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INFLUENCE OF PROCESS PARAMETER ON PROPERTIES OF CAST IRONS

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ABSTRACT

The properties of cast irons depend on the graphite morphology and characteristics of metallic matrix. Perhaps the most interesting feature of the family of cast irons is the morphology of the graphite phase, and the modifications of that morphology, which occurs as a result of changes in chemical composition, melting and melt handling techniques and the process of solidification and subsequent cooling. In this work an attempt is made to study the effects of process parameters like cooling rate during solidification, centrifugal casting process and gravity casting process of cast irons on morphology and tribological properties. A comparison of microstructure of constituents and tribological properties of specimens is made in gravity cast with natural and rapid cooling, centrifugal and gravity casting techniques. In microstructure for flake graphite iron it has been observed that the gravity casting process with natural cooling produces a flake size range 1 to 2 whereas rapid cooling produces a flake size range 2 to 3. It shows that the natural cooling produces more flakes of type A, approximately by about 50% over that in rapid cooled structure. For spheroidal graphite iron it has been observed that the centrifugal casting produces an increase in the number of bigger nodules and decrease in the number of smaller nodules and an increase of nodules per square mm. It has no effect on nodularity percentage. The result shows that flake graphite iron with normal cooling produces a reduction in coefficient of friction and decrease in wear over that of rapid cooling process. It has been observed that for spheroidal graphite iron the centrifugal effect produces a lower coefficient of friction and decrease in wear compared to gravity cast.

Keywords: *Flake graphite iron, Spheroidal graphite iron, Gravity cast, Centrifugal cast, Microstructure, Nodules, Wear and Coefficient of friction.*

1. Introduction

Gray cast iron is traditionally used in many industries because it is characterized by flexibility of use, excellent castability, low cost, wide range of achievable mechanical properties [1, 4, 5]. Perhaps the most interesting feature of the family of cast irons is the morphology of the graphite phase, and the modifications of that morphology, which occurs as a result of changes in chemical composition, melting and melt handling techniques and the process of solidification and subsequent cooling. In any given composition of cast iron, its structure will depend on the rate of cooling (wall thickness) of the casting. The structure obtained depends on the composition (Si+C content) and the cooling rate (which intern depend on the wall thickness of the casting) [4]. When the composition of the molten iron and its cooling rate are appropriate, the carbon in the iron separates during solidification and forms separate graphite flakes that are interconnected within each eutectic cell. The graphite grows edgewise into the liquid and forms the characteristic flake shape. The significance of these differences to graphite morphology is observed primarily in their effect on the physical and mechanical properties of the iron, but in the foundry they are well known to influence the ability to manufacture sound and dependable castings. Factors affecting the morphology of graphite in cast irons have, therefore, been the principle focus of cast iron research over the years, although there are many aspects of this complex materials science problem that are still not well understood. [2, 3].

The properties of cast irons are mainly controlled by the shape of the graphite particles in combination with the matrix constituents, and wide spectrum of properties is observed in the different cast iron grades. The main reason for this difference in properties is the shape of the graphite particles and the high anisotropy of the graphite phase. [6].

The properties of gray iron are influenced by the size, amount and distribution of the graphite flakes, and by the relative hardness of the matrix metal around the graphite. These factors are controlled mainly by the carbon and silicon contents of the metal and the cooling

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rate of the casting. Slower cooling, higher carbon and silicon contents tend to produce more and larger graphite flakes. The flake graphite provides gray iron with unique properties such as excellent machinability, wear-resisting characteristics and vibration damping. The amount of graphite presence, size and its distribution are important to the properties of the iron.

Ductile iron is a category of cast iron, in which the shape of graphite is spherical. This morphology keeps the continuity of graphite matrix better than that of flake graphite. An unusual combination of properties is obtained in ductile iron because the graphite occurs as spheroids rather than as individual flakes as in gray iron. The solidification of ductile iron begins with the nucleation and growth of spherical graphite in the melt. After the formation of graphite, the concentration of carbon in the covering layer decreases. Owing to under cooling in the layers, an austenite shell forms around the graphite and after the formation of shells, the graphite only grows by diffusion of carbon through them [7, 8].

Chemically ductile iron is the same as gray iron and is iron-carbon-silicon alloy. This mode of solidification is obtained by adding a very small, but specific, amount of Mg to the molten iron of a proper composition. The added Mg reacts with the sulfur and oxygen in the molten iron and changes the way the graphite is formed. Control procedures have been developed to make the processing of ductile iron reproducible. The amount and form of the graphite in ductile iron are determined during solidification and cannot be altered by subsequent heat treatment. The principal factor in determining the different grades of ductile iron in the specifications is the matrix structure. In the case as-cast condition, the matrix will consist of varying proportions of pearlite and ferrite. The superior performance of ductile iron over gray iron has been attributed to the dissimilarity in graphite morphology between the two materials. The common feature that all ductile irons share is the roughly spherical shape of the graphite nodules. These graphite nodules are nucleated on small inclusions during the solidification [9]. The relative possibilities for nucleation and growth depend upon foreign particles or solutes present in the liquid, whether as trace impurities or as deliberate additions [10].

Flake and spheroidal graphite cast irons have excellent castability, wear resistance, high damping, good machinability and relatively low cost compared with alloy steels with similar mechanical properties. Both irons are used as engineering materials in high temperature applications (ex. Furnace parts, exhaust manifolds and turbocharger housings) that require high-temperature corrosion resistance [11].

Wear is a phenomenon which is observed whenever two materials in contact have relative motion. It is the progressive loss of material resulting from the surface of the materials in contact. Wear studies are finding importance now a day in characterizing the material for different applications. Cast iron has been used over the past in a variety of tribological applications encountering sliding motion with or without lubrication [12, 14]. The cast irons are evaluated for wear under laboratory conditions as well as field – testing. Extensive research work is being carried out to understand the mechanism of solidification of cast iron from a molten state to solid state and many researchers/scientists put forth their thoughts and views through experimental work, modeling simulation for gravity (1G) cast. But few are the attempts on modeling centrifugal cast (say >1G) or the process parameter like cooling rate during solidification, during centrifugal and gravity casting process of cast irons (Flake graphite iron and Spheroidal graphite iron) on morphology and tribological properties. The purpose of the present work is to study the effect of process parameter like cooling rate during solidification, centrifugal casting process and gravity casting process of cast irons on morphology and tribological properties. A comparison of microstructure of constituents and dry sliding wear properties of different cast iron specimens are made in gravity cast with rapid cooling and natural cooling, centrifugal and gravity casting technique. Literature review reveals a little information on this subject/Published data are not available.

With this motivation and background, an attempt is made to study of the effect of process parameter like cooling rate during solidification, during centrifugal and gravity casting processes of cast irons on metallic matrix morphology and wear properties.

2. Experimental Work

2.1 Effect of cooling rate on flake graphite iron (FGI)

The alloy used in the experiment was melted in a solid state thyristor controlled medium frequency induction furnace of 300 kg capacity and with the chemical composition C 3.22%, Si 2.1%, Mn 0.78%, S 0.068%, P0.081%. The molten metal is poured into green sand mold. Immediately after knocking from the mold at red hot condition, one of the casting was subjected to normal cooling and the other one is subjected to forced cooling during solidification. This is to study the effect of cooling rate during solidification of FGI in gravity casting process on microstructure and wear properties.

For micrographic analysis samples were ground on abrasive papers with grades ranging: 180, 240, 400, 600, 800 and 1000. The samples were polished with Alumina polishing Suspension on velvet cloth. The graphite flake is evaluated in accordance with the STD ASTM A247. The graphite flake size and types are evaluated using image analyzer Metlite with optical microscope Dewinter DMI-CROWN-I.

2.2 Effect of gravity and centrifugal casting processes on spheroidal graphite iron (SGI)

The alloy was melted in the induction furnace of 300 kg capacity. The chemical composition assessed reads as follows C 3.57%, Si 2.57%, Mn 0.438%, P 0.0230%, S 0.0063%, Cr 0.0240%, Ni 0.240%, Mo <0.0020%, Al 0.018, Cu 0.54%, Ti 0.0019%, V <0.0010%, Pb 0.00410% Mg 0.036%, Sn 0.0032%, Zn 0.0065%, Ceq 4.57%. Fe 92.300%. Molten metal was melt treated with Mg alloy. Method of Casting process adapted was

i) Gravity process – Treated molten liquid metal is poured into the mold cavity and solidifies naturally

ii) Centrifugal process – Treated molten liquid metal is poured into the horizontal rotating mold with the known quantity of the metal poured for controlling the wall thickness and it solidifies fast. This is to study the effect of casting process on microstructure and wear properties. Cast samples were ground and polished to study the microstructure.

Micrographic analysis samples were prepared as usual. The shape of the nodules is evaluated in accordance with the STD ASTM A247. The characterization of graphite particles in SGI is performed using a computer-based image analyzer Metlite. The Nodule number and perfection of shape (nodularity) are evaluated.

Tribological test for all the samples were conducted according to ASTM G99 using 6.5 mm diameter pin under dry condition. A Ducom pin on disc wear test machine was used to carry out the test. The disc is made up of hardened steel En31. The disc and test pin were polished to a roughness value (Rz) of about 0.8µm prior to all the test runs. The disc and the pin were degreased before the test. The test was conducted for a duration of 10 minutes for different loads (2kg, 4kg) and speeds (300rpm, 100rpm) combinations on track diameters (80mm, 90mm). Wear test setup is shown in fig. 1

Fig. 1 Wear Test Set-Up

3. Results and Discussion

3.1 Effect of cooling rate on structure of FGI

The effect of cooling rates during solidification of FGI on their microstructure and wear were evaluated. As cast samples of FGI cast by a gravity process with normal cooling (natural cooling) and by rapid cooling (forced cooling) are studied for flake graphite size, type and distribution. In normal cooling the graphite is flake shaped, elongated and randomly oriented in a matrix which is pearlitic. The graphite particles are longer, thicker with sharp edges irregular and at some point appears as a lump as seen in fig. 2A. In rapid cooling the graphite particles are flake shaped, shorter in length, thinner with sharp edges and irregular as compared to normal cool as seen in fig. 2B. Results show that the gravity casting process with normal cooling produces a flake size range 1 to 2 (320 µm to 1280 µm) and flake type A of 52.6%, whereas rapid cooling produces a flake size range 2 to 3 (160 µm to 640 µm) and flake type A of 25.2% (Refer Table 1). It shows that the natural cooling produces more flake of type A than that in the rapidly cooling process.

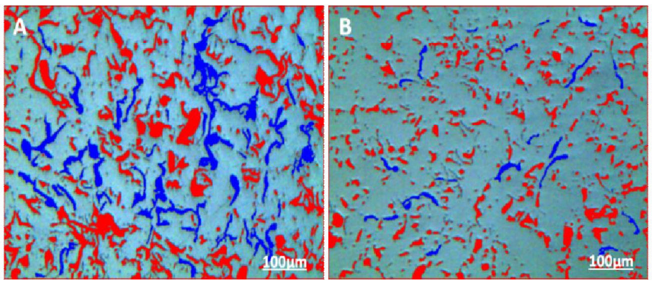


Fig. 2 Typical Analyzed Microstructure of FGI for A. Natural Cool (NC) and B. Rapid Cool (RC).

Table 1: Test report of FG iron flake size and type for A. NC and B. RC

Flake Size	Flake A	Flake B	Flake C	Flake D	Flake E	Flake Comb
1 To 2	52.6 %	0	0	0	0	47.4

A. Natural Cooling (NC)

Flake Size	Flake A	Flake B	Flake C	Flake D	Flake E	Flake Comb
2 To 3	25.2 %	0	0	0	0	74.8

B. Rapid Cooling (RC)

3.2 Tribological test of flake graphite iron (FGI)

Wear test was conducted with the following conditions.

Hardened Steel disc is used against Pins of 6.5 mm diameter of FGI manufactured by a) Natural Cooled (NC) b) Rapid Cooled (RC) Track diameter-80mm, Speed-100rpm, Test duration-10minutes. Figure 3A and 3B show the result of FGI with NC and RC. At 600seconds NC wear is 23 µm. Mean coefficient of friction is 0.716. For RC after 600 seconds wear is 13 µm. Mean coefficient of friction is 0.596. The result shows that the flake graphite iron with NC produces a low coefficient of friction by about 17.6% and decrease in wear by about 45.45% over that of the RC process see fig. 4 (A,B).

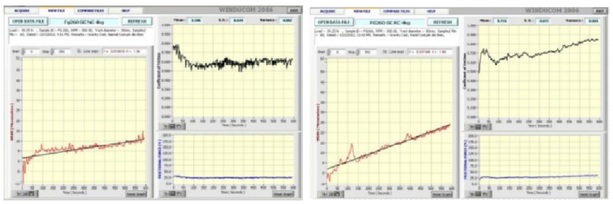
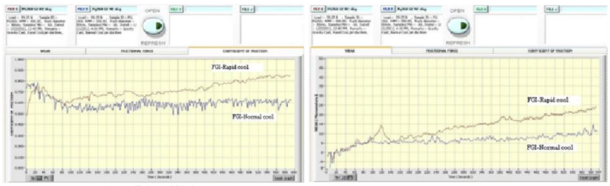

A. Normal Cooling (NC) B. Rapid Cooling (RC)

Fig. 3 Wear, Coefficient of Friction and Frictional Force v/s Time of FGI. A. NC and B. RC



A. Coefficient of friction B. Wear

Fig. 4 Comparison of Wear Characteristics of FGI for NC and RC A. Coefficient of Friction and B. Wear

3.3 Effect of centrifugal and gravity casting processes on microstructures

The result (refer Table 2, Figure 5 and 6) shows that the smaller nodules (range 2 to 243µm) count and its percentage is more in gravity cast sample than those of centrifugal cast sample. The bigger nodules (range 243 to 483, 485 to 727 and 727 to 970 µm) count and their percentage are less in gravity cast sample than in centrifugal cast sample. Also the result (refer Table 3, Figure 7 and 8) shows that the nodule count and nodules per square millimeter is more in centrifugal casting than that in gravity casting. The nodule size distribution and form type (refer Figure 9) are also affected but nodularity percentage is unaltered by processing route. It has been observed that the centrifugal processing produces an increase in bigger size (Range 247-485, 485-727, 727-970 µm) nodule count of about 17%, 32%and 20% respectively and decrease in smaller sizes (2 to 247 µm) nodule count of about 47% and an increase of nodules per square mm of about 15% over that in the gravity casting technique [15].

Table 2: Comparison of Nodule Count and Percentage of Centrifugal Cast and Gravity Cast

Range		Centrifugal cast		Gravity cast	
From (µm)	To (µm)	Count	Percentage	Count	Percentage
2	243	110	48.67	162	60.67
243	485	54	23.89	45	16.85
485	727	32	14.16	22	8.24
727	970	15	6.64	12	4.49

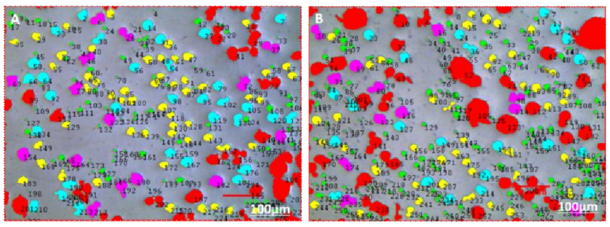
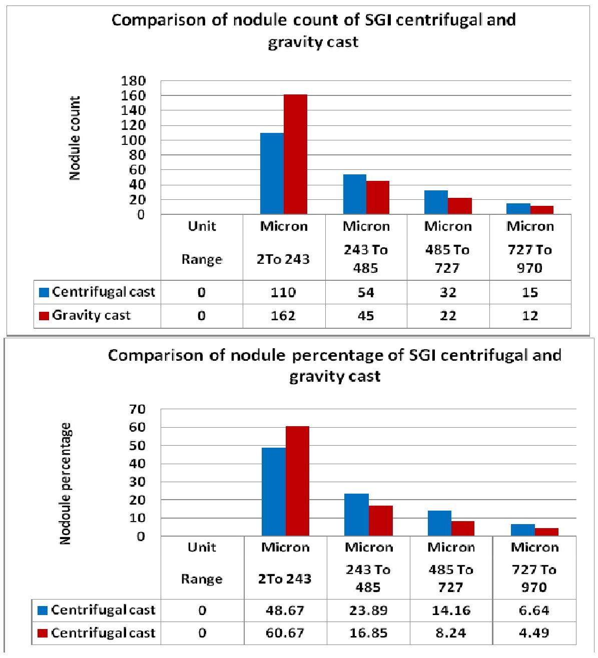


Fig. 5 Typical Analyzed Microstructure of SGI Showing Nodule Count and Percentage for A. Centrifugal Cast and B. Gravity Cast



	Unit Range	Micron 2To 243	Micron 243 To 485	Micron 485 To 727	Micron 727 To 970
🟦 Centrifugal cast	0	110	54	32	15
🟥 Gravity cast	0	162	45	22	12

	Unit Range	Micron 2To 243	Micron 243 To 485	Micron 485 To 727	Micron 727 To 970
🟦 Centrifugal cast	0	48.67	23.89	14.16	6.64
🟥 Centrifugal cast	0	60.67	16.85	8.24	4.49

Fig. 6 Effect of Centrifugal and Gravity Casting Processes on Nodule Count and Percentage of Spheroidal Graphite Iron

Table 3: Comparison of Nodule Count and Percentage of Centrifugal and Gravity Cast Samples

	Gravity	Centrifugal
Nodules count	160	120
Nodularity percentage	91.95	90.91
Nodules / Sq.mm	620.90	462.90

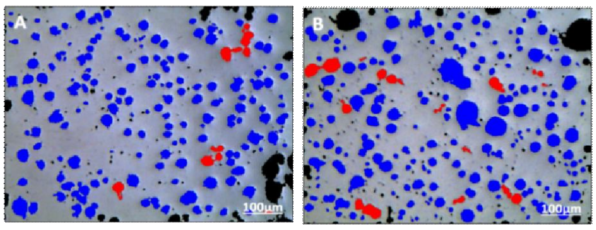


Fig. 7 Typical Analyzed Microstructure of SGI Showing Nodules (Blue color) and Non Nodules (Red color) for A. Centrifugal Cast and B. Gravity Cast

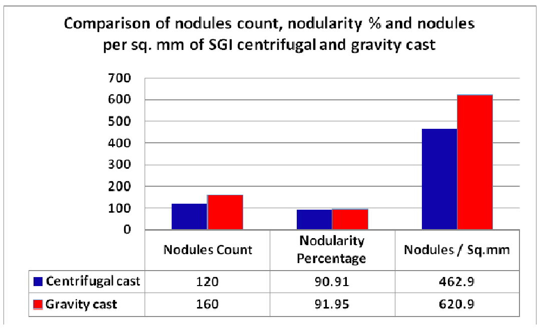
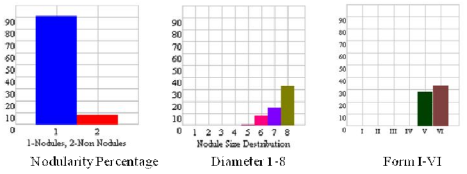
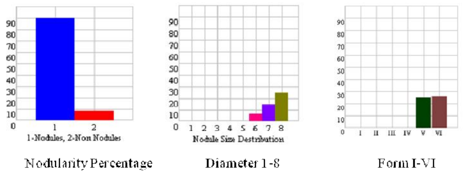


Fig. 8 Effect of Centrifugal and Gravity Process in Nodule Count, Nodularity Percentage and Nodules per Square Millimeter of the Different Samples



A. Centrifugal cast



B. Gravity cast

Fig. 9 Nodularity Percentage, Nodule Size, Nodule form Type and Distribution of Centrifugal and Gravity Process

3.4 Tribological test of Spheroidal Graphite Iron (SGI)

Wear test was conducted with the following conditions.

Hardened Steel disc is used against Pin of SGI manufactured by A) Centrifugal cast and B) Gravity cast, Pin diameter-6.5 mm, Track diameter-90 mm, Speed-100 RPM, Test duration-10 minutes. It is observed that for gravity cast wear is 30μm after 600seconds and mean coefficient of friction is 0.698. For centrifugal, Wear is 20μm after 600 seconds and mean coefficient of friction is 0.399. The result shows that the spheroidal graphite iron in centrifugal produces lower coefficient of friction of 55% and a decrease in wear of 33.33% over gravity casts.

4. Conclusion

Influence of process parameter on microstructure and wear properties of cast irons as the cast has been studied and the following conclusions may be drawn based on experimental study.

Different cooling rates during solidification of the same cast iron show difference in microstructure in respect of flake size, type and distribution.

i. Normal cooling produces flake size 1 to 2 and RC produces flake size 2 to 3 and NC produces more flake type A by 50% over RC.
ii. Gravity cast and centrifugal casting of the same spheroidal graphite iron show difference in microstructure.
iii. Graphite nodule counts, percentage and nodules per square millimeter are different for samples made by the two different casting processes.
iv. The centrifugal effect produces more number of bigger size nodules and lesser number of smaller size nodules and an increase of nodules per square mm as compared to gravity process.
v. FGI with NC produces a reduction in the coefficient of friction by 17.6% and decrease in wear by about 45.45% over that of RC process.
vi. Centrifugal effect for SGI produces a reduction in the coefficient of friction by 55% and decrease in wear by about 33.33% over that of gravity cast.

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