Total Methoding: a new approach to controlling the structure of castings

Introduction

In the automotive industry customer requirements are changing so rapidly that manufacturers now have to increase efforts to produce vehicles that are desireable in terms of price, comfort, performance and safety.

Part of the production chain is the foundry which itself needs to constantly develop to meet these challenges and contribute to the overall process.

As pressure on the foundry to be more efficient has increased, consumable supplier/producer partnerships have grown in importance (1).

These partnerships now need to consider all areas of the casting process not only specific product/process areas.

One such approach, called 'Total Methoding' is discussed in the paper and illustrated by the example of the co-operation between the PSA Peugeot Citroën Group's Sept Fons Foundry and FOSECO.

For instance, to achieve the required specification for the new generation of flake graphite cast-iron ventilated brake discs, the supplier/producer are now together deeply involved in all areas of the production process including melting, moulding, laboratory, methoding and quality.

In the paper specific areas such as late stream inoculation are discussed and the effects of improvements in dispensation equipment and types of inoculant.

Also, using a filling and solidification simulation programme has assisted in specifying optimum running systems to ensure smooth regular filling of the mould with the required thermal gradients and defined range of casting temperatures.

Brake Components

Ventilated discs

Flake graphite cast iron ventilated brake disc technology is developing fast (2). The current trend is to replace the drums on rear wheels by solid discs and replace the solid discs on front wheels by ventilated discs.

The components are configured to guarantee:

❑ Heat capacity and mechanical strength.

Heavier vehicles, more powerful engines, the increasing efficiency of brake callipers, greater friction areas, repeated braking caused by ABS systems, etc., are all factors putting far greater thermal and mechanical demands on braking surfaces (3). Flake graphite cast iron remains the material best able to meet these constraints.

To check the requirements demanded by the specifications, a representative sample of the production batch is subjected to a destructive braking test on a test-bench. The ventilated disc tested must withstand harsh braking 20 consecutive times under loading conditions equivalent to a 2,500 kg vehicle running at 240 km/h.

❑ Wear

It is necessary to ensure regular distribution of wear on braking surfaces and increase their life, but service intervals for some vehicles are now every 30,000 kilometres. Consequently, manufacturer's specifications now requires a difference in hardness on braking surfaces at all wear-points of less than 20 HB.

❑ Comfort

Quite clearly, the ventilated brake disc is a safety component but it also affects the general comfort of the vehicle.

The goal of minimising or even eliminating vibration during braking, has resulted in dimensional constraints allowing the end float only to be of a maximum of 0.6 mm (figure 1).

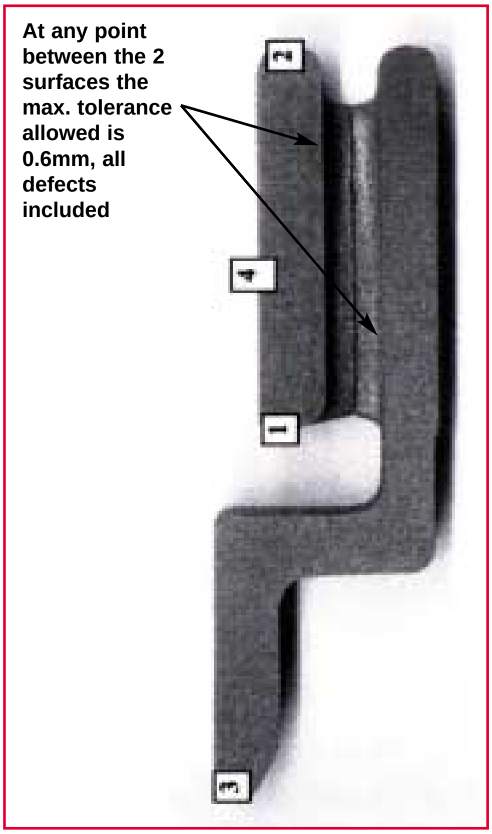


Figure 1: Minimising vibration faults

The Process

To best satisfy the dimensional criteria given above, vertical moulding is required and excessive stress on the core that may cause distortion should be avoided (figure 2).

Moulds are poured using a channel-type furnace with a working capacity of 6 tonnes, fitted with a stopper rod. The pouring time is 7-8 seconds for a layout weight of 26 kg. Pouring is managed automatically with continuous temperature control of the metal stream. Late stream inoculation is at a rate of 0.1%

Figure 2: Bottom filled system with 2 cavities

Prototype parts

When testing prototype parts on a test-bed, discs were breaking at the outer surface fin connection. Micrographic inspection of the fractured area near to the hub revealed the presence of type 'D' graphite, also known as under-cooled graphite, which is an interdendritic graphite without preferential direction. Its presence is usually associated with fast cooling. The area was very localised (figure 3), the structure of the rest of the part was within specification, in other words type A graphite in a pearlitic matrix.

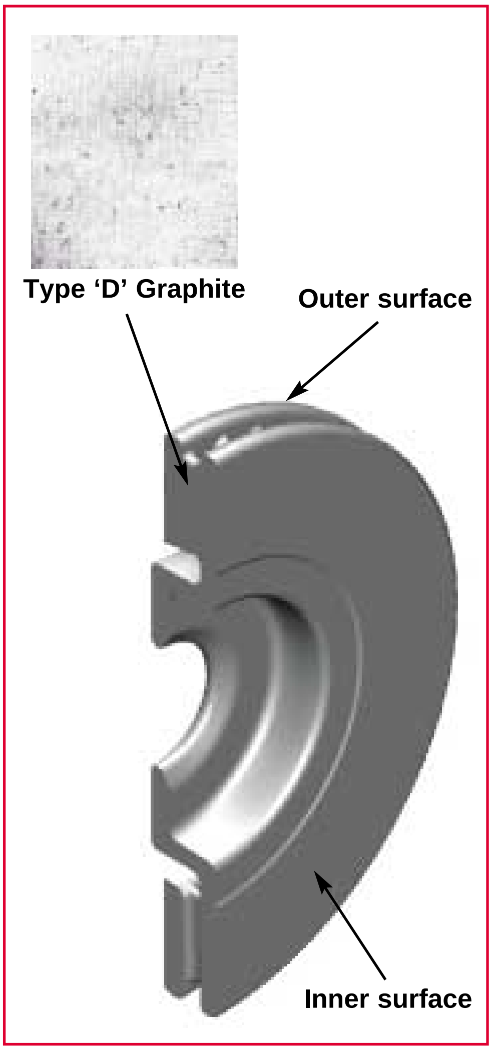


Figure 3: Area of disc with type 'D' graphite present

Whenever such a problem occurs, the first thing to do is to conduct metallurgical tests to identify the problem and ammend accordingly:

- ☐ Modify the carbon equivalent within the limits of the specifications,
- ☐ Modify the inoculation rate and type of inoculant in the transfer ladle
- ☐ Modify the rate of late stream inoculation and type of inoculant
- ☐ Increase the pouring temperature

Results

Without going into great detail, the one factor that appreciably improved the situation, was the increase in pouring temperature. This is because the thickness and area of the zone containing under-cooled graphite disappeared totally at a temperature above 1,430°C. This confirms that:

The structure of flake graphite cast iron depends both on the rate of solidification and cooling, and on the chemical composition.

However, with the increase in pouring temperature, shrinkage can be a problem.

To get out of this spiral, we turned to a filling and solidification simulation programme. The use of this software for feeding, filling and gating system design is now common practice, however, in this case we used the tools specifically for the purpose of improving metallurgical consistency.

First scrutiny of the filling and cooling simulation very clearly shows an area of "cooler" metal in the upper portion of the casting, which is the defect zone. There is certainly a correlation showing under-cooled graphite (figure 4).

Figure 4: Area of cold metal corresponding to the presence of under-cooled graphite

Current running system

The cavity is filled by a pressurised running system with ingates that are located at the bottom of the inner surface and the flow-off is located in the upper part in the same plane (figure 5).

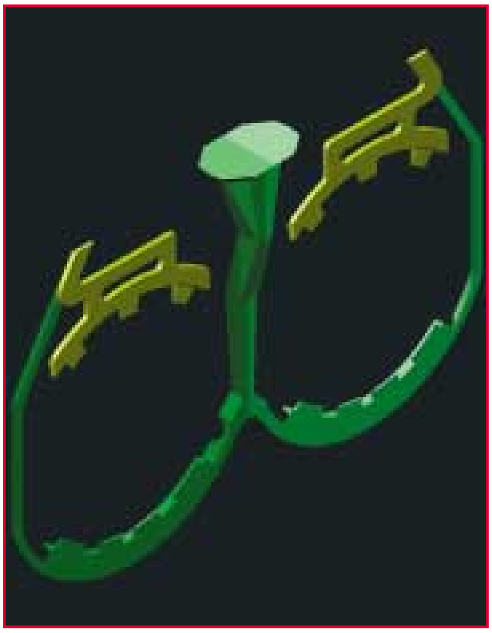
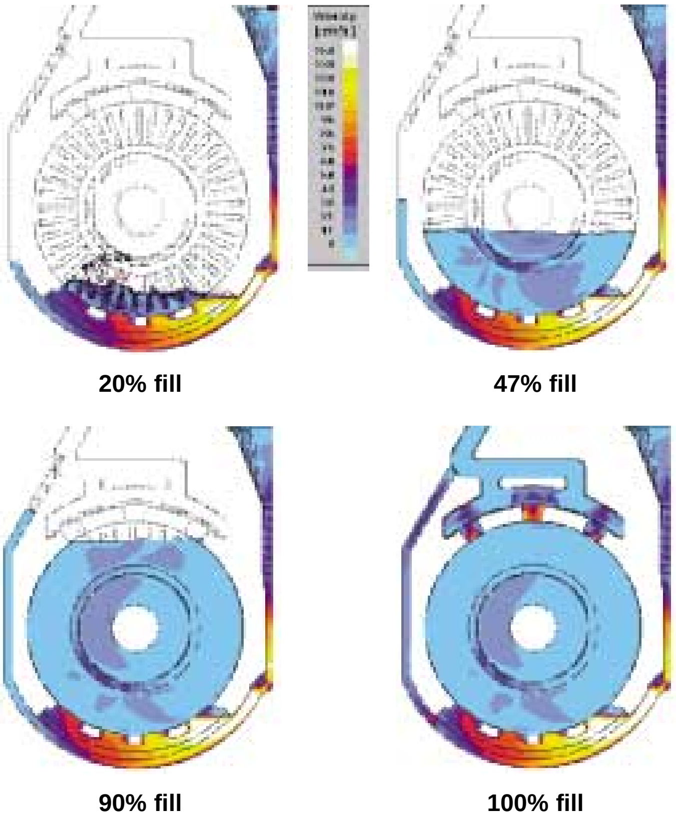


Figure 5: Current running system. The ingate and flow-off are in the same plane

The filling simulation sequences for the current system at different rates (figure 6) show very clearly that the speed of the metal at the first two ingates is over 1 metre per second and reaches 1.5 metres/second at the first ingate. This has the effect at the start of filling of causing the metal to splash and giving it a clockwise rotating movement, which is shown by the dark blue colouring. The consequences are a risk of erosion of the fins and a substantial thermal gradient in the same surface and between the 2 surfaces of the ventilated disc, this point is confirmed later on in the article.



20% fill **47% fill**

90% fill **100% fill**

Figure 6: Simulation sequences at different fills. Significant imbalance of fill speeds at the different angles

Modification of the running system

With the help of the Magmasoft programme and its wide experience (4) in the application of ceramic foam filters, FOSECO has made a proposal for an non-pressurised type running system with ingates at the bottom of both inner and outer sections of the casting (figure 7).

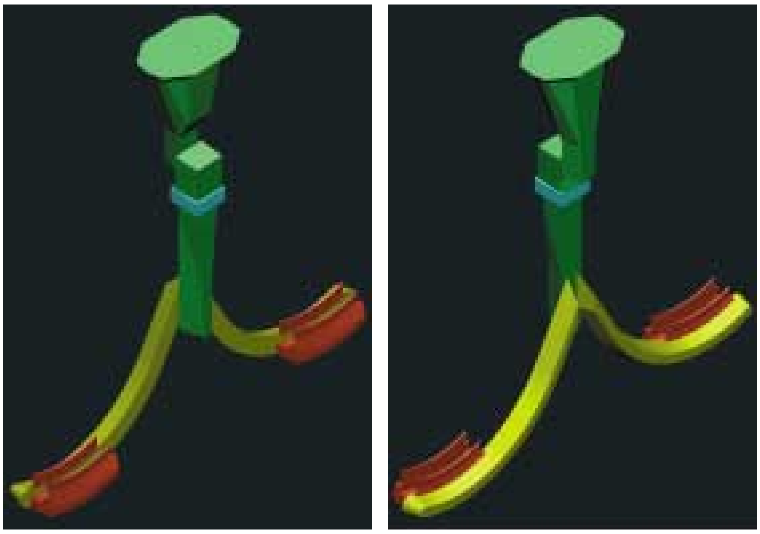
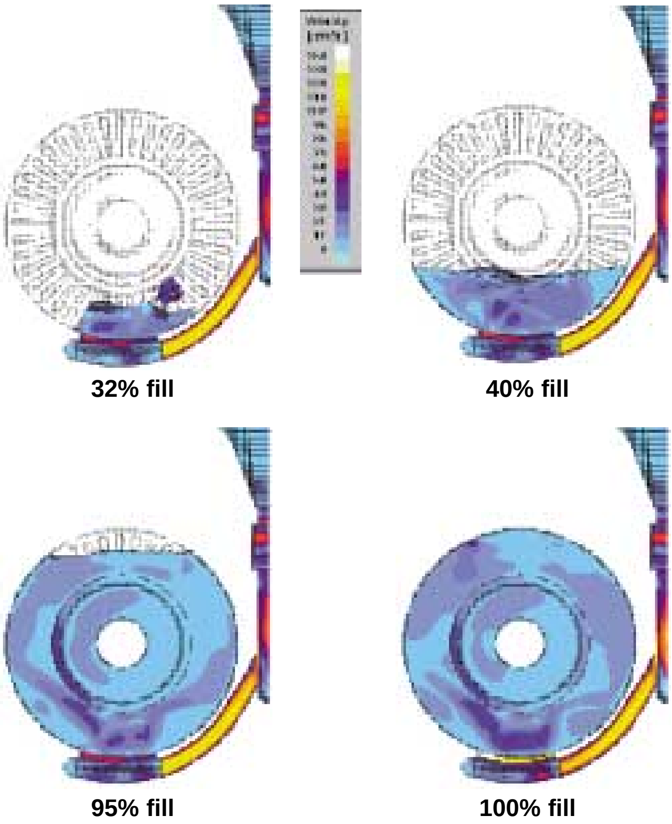


Figure 7: FOSECO proposal: 1 ceramic foam filter and ingates on both brake tracks

The improvements are visible (figure 8), the speed of the metal at the ingates is less than 0.5m/s. Splash at the start of filling is minimal. The metal fills evenly and is well distributed.



32% fill

40% fill

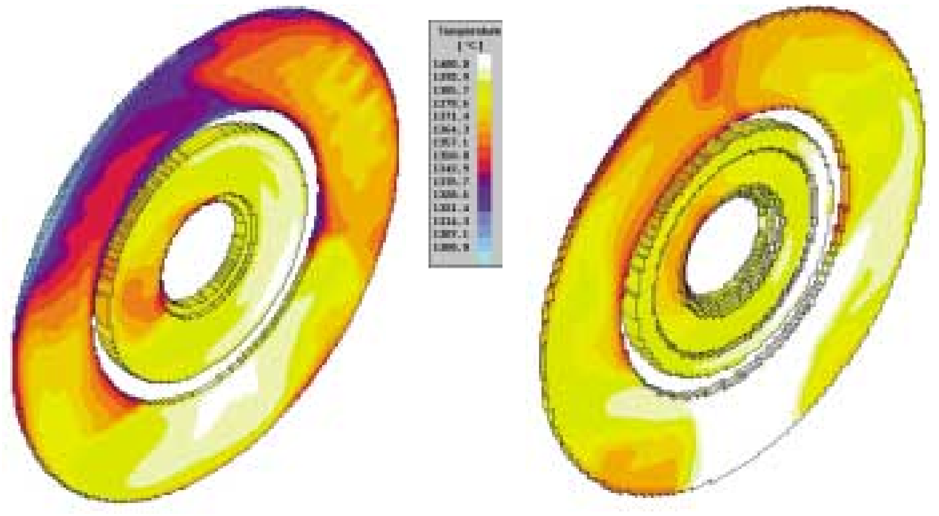
95% fill

100% fill

Figure 8: Simulation sequences at different fills. The speed of the metal is less than 0.5m/s at the ingates with better distribution in the mould

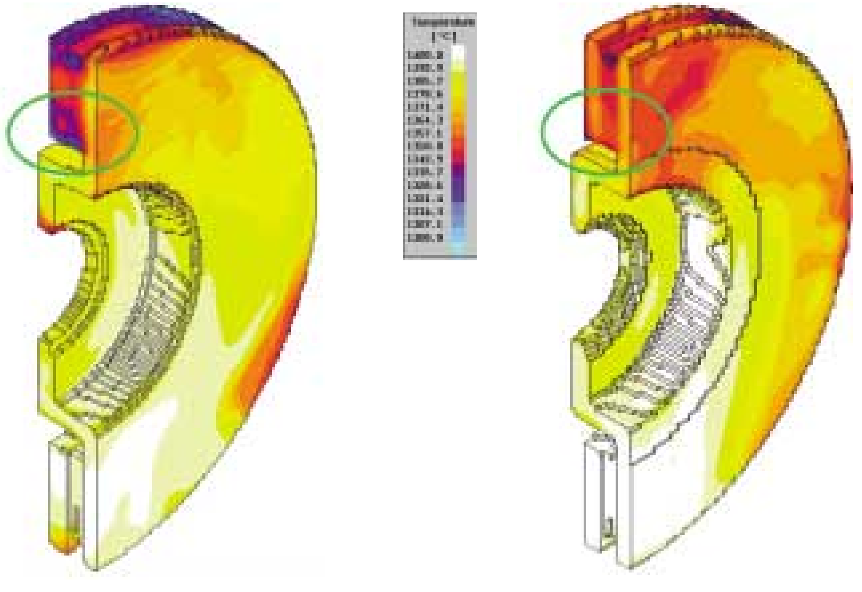
Cooling simulation

The representation of the isotherms (figures 9 and 10) just after the pouring of the discs at 1,420°C tells us a great deal and clearly shows the difference in results both for the lengthways cut of the outer surface and for the cross-section of the disc according to the running system:



Filling via inner surface **Filling via both surfaces**

Figure 9: Pouring temperature 1,420°C. Lengthways cut of the outer surface, showing the thermal gradients



Filling via inner surface **Filling via both surfaces**

Figure 10: Pouring temperature 1,420°C. Cross-section of the disc, showing the thermal gradients

Pouring via the inner surface

The "coldest" zone at the top left of the outer surface is in a range of 1,310 to 1,350°C. It is the defect area containing type ‘D’ graphite. The spread of temperatures across the whole of the cut is between 1,310 and 1,400°C. In the cross-section we see on the inner surface a greater uniformity of temperatures, which are between 1,350 and 1,400°C. This in part certainly explains the occasional appearance of shrinkage.

Pouring via both surfaces

We see a greater uniformity of temperatures and a narrower spread between 1,340 and 1,400°C across the whole of the cut of the outer surface. On the cross-section on the inner surface, the temperature difference is between 1,340 and 1,400°C. These are the optimum conditions to ensure a uniform metallurgical structure on cooling of the part.

Inoculation

After optimising the filling system to give a closer, better spread of isotherms, the structure, which depends both on the conditions of cooling and on the metallurgy, should be more uniform and more reproducible provided that the late inoculation is adequate and under control.

Inoculation is the operation that consists in introducing nucleii into the cast iron, in order to precipitate the dissolved carbon in the form of flake graphite. The type of inoculant with regard to its chemical analysis and granulometry and the way in which it is applied are crucial in the process of making reproducable, sound iron castings.

The ideal situation is to introduce the optimum quantity immediately before the mould is filled. The constraint is to ensure constant, even distribution during the filling of all components, and a process able to achieve this.

In Figure 11, we have an example of poor late inoculation. A trough-vibrating distributor was in use where additions were inaccurate. Furthermore, we can see that the inoculant stream is directed at the pouring bush. When it is primed, the inoculant will float and only go into solution with difficulty.

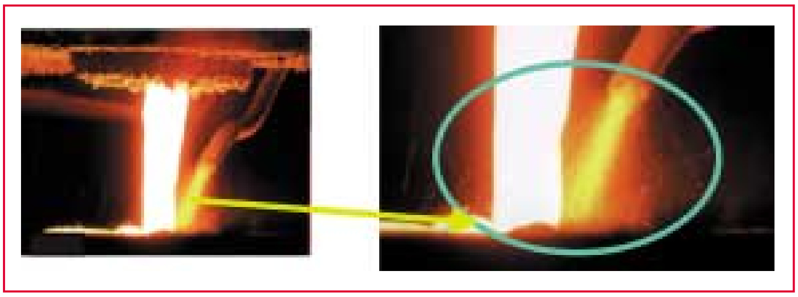


Figure 11: Example of poor late inoculation: the inoculant is not directly aimed at the iron stream and also contains too many fines

On closer inspection, we can see a halo of fines framing the main stream. Although the sizing of the inoculant is within specification (from 0.2 to 0.7 mm), the sieve grading is spread across 5 screens.

In the second example (figure 12), we have a gravity type dispenser with a measuring accuracy of plus or minus 5%. The 0.2 - 0.7mm inoculant has a more consistent granulometry (spread across just 3 screens), and is directed effectively onto the metal stream at a controlled speed so as to improve the dissolution of the inoculant.

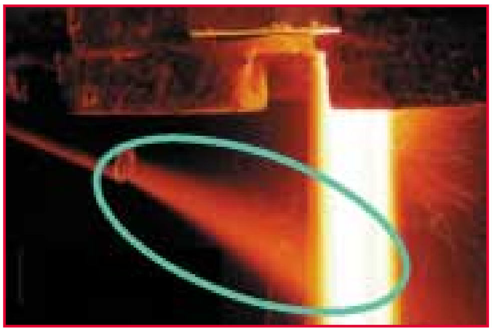


Figure 12: Late stream inoculation employed using optimum conditions

As a result of the change in inoculation practice, metallurgical consistency was improved and the scrap rate decreased. Moreover, due to the increased effectiveness of the gravity distribution system and a more consistent inoculant product, the addition rate was reduced by 15%.

Conclusion

Ongoing developments in the automotive market to meet environmental requirements, improve vehicle safety and reliability, reduce purchase and maintenance costs, and the faster turnover of models, makes the work of foundries supplying castings increasingly difficult.

The PSA Peugeot Citroën Group's Sept Fons Foundry and FOSECO have combined their respective strengths and expertise to meet the requirements of the new quality specifications for ventilated brake discs.

Total methoding is a new approach to the supplier / customer partnership that incorporates the entire manufacturing process including core-making, feeding, casting and metallurgical properties.

Our sincere thanks to the management of the Sept Fons Foundry for kindly allowing us to publish this research.

References

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