The Inmold process
—another look

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The ability to produce cast iron with graphite in the nodular form from the melt as opposed to cast iron with the nodular graphite produced by heat treatment has been known since the 1920s when Meehan claimed to have manufactured it using alloys containing magnesium, nickel, calcium and silicon.

During the late 1940s, Morrogh and Williams and other workers in Germany and America, demonstrated a commercial method for the production of nodular cast iron, obtaining elevated mechanical properties equalling many of the properties of cast steel.

The inmold process is probably the greatest advance in the metallurgical processing technology of cast iron since the production of nodular cast iron was first discovered.

Since the first inmold patent was filed in 1968 and news released in 1971 to the foundry industry on the process, it has excited the thoughts of metallurgists and foundrymen alike, concerned with the production of nodular iron castings.

Many technical articles have been written about it and the technology has been well explored.

Some researchers have gone into a lot of theoretical data, in order to explain the phenomena of the inmold process, but, generally speaking, as they have started from the wrong base criteria, their conclusions are of little assistance in explaining it.

However, perhaps it is time that we now stood back and took a good look at the process and viewed its achievements dispassionately and objectively.

Although the general principles are well known, it might be advantageous if they are reiterated here simply, so that any reader will know what we are talking about.

As is well known, the production of nodular cast iron usually takes place in a ladle or reaction vessel of some sort and this process has a number of technical disadvantages.

On the other hand, the inmold process is, as the name suggests, a metallurgical processing operation for the production of nodular cast iron, which actually takes place within the mould.

This operation is usually carried out in a horizontally-jointed mould, but systems are available where the joint line can be vertical. In both bases however, the process consists of moulding into the gating system, before the ingates, a block or reaction chamber.
Into this reaction chamber, a predetermined weight of nodularising alloy is added, which is just sufficient to change the graphite form of the metal poured into the mould from flake to nodular, without any substantial excess of alloy being added.

When the mould is closed, the iron is poured down the down-gate. This flows over the top of the nodularising alloy in the reaction chamber, passing through the gating system into the casting.

It has been shown that, in the absence of oxygen in the moulding system, the alloy goes into solution quietly and evenly through the duration of the pour. Therefore, a constant amount of magnesium is picked up by the metal throughout the pouring operation and it is nodularised just before entering the mould.

Through predetermined criteria, it is possible to accurately calculate the size of the reaction chamber and the important factor, which is the surface of the nodularising alloy exposed to the flow of metal and which regulates the speed at which the alloy is dissolved by the metal.

This factor is termed the solution factor and is covered by a number of letters patent. It is the key to success of the operation.

It is essential that the nodularising alloy is produced to very closely defined granular limits, in order to ensure that the solution factor of the alloy is constant. In fact, the whole process is built around complete consistency of operation. The basic design of the reaction chamber is shown in Fig. 1.

Due to the whole concept and development of the process, it is a process most suitable for use in the high-production foundry and the foundry producing castings in long series. Some foundries are, however, using the process where they are producing short-series castings and they are on a recurring basis and, in this case, the foundry is certain that consistency is always going to be maintained from casting to casting and batch to batch.

This is basically the reason why the process has been selected by the large automobile manufacturers throughout the world for the production of nodular cast iron. Although it is the most satisfactory method for the production of high-integrity castings for automobiles, it is also the easiest to install on a high-production line, with nominal capital expenditure and minimal changes to the pattern equipment.

There have always been problems associated with the production of nodular cast iron and these are aggravated where large quantities of iron are being treated continuously throughout the day, or over several shifts.

What may be tolerated for a small-scale or intermittent production is certainly not tolerable for large-scale production and, particularly, automated production.

In the majority of these cases, the physical disadvantages are even greater than the metallurgical disadvantages. To start with, one may quote the bad environmental conditions for the workers; for example, the heat coming from the ladles when the alloy is added to them. During the nodularising operation, there is a high content of flame and flare, which can be likened to a pyrotechnic display, together with the production of copious quantities of white fume of magnesium oxide. Following treatment, there is the skimming of the reaction products from the surface of the ladle.

All too frequently, these processes also entail very heavy capital investment in plant, such as processing vessels and large fume-extraction systems. In ecologically-aware countries, it is also necessary to install, apart from the massive fume-extraction system, a fume collection system, in order to prevent the copious fumes passing into the outside atmosphere.

Where automobile castings and high-quantity castings are concerned, one of the main criteria is absolute consistency. Utilising the traditional nodular processing methods, there is the well known phenomenon of fading, which is progressive from the very moment at which the iron is nodularised. From the first castings poured from a ladle to the last castings, there is a variation in properties and decreasing mechanical properties. In fact, the matter becomes even more acute where there is an automatic moulding line and the pouring to be in phase with the pouring track, but, as frequently happens with automatic moulding lines, there are stoppages. Therefore, it is not possible to dispose of the metal into other moulds as one might do in a jobbing foundry. There is either a deterioration of properties or the iron which has been nodularised at no little cost, has to be poured down, and the cost of treatment is lost. In addition, to maintain the mechanical properties as far as possible, there is generally a post-insulation.

Most other processes rely upon the magnesium in the magnesium-bearing alloy to reduce the sulphur to acceptable levels and consequently, there are variations in retained magnesium levels. Frequently, these rise to abnormal proportions, promoting the presence of free carbides, particularly in very light sections.

Rigid moulds are preferable and these are common in high production foundries. These may be either green sand under high pressure, or shell moulds which are backed up, but the essential point is that there is no mould dilution. Therefore, the castings produced are true to form and constant in weight, so that one may even consider this disadvantage an advantage to the customer.

Using traditional green sand moulding, castings of equal mechanical properties may be obtained, but there may be a slightly increased alloy consumption, due to allowance for mould wall movement. What may be considered by some to be a drawback is that it is essential to start with a low sulphur content iron and it is generally considered that 0.01% of sulphur is the maximum level. This is achieved easily by any of the desulphurisation processes, such as by shaking ladles or the Osmas process for gaseous agitation and desulphurisation, or using the pure metal charged in an electric furnace, where the charged sulphur will be low enough without desulphurisation.

On continuous tapping cupolas, the continuous desulphurisation process which was developed by The International Mechanite Metal Co. Ltd., utilising the porous plug in the launder of the continuous tapping cupola, also reduces the sulphur to acceptable levels.

Maximum desulphurisation has the effect that the sulphur is reduced to a pre-determined level and therefore there is...
no reliance upon the uncertain reaction of magnesium in order to reduce the sulphur, and there is a reduced risk of magnesium sulphide inclusions.

Therefore, the nodularising alloy which is used is kept to an absolute minimum and, in fact, an efficient foundry will produce nodular structures with 0.2% of nodularising alloy and certainly all foundries using the Inmold process can maintain the nodularising alloy not in excess of 1%. The nodulariser is added to the reaction chamber within the mould, either by means of a volume measure at the coring-up station, or, on automatic moulding lines, is generally added automatically by a pre-weighing system which discharges the alloy into each reaction chamber and then checks the mould to ensure that it has been placed and there is no malfunction of the pre-weighing system.

Should there be a malfunction of the pre-weighing system, then the moulding line is automatically stopped, so that there is no risk of castings being poured without being nodularised.

As this takes place prior to the closing of the mould, it is nowhere near the heat zone and therefore environmental conditions for the workers are maintained at normal for the foundry.

After closing, the mould is poured in the normal way with the desulphurised iron. It is a completely fume-free pouring operation, as there is no generation of magnesium oxide fumes. Therefore, there are no fume-extraction systems necessary and a clean environment is maintained. Of course, one must also consider that the process is inherently safe as, due to the fact that a low magnesium-bearing alloy is used and it is contained within a mould, there is no danger whatsoever. There is no record of any worker ever being injured due to the Inmold process.

Metallurgically, the system produces nodular structures which are consistent from casting to casting. Because of the fact that the iron has no chance to fade before solidifying (as one obtains with other methods where the treated metal is held and poured from a ladle), there is a very small nodule size with a high nodule count. In the Inmold process, the silicon in the magnesium-bearing alloy acts as a late inoculant and the chilling tendency of the iron is practically eliminated, due to this high nucleation and inoculation effect of the alloy.

It is not infrequent for castings with sections as low as 3 mm to be produced completely carbide-free and freely machinable. In fact, it might be said that the amount of ferrite produced by the process can even be an embarrassment in some instances, where a pearlitic matrix is required.

Because of the fact that low percentages of nodulariser are used and these are also low in magnesium, the amount of retained magnesium in the casting is also relatively low. This is principally because the recovery of magnesium is very high and recoveries in the order of 80% have been recorded. The major difference, when using the Inmold process, lies in the field of quality control, when compared with other nodular iron processes using vessel or ladle treatments.

Because of the inherent features of the Inmold process, metal structure assessment of castings is carried out rather than on separately cast samples.

The International Meehanite Metal Co. Ltd. has always placed a great emphasis on the ultrasonic testing of castings and particularly in the determination of physical properties in nodular cast iron by means of ultrasonics.

This experience was put to good effect with the development of the Inmold process and, where there is a high-production foundry, it is advantageous for every casting to be checked ultrasonically. Firstly, it determines if the casting is nodular, but, at the same time, the automatic systems even determine the degree of nodularity. One might say that there is no real disadvantage because, in the case of high-integrity castings for automobile manufacture, each one should be inspected in any case for mechanical properties. Where these are combined in an automated system, which also checks for dimensional accuracy, there is a hidden advantage. The process has a higher degree of consistency of mechanical properties than any other nodularising system. The prime examples of this are the now classic graphs produced by Dr. M. Remondino of Fiat and these are shown in Figs. 2 and 3.

These diagrams are self-explanatory and only serve to show the superior physical properties which can be obtained with the Inmold process and also the very high degree of consistency which is obtained when compared to other conditions.

One might ask: "Well, where has this development got us?"

The answer could be that, due to the ecological advantages, together with the inherent safety of the process and the high physical properties obtained, a very high proportion of the nodular iron castings throughout the world are being made by the process. This has replaced many malleable components and, in the heavy automotive industry, replacing many steel castings. This is due to the inherent consistency, reduction in the necessity for heat treatment, high machinability and greater consistency of the irons as opposed to the alternative materials.

One could say that the process has opened new fields to the designer.

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**Fig. 2**

Fatigue strength of nodular-graphite iron (B) made by the Inmold Process compared with nodular-graphite iron treated in the ladle by the "Sandwich" process (C). A comparison is also made with forged C40 0.4% carbon steel (A). The fatigue limit of C40 steel is taken as 100. The diagram represents four years of continuous tests on crankshafts in these three materials.

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**Fig. 3**

Comparison of UTS measured on specimens cut from crankshafts cast in Inmold-produced nodular-graphite iron (normalized) (B); ladle-treated nodular-graphite iron (normalized) (C); and forged C40 steel (quenched and tempered). (A). The results are based on a four-year period of continuous tests.
In the future, where is the process leading us?

One can only cite the many other processes which are being developed competitive to the Indumold process. It can be seen that researchers have been inspired by the process and therefore metallurgists and foundrymen alike have had a new tool put into their hands, which they are capable of developing in the field of metallurgical processing.

One might look at mould inoculation and the way in which this has grown. It is now a common treatment in the foundry.

Instinctively, foundrymen are looking for fume-free methods for the production of nodular cast iron and one turns automatically to the Indumold precept—that is, the production of nodular iron in a confined space. Therefore, for the larger castings or larger treatments, one can see this concept in the Flotret Process, where larger quantities of iron are treated in refractory systems. The iron is poured through the refractory system, entering one end as grey cast iron and leaving the other end of the system as nodular cast iron. This is on a predetermined ladle weight basis, fume-free and with a high magnesium recovery. The only disadvantage in relation to the Indumold process is that, as the metal has to be transported in a ladle from the Flotret treatment reaction box to the pouring station, there can occur the phenomenon of fading.

The Flotret process is being developed even further and now alloys are being added on a continuous basis for larger quantities of iron and metal is being poured straight from the melting furnace through the treatment system, so that the iron, which is collected in the pouring ladle, is clean and nodularized.

In conclusion, one may say that the original brilliant concept of the Indumold process has placed another tool in the hands of the metallurgist and is being applied on an ever-widening basis. One can envisage many other graphitic structures being produced on the same principle.

The efficacy of the process is shown by the fact that probably the greatest tonnage of engineering castings in the world is being produced annually by the Indumold process. There are Licensees for the process in nearly every industrialised country in the world.

It should be noted that the Indumold process is a patented process and production is only permitted under licence from the Principal Licensor, namely Materials and Methods Ltd, or its Agents.

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