General Introduction
Compacted (Vermicular) graphite irons (CGI) have been produced since the inception of spheroidal graphite (nodular or ductile) irons in the late 1940's. Invariably the structure was produced by accident (and still is) due to the breakdown of process control during production of SG. However, as the emphasis moves towards stronger, lighter materials, applications have been found for the unique mechanical properties offered by the compacted form of graphic irons. High strength with good thermal conductivity and mechanical damping have ensured its application in brake discs, diesel engine blocks, turbo housings, exhaust manifolds and ingot moulds.

The production of CGI requires careful selection of materials and very close metallurgical control to ensure uniform and consistent compacted graphite structures. This is especially crucial for thin wall sections designed to resist high compression pressures.

Properties of Compacted Graphite Iron
The compacted graphite form lies between grey iron, where graphite is in flake form, and ductile iron where graphite is in nodular form. The 'worm-like' or vermicular compacted-graphite shape provides physical properties that mirror the most beneficial properties of grey and ductile irons. Thermal conductivity and damping properties are on par with grey iron and tensile strengths and stiffness are comparable to ductile iron.

Applications for CGI
Compacted Graphite Iron was first used for brake discs for high speed trains, but its main application is for large capacity diesel engine blocks. Diesel engines operate at increased compression pressures compared to petrol engines; therefore, wall thickness, strength and weight are crucial factors for diesel engine design which make CGI attractive.

Future for CGI
Increasing demands for engines with improved fuel efficiency, lower emissions and lighter weight have ensured the future use of CGI for automotive engine blocks. One would also expect to see further research and development into areas where CGI castings can be technically and cost effectively utilised.

Important Factors for Formation of CGI
The main factors affecting the formation of CGI are the following:
- Sulphur content
- Oxygen content
- Active Magnesium
- Nucleation status
- Cooling rate

A close balance between these five variables is required.

Unlike gray and ductile irons, the sensitivity of CGI to Magnesium and inoculant additions prevents foundries from adopting the traditionally conservative philosophy of overtreatment. Therefore, reliable CGI production requires simultaneous control of active Magnesium and inoculation throughout the process.

Control of Magnesium
After Magnesium reacts in the melt with Sulphur and Oxygen, the residual Magnesium is classed as active Magnesium. Active Magnesium content needs to be closely controlled to suit the section or modulus (cooling rate) of the chosen casting to ensure that suitable CGI structures are produced. Too high an active Magnesium content results in a high proportion of nodules, reducing thermal conductivity and decreasing mechanical damping. Too low an active Magnesium results in the formation of flake iron, reduced mechanical strength and ductility.

Fast cooling promotes nodule formation and slow cooling promotes flake iron. Some nodularity is allowed (and usually inevitable) but flake graphite should not be present. Active Magnesium should be controlled within very tight limits of less than +/- 0.005%.

Control of Inoculation
Inoculation levels need to be tightly controlled to minimise the formation of flake or carbides but limited to prohibit the formation of excessive nodules. The only reliable method available to monitor nucelation levels and performance of different Ferro Silicon inoculants is with the use of thermal analysis.

Titanium Method of CGI Production
A wide window of opportunity is available if the titanium method of CG production is utilised and complete CGI structures can be produced in castings with wide cross sectional variation. The downside is reduced machinability.

This method is usually limited to ingot moulds, brake discs (the cuboids enhance the brake disc wear properties) or parts requiring limited machining. However for general engineering castings, requiring extensive machining, alternative methods are required.

If the titanium method is not applicable, very tight control of base iron metallurgy is necessary. Active Sulphur, Oxygen, Magnesium levels and nucelation status need to be measured and controlled.

Technical Introduction
Metallurgical Process Control for Compacted Graphite Irons

Fig. 1 – Microstructure of CGI showing the worm like or vermicular graphite particles.

Fig. 2 – CGI Diesel Engine Blocks are used by many of the world’s leading automotive companies.

Metallurgical Process Control of CGI
Spectrographic analysis gives a good indication of levels of tramp elements or alloying agents but cannot measure the interaction of these elements. Thermal Analysis allows the measurement, and ultimately, control of these interactions and allows a true picture of how the metal will react with Magnesium and ultimately solidify to the required structure.

NovaCast Systems has further refined the ATAS® (Advanced Thermal Analysis) process control specifically for the production of CGI. This system allows the accurate monitoring of base oxygen and nucleation levels. Control of active Sulphur and Oxygen allows an accurate assessment of magnesium additions required to achieve residual active Magnesium levels. The final nucleation state can be assessed and levels of inoculation adjusted accordingly.

The aim of the casting engineer is to ensure that metal with a consistent thermal fingerprint is poured from furnace to treatment ladle (or in-mould methods) and from ladle to mould. Thermal Analysis in conjunction with spectrographic analysis is currently the most reliable method for consistent, machineable CGI production.

Asmet’s Products for CGI
Asmet can provide a complete service including technical assistance and supply of specialist products.

Preconditioners for Base Iron
Iron BiSulphide
Rare Earth Silicide

Ferro Silicon Magnesium Alloys
GC-Ti-Mg Alloy
Ertalloy™ MgFeSi alloys

Magnesium & Inoculation Treatment Wires
The use of wires for the addition of treatment alloys allows very close and consistent control of additions. Specialist Magnesium and inoculation treatment wires are available from 4-15mm diameter. Fill rates and compositions are supplied to suit customer process requirements.

Ferro Silicon Inoculants
Castron LC™ Strontium Inoculant
Ferrocast™ Zirconium Inoculant

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