Effect of Graphite Nodularity on Mechanical Properties of Ductile Iron for Waterworks Fittings and Accessories

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***Abstract*— Waterworks fittings and accessories are important applications for ductile irons. Although, in the design of these components the graphite nodularity is a critical attribute for material selection, the International Standard ISO 2531 does not include the minimum required value of graphite nodularity and its definite effect on mechanical properties. In this research the effect of graphite nodularity on tensile strength, elongation, impact strength and wear rate was studies. Different samples from four heats of cast iron containing several of graphite nodularities were cast. Different degrees of graphite nodularities from low graphite nodularity of about 21% up to high graphite nodularity of 94% were produced by treatment cast iron by different amount of spheroidizing (Mg) and antispheroidizing (Ti) elements. It is concluded that all properties relating to strength and ductility decrease as the graphite nodularity increase, and those properties relating to failure, such as tensile strength and impact strength are more affected by changing of graphite nodularity. The minimum graphite nodularity of 60% can be considered for design as satisfactory values of ductile iron fittings and accessories for all DN values.**

Index Terms— graphite nodularity, mechanical properties**,** ductile iron, fittings

I. INTRODUCTION

Materials serve as an enabling technology contributing to solutions in problems of concern to society. The civil and environmental profession can contribute to improvements in the quality of life by seeking solutions to infrastructure deterioration, hazard mitigation, structural safety, sustainability, environmental protection, and construction

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productivity. Although there are currently aplenty of new and advanced materials, cast irons still the most used casting alloy for its considerable reduction in their production. Their popularity stems from an ability to cast complex shapes at relatively low cost and the wide range of properties that can be achieved by careful control over composition and cooling rate.

In Ductile Iron (DI) the graphite is in the form of spherical nodules rather than flakes, thus inhibiting the creation of cracks and providing the enhanced ductility that gives the alloy its name. In order to improve the properties of cast iron a method was developed to give the graphite a spherical shape by adding cerium to the melt. Later on, the method was improved by using magnesium instead of cerium, cast iron with spherical shaped is today well known as ductile cast [1]. DI is not a single material, but a family of materials offering a wide range of properties obtained through microstructure control. The common feature that all ductile irons share is the roughly spherical shape of the graphite nodules. These nodules act as crack-arresters and make DI ductile. This feature is essential to the quality and consistency of DI, and is measured and controlled with a high degree of assurance by competent DI foundries. By changing the graphite nodularity from spheroid to compacted one until about 20 % graphite nodularity, a relatively new type of cast iron can be found called Compacted Graphite Iron (CGI).

Graphite morphologies in CGI are randomly oriented, elongated and interconnected within eutectic cells as in gray iron, but stubby, blunt-edged and have rounded ends and rough interfaces with matrix, and generally considered as a transitional form between flake and nodular. Therefore, CGI provides higher strength and ductility than gray iron and better thermal conductivity and damping properties than nodular iron, which represents an optimal combination of strength, ductility and thermal properties for certain engineering applications and has received considerable attention especially during recent years [2]. Although the tensile strengths of compacted graphite iron (CGI) are lower than those of spheroidal, or ductile, graphite irons (DI), CGI has several superior characteristics such as improved castability, damping capacity and machinability [3]. This means that decreasing graphite nodularity in DI can lead to CGI, which can be used in many applications.

This research work is concerning with the effect of graphite nodularity on mechanical properties of ductile iron waterworks fittings and accessories. Also, indentifying the value of graphite nodularity that leads to the minimum values of mechanical properties required standard to DI for waterworks fitting and accessories.

II. EXPERIMENTAL

A. Casting procedure

The alloy was melted in a 350 kg capacity medium frequency induction furnace with a silica lining and treated with Fe–Si–Mg alloy and Fe–Si–Mg–Ti alloys using a sandwich method. Four heats of cast iron containing several of graphite nodularities were cast into 25mmY-blocks made from green sand moulds. A treatment alloy containing about 5% Mg and 0.3% Ce balanced by about 9% Ti was used in order to obtain different amounts of residual Mg, different amounts of residual Ti, and low levels of cerium in the final cast iron (see Table 1). All the Y-block specimens were poured from the same base melt to keep the carbon equivalent and alloying elements constant. The samples material in current research was used in other research in heat treated condition [4].

TABLE I

CHEMICAL ANALYSIS OF CAST IRON SAMPLES AND CHEMICAL COMPOSITION OF TREATMENT ALLOYS, WT-%.

	95% graphite nodularity	77% graphite nodularity	52% graphite nodularity	21% graphite nodularity
C	3.61	3.59	3.58	3.60
Si	2.26	2.19	2.25	2.21
Mn	0.22	0.22	0.21	0.22
S	0.01	0.02	0.02	0.01
P	0.03	0.03	0.03	0.03
Ni	1.51	1.48	1.50	1.50
Mo	0.31	0.31	0.30	0.32
Cr	0.03	0.03	0.03	0.03
Ti	0.02	0.22	0.21	0.24
Mg	0.03	0.05	0.03	0.02
Fe	Bal.	Bal.	Bal.	Bal.

B. Metallographic analysis

Specimens used for metallographic examination in the as-cast condition were ground, polished and hen etched with 3% nital. After etching the specimens were examined and photo micrographed using optical microscope fitted with a 35mm camera. The nodularity was determined by the ratio between the number of type I and II (nodular) graphite particles (ASTM A247) and the total number of graphite particles [5].

C. Mechanical Properties

Unnoutched charpy specimens (55x10x10mm) and tensile specimens conforming to ASTM A439-71 dimensions were machined from as cast samples. Unnotched charpy specimen were tested at room temperature using" Shimadzu 30 kgf.m capacity charpy test machine. Tensile testing was performed on a 50 KN SHEMADZU universal testing machine with constant speed. The ultimate tensile strength, 0.2% proof stress and elongation to failure were recorded. Hardness measurements were made using a standard hardness tester with a 10-kg load. Each measurement represents the average of seven indentations. Wear tests were conducted on tribometer testing machine with 70 mm outer diameter. All texts were carried out under pure sliding and dry condition between the specimens and the used adhesive disc. The revolving speed of adhesive disc was 265 rpm and 1.5 normal load. Before testing, specimens were ground silicon carbide abrasive paper 1000CW.

III. RESULT AND DISCUSSION

Four levels of graphite nodularity in a ferritic pearlitic matrix were obtained and were examined in the as-cast condition by metallographic techniques (see Fig. 1). The determination of nodularity, ferrite and pearlite were counted using image analyzer program (Table 2). It is evident that ferritic fraction for all levels of graphite nodularity are approach to the same value**.** As shown in Figure 1(d), the graphite phase in law graphite nodularity iron (CGI) appears as individual 'worm-shaped' or vermicular particles.

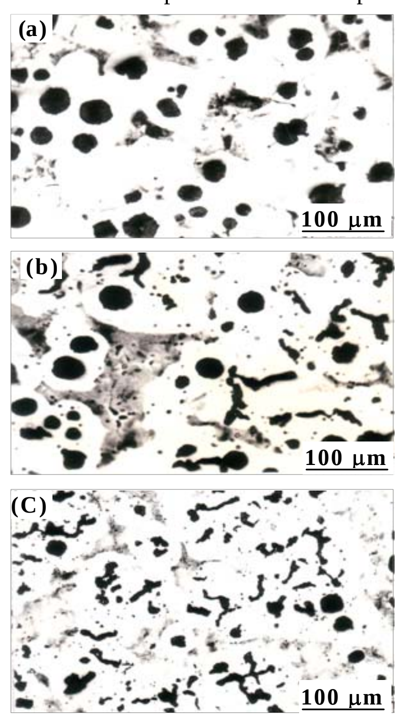

Fig.1 Typical as-cast structure for samples containing different graphite nodularity.

The particles are elongated and randomly oriented as in gray iron; however they are shorter and thicker, and have rounded edges.

TABLE II
QUANTITATIVE MEASUREMENT OF STRUCTURE FEATURE OF CAST IRON.

Specimens	Nodularity (%)	Ferrite (%)	Pearlite (%)	Graphite (%)	Hardness (Hv 10)
A	95	64.8	25.7	9.4	244
B	77	65.8	25.0	9.2	233
C	52	68.5	22.0	9.5	221
D	21	70.0	20.7	9.3	216

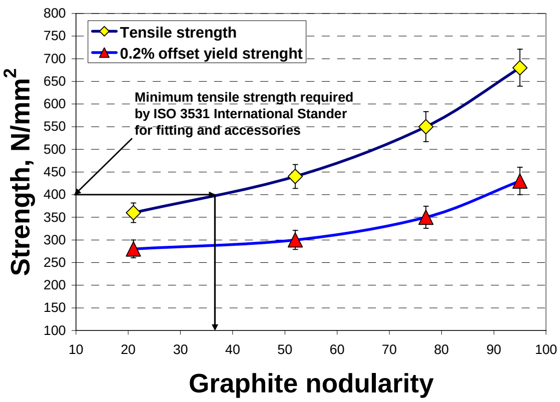

Fig. 2 Influence of graphite nodularity on the strength.

The as-cast tensile properties, impact strength wear rate were measured and were summarized as a function of graphite nodularity in Figs.2 - 5. The current study and previous study[5] in a good agreement that all of properties related to strength, decreases as the proportion of non-nodular graphite increase, and those relating to failure, such as tensile strength and impact strength, are more affected by small amount of non-nodular graphite.

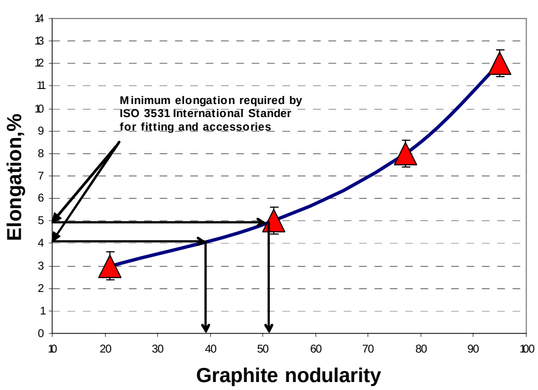

Fig. 3 Influence of graphite nodularity on the Elongation

The graphite morphology plays an important rule and the more the graphite shape deviates from the ideal spherical shape the lower is the ductility and strength [6,7] . Damaging micromechanisms are strongly affected by microstructure; both graphite elements and metal matrix are involved[8]. The difference in strength properties for different graphite nodularity levels seams to be principally due to the easier crack propagation with lower degree of graphite nodularity.

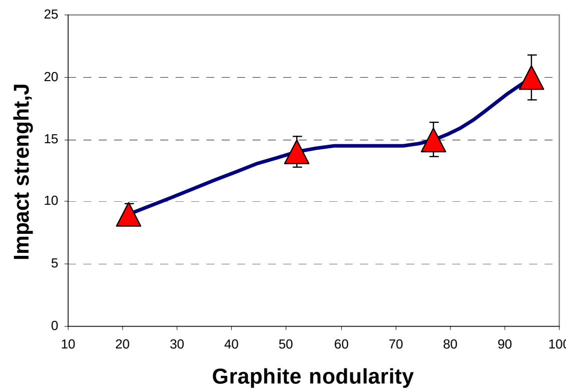

Fig.4 Influence of graphite nodularity on the impact strength.

Fig. 5 shows the wear rate as a function of graphite nodularity in dry wear test condition. It is clear that decreasing in graphite nodularity results in a significant increase in wear rate. This is due to a relatively better continuity condition of the matrix in case of high graphite nodularity iron and its relatively smaller stress concentration effect of graphite [9].

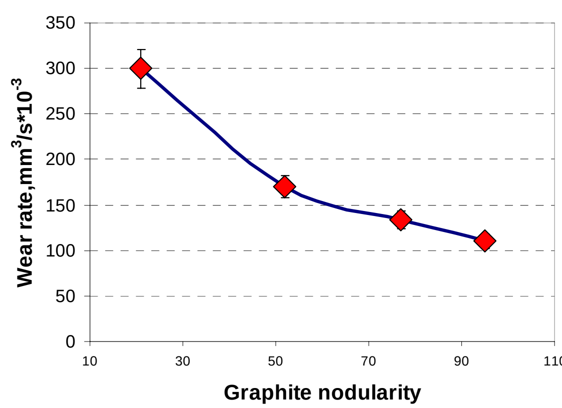

Fig.5 Influence of graphite nodularity on the wear rate.

It has been established that all of the mechanical and physical properties characteristic of DI are a result of the graphite being substantially or wholly in the spheroidal /nodular shape such that its bulk physico-mechanical properties are determined primarily by the steel -like matrix. Any departure from this shape or a proportion of the graphite will cause a drastic deviation from these properties. Occasionally, a consistent spheroidal type of graphite is not obtained in regular production of DI. This may result from insufficient or excessive nodulariser, or non -uniform treatment or the presence of inhibiting elements. Also, the problem may be the choice of nodulariser, mode of addition, and environmental and/or human considerations. However, unlike other renowned engineered materials, requirements concerning graphite "nodularity" in DI seldom appear in users' specifications. In essence, commercial DI castings are designed on the basis of their properties and rarely on the basis of their graphite morphology, shape or structure. Graphite nodularity, usually evaluated by visual assessment, might be utilized as a simple form of selection for castings to determine which should and should not be accepted [10, 11].

Waterworks fittings and accessories are important applications for ductile cast irons. Although, in the design of these components the graphite nodularity is a critical attribute for material selection, the international standard ISO 2531 does not include the minimum required value of graphite nodularity and its definite effect on mechanical properties. As a result there are lot of confusion and misconceptions between the produces and investigators who decided the quality of the products and its matching to the standard. According to international standard ISO 2531 the DI for waterworks fittings and accessories, the graphite of DI must in a good nodularity. It is still badly needed to determine a specified range for graphite nodularity which should and should not be accepted.

TABLE III
MINIMUM TENSILE PROPERTIES OF PIPE AND FITTINGS, ISO2531.

Type of casting	**Minimum tensile strength, N/mm²**	**Minimum elongation after fracture,%**	
	DN 100 to 1600	DN 100 to 1000	DN> 1000
Pipe centrifugally	420	10	7
Fittings and accessories	400	4	5

Table 3 shows the minimum tensile properties of pipe and fittings according the international standard ISO 2531. For fittings and accessories the minimum accepted value of tensile strength is 400 N/mm^2 and the minimum accepted value of elongation is 4 or 5 depend on the diameter DN. Here by applying these values of tensile strength and elongation in Fig. 2 and Fig 3, the minimum Value of graphite nodularity can be determined. As a result the minimum graphite nodularity of 38 and 52 % can be considered as satisfactory values of DI fittings and accessories for DN 100 to 1000 and DN> 1000 respectively. Also the minimum graphite nodularity of 60 % can be considered for design as satisfactory values of DI fittings and accessories for all DN values.

The impact strength Shown in Fig. 4 and wear rate shown in Fig. 5 as a function of graphite nodularity have relatively considerable values at graphite nodularity value of 60%.

IV. CONCLUSION

Effect of graphite nodularity on mechanical properties of as-cast ductile iron for waterworks fittings and accessories has been investigated and the following conclusions may be drawn:

1. Different degrees of graphite nodularity, from low graphite nodularity of about 21% to high graphite nodularity of about 95% were produced by treatment cast iron of suitable base composition by different amount of spherodizing(Mg) and antispherodizing(Ti) elements.
2. All of properties related to strength, decreases as the proportion of non-nodular graphite increase, and those relating to failure, such as tensile strength and impact strength, are more affected by small amount of non-nodular graphite.
3. The minimum graphite nodularity of 38 and 52 % can be considered as satisfactory values of DI fittings and accessories for DN 100 to 1000 and DN> 1000 respectively.
4. The minimum graphite nodularity of 60 % can be considered for design as satisfactory values of DI fittings and accessories for all DN values.

5- The obtained data help in establishing complete criteria to investigate and select DI for waterworks fittings and accessories.

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