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Article on Product of Cast Iron with Vermicular Graphite (CGI)

Introduction

The material cast iron with vermicular graphite (CGI) is involved in the development of the material cast iron with nodular graphite (DI) to some extent. While DI commenced on its triumphal course after the Second World War, the more recent material CGI was only registered as an undesired form of graphite in the production of DI. The micrograph of what is known as quasi-flake graphite is familiar from academic texts [1]

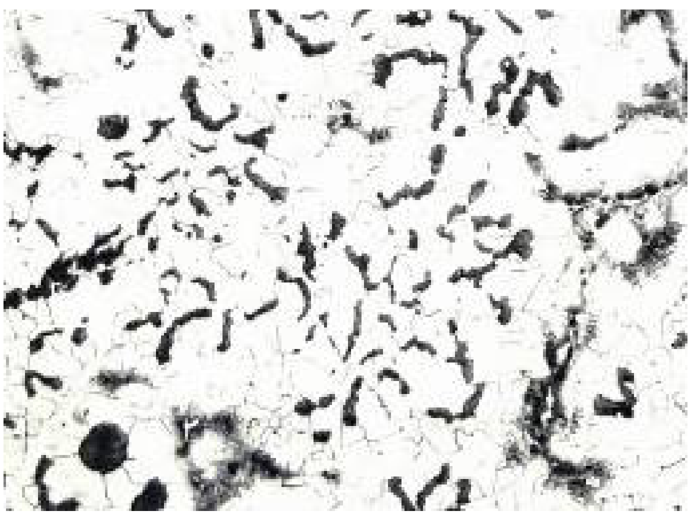

Fig. 1: "Quasi-flake" graphite

In the past, there were a series of development projects [2 to 5] which allowed the material with the vermicular graphite formation to become known and which also gave the graphite its name vermicular graphite.

These were followed by investigations and publications which dealt with the material [6 to 16] in recent years.

The practical benefits of the material, classified between DI and grey cast iron (GI), were quickly discovered.

It exhibits the following positive features compared with DI: Lower expansion coefficient, higher thermal conductivity, better thermo-shock behavior, lower elasticity modulus, lower tendency to distort at high temperatures, better damping capacity and good castability.

On the other hand, when compared with GI the following favorable properties come to light: Lower wall thickness dependency of the properties, a lower tendency to oxidate with less growth in the high-temperature range, higher strength without alloying elements and higher ductility and toughness.

From this it can clearly be seen that the material with this combination of properties is particularly suited to parts which are used at higher temperatures and temperature changes. These include the cylinder crankcase, exhaust manifold and turbocharger, clutch disks, brake disks, hydraulic sections and glass molds. As far as larger castings are concerned, the material can be used for slag ladles.
What is noticeable is that, despite the good combination of properties, the quantity of CGI manufactured in Germany and globally is only a small share compared with DI, let alone GI.

On the one hand, the reasons for this seem to be in the specific parts spectrum. On the other hand, it must be observed that the manufacturing process and the properties to be achieved place

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Manufacturing Method for Cast Iron with Vermicular Graphite

The basic prerequisite for the production of castings from cast iron with vermicular graphite is compliance with parameters that are as uniform as possible in all process steps, starting with the analysis of the base iron and continuing to casting. The key step in all technologies used to produce CGI today is undertreatment with magnesium. However, this is carried out in different ways and using different magnesium carriers. Furthermore, magnesium treatment is also usually accompanied by one or more additional work steps which are often critical to success. This often depends on the product, for example, it is essential to work with a titanium additive for castings with very thin walls such as exhaust manifolds or turbocharger housings.

The following are the state-of-the-art variants for producing CGI:

- Targeted Mg undertreatment with master alloy or wire with the addition of Ti, FeTi
- Preconditioning and subsequent wire or master alloy treatment with and without Ti additive
- Undertreatment with master alloy or wire and subsequent correction with treatment and/or inoculation wire with support from the TA (thermal analysis)
- Wire undertreatment and wire inoculation based on the value of the previous charge (determined by TA)
- Targeted Mg undertreatment with wire or master alloy plus

Mechanical Properties of CGI

The VDG Information Sheet W 50 [17] can represent a basis with respect to the mechanical properties to be achieved. As for DI, here the mechanical characteristic values can also be determined

- from separately cast test pieces,
- from cast-on test pieces or
- from test pieces carved out of the component.

The following Table 1 shows the required mechanical properties according to the Information Sheet specified.

Werkstoffbezeichnung Kurzzeichen	Zugefestigkeit[1] R_m N/mm² min.	0,2 % - Dehngrenze $R_{p0,2}$ N/mm² min.	Bruchdehnung A % min.	Brinelhärte HBW 30 Richtwerte
EN-GJV-300	**300** - 375	**220** - 295	1,5	140 - 210
EN-GJV-350	**350** - 425	**260** - 335	1,5	160 - 220
EN-GJV-400	**400** - 475	**300** - 375	1,0	180 - 240
EN-GJV-450	**450** - 525	**340** - 415	1,0	200 - 250
EN-GJV-500	**500** - 575	**380** - 455	0,5	220 - 260

1) Zum Zweck der Annahme muß die Zugfestigkeit einer gegebenen Sorte zwischen ihrem Nennwert n (Position 5 des Werkstoffzeichens) un (n +75) N/mm² liegen.

Table 1: Mechanical properties measured on samples which were produced by mechanical processing using separately cast test pieces

The corresponding modalities must be agreed on.

ISO 16112 [18] is used by other manufacturers as a basis for production and evidence of the mechanical characteristic values. Table 2 shows the corresponding characteristic values.

Werkstoffbezeichnung Kurzzeichen	Zugefestigkeit[1] R_m N/mm² min.	0,2 % - Dehngrenze $R_{p0,2}$ N/mm² min.	Bruchdehnung A % min.	Brinelhärte HBW 30 Richtwerte
ISO 16112/JV/300/S	300	210	2,0	140 - 210
ISO 16112/JV/350/S	350	245	1,5	160 - 220
ISO 16112/JV/400/S	400	280	1,0	180 - 240
ISO 16112/JV/450/S	450	315	1,0	200 - 250
ISO 16112/JV/500/S	500	350	0,5	220 - 260

While the HB values are comparable with the Information Sheet, there are small differences for the other properties which should be considered.

With respect to the graphite formation, the customer requirements above all must be fulfilled. There must be no lamellar graphite. According to the ISO specified above, 80% vermicular graphite (graphite form III) is required and 20% nodular graphite is permitted (graphite forms V and VI). However, other ratios such as 90/10 or 60/40 may also appear in the supply specifications. The customer usually specifies what ratio is permissible for the graphite formation. What is critical for all CGI types it that no lamellar graphite formation is permitted. The following, figure 2, from ISO 16112 [18] shows the graphite formation with different percentages of vermicular graphite formation and nodular graphite

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Article on Product of Cast Iron with Vermicular Graphite (CGI)

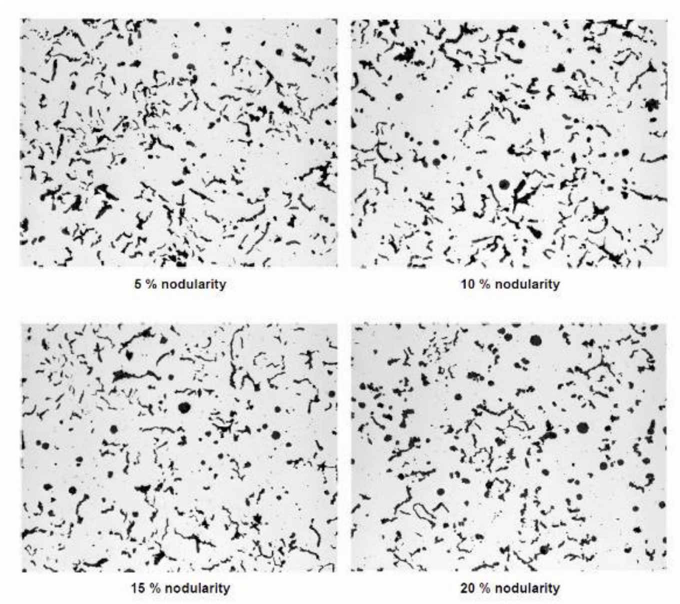

Fig. 2: CGI structure with different percentages of nodular graphite according to ISO 16211

As a newcomer in the production of CGI, it is important to always remember to only carry out the graphite assessment on non-etched ground surfaces.

As far as the structure of the metallic matrix is concerned, a ferritic matrix is assumed to a very large extent for CGI 300. CGI 350 has a ferritic pearlitic structure while the sorts from CGI 400, CGI 450 and CGI 500 show a pearlitic structure to a large extent.

Mechanical Properties of CGI

Sulfur and Titanium Contents

The sulfur content naturally plays a critical role when adjusting the initial analysis. Based on our experience, the sulfur content in base iron should preferably be adjusted to between 0.010% and 0.012%. These values are a good prerequisite for the production of CGI. As already mentioned, compliance with all parameters plays a very important role for this material. If the sulfur content is < 0.010%, FeS can be added to correct this. For values > 0.012%, correction is possible through charge make-up. If this is not complied with, it can quickly lead to undesired lamellar graphite or increased percentages of nodular graphite.

Titanium is another element which should be mentioned here. Ti is known to be a interfering element for nodular graphite and is not always used for the production of CGI. The interfering effect can be utilized in CGI production by achieving a change in the nodular graphite which is very similar to vermicular graphite by adding certain contents.
Ti is principally used for manifolds, where undesired graphite nodules can form even with the lowest Mg contents without Ti due to the thin walls and fast cooling. However, certain Ti contents can also be requested by the users for other parts to contribute to ensuring vermicular graphite formation. If Ti is used, the content can be between 0.06% and 0.20%. A diagram compiled from literature references [19] clearly shows the influence of Ti on ensuring vermicular graphite formation. What is known as the "window" can be increased significantly when working with Ti.

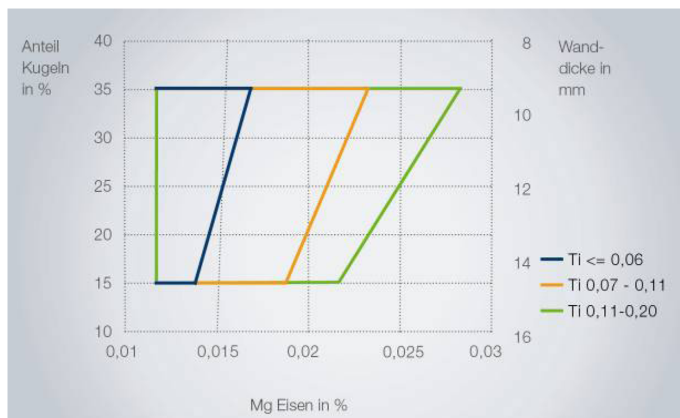

Fig. 3: Influence of Ti on the CGI "window"

Article on Product of Cast Iron with Vermicular Graphite (CGI)

When using Ti, it is essential to be aware that titanium carbides might be produced. This could be problematic for processing (fig. 4).

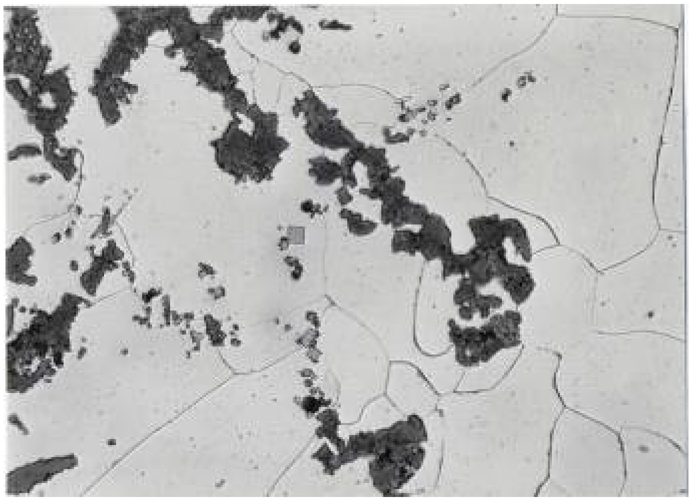

Fig. 4: Titanium carbides in CGI

Since the foundries which produce CGI usually also produce DI, the separation of returns is absolutely essential. The danger of contamination with Ti in DI production can have very serious consequences. If it is not expressly prescribed that Ti is used, manufacturers will always try to work without Ti in order to avoid possible Ti contamination. Cylinder crankcases and a large number of pressure plates are today successfully produced in large quantities without using Ti. If Ti is used, FeTi is added to the smelting unit.

Preconditioning

While the sulfur content in the base iron is known, the oxygen content in the molten metal is not always clear. In most cases, the oxygen content is unknown despite playing a critical role in the production of DI and even more so for CGI. Since oxygen uses twice as much Mg as sulfur, it should be low. The calibration of low overall oxygen contents and oxide contents before the Mg treatment is important for the production of CGI. If the overall oxygen content and oxide content in the molten metal are high, there is always the risk that when the same amount of Mg is added, the Mg could chemically combine to create MgO and more lamellas than desired could result.

ASK Chemicals Metallurgy GmbH (ASKCM) has provided the product VL(Ce)2 [20] for preconditioning for many years.

Preconditioning using VL(Ce)2 and CerMM reduces the overall oxygen content and oxide content in the molten metal. Addition takes place during tapping, before Mg treatment. In addition to reducing the oxygen content, cer-oxi-sulfides are formed which act as nuclei and are further strengthened by Mn and Zr.

An overall oxygen content of approx. 30 ppm and an oxide content of 1 to 2 ppm before treatment are a good prerequisite for successful CGI treatment [12].

In investigations, a total oxygen content of 22 ppm was obtained after preconditioning before the Mg undertreatment and 24 ppm was obtained in another measurement.

Wire Treatment for Production of CGI

After preconditioning during tapping, the ladle is transferred to the wire treatment station. If there is noticeable slag on the bath surface, this must be removed before the Mg treatment.

ASKCM has developed special wires for the Mg treatment; these are used to perform undertreatment.

For a specified initial sulfur content of 0.010% to 0.012%, 8 to 10m/t wire are added. This means 3 to 4 kg wire/t. At a filler content of approx. 60% of the total wire weight, this is 1.8 to 2.4 kg/t treatment agent. The treatment times are between 20 and 30 seconds.

Deslagging must take place after the Mg treatment. Inoculation can take place during pouring into a pouring unit.

The low-Al inoculant SRF 75 [21] is highly suited for the inocula-

Article on Product of Cast Iron with Vermicular Graphite (CGI)

The casting temperature to be selected is between 1,380 and 1,420°C (e.g. clutch pressure plates). Higher casting temperatures must of course be selected for exhaust manifolds made of CGI SiMo. The casting times for a batch of 1t, for example, should not exceed 10 minutes, since a subsidence effect also occurs here and could have a negative effect on the graphite formation.

If DI and GI are produced as well as CGI on a daily basis and cast in one furnace, the sequence GI, DI, CGI must be selected. CGI must not be produced after GI if the same pouring furnace is used.

Pouring facilities where only CGI is produced are ideal so that mixing cannot take place in transitions.

Fig. 5: Wire treatment booth for the production of CGI

Examples of CGI Production with Wire Undertreatment

Example 1: Production of CGI 350 with the Ti content requested by the customer

- Base iron with 0.11% Ti
- Tapping quantity: 1,000 kg
- Preconditioning with VL(Ce) + CerMM
- Wire undertreatment [22]
- Inoculation with SRF 75 when pouring
- Treated iron: 0.015% S and 0.012% Mg
- Mechanical properties of the Y2 sample: Rm 406 MPa, Rp0.2 333 MPa, A 2%, HB 199
- Graphite structure: 80% graphite form III and 20% graphite form VI

Fig. 6: CGI graphite structure from example 1, ratio 100:1, not etched

Example 2: Production of CGI with customer requirement Rm > 385 MPa and 0.10% Ti

- Base iron: 0.10% Ti
- Tapping quantity: 1,500 kg
- Preconditioning with VL(Ce)2
- Wire undertreatment
- Inoculation with SRF 75 when pouring
- Treated iron: 0.011% S and 0.014% Mg
- Mechanical properties of the cast-on sample: Rm 397 MPa, Rp0.2 318 MPa,
- A 1.7%, HB 210
- Graphite structure: 80% graphite form III and 20% graphite form VI

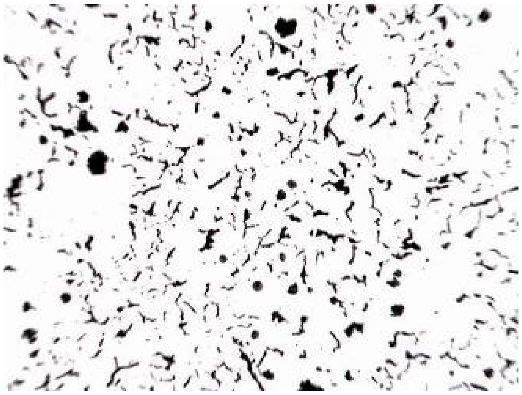

Fig. 7: CGI graphite structure from example 2, ratio 100:1, not etched

Article on Product of Cast Iron with Vermicular Graphite (CGI)

Example 3: Production of CGI SiMo,
Rm min. 400 MPa, A min. 3% and max. 0.20% Ti

- Base iron: 0.14% Ti
- Tapping quantity: 1,200 kg
- Preconditioning with VL(Ce)2 + CerMM
- Wire undertreatment
- Inoculation when pouring with FeSi 75
- Treated iron: 0.010% S and 0.018% Mg
- Mechanical properties of the Y2 sample: Rm 545 MPa, Rp0.2 492 MPa, A 3.5%, HB 228
- Graphite structure: 70 to 80% graphite form III and 20 to 30% graphite form VI

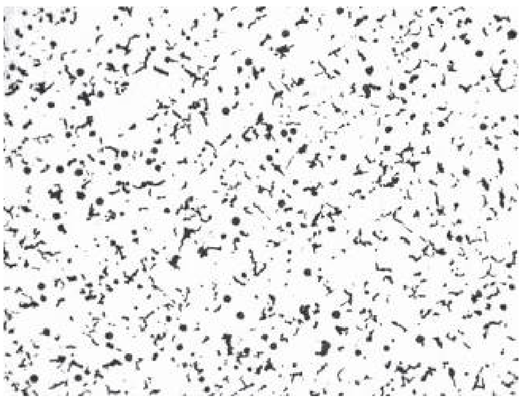

Fig. 8: CGI SiMo graphite structure from example 3, ratio 50:1, not etched

Test Methods in CGI Production

Despite all the automatic tests, the foundry personnel should be aware of the following general criteria between CGI and GI for assessment.

General features:

CGI: - Graphite length approx. 50 µm
- Length to breadth ratio < 10
- Graphite ends are rounded off

GI: - Graphite length of lamellas is up to 500 µm
- Length to breadth ratio 50 to 100
- Graphite ends are pointed

The CGI structure can be tested using the following methods:

- Chemical analysis using spectral samples (also Mg/S ratio)
- Measurement of the oxygen activity using EMF measurements
- Evaluation using thermal analysis
- Metallographic examinations (e.g. so-called quick samples of each treatment)
- Measurement of the oxygen activity using EMF measurements
- Resonance frequency tests
- Ultrasonic examinations

Conclusions

Today the use of Mg treatment wires in iron foundries are a well established technology. As well as the production of DI, certain wires are also highly suitable for producing CGI parts. The procedure selected here with preconditioning which leads to reduced overall oxygen and oxide values are good metallurgical prerequisites for a subsequent wire undertreatment for the production of CGI castings. This pairing of preconditioning with VL(Ce)2 and wire undertreatment with Inform® cored wire is a simple, reliable method for the CGI production of disk flywheels, clutch and brake disks as well as exhaust manifolds, for example. Complying with the specifications allows the test expenditure to be reduced.

Article on Product of Cast Iron with Vermicular Graphite (CGI)

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