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BRIEF COMMUNICATION

Influence of Heat Treatment on Microstructural and Mechanical Properties of Nodular Cast Iron

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Abstract Spheroidal Graphite Iron (SG Iron) is popularly known as ductile iron or nodular cast iron which is a special case of cast iron having carbon content of more than 3 wt% in volume and graphite is in the form of spherical tiny sized particles. Since the last three decades, the demand for SG Iron has been increasing due to its superior mechanical properties such as high strength and toughness, this nature leads to the usage of SG Iron in numerous industrial applications. From the earlier studies, it has been proved that addition of alloying elements to SG Iron leads to change in properties such as increased tensile strength and hardness. Heat-treatment of alloys is one of the valuable methods to achieve better properties. In the present study, the microstructures and mechanical properties of SG Iron were studied after various heat treatments beyond the limits, and tests were done to measure its mechanical properties like tensile strength, hardness, impact strength. Digital microphotographs, scanning electron microphotographs were analysed before and after the heat treatment. Results indicated great change in mechanical properties after the heat-treatment. From the results it can be concluded that the heat treatment of SG Iron results in changed composition of alloys, which also leads to economical growth of SG Iron.

Keywords Microstructures · Heat-treatment · Graphite · Hardness · Tensile strength

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Introduction

Since the last three decades the usage of nodular cast iron or Spheroidal Graphite Iron has been increasing due to its suitability for versatile applications. Now-a-days it is widely used for engineering applications because of its excellent castability. Moreover, it is cost effective and possesses good mechanical properties [1]. The achievement of good mechanical properties by nodular cast iron is depends on many factors such as chemical composition, charge composition, method of inoculation, size of graphite nodules, proportion of ferrite in the matrix [2]. In recent studies nodular cast iron has increased in popularity and is rapidly replacing grey cast iron and some low strength steels due to its versatile characteristics [3]. Mostly, nodular cast iron also contains substantial amount of pearlite and due to this, there is a development of relationship between pearlite content and material hardness [4]. Due to the presence of nodular graphite in the matrix, nodular cast iron is more flexible and elastic in nature. The formation of these nodules is achieved due to the addition of magnesium and cerium. Some of the charge components added in nodular cast iron are manganese and chromium [5]. In nodular cast iron, graphite is present in the form of spherical nodules rather than flakes as in grey cast iron [5]. Mostly, nodular cast iron is manufactured or produced by melting in cupolas and induction melting furnace. However, the quality is good when one uses rotary furnace [6]. At higher heat treating temperatures, it results in high ductility, high fatigue, high tensile strength, and high wear resistance. Due to this, the ductility and impact strength may be reduced [7–9]. In the present study, experiments were conducted for nodular cast iron in order to observe mechanical properties like tensile strength, hardness, impact strength. Scanning electron micro photographs and microstructures were also studied. These properties were found to give better response and good results after the completion of the tests.

Materials and Experimental Procedure

The experimental procedure started with preparation of test specimens. Specimens were prepared according to the ASTM standards. To get the required specifications, the specimens were made to undergo several operations such as turning, facing, grinding. For each and every test, three specimens were prepared. The dimensions of the prepared specimens were tabulated in the tabular column as shown in the Table 1. Initially, these specimens were made to undergo tensile test in order to know their tensile strengths. The tensile test was done on the universal tensometre. The average value of the tensile strength was noted. Later, another set of specimens were prepared and they were subjected to heat-treatment in order to find out the percentage change in tensile strength after the heat-treatment. The heat-treated specimens were subjected to annealing process where the specimens were heated up to critical temperature (above 723 °C) and there after cooled in still air. Several sets of experiments were undertaken in order to find out the hardness, shear stress, impact strength, density. The temperature maintained for all the tests was above austenite formation temperature. Each and every test was conducted before as well as after heat-treatment and

Table 1 Dimensions of the specimens

S. no.	Specimen no.	Specifications of specimen (mm)					
		Before heat treatment			After heat treatment		
		Inner diameter	Outer diameter	Length	Inner diameter	Outer diameter	Length
1	1	4.56	7.48	15.06	4.56	7.44	16.92
2	2	4.56	7.48	15.22	4.52	7.48	15.78
3	3	4.58	7.62	15.56	4.53	7.42	15.46

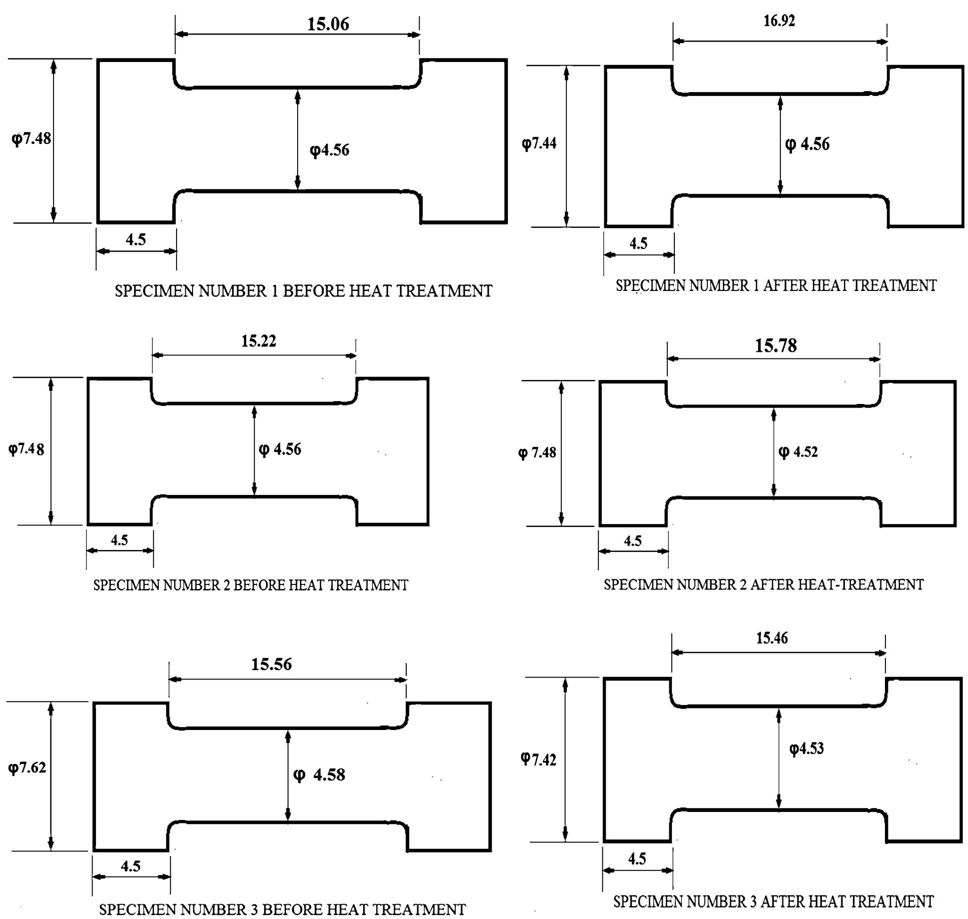

Fig. 1 Tested specimens before and after heat treatment

percentage change in the results were noted and reported in the results and discussions.

From Fig. 1, it can be observed that after heat treatment there is a slight increase in length and corresponding decrease in diameter. This may be due to expansion and randomness of the molecules caused during heating of the specimens (Table 2).

Results and Discussion

Optical metallographs are shown in Figs. 2 and 3.

Table 2 Chemical composition of the test material

C%	Mn%	Mg%	Si%	Cu%	S%	P%
3.82	0.31	0.037	2.62	0.35	0.01	0.02

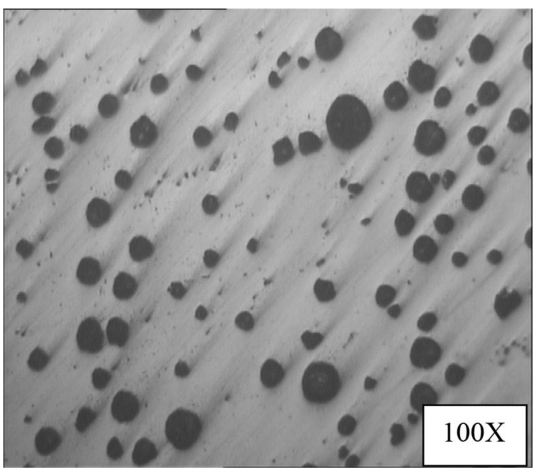

Fig. 2 Optical micro photographs of SG iron before heat treatment

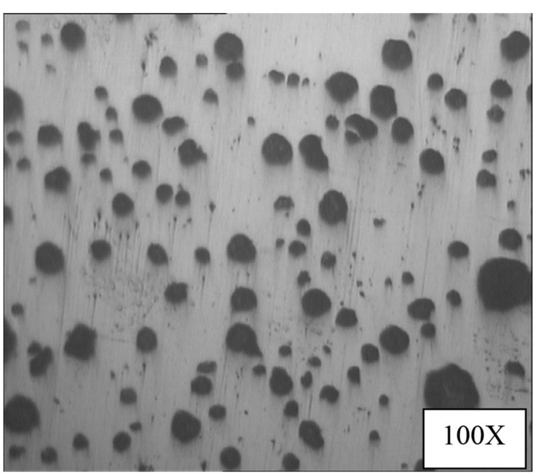

Fig. 3 Optical micro photographs of SG iron after heat treatment

SEM photographs are shown in Figs. 4 and 5.

The above figures show that after the heat-treatment of nodular cast iron there is no appreciable change in size and shape of the nodules but the matrix in which these nodules may get affected by the heat treatment and the change in properties may be observed. This change in properties leads to slight occurence of solidification and there is an expansion of graphite nodules or shrinkage of the iron matrix.

Figures 6 and 7 show the variation of break tensile strength and peak tensile strength after the process of heat-treatment. The machine employed for tensile testing is tensometre. The specimen was prepared according to the ASTM standards and directly set into the machine and ultimately the tensile strength was noted. From the figures shown hereafter it is observed that decrease in tensile strength is due to the increase in hardness of the material.

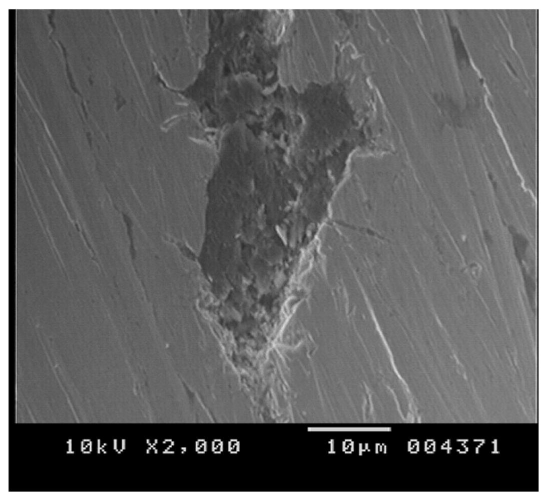

Fig. 4 SEM photographs of SG iron before heat treatment

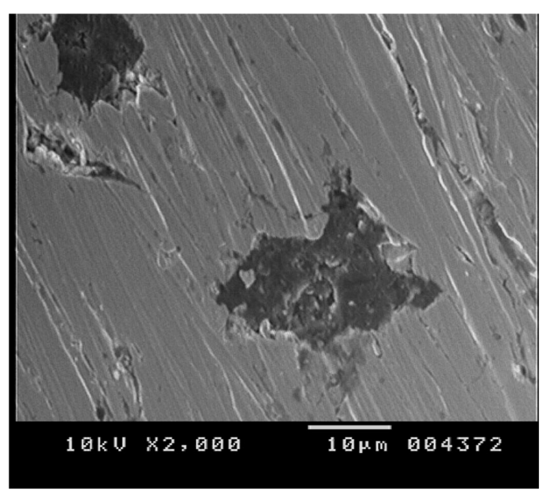

Fig. 5 SEM photographs of SG iron after heat treatment

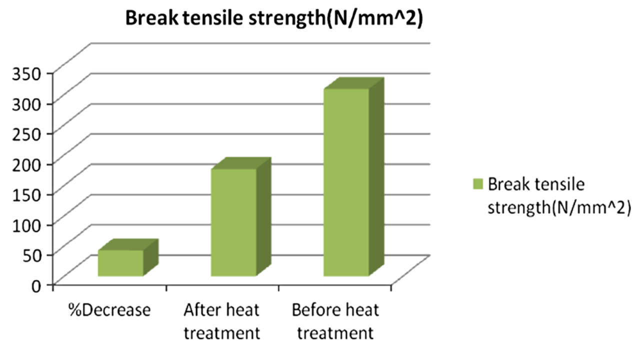

Fig. 6 Percentage change in break tensile strength

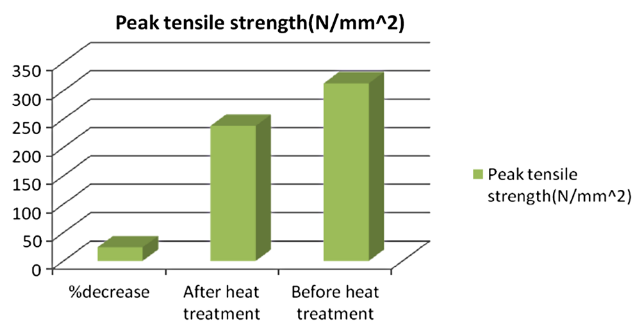

Fig. 7 Percentage change in peak tensile strength

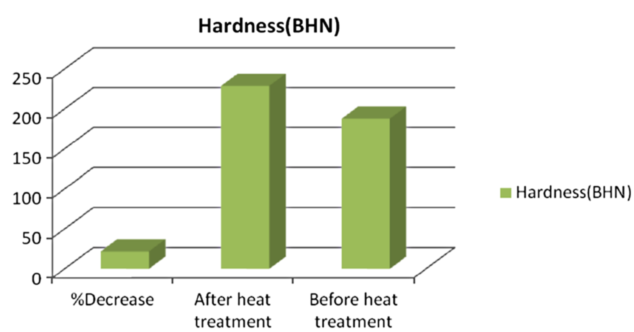

Fig. 8 Percentage change in hardness

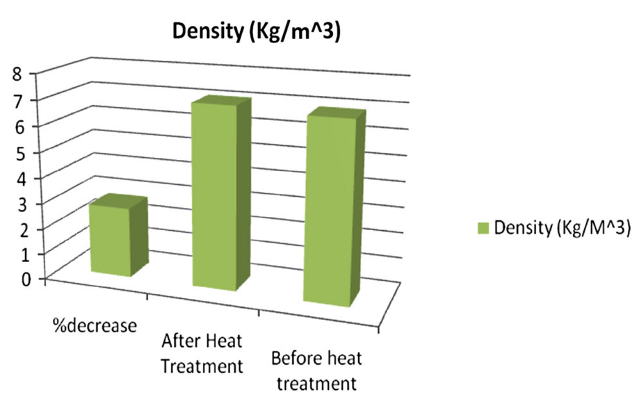

Fig. 9 Percentage change in density

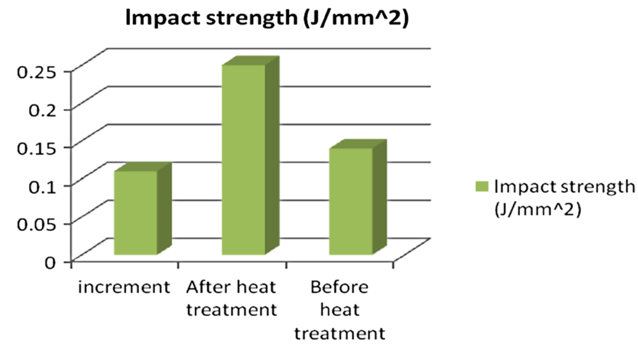

Fig. 10 Percentage change in impact strength

Table 3 Experimental values of before and after heat-treatment

Name of the test	Before heat-treatment	After heat-treatment	% increase	% decrease
Break tensile strength (N/mm^2)	309.3	176.9		42.80
Peak tensile strength (N/mm^2)	312.7	237.9		23.92
Hardness (BHN)	187.8	228.8	21.87	
Density (kg/m^3)	6.9	7.06	2.76	
Impact strength (J/mm^2)	0.14	0.25	0.11	

Figure 8 represents the variation of hardness before and after the heat-treatment process. Here, the method used for testing the hardness is Brinell hardness test. From the figure it is observed that there is 21 % increase in hardness after the heat-treatment process. This increment is due to the formation of new phases and intermetallics.

Figure 9 represents the percentage change in density after the specimen had undergone heat-treatment process. From the figure it is seen that there is slight increment in density, which is due to the formation of solidification contraction cavities.

Figure 10 shows the percentage change in impact strength of the tested specimen after the completion of heat-treatment. The test employed for measurement of impact strength of the material is Charpy test where the specimen was placed horizontally across the supports. From the figure it is observed that there is slight increment of impact strength after the heat-treatment process (Table 3).

Conclusions

This investigation shows the behaviour of nodular cast iron after it has undergone heat treatment. The results show the percentage change in mechanical properties and metallurgical properties. Some of the results are briefly discussed hereafter. These results give a better understanding of the behaviour of nodular cast iron.

- Break tensile strength and peak tensile strength reduces after completion of heat treatment.
- Hardness increases up to 23 %.
- Density increases up to 2.76 % whereas, impact strength have an increment of 0.11 %.
- Digital and SEM photographs observations support the conclusions listed.

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