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An Experimental Behavioral Study of Ductile Cast Iron Microstructure and its Mechanical Properties

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ABSTRACT

Ductile cast iron also referred to as nodular iron or spheroidal graphite iron. The Ductile Cast Iron contains graphite which is in the form of discrete nodules or spheroids. This paper deals with some factors influencing microstructure and mechanical properties of Ductile Cast Iron. Ductile Cast Iron have been used for a wide variety of application in automotive, rail and heavy engineering industry because of its excellent mechanical properties such as high strength with good ductility, good wear resistance and good fatigue properties. The properties of ductile cast iron depend on both chemistry and heat treatment. Nodular cast iron is primarily heat treated to create matrix micro structure and associated mechanical properties not readily obtained in the casted condition. Final structure and properties of Ductile Cast Iron are obtained by controlled process of heat treatment. The influence of heat treatment on microstructure and mechanical properties of ductile cast iron above austenising temperature is altered. Experiments were conducted on 600/3 and 500/7 grades of ductile cast iron and following observations were made to know the properties of metal. Results of the experiment shows that it dependence of temperature and various matrixes can be obtained (i.e. mixture of graphite, ferrite and pearlite). Different quenching media are selected to check the behaviour of the materials. Quenching Medias like vegetable oil, mineral oil and water were used for this experimental analysis. After heat treatment the tensile strength, hardness, elongation and yield stress of the specimens were obtained with respect to different quenching media.

Key words: Ductile Cast Iron, heat treatment process, austenising temperature, quenching media

INTRODUCTION

Ductile cast iron is cast iron in which the graphite is present as tiny balls in metallic matrix. Ductile cast iron is also known as nodular iron, spheroidal graphite iron, and spherulitic iron. This type of cast iron has increased strength and ductility when compared with a similar structure of grey cast iron [1]. Ductile cast iron has excellent mechanical as well as technical properties together with relatively low price. Much of the annual production of ductile iron is in the form of ductile iron pipe, used for water and sewer lines. Ductile iron is specifically useful in many automotive components. Other major industrial applications include off-highway diesel trucks, class 8 trucks, agricultural tractors, oil well pumps, fully machined piston for large marine diesel engine, bevel wheel, hydraulic clutch on diesel engine for heavy vehicle and fittings overhead electric transmission lines [2]. If ductile iron is heated at 7500°C, then it is quenched (mineral oil or vegetable oil or water or any other quenching media), then its properties are vary depending upon the micro constituents present in particular metal. In general heat treatment processes involving heating, holding and continuous cooling, due to this graphite nodules are transformed into a ferrite matrix or up to 10% pearlite although it does not contain carbides.

As-cast ductile cast iron shows following values of the mechanical properties -

- Tensile strength (N/mm2) 600 to 647 for 600/3 grade and 500 to 560 for 500/7 grade
- Hardness (HBW) 190 to 270 for 600/3 grade and 160 to 220 for 500/7 grade
- Yield stress (N/mm2) 530 to 540 for 600/3 grade and 450 to 460 for 500/7 grade
- Elongation (%) 3 to 4 for 600/3 grade and 7 to 18 for 500/7 grade

Heat treated ductile cast iron shows following values of the mechanical properties

- Tensile Strength (N/mm2) 635 to 647 for 600/3 grade and 543 to 552 for 500/7 grade
- Hardness (HBW) 215 to 226 for 600/3 grade and 189 to 197 for 500/7 grade

- Yield stress (N/mm2) 526 to 560 for 600/3 grade and 460 to 470 for 500/7 grade
- Elongation (%) 10 to 15 for 600/3 grade and 20 to 25 for 500/7 grade

Factor that affect heat treatment process and subsequent microstructures as well as mechanical properties are summarized as:

- Austenising temperature and time
- Casting quality and section size of castings

EXPERIMENTAL INVESTIGATION

Experimental material was melted in the electric induction furnace shown in Fig.1. The basic charge was formed by cold rolled high carbon scrap and foundry returns for the control of chemical composition. Iron, Silicon and magnesium alloy (Fe, Si, and Mg) modifier was used for modification and Iron Silicon (Fe, Si) granules inoculant was used in treatment ladle shown in Fig.2. Ferrite pearlitic nodular cast iron was used as basic materials for heat treatment are shown in Fig. 3.

Fig.1 Electric induction furnace

Fig.2 Treatment ladle

Fig.3 Material used for heat treatment

The Chemical Composition and Microstructure Study of As-Cast Material

Chemical composition and microstructure of the as-cast material of samples (600/3 and 500/7 samples) is presented in Table.1 and Fig. 4, 5, 6 & 7 and Graphite type, Nodularization, Nodule size, Nodule count for (600/3 and 500/7) microstructure are shown in below Table 2.

Table - 1 Chemical Composition of the used Samples

Material	Elements									
	C (%)	Mn (%)	P (%)	S (%)	Si (%)	Cu (%)	Ni (%)	Cr (%)	Mo (%)	Mg (%)
600/3	3.128	0.855	0.095	0.038	1.716	0.043	0.017	0.179	<0.001	
500/7	3.377	0.478	0.087	0.041	2.932	0.04	0.018	0.066	<0.001	0.035

Table - 2 Microstructure Study of as-Cast Sample

Specimen	Graphite type	Nodularization	Nodule size	Nodule count
600/3	Predominantly form VI and V	85%	6/8	130 mm^2
500/7	Predominantly form VI and V	90%	6/8	150 mm^2

Fig. 4 and 5 represents microstructure of the as-cast material of 600/3 grade Microstructure consists of graphite nodules in ferrite, 10% pearlite matrix with no free carbides. Fig. 6 and 7 represents microstructure of the as-cast material of 500/7 grade microstructure consists of graphite nodules in ferrite,10% pearlite matrix with no free carbides.

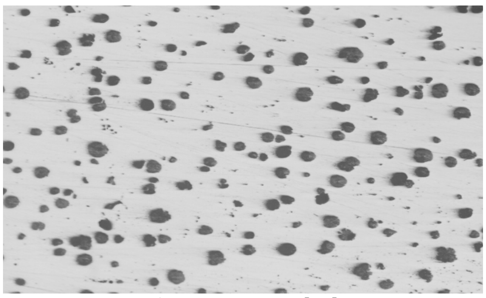

Fig.4 100X un-etched

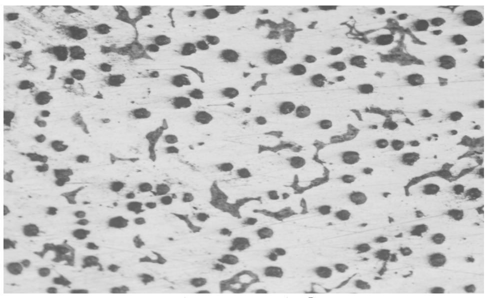

Fig.5 100X nital

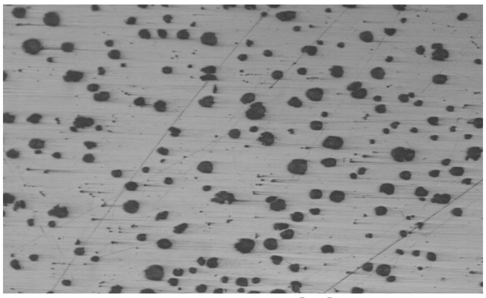

Fig. 6 100 un-etched

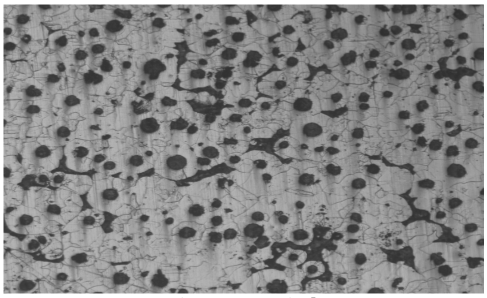

Fig. 7 100X nital

HEAT TREATMENT

All the samples were initially austenised at 750°C for 143 minutes in muffle furnace is shown in Fig.8 and they are quenched in different quenching medium like mineral oil, vegetable oil and water are shown in Fig. 9-11. After heat treatment specimens are adopted for tensile test, hardness test, yield stress, elongation and for the analysis of microstructure is shown Fig. 12.

Fig. 8 Muffle furnace

Fig. 12 Specimens for tensile test and Microstructure

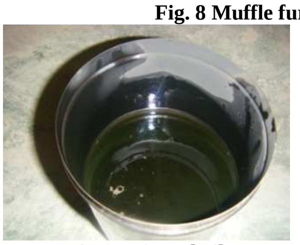

Fig. 9 Mineral oil

Fig. 10 Vegetable oil

Fig. 11 Water

TESTING

Mechanical properties investigations were carried out in the testing laboratory.

a. Tensile test was made by TUE-C-1000 of the testing equipment with loading range 0 to 35 kN.
b. Brinell hardness test was made by B-3000 of the testing equipment with the tungsten ball indenter of a diameter 10 mm pressed into the surface of specimens under the load 3000kg.
c. The microstructure of the specimens was made by optical metallurgical microscope NIKON Epiphot 200.

EXPERIMENTAL RESULTS - METALLOGRAPHIC ANALYSIS

Microstructure of the basic material 600/3 and 700/7 grade cast iron is quenched by different medium (after heat treatment) obtain ferrite and pearlitic nodular matrix for 600/3 (Fig.13-18), for 500/7 (Fig.19-24) and Graphite type, Nodularization, Nodule size, Nodule count for 600/3 and 500/7 are shown in below Table 3**.**

Fig. 13 and 14 represents the microstructure of the material of 600/3 grade quenched by sun flower oil. Microstructure consists of graphite nodules in ferrite, 25% pearlite matrix with no free carbide. Fig. 15 and 16 represents the microstructure of the material of 600/3 grade quenched by mineral oil. Microstructure consists of graphite nodules in ferrite, 20% pearlite matrix with no free carbides. Fig. 17 and 18 represents the microstructure of the material of 600/3 grade quenched by water. Microstructure consists of graphite nodules in ferrite, 20% pearlite matrix with no free carbides. Fig. 19 and 20 represents the microstructure of the material of 500/7 grade quenched by sun flower oil. Microstructure consists of graphite nodules in ferrite, 10% pearlite matrix with no free carbides.

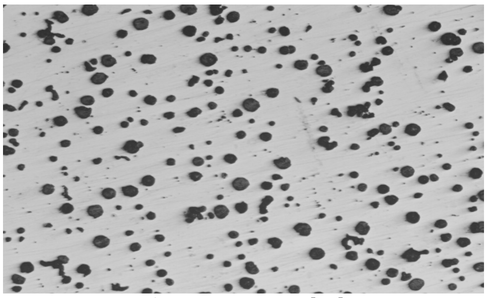
Fig.13 100X un-etched

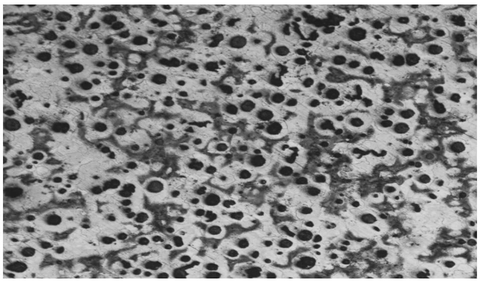
Fig.14 100X nital

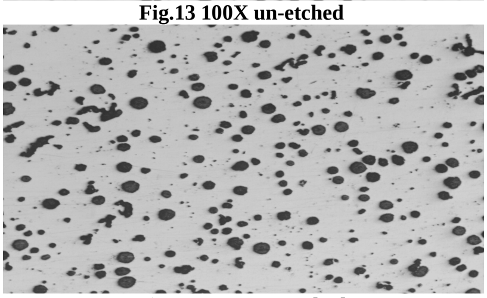
Fig. 15 100X un-etched

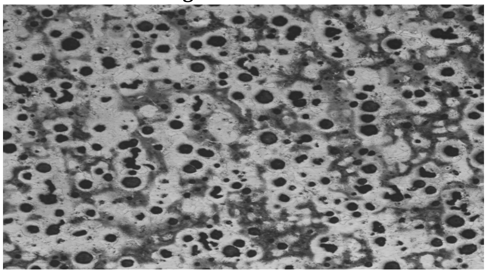
Fig. 16 100X natal

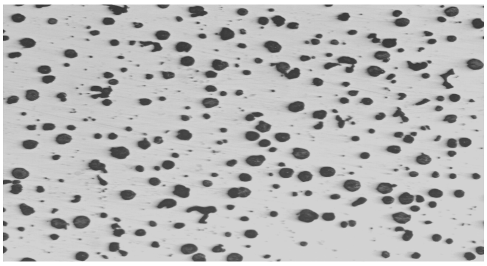
Fig.17 100X un-etched

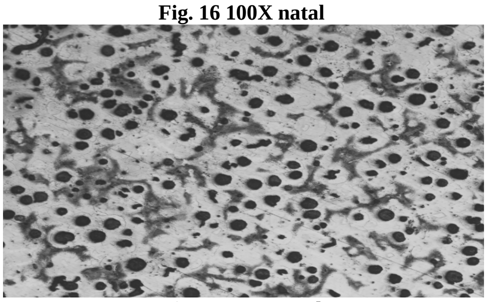
Fig.18 100X natal

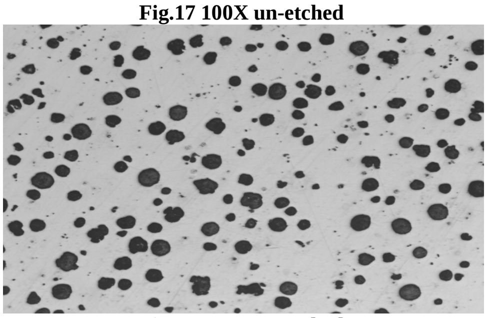
Fig.19 100X un-etched

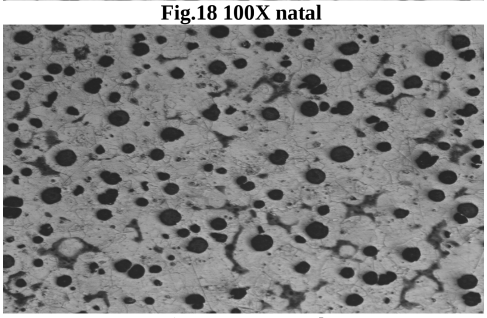
Fig. 20 100X natal

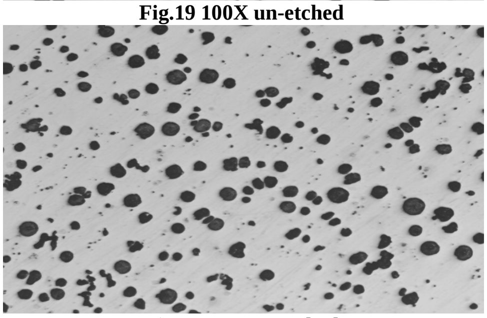
Fig. 21 100 un-etched

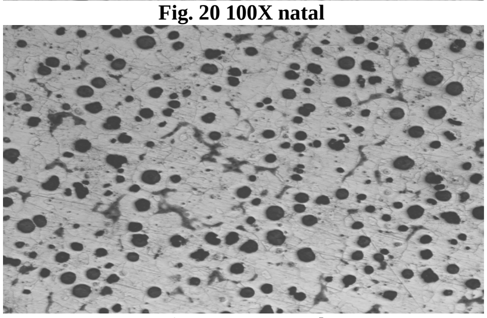
Fig. 22 100X natal

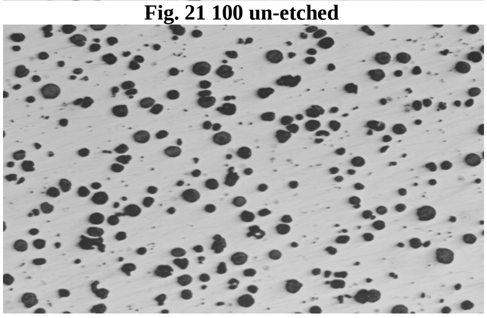
Fig. 23 100X un-etched

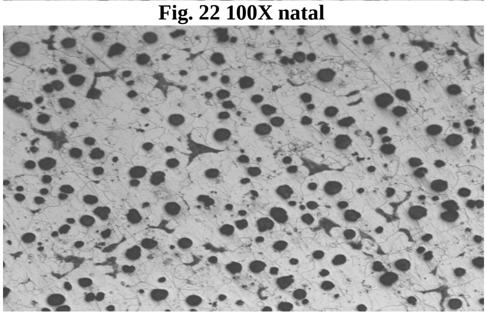
Fig. 24 100X nital

Fig. 21 and 22 represents the microstructure of the material of 500/7 grade quenched by mineral oil. Microstructure consists of graphite nodules in ferrite, 10% pearlite matrix with no free carbides. Fig. 23 and 24 represents the microstructure of the material of 500/7 grade quenched by water. Microstructure consists of graphite nodules in ferrite, 10% pearlite matrix with no free carbide.

Table - 3 Microstructure Study of Heat Treated Sample

Specimen	Quenching medium	Graphite type	Nodularization	Nodule size	Nodule count
600/3	Sun flower oil	Predominantly form VI and V with some form III	85%	6/8	210mm^2
	Mineral oil	Predominantly form VI and V with some form III	85%	6/8	210mm^2
	Water	Predominantly form VI and V with some form III	85%	6/8	210mm^2
500/7	Sun flower oil	Predominantly form VI and V	90%	5/8	170mm^2
	Mineral oil	Predominantly form VI and V	85%	6/8	180mm^2
	Water	Predominantly form VI and V	85 to 90%	6/8	210mm^2

RESULTS AND DISCUSSION

Study the mechanical properties of as-cast and heat treated (600/3 and 500/7 grade) ductile cast iron are given in the Table 4.

Table - 4 Study the Mechanical Properties of As-Cast and Heat Treated Ductile Cast Iron

Condition	Grade		Tensile strength(N/mm^2)	Yield stress (N/mm^2)	Hardness	Elongation%
As cast	600/3		647.77	539.81	269	4.69
	500/7		560.62	459.37	197	18.69
Heat treated		**Quenching medium**				
	600/3	Sun flower oil	641.25	526.87	219	15.65
		Mineral oil	646.88	555.56	215	14.38
		Water	635.12	560.73	226	10.83
	500/7	Sun flower oil	548.83	460.49	197	25.15
		Mineral oil	552.31	470.69	189	22.73
		Water	543.57	467.28	197	22.03

CONCLUSION

- After heat treatment tensile strength and hardness of ductile cast iron samples show a significant decrease.
- After heat treatment also there is no change in shape and size of graphite nodules.
- So finally conclude that the heat treatment is carried at 7500°C is second stage of graphitization.

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