Optimising Yield by Runner-Less Casting with Direct Pouring Systems

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Introduction

Over the past decade we at Foseco have been meeting the demands of our customers for higher quality castings with our feeding systems and ceramic foam filter products. Their use has resulted in considerable cost savings.

For example, by substituting sand risers with feeder sleeves, feed metal volume can be reduced by as much as 80%. This has resulted in higher yields.

Applying ceramic foam filters means that complicated traps and highly pressurised gating systems to remove inclusions are no longer necessary. Running systems can be shortened, therefore, and the gating system simplified making more efficient use of the pattern plate. This has not only resulted in higher yields but better quality castings. Figures 1 and 2 show crankshaft castings, one with a conventional running and feeding system, the other with a redesigned running system with one Sedex foam filter and one feeder for two castings.

Ceramic filters control the flow of metal, reducing turbulence, and stop inclusions in the metal stream reaching the mould cavity. As a result, the surface quality is greatly improved and castings are inclusion-free. Consequently, scrap rate is either reduced considerably or effectively eliminated. Additionally, machining tolerances can be reduced and, as machinability is improved, tool life in the machine shop is extended.

The net result, again, is cost savings for our customers.

More recently, Foseco have introduced the concept of direct pouring, i.e. casting without sprues, runners or ingates. This has now revolutionised casting technology in the ferrous and non-ferrous sectors. Our direct pouring products, DYPUR, KALPUR and STELPUR for aluminium, iron and steel respectively, combine the high filtration efficiency and flow control of a ceramic foam filter with the excellent feeding characteristics of an insulating sleeve together in a pouring cup.

This paper looks at direct pouring in detail and the benefits it gives. Case studies are presented and, where possible, the costs benefits are provided.

Mould filling can now be simulated using a fluid dynamics flow simulation software package. The package also shows temperature distribution in the mould at different stages during casting and indicates where hot or cold spots can occur and the likely position of a misrun. Foseco use this to confirm that the correct design parameters have been employed in methoding a casting, particularly where feed metal will be needed and the optimum position for the direct pour unit. The package is an extremely powerful tool giving Foseco and the foundryman the opportunity to ‘get it right first time’.

The system is described in more detail later in the presentation. An example is provided to show how powerful the package is.
Case Studies

Steel Casting

Description
This product consists of an insulating sleeve with round filter supported in a print towards the end of the tapered part. The sleeve has a neck down design to give the filter maximum support during pouring and to facilitate easier settling of the casting. Four sizes are produced, 50, 75, 100 and 125mm. Metal capacities range from 30 kg stainless steel (25 kg plain carbon) for the 50 unit to 185 kg (145 kg) for the 125.

Case Study
Figures 3 and 4 show the layout for two plain carbon steel valve housings, firstly with the conventional running system and secondly with the direct pouring system. A STELPUR 125 unit was applied to the casting. Table 1 shows the yield improvement and table 2 the cost benefits.

The cost saving is £30.50 or £15 per casting despite the extra cost of feeder sleeves and filter.

The case study exemplifies the following points:-
1. Replacing the sand risers with feeder sleeves and using a feeder/filter sleeve to replace the running system improves the metal yield from 40 to 71%.
2. A running system weighing 35.9 kg in the original casting can be replaced by a direct pouring system weighing 18.6 kg.
3. The sand risers weighing 125.8 kg can be replaced by ones weighing only 26.0 kg.
4. The amount of settling and rework in the machine shop is reduced.
5. With lower weight of returns, remelting costs are lower.
6. The overall cost saving to the foundry is over £15 per casting.

Iron casting

Description
The product consists of round Sedex filters positioned in a sleeve in a similar way to STELPUR. KALPUR is not designed for steel filtration but for grey or ductile iron instead. At the moment only two sizes are produced, 50mm diameter and 75mm diameter products. These have capacities of up to 35kg ductile iron (55kg of grey) and 70kg (130 kg) respectively.

Case Study 1
Figures 5 and 6 show the original and the new pattern layouts, respectively, for a ductile iron vice base. In the original pattern, the metal stream travels down a cope runner after exiting the sprue, it then enters the mould cavity through two cope ingates. Table 3 summarises the trial results for a conventionally poured casting versus a direct poured one.

Because there was no sprue with the modified running system, shake-out and de-spruing time was reduced by 12.5% compared with the conventional system.
The case study exemplifies the following:-
1. Higher flow rates and hence shorter pouring times were obtained with KALPUR. This would result in higher productivity.
2. The metal yield improved from 69 to 86% giving excellent savings in melting costs per casting.
3. The scrap rate was reduced from 20 to <1%. The cost of remelting returns would be reduced, therefore. Better product quality and consistency was also achieved.
4. Shake-out and de-spruing man-hours were reduced giving a further cost saving.

Case Study 2

Figures 7 and 8 show the original and new pattern layouts for a ductile iron brake housing. In the original pattern, the metal stream splits and travels along two cope runnerbars after exiting the sprue. It then enters the mould cavity through the three cope ingates off each runner bar. The trial results for a conventional running system versus direct pour are summarised in Table 4.

Shake-out and de-spruing man-hours were reduced by 18.7% and by 22% for surface grinding and inspection because of the modified running system.

The case study exemplifies the following:-
1. Because the box weight was reduced, pouring time was quicker which would result in higher productivity.
2. Again there was an excellent increase in yield from 66.3 to 92%. This would reduce the melting cost per casting considerably.
3. The major problem with shrinkage defects, which could result in a 100% scrap rate in some production runs, was effectively eliminated. Product quality was improved and a better consistency achieved.
4. Because of the reduction in man-hours spent on shake-out, de-spruing, surface grinding and inspection, costs were reduced further.

Aluminium casting

Description

The product consists of SIVEX 'F' or 'FC' filters positioned in an insulating sleeve in a similar way to STELPUR and KALPUR. This product is designed solely for use with molten aluminium and is not suitable for use with iron or steel. DYPUR with 50 and 60mm diameter filters are produced. The size used depends on the flow rate requirement. The flow rate of aluminium through a SIVEX filter is between 0.05-0.1kg/sec/cm², if fast flow rates are required, the larger size is used.

Case Study 1

Figures 9 and 10 show, respectively, an air inlet manifold casting produced in a sand mould using a conventional running system and the same casting produced using a DYPUR unit. Table 5 summarises the trial results. The nett weight of the casting was 5 kg.

In the original casting, hot spots were created by each ingate. This was countered by having a riser over each of them. Direct pouring eliminated the need for risers resulting in the saving of 4 kg of metal. In addition, the casting had better pressure tightness.

The case study exemplifies the following:-
1. Higher productivity would be achieved because of faster pouring times.
Runner-Less Casting

2. Settling time and, therefore, costs would be reduced.
3. Savings would be made in melting cost per casting because of the higher yield as well as in remelting returns.
4. Direct pouring resulted in better product quality.

**Case Study 2**

Figures 11 and 12, respectively, show a cylinder head produced by gravity die casting using a conventional running system and by direct pouring. Table 6 summarises the trial results. The nett weight of the casting was 7.5 kg.

The case study exemplifies the following:-

1. Direct pouring is applicable to permanent as well as sand moulds.
2. Because of the yield improvement from 54 to 71%, savings are made in melting costs per casting.
3. Eliminating the need for the ingates means that settling time is reduced.
4. Remelting costs for returns have effectively been reduced to zero.
5. The die temperature is lower, leading to shorter and more efficient cooling cycles which means higher productivity.
6. The pouring temperature is lower which results in lower gas levels in the metal and better mechanical properties in the casting. Energy costs are also reduced.

**Benefits of Direct Pouring**

**Yield Improvement**

In some castings, the runners, gates and risers associated with the running system can account for up to 60% of the metal poured. Direct pouring means that the running systems are minimised or eliminated altogether and that this metal is used instead to produce castings. Yields are, therefore, higher and costs are lower.

**Good Feeding Characteristics**

At the end of the pour, the hottest metal is in the insulated feeder sleeve rather than at the ingates. The hot metal feeds the casting efficiently and effectively and, as a result, no shrinkage occurs. It has been shown, conclusively, that the presence of the filter has no effect on feeding.

**Improved Mechanical Properties**

Customers have reported improved mechanical properties such as elongation. The reason for this is thought to be due to directional rather than multi-directional solidification of the casting. The removal of inclusions by the filter also produces castings with better pressure tightness.

**Reduced Fettling**

As there is no running system, there is much less fettling work to carry out on the casting. Additionally, all the direct pouring units are neck-down which facilitates easier knock-off. This saves time and reduces costs in the machine shop.
Simpler Methoding and Design

As there is no longer any need for a running system, methoding is much easier. The nett result is that either castings can be produced in smaller moulding boxes, saving on moulding material, or that more castings can be fitted onto the pattern plate, improving productivity.

Cheaper Dies

In the case of aluminium gravity diecasting, smaller, less-expensive dies can be purchased.

Reduced Casting Temperature

For aluminium in particular, casting temperature can be reduced. This means that gas levels in the metal are lower and there is less risk of porosity. There is also a possibility that the level of superheat in steel can be reduced too. This will reduce energy costs and increase the lifetime of refractories.

Good Surface Quality

The ceramic filter controls the turbulence of metal entering the mould cavity. This eliminates the risk of oxide film formation and reduces the chance of the dissolution of further amounts of gas. Both have an effect on the surface quality of the casting.

Good Filtration Efficiency

The ceramic foam filter traps inclusions on the filter face and within the body of the filter, ensuring the casting is sound and free from defects which would reduce its mechanical properties.

Higher Productivity

The higher yields mean that more castings can be poured for the same volume of metal, the lower box weights mean castings can be poured more quickly and the reduced scrap rate means that more castings per melt meet the required specifications. All these mean higher productivity.

Reduced Melting Costs

With lower scrap levels and practically no running system, the level of returns for remelting is lower. Therefore savings are made in melting costs.

Fluid Flow Simulation

Figure 13 shows an aluminium casting of an element in a conveyor system complete with running system. The casting is poured through two downsprues into two runners and a total of six ingates. Natural risers are applied to thick sections. The scrap rate is typically 8% due to turbulent mould filling which causes surface defects and inclusions in the casting.

Figure 14 shows the 'optimised' version of the pouring system with a Dypur unit replacing most of the runner system.

Figure 15 shows a shaded layout to identify the features of the system more clearly.

The next set of figures 16 - 26, show the simulation of the mould filling with metal through the DYPUR unit at different time intervals. The arrows indicate the direction of metal flow, whilst their length is proportional to metal velocity. Fig. 16 is a 3D layout of the mould cavity at t = 0.
The simulation programme shows the following:

1. The initial filling of the unit is very turbulent, as depicted by the length and direction of the arrows, but metal leaving the unit and entering the small runner system has uniform, non-turbulent flow. (Figure 17.)

2. A magnified view shows the unit in more detail 0.41 seconds into the pour. (Figure 18.) The length of the arrows indicate the metal velocity is less than the critical velocity, 0.5 metres per second, and that the flow is non-turbulent.

3. The same view after 0.7 seconds continues to show the smooth, even metal flow. (Figure 19.)

4. After 2 seconds, the plan view shows how evenly the metal fills the casting cavity. The different temperature zones are very apparent. (Figure 20.)

5. After 3.51 seconds, the end section of the casting is starting to fill. (Figure 21.) The flow of metal is still very smooth. Without the filter to control flow, the various metal fronts interact. This causes the entrapment of surface oxide films leading to defects in the castings and poorer mechanical properties.

6. Further filling has taken place after 5.01 seconds. (Figure 22.)

7. In 11.91 seconds, the casting is full. The temperature profile, (Figure 23), shows the hottest metal is still in the insulated sleeve and that this can feed the casting.

8. Figure 24 shows that after 40.91 seconds, most parts of the casting still contain liquid metal and a proportion of solid metal. Only the very thin sections are totally solid. The proportion of solid to liquid (liquid fraction) decreases the nearer the section of casting is to the pouring unit until finally the metal in the insulated sleeve is still totally liquid. This shows directional solidification and the reason why the mechanical properties of the casting are improved with direct pouring.

9. After 90.91 seconds, the metal in the sleeve is still liquid (Figure 25). At the end of the casting at the opposite end to the Dypur unit, sections have started to freeze, but there is still sufficient liquid metal in the natural risers to feed this. The uniform progression from areas with high to low solid to liquid fractions can clearly be seen.

10. After 160.91 seconds, Figure 26 shows the solidification front has almost reached the pouring unit.

11. Figure 27 shows the latest design, based on work carried out on the simulation package.

Conclusions

The case studies, above, have exemplified the benefits of direct pouring in the production of castings and shown that major cost savings are obtained.

Customers have reported better elongation properties and better pressure tightness in their castings.

The computer simulation package confirms that mould filling is controlled and non-turbulent, that metal in the insulated direct pouring unit remains liquid until last and therefore feeds the casting effectively and that solidification in the casting is directional, explaining why customers have reported improved mechanical properties in direct-poured castings.

Acknowledgements

The author would like to thank the following, Messrs Child, Tackaberry and Sibley for the case studies and Mr. Paul Jeffs for the computer simulation work.
**TABLE 1**

**YIELD IMPROVEMENT USING A STEEL DIRECT POUR UNIT**

<table>
<thead>
<tr>
<th></th>
<th>Conventional Casting Method</th>
<th>With STELPUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Box Weight (kg)</td>
<td>269.7</td>
<td>152.6</td>
</tr>
<tr>
<td>Casting Weight - 2 Castings (kg)</td>
<td>108.0</td>
<td>108.0</td>
</tr>
<tr>
<td>Cutting/Grinding Area (cm²)</td>
<td>580</td>
<td>272</td>
</tr>
<tr>
<td>Feeder Weight (kg)</td>
<td>125.8</td>
<td>26.0</td>
</tr>
<tr>
<td>Direct Pouring Unit Weight (kg)</td>
<td>-</td>
<td>18.6</td>
</tr>
<tr>
<td>Pouring Bush Weight (kg)</td>
<td>17.2</td>
<td>-</td>
</tr>
<tr>
<td>Running System Weight (kg)</td>
<td>18.7</td>
<td>-</td>
</tr>
<tr>
<td>Total Weight of Returns (kg)</td>
<td>161.7</td>
<td>44.6</td>
</tr>
<tr>
<td><strong>Yield (%)</strong></td>
<td><strong>40.0</strong></td>
<td><strong>71.0</strong></td>
</tr>
</tbody>
</table>

**TABLE 2**

**COST BENEFIT USING A STEEL DIRECT POUR UNIT (£’s)**

<table>
<thead>
<tr>
<th></th>
<th>Conventional Casting Method</th>
<th>With STELPUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting and Grinding Costs</td>
<td>9.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Melting Cost of Returns</td>
<td>42.0</td>
<td>11.5</td>
</tr>
<tr>
<td>Feeder sleeves/filters</td>
<td>-</td>
<td>10.0</td>
</tr>
<tr>
<td>Re-work Costs</td>
<td>8.0</td>
<td>3.0</td>
</tr>
<tr>
<td><strong>Total (2 Castings)</strong></td>
<td><strong>59.5</strong></td>
<td><strong>29.0</strong></td>
</tr>
</tbody>
</table>
### TABLE 3

**TRIAL RESULTS WITH VICE BASE CASTING, DIRECT POUR v. A CONVENTIONAL SYSTEM**

<table>
<thead>
<tr>
<th></th>
<th>Conventional Running System</th>
<th>With KALPUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Box Weight (kg)</td>
<td>34.5</td>
<td>27.7</td>
</tr>
<tr>
<td>Casting Weight (kg)</td>
<td>23.9</td>
<td>23.9</td>
</tr>
<tr>
<td>Pouring Time (sec)</td>
<td>14.0</td>
<td>8.0</td>
</tr>
<tr>
<td>Metal Velocity (kg/sec)</td>
<td>2.4</td>
<td>3.6</td>
</tr>
<tr>
<td>Scrap Rate* (%)</td>
<td>20</td>
<td>&lt;1</td>
</tr>
<tr>
<td><strong>Yield (%)</strong></td>
<td><strong>69</strong></td>
<td><strong>86</strong></td>
</tr>
</tbody>
</table>

* Shrinkage and slag defects.

### TABLE 4

**TRIAL RESULTS WITH A BRAKE HOUSING CASTING, DIRECT POUR v. A CONVENTIONAL RUNNING SYSTEM**

<table>
<thead>
<tr>
<th></th>
<th>Conventional Running System</th>
<th>With KALPUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Box Weight (kg)</td>
<td>175.5</td>
<td>130.5</td>
</tr>
<tr>
<td>Casting Weight (kg)</td>
<td>119.5</td>
<td>119.5</td>
</tr>
<tr>
<td>Pouring Time (sec)</td>
<td>42</td>
<td>34</td>
</tr>
<tr>
<td>Metal Velocity (kg/sec)</td>
<td>4.2</td>
<td>3.8</td>
</tr>
<tr>
<td>Scrap Rate* (%)</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td><strong>Yield</strong></td>
<td><strong>66.3</strong></td>
<td><strong>92</strong></td>
</tr>
</tbody>
</table>

* Shrinkage defects.
### TABLE 5

TRIAL RESULTS WITH AN AIR INLET MANIFOLD, DIRECT POUR \textit{v.} A CONVENTIONAL RUNNING SYSTEM

<table>
<thead>
<tr>
<th></th>
<th>Conventional Running System</th>
<th>With DYPUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of Runners (kg)</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Weight of Risers (kg)</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Number of Risers</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Pouring Time (sec)</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>Fettling</td>
<td>3 ingates</td>
<td>-</td>
</tr>
<tr>
<td>Quality (Pressure/Radiography)</td>
<td>Good</td>
<td>V. Good</td>
</tr>
<tr>
<td><strong>Yield (%)</strong></td>
<td><strong>50</strong></td>
<td><strong>83</strong></td>
</tr>
</tbody>
</table>

### TABLE 6

TRIAL RESULTS WITH A CYLINDER HEAD CASTING, DIRECT POUR \textit{v.} A CONVENTIONAL RUNNING SYSTEM

<table>
<thead>
<tr>
<th></th>
<th>Conventional Running System</th>
<th>With DYPUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of Runners (kg)</td>
<td>2.4</td>
<td>0</td>
</tr>
<tr>
<td>Weight of Risers (kg)</td>
<td>4.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Number of Risers (kg)</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Pouring Time (sec)</td>
<td>14</td>
<td>11</td>
</tr>
<tr>
<td>Pouring Temperature (°C)</td>
<td>730</td>
<td>690</td>
</tr>
<tr>
<td>Die Temperature (°C)</td>
<td>350</td>
<td>200</td>
</tr>
<tr>
<td>Fettling</td>
<td>8 gates</td>
<td>0 gates</td>
</tr>
<tr>
<td>Quality (Pressure/Radiography)</td>
<td>1% Scrap</td>
<td>0 Scrap</td>
</tr>
<tr>
<td><strong>Yield (%)</strong></td>
<td><strong>54</strong></td>
<td><strong>71</strong></td>
</tr>
</tbody>
</table>
Runner-Less Casting

Fig. 1 Crankshaft casting with conventional running and feeding systems

Fig. 2 Re-designed, shorter running system with a single feeder for two castings

Fig. 3 Valve housing castings with a conventional running and feeding system

Fig. 4 Redesigned running system for valve housing casting incorporating a direct pouring unit and feeder sleeves
Fig. 5 Pattern layout for a ductile iron vice base casting. Metal enters the cavity through two cope ingates off a cope runner.

Fig. 6 Vice base casting pattern layout with a direct pouring unit incorporated.

Fig. 7 Pattern layout for a ductile iron brake housing. Metal travels along two cope runner bars after exiting the sprue. It then enters the cavity through three cope ingates off each runner bars.
Runner-Less Casting

Fig. 8 Brake housing casting with a direct pouring unit incorporated

Fig. 9 Air inlet manifold casting produced in a sand mould. A riser is positioned over each ingate to counter hot spots

Fig. 10 Air inlet manifold poured with a direct pouring unit. No risers are needed now

Fig. 11 Cylinder head casting produced in a die, with a conventional running system

Fig. 12 Cylinder head casting poured using a direct pour unit

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Fig. 13  Conveyor belt element casting with a conventional running system comprising two downsprues and a total of six ingates.

Fig. 14  Conveyor belt element poured with a direct pouring unit.

Fig. 15  Filled 3D SIMULOR representation of conveyor belt element casting with direct pouring unit.
Runner-Less Casting

Fig. 16  3D representation of casting at $t = 0$, i.e. before casting

Fig. 17  At $t = 0.2$ seconds, showing metal turbulence inside pouring unit (NB length of arrows)

Fig. 18  At $t = 0.41$ seconds, showing non-turbulent filling of short runner bar section after leaving the direct pour unit
Runner-Less Casting

Fig. 19  At $t = 0.7$ seconds, metal is entering the mould cavity. No arrow is greater than 0.5 m/s indicating the filling is controlled and non-turbulent.

Fig. 20  At $t = 2$ seconds, the metal is shown filling the mould cavity evenly in this plan view. None of the metal fronts is interacting. No oxide films are folding over, therefore.
Fig. 21  At $t = 3.51$ seconds

Fig. 22  At $t = 5.01$ seconds, the mould cavity is filling. This has been smooth and non-turbulent throughout.

Fig. 23  After 11.91 seconds the casting is complete. The temperature profile shows that the hottest metal is in the insulated sleeve and this is able to feed the casting.
Fig. 24  This representation shows the proportion of liquid to solid metal in different parts of the casting after 40.91 seconds. Only the very thin sections have totally solidified. There is still liquid metal in the two natural risers to feed the thick section of the casting. In the insulated sleeve the metal is still completely liquid.

Fig. 25  The sections of the casting furthest away from the direct pouring unit have solidified after 90.91 seconds. Both figure 24 and 25 show the directional solidification of the casting.
Fig. 26  After 160.91 seconds the solidification front has reached the direct pouring unit. This still contains liquid metal.

Fig. 27  This is the latest design of the casting after further work on the simulation package. Note the more economic use of the pattern plate.