Mechanical and Structural Properties of Ductile Cast Iron

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Ductile cast iron round bars were prepared using alloys with carbon equivalent percentage (C.E) ranging between 4.50 % and 4.76 %. Different measurements were carried out on as – cast and heat-treated specimens. Ductile cast iron is essentially a family of materials with a wide verity of properties which are satisfactory for different engineering requirements. The soft ferrite grades are available to use when toughness and ductility are needed, while the harder pearlitic grades are used when higher strength is required. Grades with mixture of pearlite and ferrite in the matrix are also available. In addition heat treatments of the previous types present different and better combination of properties for application with special requirements [1]. Ductile cast iron behaves elastically over a considerable stress range in both tension and compression. Previous works [1, 2] on ductile cast iron showed that the main factors affecting the mechanical properties are metallurgical structures. Results revealed that mechanical properties decrease with increasing size of casting module. Annealing reduces mechanical properties and hardness. Ultrasonic velocity and attenuation coefficient increase with increasing of carbon equivalent percentage and decreased with increasing size of casting module.

Introduction:

Ductile cast iron frequently referred to as nodular or spheroid graphite iron is a recent member of the family of cast irons. It contains spheroid graphite in the as cast condition, through the addition of nucleating agents such as cerium or magnesium to the liquid iron [2, 4].

In fact ductile cast iron provides a wide spectrum of mechanical properties that can be obtained either by altering certain processing variables or through various heat treatments which present different and better combination of properties for application with special requirements [3].

Previous works [2, 4] showed that the main factors affecting the mechanical properties are the metallurgical structures. Most of published researches for ductile cast iron were devoted to study the microstructure and other properties [5-12]. Some of these researches [13-15] were devoted to the study of such properties by nondestructive techniques among these ultrasonic has found appreciable application.

Cast iron is a complex alloy containing mainly a total of up to 10% carbon, silicon, manganese, sulpher and phosphorous as well as varying amount of nickel, chromium, molybdenum, vanadium and copper [10]. The metallic matrix of common boundary cast iron consists of pearlite and ferrite. An increase in pearlite in the structure with the same form of graphite precipitation improves the mechanical properties.

Ultrasonic has been found to be a practical method for evaluation of castings qualita tively and quantitatively.

By means of models and empirical relationships, one can interpret certain changes in the structure of the material or the existence of an inclusion--- etc. The evaluation of the quality of a material always depends upon the reliability of the concept regarding the interpretation of the signal [3].

Different ultrasonic testing methods are used to suit the type of measurement. Among these is the pulse transit time (echo) method. It uses the signal, which is reflected from a discontinuity in the material. The probe can be used as an alternating transmitter and receiver.

Several authors have used this technique for calculating the speed and attenuation of ultrasonic waves for tempered and no tempered in cast iron with different nodularities [16, 17].

In this work, we used the pulse echo method for the measurement of both ultrasonic velocity and attenuation of our ductile cast iron specimens.

The aim of the present paper is to study the mechanical properties, hardness and microstructure and their relation with chemical composition, casting modules, nodularity, and matrix, as well as to deduce some relations to evaluate the properties of castings by ultrasonic waves and apply it for quality control of castings.

Experimental procedure:

Various methods are recommended for adding the inoculation agent to the molten iron such as open ladle, the sandwich, the pressure ladle and plunging techniques. Good inoculation, nodularization practice and control over detritus elements are necessary to achieve high nodule count and good spheroidality and avoid carbide formation. Low alloying additions or heat treatment may be used to obtain different spheroidel cast iron grades.

Our cast iron melts were prepared in an induction furnace of 14 tons capacity. The open ladle treatment technique [18] was used for preparing the treated melt. In this technique, the magnesium (nodularizing) alloy is placed on a pocked in the bottom of an open heated ladle. The melt is poured on the other side to react with the magnesium alloy effectively. The chemical composition of our melts before and after treatment and the nodularizing alloy (FeSiMg 5%) used for the treatment of melts is listed in Table (1, 2, and 3).

Table (1): The chemical composition of the melt before treatment.

Sample No.	C%	Si %	Mn %	P %	S %	Cr %	Ni %	Cu %
I	3.9	1.38	0.17	0.031	0.017	0.03	0.03	0.35
II	3.81	1.37	0.22	0.031	0.018	0.03	0.03	0.34
III	3.61	1.28	0.21	0.030	0.020	0.03	0.03	0.32
IV	3.71	1.35	0.22	0.031	0.017	0.03	0.03	0.34

Table (2): The chemical composition of the melt before treatment.

Sample No.	C%	Si %	Mn %	P %	S %	Cr %	Ni %	Cu %	Cu %
I	3.54	1.83	0.19	0.032	0.018	0.03	0.03	0.37	0.041
II	3.61	1.8	0.21	0.031	0.019	0.03	0.03	0.34	0.050
III	3.65	1. 8	0.21	0.031	0.019	0.03	0.03	0.32	0.055
IV	3.82	1.79	0.21	0.031	0.018	0.03	0.03	0.34	0.041

Table (3): The chemical composition of the (FeSiMg 5%) nodularizing alloy.

Si%	Cr%	Ca%	Al%	Mg%	Fe%
46.5	0.35	0.44	0.9	6.3	balance

The carbon equivalent (C.E) and saturation factor are calculated as:

$$C.E. = C\,\% + 1/3\,(Si\,\% + P\,\%)$$

$$Sc = \frac{C\%}{(4.23 - 0.31Si\% - 0.27P\%)}$$

Their values are listed in Table (4).

Table (4): Carbon equivalent and saturation factor.

Sample No.	C.E.	Sc
I	4.30	1.06
II	4.55	1.08
III	4.60	1.09
IV	4.76	1.14

Utmost precautions were taken to overcome hygroscopic, formation of shrinkage cavities and to ensure homogeneity. The temperature of the melt after 7 minutes from the beginning of the treatment was 1400 ± 50 c^{o} then it was poured in short time (about 3 minutes) to avoid fading of graphite. As shaking time, is an important factor affecting the matrix, consequently its mechanical properties, it was necessary to be kept constant for all castings (about 2 hours). To obtain ferritic matrix, our cast iron bars were annealed by heating to a temperature of 680 ^{o}C with 1.5 ^{o}C / min heating rate then hold for six hours followed by normal air cooling to room temperature [18].

Standard tensile test spectra were prepared according to ISO – 1083. A universal Shimadzu 50T testing machine was used for the tensile test. Brinell hardness measurements were carried out using Wolpert –Germany hardness test machine with 2.5-mm steel ball diameter indenture and 187.5 Kg load.

Ultrasonic velocity and attenuation measurements were performed by the pulse echo method, where an automatically adjusted short duration (1 ~ 2 μ sec) pulse of high frequency (1, 2 and 4MHz) is applied to a broad band transducer which was driven at its central frequency.

Results and Discussion:

Automatically plotted typical load–tension diagrams for the as cast and annealed ductile cast iron with two matrices (ferritic and pearlitic) and different casting modules are presented in Fig. (1, 2).

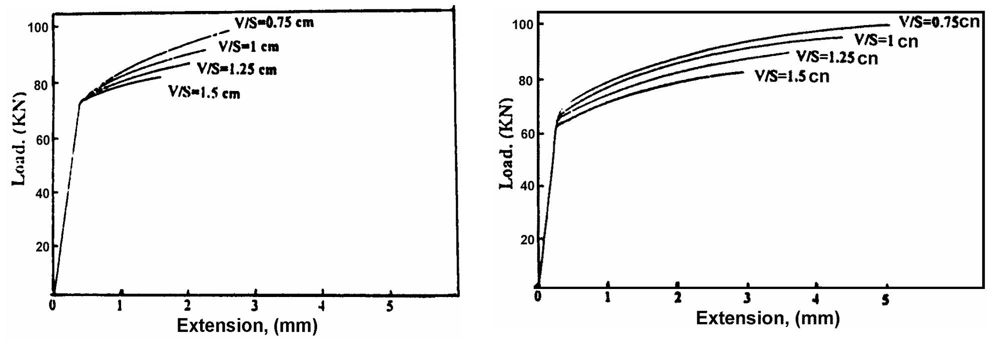

Fig. (1, 2): Typical load-extension diagram for as-cast and annealed tensile test.

As it is clear from these figures, the tensile strength decreases as the casting modulus increases; its value for the mostly ferritic matrix is less than that for the mostly pearlitic matrix. The variation of elastic modulus could not be distinguished and its approximate value is 190 MPa.

The variation of mechanical properties; namely ultimate tensile strength (σ_u , 0.2% offset yield (0.2% Y) and elongation percentage (El %), with size of casting module are presented in Fig. (3).The figure which shows for both materials that the ultimate tensile strength as well as elongation linearly decrease with increasing size of casting module. The 0.2%-offset yield showed very slight decrease and could be considered constant. It is worth to note that the as-cast material showed lower elongation percentage, higher strength and offset yield than, the annealed one. This is due to the fact that annealing relieves the material from internal stresses and recrystallizes its grains and consequently increases its ductility.

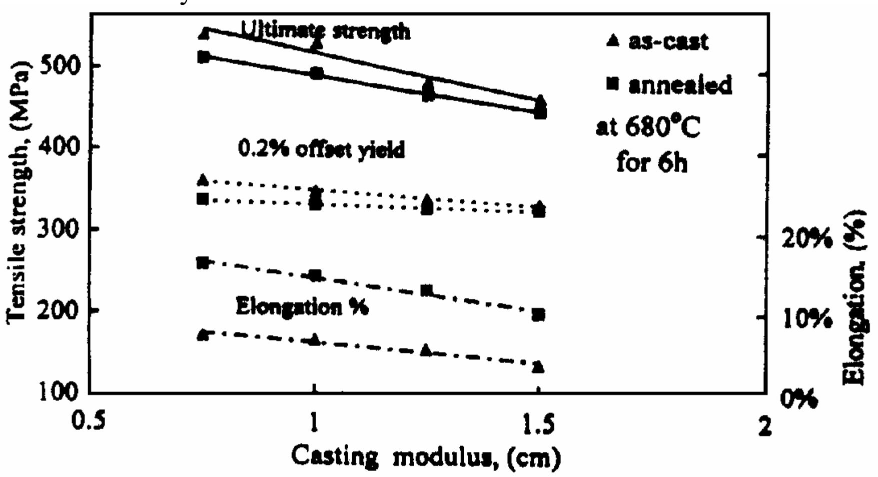

Fig. (3): Variation of mechanical properties with casting modulus for as-cast and annealed ductile cast iron.

The linear relationship between ultimate tensile strength and size of casting module for the as-cast and annealed specimens could be expressed as:

$$\sigma_u = a_1 - b_1 (v/s) \qquad (3)$$

where a_1 and b_1 are constants depending on the size of casting module and the material type and their values are given in Table (5) for the as – cast and annealed materials. A similar relationship between elongation and size of casting module was found:

$$EL \% = a_2 - b_2 (v/s) \qquad (4)$$

where a_2 and b_2 are constants depending on the material type and there values are listed in Table (5) which is in good agreement with previous work [11,14].

Table (5): Values of constants for calculation of ultimate tensile strength Elongation and hardness.

Material	Ultimate tensile strength (σu)		Elongation % (El %)		Hardness (H)	
	a1	b1	a2	b2	a3	b3
as-cast	632	112	0.22	0.08	200	39
annealed	578	86	0.11	0.05	167	29

The linear decrease of hardness with increasing size of casting module could be expressed as:

$$H = a_3 - b_3 (v/s) \qquad (5)$$

where a_3 and b_3 are constants depending on the material type and on hardness . Their values are given in Table (5).

The decrease of ultimate tensile strength and elongation with increasing size of casting module may be attributed to the large nodules formed with large casting modules. The density of these nodules (graphite) is much smaller than that of the metallic matrix (iron). They could be considered as internal flaws.

The linear decrease of hardness with size of casting module for both the as–cast and annealed materials is shown in Fig. (4). The as – cast material has higher hardness values than the annealed ones. This is due to the decrease of tensile strength with increasing size of cast module. The hardness of the as – cast specimens ranges from 140 to 170 BHN and that for the annealed material ranges from 123 to 145 BHN, which is in good agreement with that reported by other authors [17].

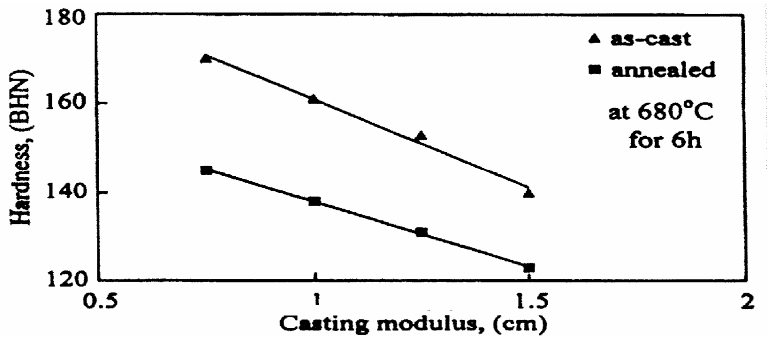

Fig. (4): Variation of Brinell hardness number with casting modulus.

Ultrasonic measurements of the longitudinal velocity and attenuation coefficient for the as – cast and annealed specimens before and after tension are presented in Fig. (5, 6). Appreciable decrease in ultrasonic velocity and slight increase in ultrasonic attenuation are observed. The variation in these ultrasonic parameters before and after tensile may arise due to defects formed during failure through tensile test. These results can give information about the plastic deformation of the in service materials.

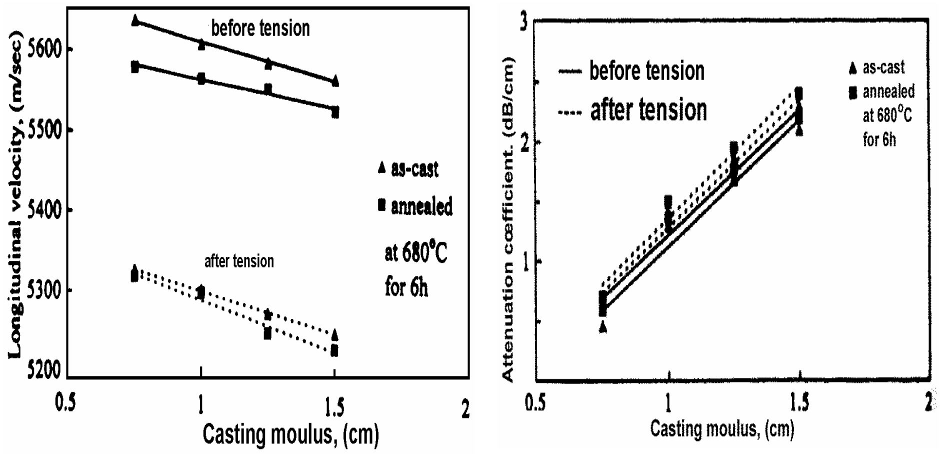

Fig. (5,6): Variation of longitudinal velocity and attenuation coefficient before and after tensile tension.

Figures (7, 8) show the relations of mechanical properties (ultimate tensile strength, 0.2%-offset yield, elongation percentage and hardness) with nodule count for as – cast and annealed materials. It could be seen that as the nodule count increases, mechanical properties increase. Since nodule count is inversely proportional to nodule size of graphite and considering the graphite nodules as discontinuities; so, these discontinuities affect the mechanical properties.

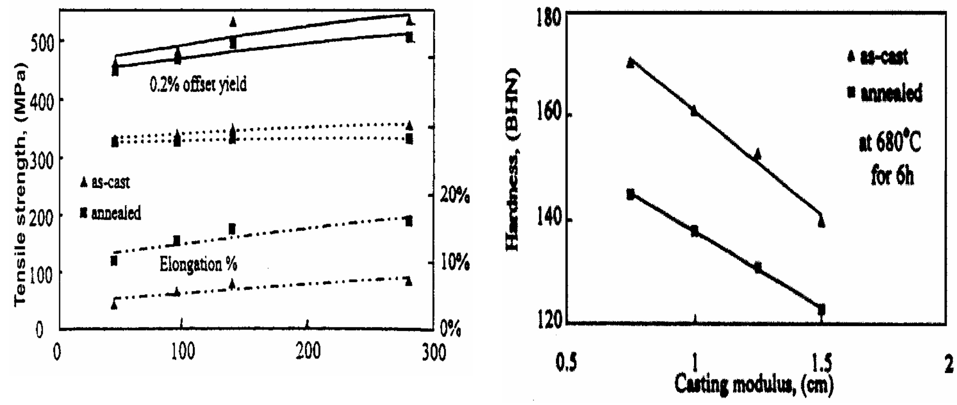

Fig. (7, 8): Variation of mechanical properties with nodule count for as-cast and annealed ductile cast iron.

So, we can conclude that metallurgical examination can help in getting information about mechanical properties of some spare parts.

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