

Effect of Microstructure on the Tensile Strength and Impact Toughness of Gray Cast Iron

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Abstract– Ferro-silicon of different percentage (1.00w%, 1.50w%, 2.00w%, 2.50w% and 3.00w%) in the chemical composition, together with constant amount of cast iron scraps and graphite 1.0kg each, were used to produce gray cast irons samples. A mixture of 80% white silica sand, 10% bentonite as binding agent 2% coal dust as carboneous material to enhance permeability and 8% water to activate the clay and to enhance mod-ability and flow-ability of the sand, were used to prepare the mould. The mould were molded in moulding boxes and carbon (iv) oxide was conducted to pass through the mould in order to eliminate moisture and to enhance the hardness of the mould. The charge materials were introduced into a rotary furnace and heated to 1300°C to produce melt. 1.00% of Ferro-silicon was added to the mixture and the furnace was tilted to allow the melt pass through the out let into a preheated ladle and then poured into the prepared mould of the same dimensions (20mm diameter and 25mm long). The melt was repeated for more four times for different percentage of ferrous silicon (1.50w%, 2.00w%, 2.50w% and 3.00w% in the chemical composition. The melt was allowed to cool and solidify for 24 hours in order to obtain solidified cast samples. Polishing machine, emery paper of different grits and etchant solution were used to prepare the surfaces of the cast sample for microstructural examination. The sizes and orientation of the graphite flakes in the ferrite matrix through observation differ from one sample to another as the amount of Ferro-silicon varied. The samples were also subjected to mechanical testing such as tensile strength and impact toughness, using Intron Universal and impact testing machine respectively. The result shown that the tensile strength of the test samples decreases with increase in the percentage of Ferro-silicon, however, the impact toughness increases with increase in the percentage of Ferrous-silicon.

Keywords– Cast Samples, Chemical Composition, Ferro-Silicon, Ferrite Matrix, Graphite Flakes, Impact Toughness and Tensile Strength

I. INTRODUCTION

A) Background

The microstructure of gray cast iron consists of graphite flakes embedded in the steel matrix that is varying proportions of ferrite and pearlite. The properties of gray iron are

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determined by the properties both of the matrix and the amount, sizes, shapes and distribution of graphite inclusions. Graphite flakes have weakling and brittle effects, as graphite is soft, powdery and brittle and can be considered in approximation as voids or cracks, breaking the continuity of ductile matrix. The shape end of each flake acts as internal notch, which under stress tries to propagate the crack in the plastic matrix and give rise to brittle, sooty, gray fracture at low stresses from 150MNm⁻² to 350MNm⁻² depending on the nature of the matrix, the maximum value being when the matrix consists of only fine pearlite. The properties of gray iron are lower when there is larger volume of voids (that is graphite) present, coarser are the flakes, as they break the continuity of matrix to greater extent. The worst mechanical properties are obtained when the graphite flakes form closed network (Zhycasting 2023).

B) Justification

Microscopically, all gray irons contained graphite flakes in a matrix. How much graphite is present the length of the flakes and how they are distributed in the matrix directly influences the mechanical properties. The basic strength and hardness are provided by the matrix in which the graphite occurs. The matrix can be entirely ferrite for maximum machinability, but the iron will have reduced strength and wear resistance. The matrix can be entirely pearlite characterized by high strength and hardness. This research is therefore focused on the production of gray cast irons with matrix microstructure of both ferrite and pearlite in order to obtain intermediate strength and impact toughness for engineering applications. (Thomas 2025)

C) Statement of the problem

Fine graphite flake inclusions in pearlite matrix of gray irons have higher hardness and strength, it is brittle in nature, which makes it limited in engineering applications. This implied its susceptibility to impact fracture at low energy absorption. The research is therefore focused on the means of obtaining moderate graphite flakes enlargement that will give better mechanical properties for iron founder and design engineers (Baharudin, Ayob, and Abbdul Rahim 2022).

D) Aim of the research

The aim of the research is to investigate the effect of microstructure on the tensile strength and impact of toughness of gray cast iron samples.

E) Specific Objective of the Research

The specific objectives are to:

- produce cast samples of gray cast iron of different chemical composition of Ferro-silicon,
- determine the mechanical properties (tensile strength and impact toughness) and,
- determine the microstructural properties of the produced samples in (i).

II. MATERIALS AND METHODS

A) Equipment and Methods

Pattern Making; A wooden material obtained from hard wood was machined with woodworking lathe machine model MCF3020 that will take the replica of the sample shape. Each of the patterns was made 300mm long and 25mm diameter. The sizes of the patterns were also made 0.8% oversize than the specific dimension to compensate for metal contraction during solidification. The down sprue of 50mm, tapered to diameter 40mm and 30mm long was also made.

B) Mould Preparation

The 78% silica sand was mixed with 20% sodium silicate as binding agent to give the moulding sand strength and plasticity and 2% of water was added to activate and enhance moldability and flow-ability of the mixture. It was molded in moulding boxes of 500mm by 350mm by 250mm to produce mould for the cast irons melts. Subsequently, carbon iv oxide was conducted to pass through the molds to eliminate moisture and to enhance hardness and strength.

Melting and Casting; the charge materials (iron scraps and graphite) were charged into a rotary furnace of 1000kg capacity and heated to 1300°C to produce melt. The furnace was tilted to allow the melt pass through the outlet then into a preheated ladle from where it was poured into the prepared molds where it was allowed to cool and solidify. The solidified castings were obtained 24 hours after cooling.

Cleaning and Machining; the sand that adhered to the castings were removed using stainless wire brush and fettling was done with the use of cutting wheel machine to remove gates and risers. Subsequently Don Jim Hydraulic power hack saw was used to cut the cast samples and universal lathe machine Type 80 was used to machine the cast samples into standard test samples for strength, impact and microstructural examination.

C) Experimental Setup

Tensile Strength Testing

Intron universal testing machine of model 3369 at speed of 0.02ms^{-1} was used to carry out tensile tests. The samples were machined with Universal Lathe machine Type C80 to produce standard test sample shown in Fig. 1. The test was repeated three times the same sample of chemical composition (percentage of ferrous silicon), average values were recorded and shown in Table I.

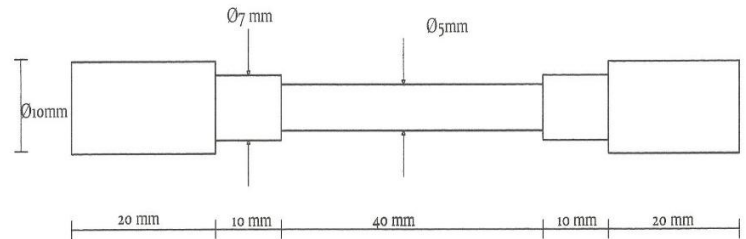


Fig. 1: A Tensile Test Sample

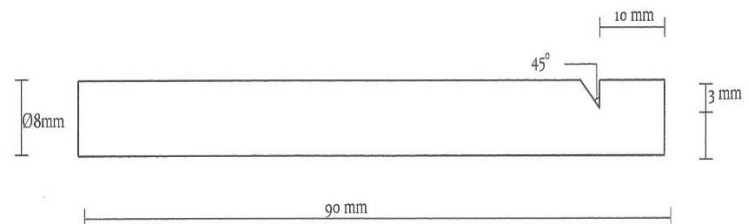


Fig. 2: Impact Testing Sample

Impact Testing

The test sample for the impact toughness was machined to 90mm long and 8mm thickness shown in Fig. 2. Notches were made to depths of 3mm at 45° at 10mm from one end of each of the test samples. Avery Denison Impact testing machine was used to measure the impact toughness. The test was repeated three times for the same sample of chemical composition (ferrous silicon), average values of the energy absorbed in fracturing the test samples were measured and shown in Table II.

Metallographic Examination

The test samples for metallographic examination were mounted on plastic materials for convenience for handling. SBT MODEL 900 Mastaserv 2000 Polisher was used with emery paper grits 60, 120, 240, 320, 400 and 800 to produce flat stable surface of the test samples. 2% nitric acid and 98% alcohol were used to prepare etchant solution that was applied on the sample surface for 10 seconds. Optical metallurgical microscope model AXIA 1m was used to carry out microstructural analysis and the microstructures obtained were carefully examined and uploaded (Boracz, Szalai, and Lajos 2026).

D) Results

Mechanical analysis

The results of the tensile and impact tests are shown on Table I and Table II respectively.

Table I: Tensile Test Result

Test sample	Ferro-silicon (%w)	TESTS (MPa)			AVERAGE VALUE (MPa)
		TEST 1	TEST 2	TEST 3	
A	1.00	280.30	279.40	278.20	279.30
B	1.50	261.10	259.50	254.30	258.30
C	2.00	268.00	263.10	266.00	265.70
D	2.50	235.30	233.20	235.00	234.50
E	3.00	224.30	223.80	221.40	223.20

Table II: Impact of Toughness Test Result

Test sample	Ferro-silicon (%w)	TESTS (J/mm ²)			AVERAGE VALUE (J/mm ²)
		TEST 1	TEST 2	TEST 3	
A	1.00	5.15	5.17	5.19	5.17
B	1.50	5.26	5.22	5.25	5.24
C	2.00	5.19	5.21	5.20	5.20
D	2.50	5.30	5.32	5.28	5.30
E	3.00	5.25	5.35	5.39	5.37

The various bar charts obtained from tensile strength test and impact toughness tests are shown in Fig. 3 and Fig. 4 respectively.

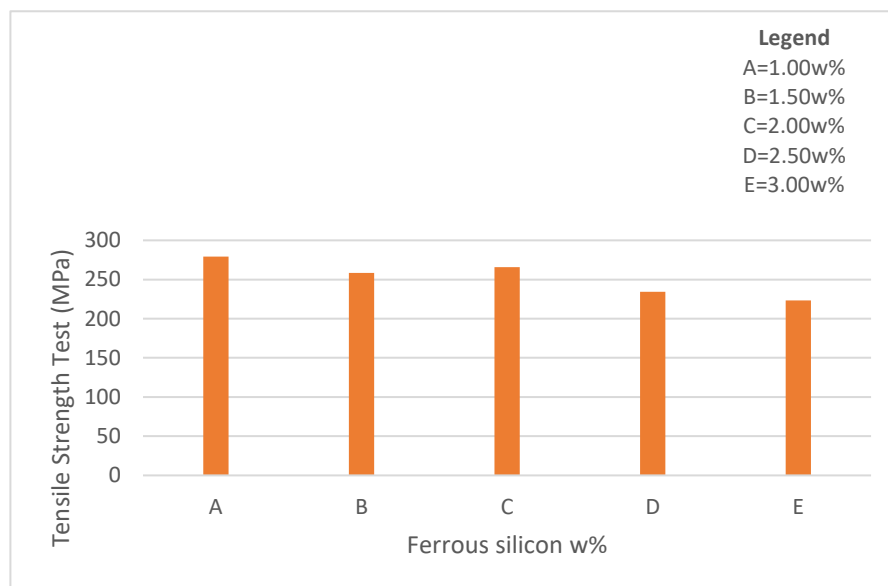


Fig. 3: Variation of Tensile Strength (MPa) with Ferrosilicon w% (chemical composition)

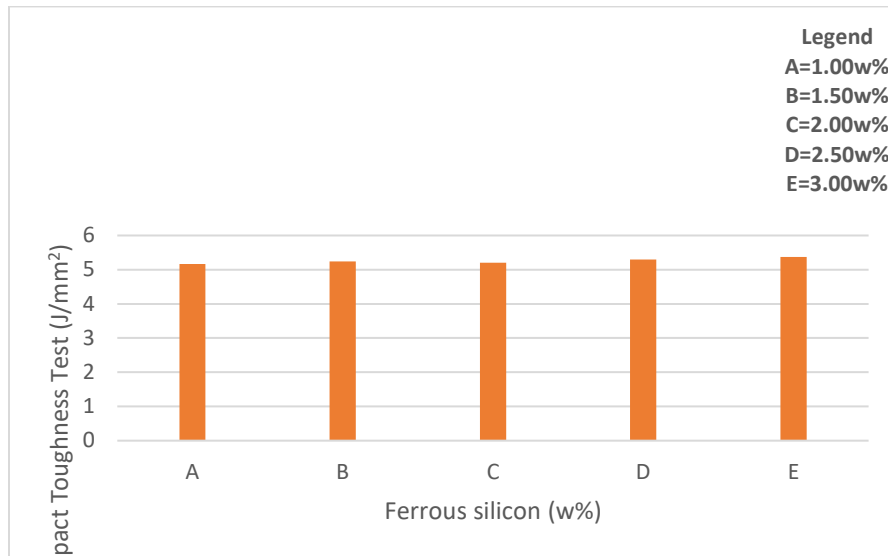


Fig. 4: Variation of Impact Toughness (J/mm²) with Ferrosilicon w% (chemical composition) Plates

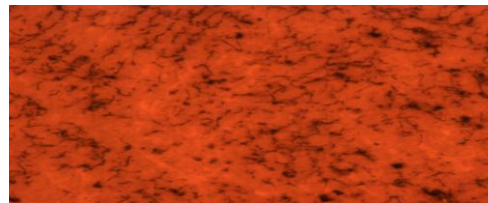


Plate A: Microstructure of Sand Cast Grey Iron of 1.0%wt Ferrous-silicon showing Fine Graphite Flake in Pearlite Matrix Type B flakes(x100). Etching time 10 seconds.

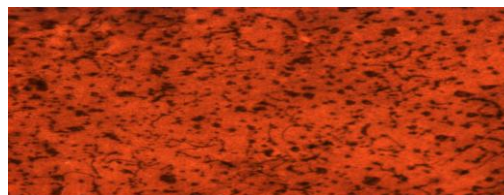


Plate B: Microstructure of Sand Cast Grey Iron of 1.5%wt Ferrous-silicon Graphite Flakes inclusion in Ferrite Matrix Type E flakes(x100).Etching time 10 seconds.

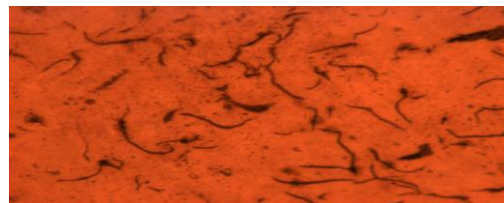


Plate C: Microstructure of Sand Cast Grey Iron of 2.0%wt Ferrous-silicon showing Graphite Flakes breaking the continuity of the Ferrite Matrix Type A flakes (x100).Etching time 10 seconds.

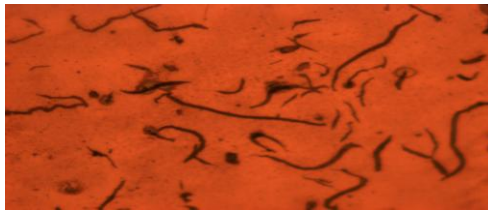


Plate D: Microstructure of sand cast grey iron of 2.5%wt Ferrous-silicon showing graphite flakes extension in pearlite matrix Type C flakes(x100).Etching time 10 seconds.

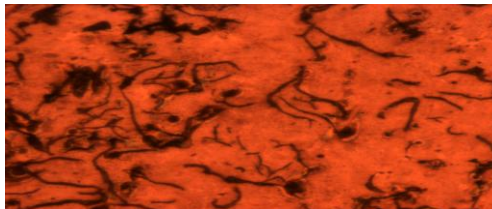


Plate E: Microstructure of Sand Cast Grey Iron of 3.0%wt Ferrous-silicon showing Graphite Flakes Network in Ferrite-Pearlite Matrix Type C flakes(x100).Etching time 10 seconds.

III. DISCUSSIONS

A) Mechanical analysis

As the amount of ferrous silicon in the chemical composition varies to produce test samples (A, B, C, D and E), the mechanical properties such as the tensile strength and impact toughness varied respectively. They are carefully analyzed with respect of the Tables and figures.

From Table I and Table II, 1.00wt of Ferro-silicon was used to produce sample A, when subjected to tensile and impact testing resulted in 279.30MPa and 5.17 J/mm² respectively. As the amount of Ferro-silicon increases (1.50, 2.00, 2.50, and 3.00)wt in chemical composition to produce samples (B, C, D and E), the tensile strength tests increases (258.60, 265.40, 234.80 and 225.50)MPa and impact tests and (5.24, 5.20, 5.29, 5.35)J/mm² respectively.

Fig. 1: the tensile strength of test sample A was observed to be 279.30MPa and that of test sample B was 258.60MPa. There was slight decrease in the tensile strength when the amount of ferrous silicon in the chemical composition increased from 1.0% to 1.5%. Further increase in ferrous silicon to produce sample C (2.0%) resulted in drastic increase in tensile strength 265.40MPa. increase ferrous silicon by 0.5% to produce sample D (2.5%) and E (3.0) resulted in 234.80MPa and 225.50MPa in the strength of the test samples respectively. The figure shows that as the amount of ferrous silicon increases, the tensile strength test decreases.

Fig. 2: The impact toughness, the amount of energy absorbed to fracture test sample A (1.0%) was 5.17J/mm and B (1.5%) was 5.24J/mm. There was remarkable increase in impact toughness. When amount of ferrous silicon was increased by 0.5% to produce 2.0% sample C, the impact toughness was 5.20J/mm. However, there was gradual improvement in impact toughness (5.29J/mm and 5.35J/mm) to fracture test sample D (2.5%) and E (3.0%) respectively.

B) Microstructural analysis

An optical metallurgical microscope was used to examine the microstructures of the produced samples. The microstructure revealed different orientation, sizes and dispersion of graphite flakes embedded in the pearlite and ferrite matrix. These are also attributed to the alteration in the mechanical properties of the produced cast iron samples.

Plate A: The microstructure revealed uniform dispersion of graphite flakes embedded in pearlite matrix. The flakes were relatively fine with no inter flake spacing. The formation of pearlite matrix was due to fast cooling rate, resulting in high strength and low impact toughness. This structure may have limitations in engineering applications due to the brittle nature of the cast iron.

Plate B: The microstructure revealed pearlite and ferrite matrix due to increase in ferrous silicon in the chemical composition. The flakes were uniformly distributed over the matrix but less finely compared to microstructures in plate A. the formation of ferrite matrix resulted in drastic reduction in tensile strength and slight increase in impact toughness.

Plate C: When the amount of ferrous silicon was increased to 2.0% for sample C production, the microstructure shown notable increase in the length of the flakes, across the ferrite matrix. This resulted to an increase in the strength of the cast iron sample and a corresponding decrease in the impact toughness.

Plate D: The microstructure of sample D (2.5%) shows remarkable observation. The sizes of the flakes became enlarged and thicker and were superimposed in random orientation. The enlargement of the flakes reduced the pearlite matrix. This morphology was due to further increase in ferrous silicon in the composition, resulting in a high decrease in the tensile strength of the cast sample

Plate E: The amount of ferrous silicon in the chemical composition was 3.0% higher among others to produce sample

E. the microstructure shown close network of graphite flakes in pearlite-ferrite matrix. The sample also revealed thick black spots in the microstructure, indicating coarse nature of the flakes. This resulted in very low tensile strength, which may be detrimental in engineering applications. This morphology further revealed significant increase in impact toughness as the ferrous silicon percentage increases in the chemical composition.

IV. CONCLUSIONS

From the experiment, it was observed that the tensile strength and impact toughness properties were influenced by the size and orientation of the graphite flake inclusions. Therefore, the following conclusions were drawn:

- i. Increase in the amount of ferro-silicon enlarges the sizes of the flakes distributed in ferritic matrix
- ii. Excessive amount in ferro-silicon results network formation of flakes, breaking the continuity of ferrite matrix
- iii. Enlargement of flakes in the matrix reduces the tensile strength properties of gray cast irons but shows slight increase in impact toughness
- iv. Coarse flakes results to worst tensile strength properties

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