameter and filter unit surface area (square inches of entry face per cubic inch of filter) remain balanced within certain limits. The overall size (frontal area) of the filter, however can be varied to accommodate the size of the metal casting stream and the amount of metal to be poured through it.

**Comparative Parameters.** A comparison of triangular- and square-cell filters and round-hole strainer cores in the 90 cps range clearly shows the differences in hydraulic diameter, open frontal area and internal passage surface area (major factors affecting filtration efficiency and flow) (see table 1).

Comparative filter parameters				
	Triangular Cell filters		Square Cell filter	Round Strainer core
Cells per sq. in. (cps)	110	150	100	90
Hydraulic dia.	0.075	0.0738	0.0854	0.0899
Depth (thickness)	0.493	0.493	0.493	0.500
Flow rate	0.0281	0.0281	0.0342	0.0282
Open frontal area (%)	65.7	68.0	65.7	56.0
Cell wall thickness	0.0175	0.0158	0.020	
Geometric surface area	35.1	36.8	30.8	

Table 1

The filter manufacturer has developed two grades of triangular-cell extruded ceramic filters based on two cell geometries, a 110 cpsi filter for standard ductile iron filtration and a 150 cpsi filter for enhanced filtration. Each is available in thicknesses of 0.375" and 0.493". Both triangular-cell filters have demonstrated significant inclusion reductions, compared to 100 cpsi square-cell filters. Selection of one grade or the other is determined by the "cleanliness" of the heat and the desired level of quality.

Foundry trials of triangular cell filters, including those at Wagner Castings described below, and laboratory analyses of castings made under actual production conditions, have confirmed substantial improvements in filtration efficiency over square-cell filters of similar cell density.

**Filter Usage at Wagner Castings.** As part of its overall quality program to reduce foundry scrap rates and provide its major automotive customers with castings having improved machinability, Wagner Castings began filter evaluations in 1991 and adopted the use of square-cell extruded ceramic filters in 1992. At that time, they documented a reduction in scrap rate to 3% from slag inclusions, compared to a rate of 5% in the earlier production of the same castings without filtration.

In 1997, they agreed to trial the new 110 cpsi triangular-cell filters on their automatic molding and pouring line during production of automotive components such as steering knuckles, idler arms, steering yokes, etc. Results of these trials showed a scrap rate of 1% from slag inclusions (compared to 3% with square-cell extruded filters). Trials to evaluate the effects of using the 150 cpsi triangular-cell filter were then conducted, initially in specific safety-critical ductile iron castings. Nearly a 100% enhancement in machine shop tool life was reported.

**Laboratory Test Results.** A representative sample of the castings from the Wagner trials was sent to Case Western Reserve University in Cleveland, Ohio, for laboratory analysis. Visual analysis and Scanning Electron Microscope (SEM) examinations of internal microstructure have corroborated that the improvements were obtained.

Based on the successful results of these trials, Wagner adopted the use of the triangular-cell filters in their standard molding practice. The additional two percentage point foundry scrap reduction from slag inclusions alone has resulted in cost savings which are more than enough to offset the cost of the new triangular-cell filters.

In addition, Wagner's customers have reported substantial increases in machine tool life which represent a significant saving in tooling cost, as well as labor.

Currently, the foundry is using a combination of finer (150 cpsi) and coarser (110 cpsi) triangular-cell ceramic filters and is considering extending the use of the finer filter to other castings. The machine shop also is encouraging greater use of the finer triangular filter. Based on the improved performance so far, Wagner, Corning and Foseco are now working on an even finer triangular extruded cellular ceramic filter for further improvements in tool life.

Readers are invited to contact the authors for additional details and results of the ongoing testing program to evaluate these new filters.

### End notes

The results of triangular-cell filters at Wagner Castings represent Wagner's product mix, equipment, melting practices, gating designs and molding practices. Trials of these new filters conducted at other ductile iron foundries confirm similar improvements. Depending on individual situations, users may expect varying results.

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