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Study of Vertical Centrifugal Process of Nodular Graphite Iron through the correlation between Microstructural Analysis and Tensile Property

Tejas Kumar S[1,2,3], Avinash Xavy[2,3]

[1]*Head of New Product Development*
[2]*Metallurgist*
[3]*Vijay Spheroidals Pvt, Bangalore, India*

Abstract – *In the Centrifugal casting process, the molten metal is poured into vertical or horizontal molds which rotates at different speeds. This process causes (a) washing of dendritic or columnar structure formed at the mold metal interface and (b) separation of denser phases thrown towards peripheral region of the casting by centrifugal force. The lighter phases (like slag etc.) get separated and concentrated at the center of the casting from where it rises to the top of the casting (i.e., riser) zone.*

This paper investigates the effectiveness of centrifugal force on the casting process in removing slag and other impurities in Spheroidals Graphite (SG) iron castings (IS 1865:1991) of size 120 x 120 x 500 mm. It also reports the changes in (a) optical microstructures and (b) mechanical properties of Spheroidal Graphite (SG) iron castings of size 120 x 120 x 500 mm.

Key Words: **Vertical Centrifugal casting process, Spheroidals Graphite Iron, Microstructure, Centrifugal force, Slag, Dross**

1.INTRODUCTION

Foundry Industries are always target to achieve (a) defect-free castings and (b) eliminating impurities formed during melt treatment and casting process. In case of Spheroidal Graphite (SG) iron production, during magnesium (Mg) treatment, lot of slag and unwanted impurities are produced. If they are not removed properly, the cast component will fail in service and can cause cataphoric failure. Foundries are extremely keen to adopt a green and commercially viable technology to control such defects.

1.1 Trail Setup

For the investigation, trials were conducted on EN GJS 450/10 or IS 1865 SG 450/10 [with alloy chemistry C: 3.50-4.00, Si: 2.20-2.90, Mn: 0.3-0.6, P: 0.03-0.06, S: 0.02-0.040, Mg: 0.020-0.060] material using 250kg teapot spout ladle and vertical centrifugal Casting (CC) machine. Size of cast ingots is 120mm x120m x 500 mm (plus riser) from heat No.1022-329 is shown in Fig. 1. And five microsamples were taken from L_2 (Fig 2) that is below the gating region from heat No. 0823-07-217, 0823-18-557, 0823-07-203,0823-09-265 and 0723-05-149 respectively, to study the correlation between microstructure and mechanical properties,

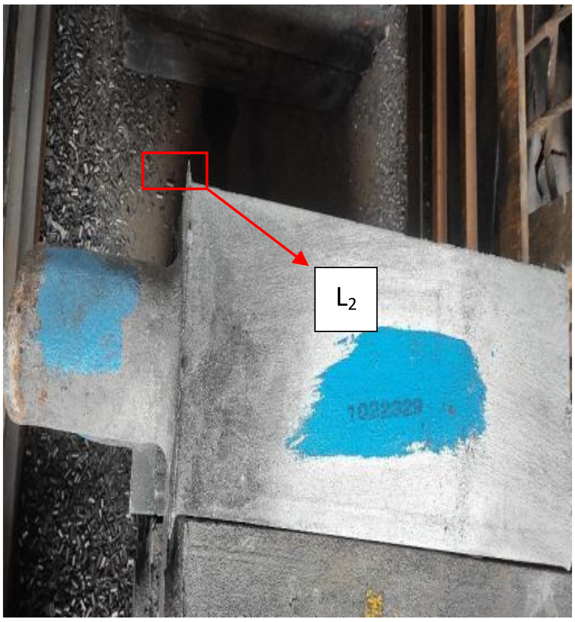

Fig -1: Selected casting for investigation with heat no 1022-329 (EN GJS 450/10 or SG 450/10)

Fig -2: Samples taken from edge of casting, below the riser L_2

Fig -3: Samples taken from edge of casting, riser region- L_1

Fig. 2 and Fig. 3 shows the points (L_2 & L_1) in cast ingots where samples for (a) optical microstructure. Fig.2 shows the location of samples taken from five alternating heats for (a) optical microstructure and (b) mechanical properties has been collected to evaluate the effectiveness of the vertical centrifugal casting process to reduce slag inclusions and to study the correlation between microstructure and mechanical properties respectively, keeping melt chemistry and other parameters identical, five samples were collected (shown in Fig 4) from five alternating heats. The data are compared with IS 1865:1991and DIN EN 1563:2012-03 SG iron castings to determine the effect of the vertical centrifugal casting process on microstructural properties which in turn affects the mechanical property of the component. unavoidable.

Fig -4: Sample taken from five different heats of SG 450/10

2. EXPERIMENTAL DETAILS

2.1 Melting of alloy and microstructural analysis of samples collected from top of riser and bottom of the casting.

The experimental alloy composition is C: 3.50-4.00, Si: 2.20-2.90, Mn: 0.3-0.6, P: 0.03-0.06, S: 0.02-0.040, Mg: 0.02-0.06 which is as per with IS 1865:1991 SG 450/10 [equivalent to grade DIN EN 1563:2012-03 or EN-GJS-450-10C] [9]. The charge materials melted in an air induction furnace. After melting the slag former SLAX® is used to form the slag and the slag is then removed. The molten metal is then tapped (at 1515°C) in the treatment ladle which is preheated to 650°C and thoroughly cleaned (from slag and other impurities) before pouring. After Mg treatment in the treatment ladle, the melt is poured into a hand shank where inoculation of 0.40% and 0.20% of Bismuth with respect to casting is maintained (as per process sheet) is given in the stream. After treatment, the slag generated in the hand shank is carefully removed by a spoon.

The molten metal is then poured into a rotating mold with sand thickness of 12.5mm for both casting mold and top gating flange (which act as refractory) at lower speeds 50 - 100 rpm (casting size: 120 X 120 X 500 mm). The pouring continued till melt fills 80 % of the riser and it ensured the pouring is completed within first 6mins after initial tapping. Gradually the speed of the rotating mold is increased to 130 - 200 rpm. At the end of freezing, the castings are knocked out at 451°C and air cooled the casting to room temperature. Samples for metallographic study (Fig. 3 and Fig.2) are taken from the top of riser (L_1) and from the lower side of the casting (L_2). For micro-analysis, both unetched and etched microsamples are studied using Dewinter Metallurgical microscope. The following results from same micro sample L_1 are tabulated (in Table 1) and compared with ASTM A247-19. Fig 4 shows the Tensile testing machine and Fig 5 shows the broken sample pieces after testing.

Table -1: Showing Nodularity, nodule count, ferrite % and pearlite % from sample L_1

SL. No	Nodularity	Nodule Count	Ferrite	Pearlite
1.	46.65%	147/mm²	30.43%	69.57%
2.	41.62 %	136/mm²	26.54%	73.46%
3.	36.65%	108/mm²	36.54%	63.46%
4.	23.91%	97/mm²	25.67%	74.33%
Average	37.20%	136/mm²	29.79%	70.20%

2.2 Investigating the co-relation of microstructure and mechanical properties of five heats.

From the selected component of size 120mm x120m x 500 mm of alloy composition C: 3.50-4.00, Si: 2.20-2.90, Mn: 0.3-0.6, P: 0.03-0.06, S: 0.02-0.040, Mg: 0.02-0.06 which is as per with IS 1865:1991 SG 450/10 [equivalent to grade DIN EN 1563:2012-03 or EN-GJS-450-10C] [9] maintained as per process parameter in above mentioned from varying heat Nos. of 0823-07-217, 0823-18-557, 0823-07-203,0823-09-265 and 0723-05-149 respectively. Five test bars are machined as per IS 1865:1991 from same heat no of same grade. All the process parameters are kept as per the process sheet of SG 450/10. And it is specifically ensured that the components for the case study are free from foundry defects.

The Experimental apparatus includes a centrifugal machine, a component of size 120 x 120 x 500mm from which the test bar is machined from the bottom of the component. The test bar along with heat no, is tested in the universal testing machine for tensile property. The results are compared with IS 1865 and DIN EN 1563, the consolidated results are compared with microstructural analysis of samples from their respective heat no. Fig 5 Shows the tensile testing machine and Fig 6 shows the broken sample pieces after testing.

Fig -5: Machined test bars are tested in universal Testing Machine (UTM)

Fig -6: Tested Test bars of SG 450/10

3. RESULTS AND DISCUSSIONS

3.1 Comparison study of microstructural analysis of sample from top gating and near gating system

As per ASTM A247-19, the sample taken from top riser L_1 which shows an average nodularity of 37.20%(Table -1), which is lower than the required value as per IS 1865:1999-SG 450/10 or EN GJS 450/10. The etched micro-image of the sample from riser area L_1 (Fig -7) shows excessive pearlitic matrix, without any addition of pearlitic promoters such as Cu or Mn. This is due to faster rate of heat extraction through metallic mold will not happen as sand thickness of 12.5mm is present at the top gating which act as refractory. Fig -7 also shows the presence of slag skin which is entrapped due to fast cooling of the sample. This slag is Mg-Ca-silicate is formed after Mg treatment followed by inoculation. The slag density (2.5 to 3.5 g/cc) is very less compared to the density SG iron (6.9 to 7.8 g/cc). So, during rotation in CC machine, the lighter slag is accumulated at the peripheral region of the casting and then floats up to the riser. Thus, it is separated from the base metal and yields good casting.

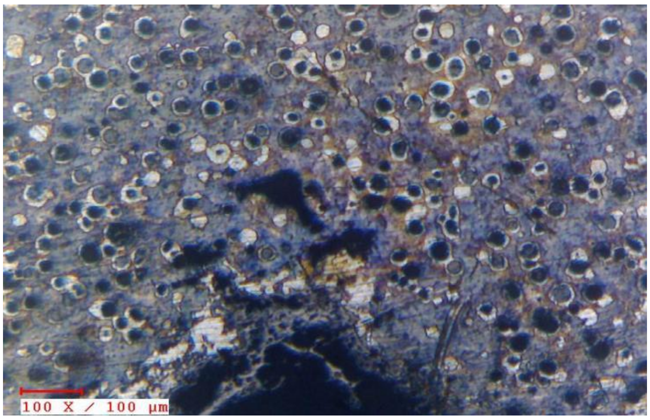

Fig -7: Etched Micro-image of a sample from riser area L_1 at 100x

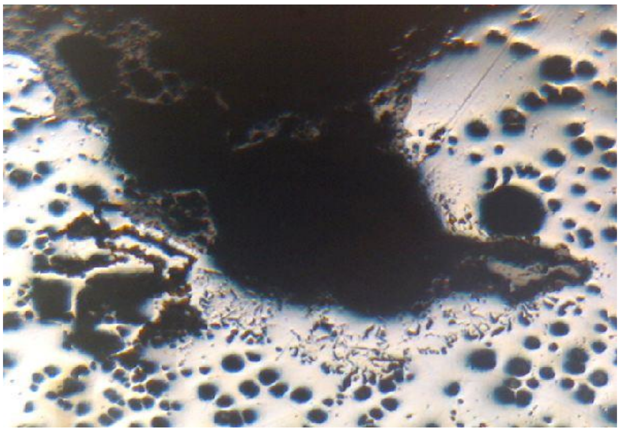

Fig -8: Unetched Micro-image of a sample from riser area L_1 at 100x

Fig -7 and Fig -8, shows the micro image of dross, which is formed when the inoculation is not mixed properly. As a result, the nodules will not be formed instead smaller flaker will be formed. These micro defects can be only observed under a microscope. Dross is Mg-Ca-silicate which is formed during the casting process, during reoxidation of Mg rejected by the cast metal precede to its solidification [4]. Table -2 gives the consolidated Nodularity, nodule count, ferrite %

and pearlite % from sample L_1. Many micro-defects were also observed in the sample. The average value from different regions of the sample show that L_1 sample is not as per ASTM A247-19.

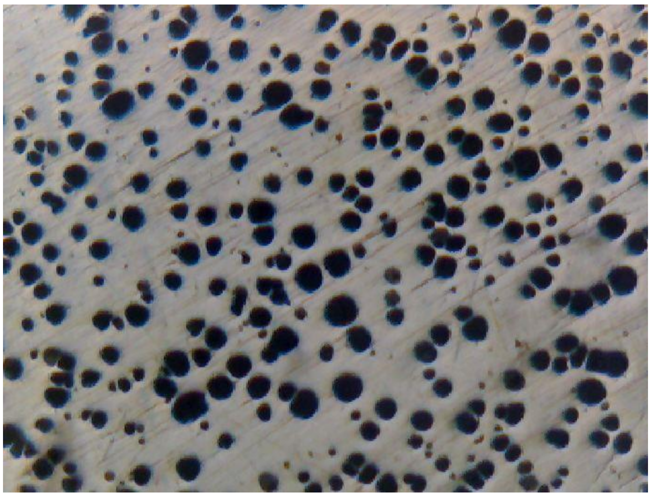

Fig -9: unetched micro-image of a sample from below gating area L_2 at 100x

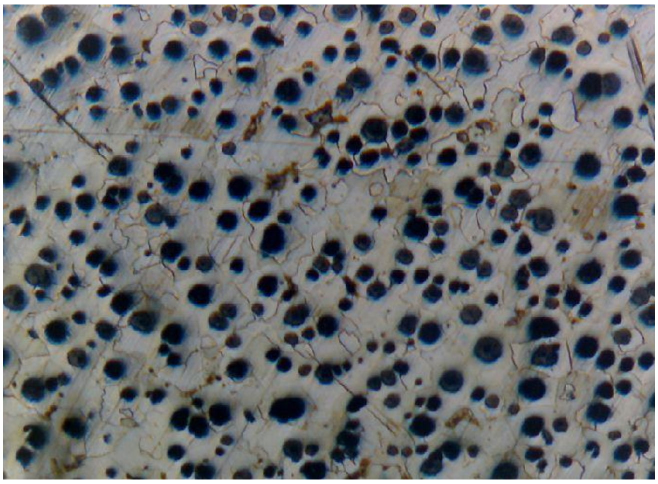

Fig -10: Etched micro-image of a sample from below gating area L_2 at 100x

Fig -9 and Fig -10, shows the unetched micro-image of the sample from the lower side of gating region of the casting, L_2. It shows (a) average nodularity was 96.57%, (b) nodule count 364/mm² and (c) free from any micro-defects. The image is matching with ASTM A247-19 with Type I and Type II graphite. Fig -10 shows the micro image of etched sample L_2 containing ferrite – 94.84% and pearlite -5.15% phases (table -2).

Table -2: Showing Nodularity, nodule count, ferrite % and pearlite % from sample L_2

SL. No	Nodularity	Nodule Count	Ferrite	Pearlite
1.	96.57%	364/mm²	94.84%	5.15%

3.2 Co-relation between microstructural properties and mechanical properties of centrifugal cast test bars.

Table -3 and Table -4 shows results of metallographic and mechanical testing of five samples from different heats.

Table -3: Showing Nodularity, nodule count, ferrite % and pearlite % of different heats with corresponding heat no.

SL. No	Heat No.	Nodularity (%)	Nodule Count (/mm²)	Ferrite (%)	Pearlite (%)
1	0823-07-217	92.00	216	75.00	25.00
2	0823-18-557	92.23	218	89.75	10.25
3	0823-07-203	93.57	228	88.00	12.00
4	0823-09-265	94.34	236	85.07	14.93
5	0723-05-149	93.67	318	88.68	11.32

Table -4: Showing nodule count and mechanical strength of corresponding heat No of SG 450/10.

SL. No	Heat No.	Nodule Count (/mm²)	UTS (N/mm²)	Elongation (%)	Y.S (N/mm²)
1	0823-07-217	216	472.82	11.27	304.98
2	0823-18-557	218	470.42	10.93	329.75
3	0823-07-203	228	474.34	11.6	328.70
4	0823-09-265	236	479.80	12.07	347.63
5	0723-05-149	318	521.63	10.93	340.69

Based on the Micro analysis of five different heat no and corresponding tensile strength a graph is plotted. (Chart -1).

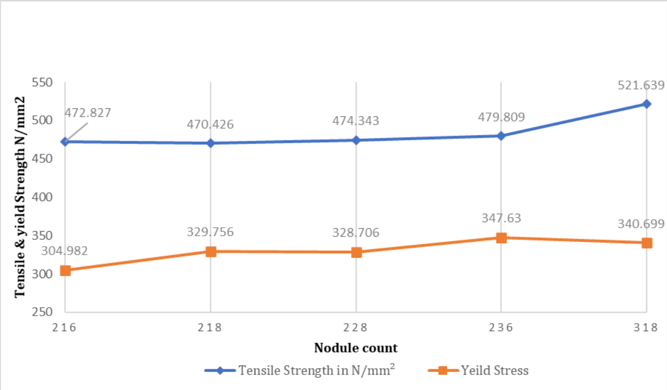

Chart -1: Depicts the relation between the nodule count, tensile strength and Yield Strength.

3. CONCLUSIONS

Micro-samples were taken from the gating region as well as below the gating region for analysis, and the following points were interpreted:

1. During micro-analysis there was the presence of pearlite in the sample even though pearlitic promoters weren't added during melting stages, this shows that the gating region has a large number of impurities and slag.
2. Pearlite has increased in the gating region because impurities such as Mg-Ca-silicate, and SiO_2 have risen to the riser region.
3. All of the defects found in the gating region and the micro-image of the samples from below the gating region are devoid of the defects due to the centrifugal force and their differences in specific gravity.
4. Generally higher section thickness of 120 x 120 x 500mm, there is a possibility of defects such as graphite floatation and chunky graphite, which is not observed in the trial, as per EN-GJS-450-10C, with relevant wall thickness 30mm< t ≤ 60mm and 60mm< t ≤300mm as a tensile strength, elongation and Yield Stress of 440 N/mm^2, 8% and 300 N/mm^2 respectively, casting mechanical in the block were observed 450 – 472 N/mm^2.

Micro samples of five different heats were analysed and results were compared to their mechanical properties from observations following points can be interpreted:

1. The edge microstructure image should be completely ferritic Microstructure, as we move toward the centre or core of the casting, we observe an increase in perlite content.
2. An increase in nodule count leads to an increase in tensile and Yield Strength as per the Table -3 and Table -4.
3. Due to the centrifugal casting process heavy section casting gives higher nodule count and Nodularity even near the core region of casting without chucky graphite or graphite floatation.
4. The centrifugal casting process gives a stabilized increase in nodule count across various heats which can seen in 5 trial Reports.
5. The centrifugal casting process is more suitable for producing high-section thickness symmetrical casting with better metallurgical properties.

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Disclaimer: Any similarity to content found on the Vijay Spheroidals website is intentional, as the same author has contributed to both this paper and the content on the website.

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BIOGRAPHIES

Tejas Kumar S, Metallurgist with 14 years of experience, currently working as Head of Design and Engineering at Vijay Spheroidals Pvt Ltd

Avinash Xavy, Metallurgist with 3 years of experience at Vijay Spheroidals pvt Ltd.