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Effect of Alloying Elements on Mechanical Properties and Production Time of Ductile Iron Castings

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A B S T R A C T

As with grey cast iron, eutectic graphite segregates from the solidified molten iron in the solidification process of ductile iron. However, due to additives added to the molten iron before to casting, graphite develops as spheres rather than the flakes typical of grey iron. Ductile iron samples with varying chemical composition were cast in CO2 sand molds to identify the effect of carbon equivalent on micro structural changes and selected mechanical properties. Carbon equivalent was varied from 3.9 to 4.5 for the experiments also the copper is varied from 0.19 to 0.25% to study the effect of copper on hardness. It was observed that hardness is directly proportional to copper content. At higher Carbon Equivalent The 0.2% Yield Strength and Ductility were higher but Ultimate Tensile Strength was lower. The main differences in ductile iron properties were due to either melt chemistry or molten metal processing variables, of the elements contained in the iron, silicon had the greatest effect on the tensile properties. Any processing variable that led to an increase in ferrite content led to greater ductility and lower strength. Moreover, in order to determine the influence of production time during casting on porosity, data was evaluated statistically, and it was discovered that the amount of time spent in casting has a substantial impact on porosity-related flaws.

Keywords: Ductile iron, Carbon Equivalent, CO_2 sand mold, Cooling Parameters, Production rate optimization.

1. Introduction

Castings are made available in a broad range of sizes, with portions that can be either extremely thin or very thick depending on the application. The varied grades are formed by tailoring the matrix structure around the graphite, which may be done either by casting or by heat treatment after the graphite has been cast. Because there are only modest compositional changes between the standard grades, it is necessary to make modifications in order to promote the ideal matrix microstructures.

Ductile iron is a ternary Fe-C-Si alloy in which the carbon and silicon percentages are generally 3.5 - 3.9 percent and 1.8 - 2.8 percent, respectively, of the total iron content [1]. The selection of the composition is controlled by the size of the casting piece and the mechanical qualities that are desired. However, despite the fact that nodule formation is influenced by C and Si levels, the quality of the alloy and the inclusion of spheroidizing elements are ultimately responsible for nodule formation. However, the two important parameters which are (i) the Si and C contents and (ii) the cooling parameters determine the quantity of graphite incorporated in the metallic phases.

If the nodularity and nodule count are homogeneous and porosity and carbide content is minimum then the mechanical characteristics of Ductile iron solely depends on the matrix and hardness of matrix [2]. The most common matrix in the various grades of ductile iron is ferrite and/or pearlite. The characteristics of ferrite includes low strength and hardness and high ductility and toughness. Whereas, pearlite consists of alternate layers of cementite in matrix of ferrite. Moreover, when compared to ferrite pearlite exhibits higher strength and hardness but it has poor ductility [3]. Ferritic-pearlitic ductile irons are distinguished by the fact that the ratio of ferrite to pearlite in the matrix determines their mechanical characteristics. This ratio is regulated in the as-cast condition by adjusting the composition of the iron while also taking into consideration the cooling rate of the casting throughout the casting process [4]. It can also be managed by the use of a heat treatment, such as annealing, to generate a totally ferritic casting, or by normalizing to increase the amount of pearlite in the casting [5].

The developer of a Ductile Iron components must know the operating temperature range and the influence of temperature on tensile characteristics when estimating design stresses. For both ferritic and pearlitic Ductile Irons, the rise in yield strength with decreasing temperature shows that greater design stresses may be applied at lower temperatures. Since most low-temperature situations also require performance at room temperature, the yield strength at room temperature must be utilized in the design stress calculation [6]. Low temperature applications can only benefit from using a yield strength-related design stress if a quasi-static (low strain rate) test can be used to simulate the applied stress state. As a result, both ferritic and pearlitic grades may suit the design requirements. Selection should be restricted to ferritic grades if the application includes impact loads or if excellent notch toughness is required [7]. It is recommended that annealed ferritic grades be utilized for certain low temperature applications that call for maximal elongation and toughness. Up to 5750 F (3000 C), as indicated previously in this section, static design stresses can be based on room temperature yield strength. Stress rupture data

should be used when deformation may be allowed but time-to-failure is crucial at temperatures over 6000F (3500C) when design stresses should be matched to creep data [8].

2. Methodology

Ten melts of nodular iron were produced using open ladle treatment method for the present study. Charges consisting Cold Rolled Cold Annealed (CRCA), Ductile Iron return (Runner, Risers and Rejected castings) and charcoal were melted in coreless induction furnace. The molten metal was tapped in a preheated mold containing Ferro silicon magnesium alloy of size 15-25mm and Ferro silicon at the bottom covered with steel scrap. The tapping temperature of molten metal was 1450 °C. At this time the sample was taken from the melt for final chemical analysis. The treated iron was poured into CO2 sand molds. The pouring temperature was 1380 °C. Similarly other melts were prepared with varying chemical composition. The chemical compositions of all the raw materials used are obtained from manufacturer's analysis.

Table 1 Details of charging materials

Charge Material	**Ratio (%)**	**Composition**
Cold Rolled Cold Annealed Steel (CRCA)	86.38	C-0.3%, Si-1.0%, Mn-0.3%,S-0.025%,P-0.025%,Cr-0.040%
Charcoal	7.66	Carbon Recovery-70%
Fe-Si-Mg	4.34	Si-45.50%,Mg-6.5%,Ca-1.0%,Al-0.5%
Fe-Si	.15	Si-75%,Ca-2%,Al-3%
Steel Scrap	1.47	C-0.54%,Si-0.18%,Mn-0.60%

Tensile testing specimens were constructed from CO2 mould castings, and their tensile strength, yield strength, and elongation were determined using a Tensometer in accordance with ASTM E9 standards. The samples for microstructural examination were collected from the center of the casting. The surfaces of the samples were ground on SiC paper from 220 to 800 grit and polished with a 1m cloth coated with diamond paste. The samples were etched with a 3 percent concentration of Nital (3 percent conc. Nitric acid and 98 ml Methanol solution). The ASTM 247 microscope standard is used. Hardness of the samples was tested using Brinell hardness test, load is applied on the sample, and the loaded ball (Steel ball of diameter 10mm) is pressed into the test sample for 15 s.

3. Results and Discussions

Under the following section major results obtained from the cast metals are discussed in details.

3.1 Spectrometer Results

Table 2 lists the chemistry of ten melts (M-1 to M-10) evaluated by spectrometer. The carbon equivalent value rises as the carbon and silicon percentages increase in the mixture. Copper and Magnesium are also on the increase. All the melts have a lower manganese content. The amount of phosphorus and Sulphur is dependent on the charge materials used in the.

Table 2 Chemical analysis of Melts.

Melt No.	**C%**	**Si%**	**Cu%**	**Mn%**	**Mg%**	**P%**	**S%**	**C.E.**
M1	3.30	2.02	.192	.38	.060	.019	.006	3.97
M2	3.32	2.04	.198	.36	.057	.018	.007	4.00
M3	3.36	2.08	.201	.35	.058	.017	.008	4.05
M4	3.38	2.12	.213	.34	.059	.018	.006	4.08
M5	3.40	2.14	.223	.32	.051	.018	.008	4.11
M6	3.42	2.18	.231	.31	.038	.020	.005	4.15
M7	3.48	2.21	.238	.30	.050	.028	.008	4.22
M8	3.52	2.24	.242	.29	.039	.031	.004	4.27
M9	3.58	2.26	.248	.28	.047	.025	.002	4.33
M10	3.64	2.30	.251	.28	.048	.023	.009	4.41

3.2 Effect of Carbon Equivalent (CE) on Mechanical Properties

On the basis of the data in Table 3, it is possible to determine the influence of carbon equivalent (CE) on the yield strength, tensile strength, and elongation of various materials. Data on mechanical characteristics were obtained using an Electronic Tensometer and are indicated by Fig. 1, 2 and 3. 0.2 % Yield strength and ductility both increased with a rise in carbon equivalent, however ultimate tensile strength decreased with an increase in carbon equivalent. It is the increase in silicon percentage which causes the increase in yield strength and ductility, as this strengthens the ferrite phase.

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Table 3 Tensile properties of Melts

Melt No.	**C.E. %**	**U.T.S.(MPa)**	**0.2% Y.S.(MPa)**	**Elongation %**
M1	3.97	571	323	13.13
M2	4.00	567	330	13.20
M3	4.05	558	335	13.26
M4	4.08	543	347	13.71
M5	4.11	531	353	14.68
M6	4.15	525	367	15.03
M7	4.22	518	370	15.34
M8	4.27	496	379	15.42
M9	4.33	482	383	16.13
M10	4.41	479	389	16.95

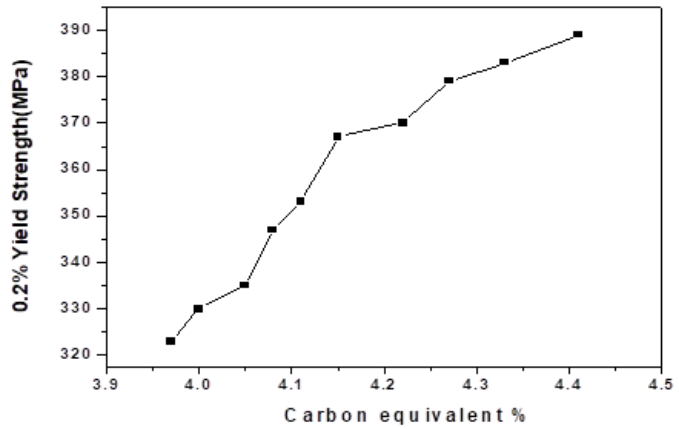

Fig. 1 Variation of 0.2% yield strength with carbon equivalent

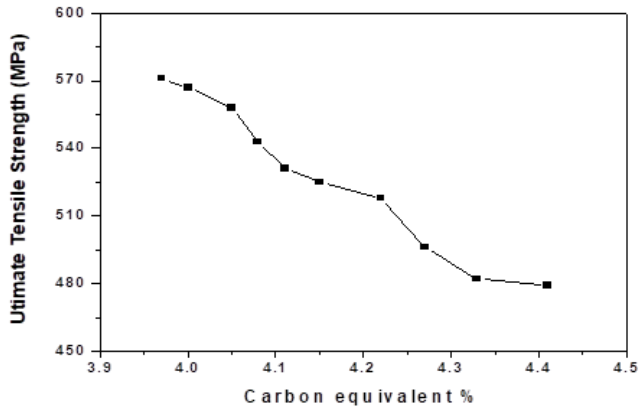

Fig.2 Variation of ultimate tensile strength with carbon equivalent.

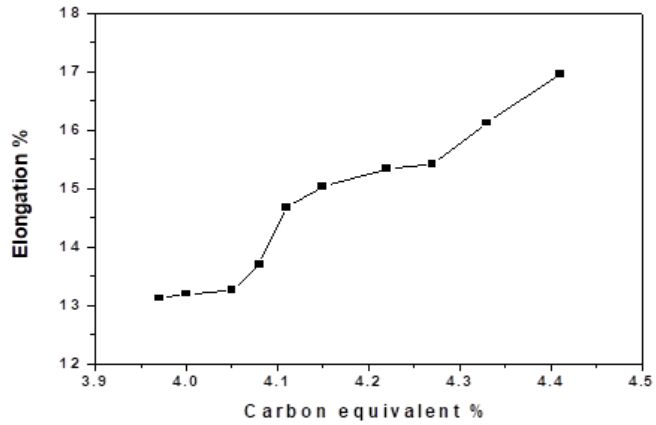

Fig. 3 Variation of elongation with carbon equivalent.

3.3 Effect of Copper

The Copper content of melts number M-1 to M-10 is given in Table 4. An increase in copper content shows increase in hardness.

Table 4 Copper content and hardness values.

Melt No.	Cu %	Hardness (BHN)
M1	.192	165
M2	.198	168
M3	.201	171
M4	.213	173
M5	.223	179
M6	.231	183
M7	.238	189
M8	.242	192
M9	.248	201
M10	.251	203

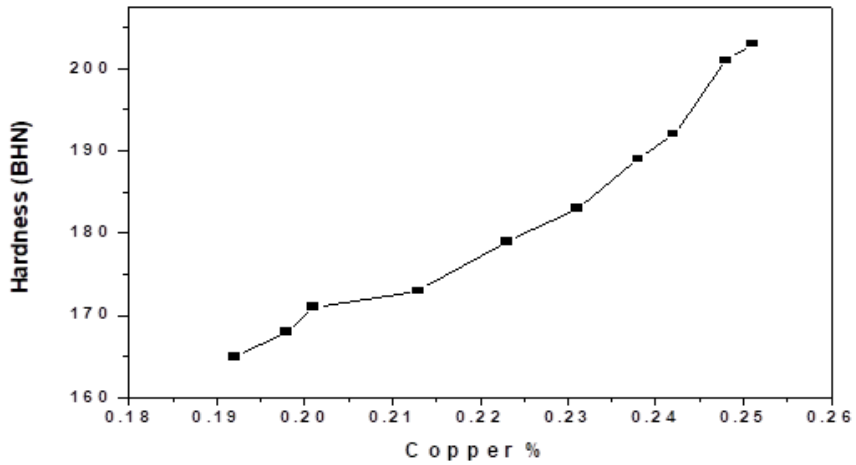

Fig. 4 Variation of hardness with copper content.

3.4 Optimization of Production Time Based on Shrinkage in Casting

The solidification shrinkage of metal occurs during the transformation of the metal from liquid to solid, and the metal experiences further thermal contraction when it cools to room temperature. Because of this, cast components are designed with shrinkage allowances in order to produce components with the appropriate dimensions. Cast steel, for example, will shrink around 14% per foot and result in castings with a rough appearance. Mold designers are familiar with the shrinkage tolerances for various metals, and they take this into consideration when constructing a mould. It has been stated in the literature that raising the flow rate can improve the flowability of a fluid. Researchers discovered a 70% improvement in fluidity by raising the flow rate from 100 grammes per second to 300 grammes per second in a preheated (970 degrees Celsius) mould with a blade-like shape [9]. They reported an additional gain in flowability by increasing the mould preheat temperature to 1150 °C; although, the flow rate employed in the above-mentioned study is modest when compared to the real casting circumstances at foundries. In order to determine the influence of production time during casting on porosity, data was evaluated statistically, and it was discovered that the amount of time spent in casting has a substantial impact on porosity-related flaws. In the Fig. 5.22, the magnitude of porosity is quantified as a function of casting time. From this analysis it is observed that at the casting time for 130 seconds the porosity is optimum, in this connection the casting time may be optimized to obtain minimum porosity. The values obtained for different melts are shown in table 5.8 which shows the casting time and the porosity percentage of melts M1 to M10.

Table 5 Porosity analysis and casting time for different Melts.

Melt No.	**Porosity (Square mm)**	**Casting Time (Sec.)**
M1	2	120
M2	4	125
M3	6	130
M4	6	125
M5	8	140
M6	10	145
M7	9	140
M8	12	145
M9	5	130
M10	16	150

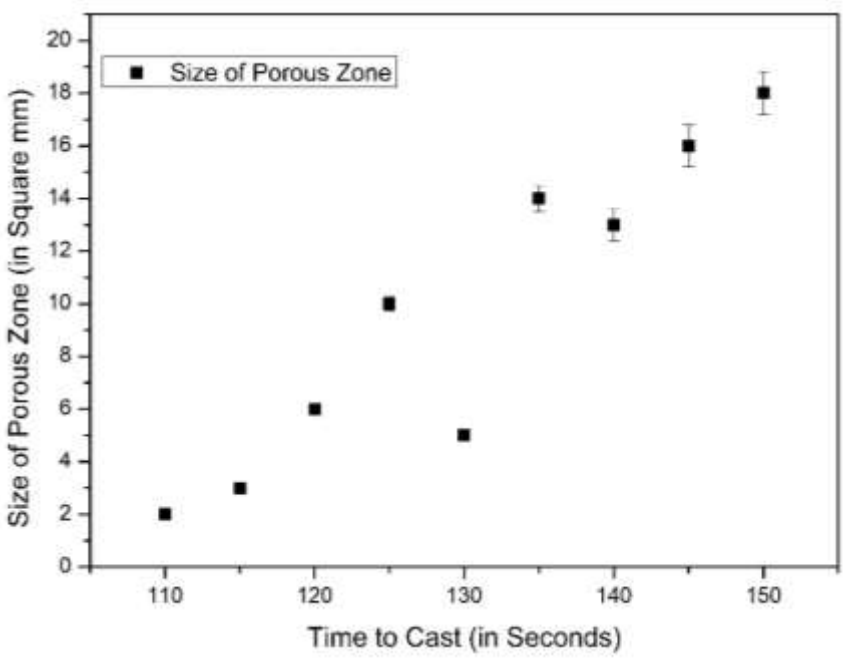

Figure 5 Effect of time to cast on shrinkage porosity.

4. Conclusions

Ductile iron is distinguished by the presence of minute spheroids of graphite in every particle. There are few instances where the graphite in commercially manufactured ductile iron is not in perfect spheres. The shape of the graphite is established when the metal solidifies. The results of the analysis might be used to draw conclusions.

- 0.2 %Yield strength increases with increase in Carbon Equivalent.
- Ductility increases with increase in Carbon Equivalent.
- Silicon has the greatest effect on the tensile properties.
- Copper has the greatest effect on hardness.
- Carbon Equivalent values greater than 4.55 and lower than 3.9 should be avoided because of graphite floatation and excessive shrinkage.
- Magnesium increases the nodularity in the matrix.
- Nodularity is generally above 80% with minimum Magnesium content of .035.

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