

Industrial experience in the filtration of cast iron at the Peugeot Citroën foundries

Introduction – PSA Group. PEUGEOT CITROËN Foundries

The PSA Group (Peugeot Société Anonyme) is a major French and International car producer with an output of ca. 2.8 million vehicles in 2000 manufactured in 21 different countries. During the year the group's four French ferrous foundries produced 350.000 tonnes of automotive castings in grey and ductile iron (see Table 1).

□ Vehicle production 2000 2,810,000 units

□ 85% sales were in Europe, 15% export

□ PSA group workforce 165,800 persons

Annual production of castings:

□ ductile cast iron: 143,000 tonnes

□ grey cast iron: 192,000 tonnes

□ aluminium alloys: 69,000 tonnes

Application of Ceramic Foam Filtration in PSA PEUGEOT CITROËN Foundries

In the seventies PSA Peugeot Citroën used a wide range of conventional gating techniques to obtain clean castings. In the mid eighties, as a result of increasing casting quality requirements and a strong pressure to reduce costs, filtration was introduced.

Novel gating system designs incorporating ceramic foam filters were introduced and used for the production of ductile iron crankshafts, grey iron camshafts, brake drums and engine blocks.

This introduction was a result of a pro-active supplier – customer partnership between FOSECO and PSA Peugeot Citroën which has proved most beneficial in improving casting quality and reducing costs.

Towards the end of 1983 the first ceramic SEDEX* foam filters in France were used at the Charleville iron foundry. They were applied for the production of triangular profiled suspension arms in ferritic ductile iron which were used on the Citroën BX

IRON FOUNDRIES		
SITES	PRODUCTION	ANNUAL TONNAGE DELIVERED
SEPT-FONS	Grey cast iron: cylinder blocks, brake drums, hubs, solid and ventilated brake disks.	110,000
DOUVRIN (FM, Peugeot Renault subsidiary)	Grey cast iron: centrifuged cylinder sleeves and camshafts. Ductile iron: camshafts, crankshafts, suspension arms, steering knuckles and exhaust manifolds.	84,000
CHARLEVILLE	Ductile iron: crankshafts, suspension arms, steering knuckles, exhaust manifolds, differential housings and various brackets.	81,000
SOCHAUX	Grey cast iron: cylinder blocks, camshafts, drum hubs, brake discs.	60,000
ALUMINIUM FOUNDRIES		
SITES	PRODUCTION	ANNUAL TONNAGE DELIVERED
CHARLEVILLE	Cylinder heads and V6 blocks, brackets, rear axle supports, inlet manifolds, gear box housings.	37,000
VILLERS LA MONTAGNE	Engine blocks and gear box housings	18,000
MULHOUSE	Engine blocks and bearing caps	14,000

Table 1: The 7 PSA Peugeot Citroën, ferrous and non-ferrous foundries.

model.¹ Since which time, the use of foam filters has now become widespread within the PSA Peugeot Citroën iron foundries.

The Charville aluminium foundry also uses the non-ceramic SIVEX* foam filters for parts such as the V6 cylinder blocks and heads in order to improve the filling of the mould cavity by reducing turbulence, oxide generation and reducing metal speed at ingates below the critical value of 0.5 m/s.

Improvements in Ceramic Foam Filters

During the period of co-operation between PSA Peugeot Citroën and FOSECO, the quality of filters and filter testing was continually improved. The rigorous testing procedures and their effects are shown below;

1. Cold strength (figure 1):

- ❑ important to give the product resistance to a variety of handling procedures
- ❑ product friability reduced (from 0.5gm to less than 0.25gm per kg of filters)



Figure 1: Cold compression test equipment.

2. Thermal shock resistance:

- ❑ This property is essential for the product to be able to resist the instantaneous change from room to operational temperatures in excess of 1400°C, it has been progressively improved.
- ❑ Using the specially developed "Impingement Test" illustrated in figures 2a and b, regular, controlled testing with liquid iron is performed, before the product is dispatched to customers.
- ❑ The test temperature (at which some filter breakage can be detected) has been increased from 1450°C 15 years ago, to 1510°C and today's tests are conducted at 1530°C.

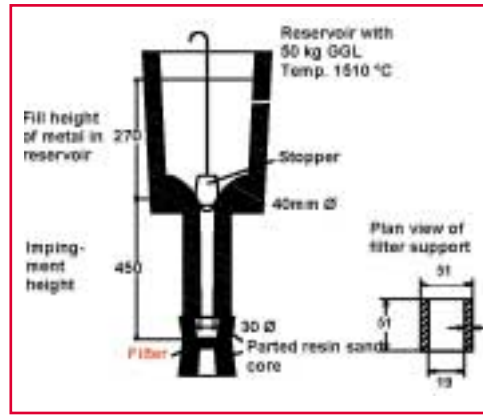


Figure 2a: Filter Impingement test unit.



Figure 2b: Impingement testing in progress with liquid iron.

3. Ferro static pressure resistance:

- ❑ The filter test height of 450 mm is intended to simulate difficult product application conditions.

4. Reticular structure

- ❑ Filter pore structure has become more open and less blocked by excess refractory.
- ❑ Figures 3a, b and c illustrate the porosity classification of FOSECO ceramic foam filters, expressed in 10 ppi coarse, 20ppi medium and 30 ppi the finest structure, (ppi or pores per linear inch).

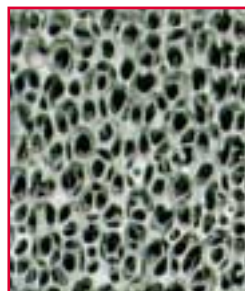


Figure 3a: 10ppi filter structure.

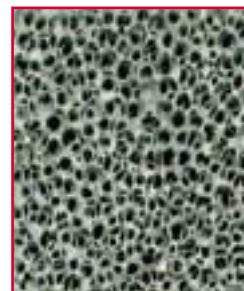


Figure 3b: 20ppi.



Figure 3c: 30ppi.

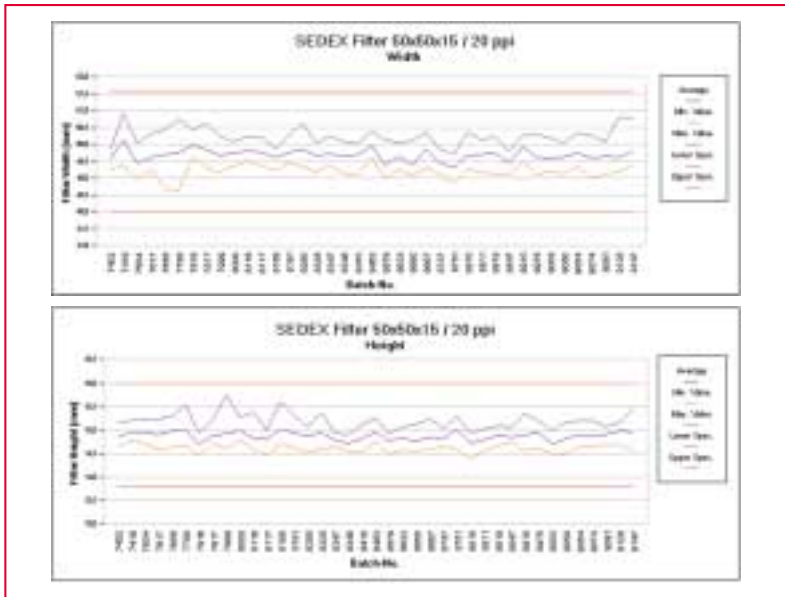


Figure 4: Typical SQC Charts for the 50 x 50 x 15mm thick SEDEX ceramic foam filters.

5. Dimensional specification:

- SQC controlled manufacturing process (see figure 4), has been incrementally improved in line with the filter's role in the production of modern high integrity, often safety critical, castings.

6. Weight specification:

- The actual weight of each filter is measured to ensure under weight filters (potentially weak) or overweight filters (with potentially poor flow) are detected and removed before packing. The special equipment used for this purpose is illustrated in figure 5.



Figure 5: Filter weighing equipment, integrated into the production line.

The combination of process improvements to the production of both ductile² and flake-graphite iron castings and the improvements in ceramic foam filter properties has resulted in:

1). An increase in filtration effectiveness:

Often enabling the use of finer porosity such as 20 ppi rather than 10 ppi for spheroidal graphite cast iron and 30 ppi rather than 20 ppi for flake graphite cast iron.

2). An increase in filtration capacity: (with same porosity and identical metal quality).

The weight of the metal passing through the filter before it becomes blocked by reaction products has increased.

3). A reduction in filter thickness:

Greater use of 15mm thick filters as opposed to the former 22mm can be made without risking the quality of the cast parts.

4). During a 15 year period the filter price has fallen by 70%, as a result of:

- optimisation of the manufacturing process
- improvements in productivity
- reduction in raw material costs

The cumulative effect of the various items listed above, foundry processes and the filter properties, have contributed to a significant improvement in the quality and reliability of the castings, combined with a reduction in the cost of their production.

A joint study was carried out by all the participants in the cost reduction programme. Summarising the results in collaboration with PSA resulted in the supplier entering as a partner. This supported the introduction of ceramic foam filters and the successful extension of their application within PSA Peugeot Citroën and subsidiary foundries.³

This was highlighted during an open day held at Française de Mécanique on the 15th October 1997 by two wall charts, one example is shown in figure 6. The tableaux describe and illustrate the historical progress, the results and benefits which the co-operation had produced during the previous 3 years.



Figure 6 The tableaux at the FM open day, describing the progress and results of the four different technical partnerships, including FOSECO.

FRANCAISE de MECANIQUE, DOUVRIN

The crankshaft production process:

The production of pearlitic ductile cast iron crankshafts began at the Française de Mécanique foundry in Douvrin in 1970 resulting in a spray of 4 castings as illustrated in figure 7, with the sand riser (at the top) and the spinner (at the bottom), Hurdebourcq has described this special production using the sodium silicate process in detail.⁴ The technique was continually improved during the next 20 years, included exploratory trials with SEDEX ceramic foam filters 50 x 100 x 22 mm in 10 ppi, followed by larger scale industrial testing on one crankshaft type, the layout used is shown in figure 8.



Figure 7: The original layout 1970



Figure 8: Exploratory trials with foam filter 1985

First stage of the partnership

Change from four to six parts per mould:

The size of the moulding box is 500 x 700 mm, the complete mould is produced from four 90 mm thick double faced jacket sub-moulds which are then assembled to create a single mould with six castings, as shown in figure 9. After assembly the mould is turned on its end and poured vertically from the bottom to ensure minimum turbulence during filling.

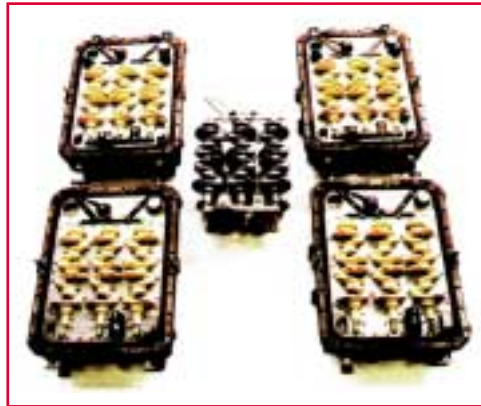


Figure 9: The pattern equipment to produce the multiple mould.

For this approach to succeed the huge feeder head and the gating system spinner, (visible in figure 7) which for twenty years had helped to guarantee an acceptable quality of crankshafts, had to be removed. So between 1995 and 1998 the challenge to move on from four to six parts in the mould was taken up.

3 years of combined effort between suppliers, technical institutions and PSA Peugeot Citroën was needed to achieve the given objectives.



Figure 10: Spray of 6 castings, poured weight 120kg.

The partnership with FOSECO contributed to this effort, resulting in the re-calculation of the running system, improving its design and the application of two SEDEX filters 65 x 65 x 18 mm in 10 ppi as shown in figures 10 and 11.



Figure 11: Open sand mould with single filter for 3 of the 6 crankshafts.

As the results were so encouraging and the use of filters rapidly expanding, PSA Peugeot Citroën at this stage, in March 1998, audited the FOSECO production and quality facility and granted site approval to FOSECO Germany.

Second stage of the partnership

In June of the same year, FOSECO in co-operation with the Française de Mécanique Quality Management team evaluated the use of filtration products in their particular industrial environment. This called for FOSECO technicians to conduct a "Return Audit" to check the extent to which "Best Practise" was being applied to filter use. This procedure included:

- ❑ correct use of the application rules, namely those concerning the running system design and calculation of the different cross sections of downsprue, runner bars and ingates.^{5, 6, 7}
- ❑ optimising application of the filter i.e. section, thickness, porosity
- ❑ aspects audited also covered; product ordering, delivery, stocking, storage and handling

This close degree of co-operation was in fact quite revolutionary for a customer supplier relationship in France!

Following an extended evaluation programme the 65 x 65 x 18 mm thick filter in 10ppi was replaced with a 60 x 60 x 15 mm thick filter in 20 ppi. This rationalisation resulted in reductions of:

- ❑ 15% in filter area
- ❑ 16% in thickness
- ❑ 25% in filtration costs

This led to economic benefits to PSA Peugeot Citroën as shown in Table 3.

The simple calculation of annual savings in the machine shop gave a value of €281,000 (a similar value in US\$). It does not take into consideration indirect benefits such as the increase in capacity of 13,500 crankshafts per year at no extra cost, also the machining costs associated with finishing those castings are not incurred. It must also be noted that the foundry scrap cost savings are NOT included in this calculation.

Filtration effectiveness continued to improve. These improvements were made possible due to the open "Win Win" partnership spirit which developed between the FM/PSA Peugeot Citroën foundrymen and the supplier, FOSECO.

Machined rejects before filtration was introduced	5 to 8 per thousand, average = 6.5
Machined rejects after filtration was introduced	1.5 per thousand
Machining cost per crankshaft	€38,10 to €45,70
Daily production details and costs:	
Crankshafts poured	12,000
Moulds produced	2,000
Filter consumption 60 x 60 x15 mm in 20 ppi	4,000
Filter price	€0,26
Number of machined castings rejected	60
Cost of rejects (a) = 60 x 250 FFr (€38,1)	€2287
Cost of filters (b) = 4000 x 1,7 FFr (€0,26)	€1037
Daily economic benefit (a – b)	€1250
Working days per year	225
Annual economic benefit = 225 x 1250	€281,000

Table 3: Summary of the direct impact of filter use on cost of machined castings.

Third stage of the partnership:

In 1999 a new challenge was presented – to use the same production technique but to produce 8 cavities in the same mould, also with no feeders. This complex new method is in an advanced stage of development, as illustrated in figures 12 to 16.



Figure 12: Eight casting layout, actual spray still in the same box size.

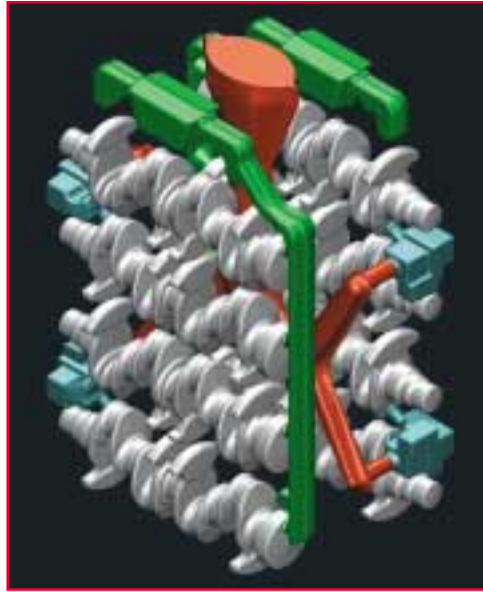


Figure 13: Eight casting layout, 3D virtual spray.



Figure 14: Eight casting spray viewed from the other side.



Figure 15: One half of the 3D virtual spray used for the mould fill simulation shown overleaf.

Figures 12 and 14 show two views of the first prototype spray of 8 crankshafts, the properties of castings are currently undergoing intensive evaluation.

Figure 13 and 15 show computer generated images which were prepared in co-operation with FOSECO to enable production aspects of the spray to be studied, including mould filling and solidification. Red is the gating system incorporating four 50 x 50 x 15 mm SEDEX ceramic foam filters, whilst green is the venting system, essential to allow the escape of mould gasses and minimise back pressure during pouring.

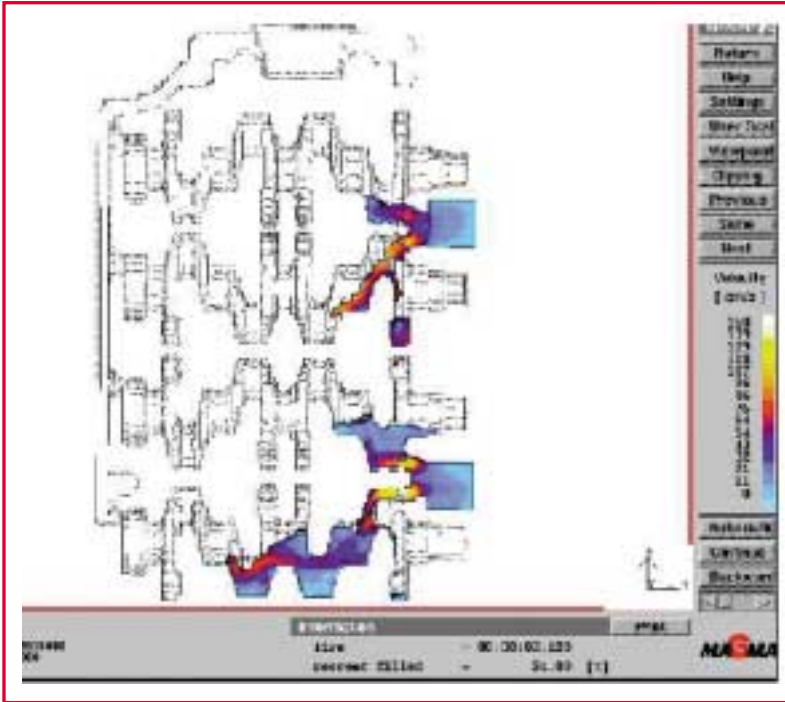


Figure 16: The beginning of filling sequence.

Figure 16 illustrates the mould fill simulation at the initial stage of pouring showing the tendency for the first stream of iron to flow past the R.H. bearing cavity; this is probably because of the high initial velocity - increasing the risk of gas and/or oxide inclusions. This simulation also illustrates the tendency for the vent channel to fill with liquid metal thus interfering with the metal stream, increasing the potential to form oxide films and gas inclusions.

Production of flake graphite cast iron camshafts:

These camshaft castings are also produced in a spray of eight (see figure 17), using exactly the same moulding techniques as described for the crankshaft production:



Figure 17: Spray of 8 camshafts.

The improved running system design and filter application technique was prepared in the same spirit of open partnership with FOSECO. Mould fill simulation of a similar casting, which although produced with the help of filtration, still showed some gating system problem areas resulting in high velocity at the ingates. However the use of SEDEX filters 40 x 40 mm x 30 ppi (see figure 18), meant that the cross-section of the ingates could actually be increased, reducing both the ingate velocity and the associated turbulence. These changes resulted in the virtual elimination of the blowhole defects.



Figure 18: Open silicate bonded sand mould.

Figure 19 shows that the level of defects averaged more than 7% before these changes were introduced. Following the introduction of the modified gating system, in conjunction with filtration, the level of defects was reduced to less than 1%. This case illustrates that use of filtration in isolation is not the complete solution to a problem, it is essential that the gating system should also be correctly designed if the maximum benefits of filter application are to be obtained.

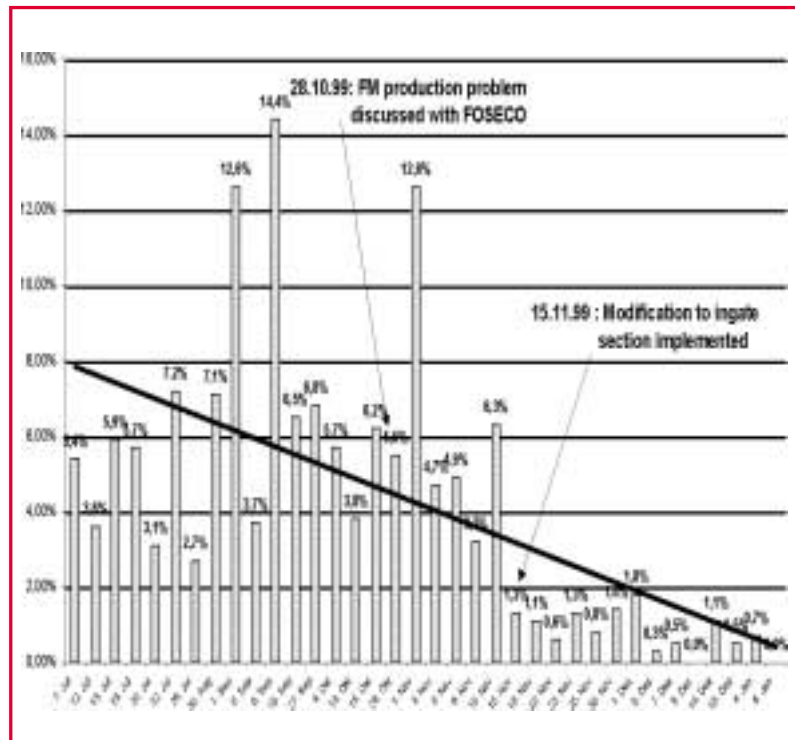


Figure 19: Record of daily camshaft scrap rate due to surface blowholes.

Brake Drum Production

PSA Peugeot Citroën, site de Sept-Fons: "Thinking Differently"

Up until 1997, running systems were designed according to long established and accepted rules. In most cases, slag was partially retained in the upper part of large runner bar(s), and it was generally preferable to use flat section ingates, positioned on the bottom face of horizontal runner bar(s).⁸ This is shown in figures 20 and 21, using two cellular filters.

Behind the ceramic foam filter the metal is clean, quiet and the speed of flow is much lower in relation to its velocity, so it is no longer necessary to place the runners in the cope part and to use double the cross-section for the runner bar(s). This concept results in a gating system design as shown in figures 22 and 23 (applied to a different drum than shown in figures 20 and 21).



Figure 20: Cope pattern plate for 12 small drums.



Figure 21: Drag pattern plate for 12 small drums.



Figure 22: Cope pattern plate of a downsprue controlled gating system.



Figure 23: Drag pattern plate of a downsprue controlled gating system.

A downsprue controlled gating system can be used and then all that is necessary is to direct the metal into the mould cavities by the shortest, simplest and most direct route. This minimises the creation of turbulence and the possible generation of oxides or gas inclusions.

The ingates must be positioned in the cope part of the mould; this will ensure that the whole runner system fills quickly and that it remains full during the pouring cycle.

This very simple but innovative design concept of ceramic foam filter application and gating system design, as shown in figure 24, was initially conceived in Germany in 1990, since when it has evolved and been further developed and refined by FOSECO world wide.⁹

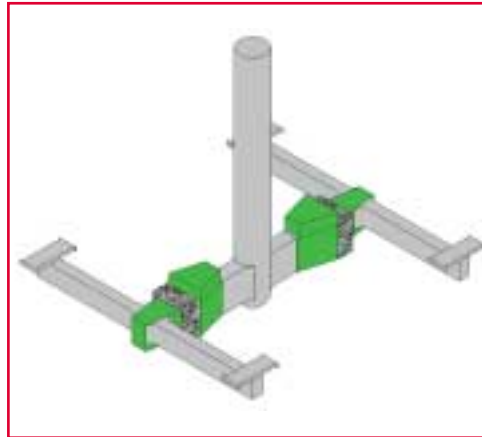


Figure 24: Application principles of the ceramic foam filter for horizontal parted moulds.

The approach described above was successfully applied to the production of flake-graphite cast iron brake drums at the PSA Peugeot Citroën foundry at Sept-Fons, resulting in:

- reduced inclusions
- improved even distribution of the liquid iron in ALL of the mould cavities
- reduced filling turbulence
- virtual elimination of surface pinhole faults
- improved yield (Table 4)

All these benefits were the result of the radical redesign of the running system which was made possible by use of the ceramic foam filter.

By applying the principles as outlined above, the foundry results obtained are shown in Table 5.

1996 - Up to this time conventional ingate controlled gating systems were used with cellular filters.

1997 - The first year of using ceramic foam filters together with a completely redesigned, downsprue controlled system, with the runner bar in the drag and ingates off the upper face of the runner bar.

1998 and 1999 - The recommended filtration application principles were introduced more broadly in the foundry which contributed to lower overall scrap levels still further.

2000 - Saw the introduction of a new type of ventilated brake disk with higher quality standards.

The current results are for a daily production of 23,000 drums and ventilated brake disks.

The initial incentive to apply foam filtration did not appear to be very high, inclusions were only 0,2%. The improvements in the overall scrap level from 7,28 to 2,5% and lower, were in fact a result of the combined use of lower mould filling turbulence, use of a well designed system resulting in even iron distribution in the whole mould and use of correctly applied ceramic foam filtration. (These ground rules are often more attentively observed in gating system designs for vertically parted moulds).^{10,11}

The machined scrap results given in Table 6, remained relatively constant although quality standards continued to rise during the period in question.

Although no machine tool wear measurement results have actually been reported so far by PSA Peugeot Citroën, Menk has shown that there is in fact a substantial reduction in tool wear when machining either filtered grey and ductile iron castings.¹²



Figure 25: Open four cylinder block mould.

Production of thin walled cylinder blocks:

The new generation of 1,9 litre diesel cylinder blocks (see figure 25), are now regularly manufactured with an average wall section thickness of 4,3 mm, with less than a 2 mm water jacket passage between the cylinder walls, which themselves are 2,5 mm thick as cast. A number of factors has made this possible:

- automation of core production
- improved robotic handling and insertion techniques
- development of improved core binders
- special inspection techniques
- use of ceramic foam filters, which help to reduce both mould filling speed and turbulence during pouring

The ability to eliminate inclusions has made a significant contribution to the reproducible manufacture of these very demanding, thin walled components.¹³

	FILTER TYPE	
	CELLULAR	CERAMIC FOAM
Filter dimensions	55 x 55 x 12,5 300 csi	50 x 50 x 15 30 ppi
Casting weight	8,65 kg	8,65 kg
Number of parts per mould	10	10
Filtered weight	103 kg	96 kg
Pouring basin weight	41 kg	41 kg
Total mould weight	144 kg	137 kg
Pouring time	12"	13"
Pouring temperature	1390-1420°C	1390-1420°C

Table 4: Pouring and filtration details of Cellular and Ceramic foam filter applications.

	1996	1997	1998	1999	2000
Target	2,50	2,50	1,63	1,32	1,28
Overall rate	7,28	2,54	1,64	1,52	1,80
Inclusions	0,2	0,02	0		

Table 5: Foundry scrap profile.

	1997	1998	1999	2000
Target	0,50	0,39	0,28	0,42
Overall rate	0,46	0,50	0,40	0,40

Table 6: Machining scrap profile.

Conclusions:

Along with the continuous improvement of the casting manufacturing processes and optimisation of pattern layouts in partnership with FOSECO, supported by the considerable potential offered by the use of ceramic foam filters, the technicians and engineers of the PSA Peugeot Citroën foundries and their subsidiary Française de Mécanique now have greater latitude for: "Re-thinking" running system design.

The use of ceramic foam filters permits much easier application of the rules proposed by Campbell for the optimum pouring of liquid metal into moulds in such a way as to avoid "metal damage" and the production of defective zones in the finished casting, these rules are summarised as:

- pour clean metal
- avoid damaging the flow
- avoid stopping the flow
- minimise turbulence
- minimise generation of gasses and risk of their distribution through the different mould cavities
- reduce the ingate speed of metal
- arrange for even mould filling to reduce segregation of metallurgical effects (such as Inmold treatment or mould inoculation).^{14,15}

It is nevertheless important to note that it is not simply the elimination of part of his scrap which is of advantage to the foundryman when the ceramic foam filter is used, but the improvement in the quality of casting production as a whole.

Considered at the start of the eighties as an "emergency" solution to be used only under exceptional circumstances, today, the use of ceramic foam filters, with the advantages shown, has now become classified by PSA Peugeot Citroën as a "Strategic Product".

In the broader global context filtration can today be considered as being a State-of the-Art support medium for the manufacture of high quality automobile and engineering components at optimum cost.

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