ACTA TECHNICA CORVINIENSIS
– Bulletin of Engineering
Tome IX [2016], Fascicule 4 [October – December]
ISSN: 2067 – 3809

[1.]Akinlabi OYETUNJI, [2.]Henry Kayode TALABI

EFFECTS OF HEAT TREATMENT PROCESS ON MECHANICAL AND MICROSTRUCTURAL PROPERTIES OF GRAY CAST IRON

[1-2.]Department of Metallurgical and Materials Engineering, School of Engineering,
Federal University of Technology, Akure, Ondo State, NIGERIA

Abstract: This study investigated the effects of heat treatment process on mechanical and microstructural properties of gray cast iron. The charged materials used were graphite, cast iron scraps and ferrosilicon which were subjected to chemical analysis using spectrometric analyzer, the charge calculation to determine the amount needed to be charged into the furnace was properly worked out and charged into the rotary furnace from which the as-cast was obtained. The as-cast was subjected to various degree of normalized heat treatment at different operating temperatures of 885°C, 893°C, 901°C, 909°C, 917°C and after which the mechanical properties of the gray cast iron produced were assessed by hardness, wear, tensile strength and microstructure tests. It was observed that hardness properties continued to increase as operating temperature increases and graphite flakes break the continuity of ferrite matrix results into an increase in hardness and tensile strength of the gray cast iron.
Keywords: Gray cast iron, Normalized, Hardness, Tensile strength, Wear, Temperature

INTRODUCTION

Gray iron is one of the oldest cast ferrous products. Gray cast iron is a very unique engineering material. It is known to be the most versatile of all foundry metals. This makes them particularly suitable for the manufacture of engineering components [1]. Possessing quite high carbon content which is responsible for the ease of melting, casting of this metal in the foundry and for ease of machining in subsequent manufacturing,

Gray iron offers a unique versatility at lower cost that can be obtained through microstructure control [2-3]. In spite of competition from newer materials and their energetic promotion, gray iron is still used for those applications where its properties have proved it to be the most suitable material available. Next to wrought steel, gray iron is the most widely used metallic material for engineering purposes.

The automobile engine is the single most important without it, the car simply will not move. Hence it is important that the engine block is built to withstand the high temperatures and pressures that are put into it and it is equally important that the engine block is built to last. Over the years, materials used for making engine blocks have changed and materials sciences have matured enough to find the best possible materials to build engine blocks. Common materials used for engine blocks include Grey Cast Iron, aluminum and compacted graphite iron (CGI) [4].

There are several reasons for its popularity and widespread use. It has a number of desirable characteristics not possessed by any other metal and yet is among the cheapest of ferrous materials available to the Engineer. Gray iron castings are readily available in nearly all industrial areas and can be produced in foundries representing comparatively modest investments. Gray iron is one of the most easily cast of all metals in the foundry, It has the lowest pouring temperature out of the ferrous metals, which is reflected in its high fluidity and its ability to be cast into intricate shapes. As a result of a peculiarity during final stages of solidification, it has very low and, in some cases, no liquid to solid shrinkage this enables sound castings to be achievable. For the majority of applications, gray iron is used in its as-cast condition, thus simplifying production.

Gray iron has excellent machining qualities producing easily disposed off chips and yielding a surface with excellent wear characteristics. The resistance of gray iron to scoring and galling with proper matrix and graphite structure is universally recognized. Gray iron castings can be produced by virtually any well-known foundry process. Surprisingly enough, in spite of gray iron being an old material and widely used in engineering construction, the metallurgy of the material has not been clearly understood until recent times. Mechanical properties of gray iron are not only determined by composition but also greatly influenced by foundry practice, particularly cooling rate in the casting.

All of the carbon in gray iron, other than that combined with iron to form pearlite in the matrix, is present as graphite in the form of flakes of varying size and shape. It is the presence of these flakes formed on solidification which characterize gray iron, the presence of these flakes also imparts most of the desirable properties to gray iron. Its versatility arises from the wide range of physical properties which are possible due to the addition of alloying elements and various heat treatment procedures [5]. This research therefore is aimed to determine the effects of heat treatment process on mechanical and microstructural properties of gray cast iron.

MATERIALS AND METHOD

Materials

White silica sand (SiO_2) obtained from Igbokoda, its geographical coordinates are 6° 21’ 0” North, 4° 48’ 0” East of Ondo State, Nigeria, bentonite, coal dust and small proportion of water were used to prepare the mould. The charged materials include; graphite, cast iron scraps, and ferro-silicon. The ferro-silicon and graphite were obtained from Engineering Materials Development Institute (EMDI), Akure, Ondo State, Nigeria.

Mould Preparation

A woodworking lathe machine model MCF3020 was used to machine the wooden pattern materials obtained from hard wood that produced the pattern, sprue and risers with adequate taper. The patterns were dimensioned 300 mm long and of different diameters; 15 mm, 20 mm, 30 mm, 35 mm. The size of the patterns was made 2% oversize than the specified dimension to compensate metal contraction during solidification. The down sprue of diameter 50 mm, was tapered to diameter 40 mm and 30 mm long was also made [6].

The mould is prepared with green sand being the main material used which comprises of the mixture of bentonite, recycled silica sand and water. The green sand has good permeability, good grain size, accurate moisture content and with a very good refractoriness which can withstand heat at very high temperature. Bentonite is added to the green sand to increase its bonding strength. Suitable moulding boxes is first selected, large enough to accommodate the pattern of its varying sizes and then rammed slowly but with good force. Facing sand was mixed into the drag and the content was well rammed. The drag was turned upside down on the mould board, the pattern as well as its accessories were placed on the board inside the flask in such a position that space is left for gate cutting. The excess sand will be cut off to bring it in line with the edge of the cope, a parting sand was properly applied for the easy removal of the mould from the pattern.

The gating system was properly designed for smooth channeling of the molten metal into the mould cavities through the sprue, runner, in-gates and riser that were perfectly placed in position [7]. The cope was placed over the drag and top parts of the pattern assembled in position.

Melting, Casting and Cleaning Operation

Rotary furnace of 100 Kg capacity was used to melt the cast iron scraps, graphite and ferrosilicon were charged and heated to a temperature of 1300°C. The rotary furnace was tilted to allow the melt flow out through the ladle and then poured into the already prepared mould of various diameters where it was allowed to cool freely in air then solidify. The solidified castings were subsequently shaken out of the mould 24 hours later after cooling [8].

Stainless wire brush was used to remove sand that adhered to the castings and fettling was done by abrasive wheel-cutting machine to remove gates and risers. Afterwards Dong Jin heavy hydraulic power hacksaw was used to cut the samples and universal lathe machine type C80 was used to machine the cast samples into standard test samples for mechanical and microstructural analysis [8].

Determination of Chemical Composition

The chemical composition of the as-cast samples of the gray cast iron was determined using spectrometric analyzer

Chemical Equivalent Value

The carbon equivalent (CE) is a simplified method of evaluating the effect of composition on cast iron. One of the most common equations used is

$$CE = Tc + \frac{\%Si + \%P}{3} \quad (1)$$

where T_C is the total carbon, and %Si and %P are the silicon and phosphorus contents [9]

The value is important because it can be compared with the eutectic composition (4.3%) to indicate whether the cast iron will behave as a hypoeutectic iron or hypereutectic iron during solidification [9]

MECHANICAL TEST

Hardness Measurement

LECO Micro hardness tester LM700AT at E.M.D.I, Akure was used to determine the hardness of the samples. The surfaces of the test samples were dimensioned to 10mm length and 8mm thickness and were properly grounded to give flat and stable surfaces. Test load 490.3 MN and dwell time of 10 seconds was applied on the test samples before taking the readings [10].

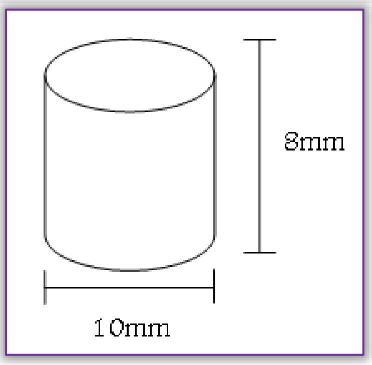

Figure 1. Hardness Test Sample

Tensile Strength Test

The samples were machined with universal Lathe Machine TYPE C80 to produce standard test samples [11]. Instron universal tensile testing machine of model 3369 at the speed of 0.02m/s was used to carry out the tensile test by subjecting it to 10KN load.

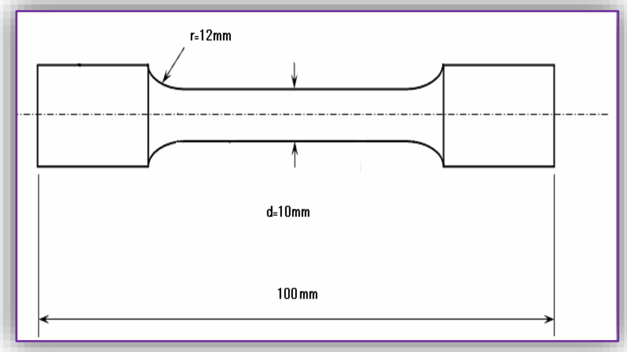

Figure 2. Tensile Test sample

Wear resistance

The wear resistance was carried out with Taber Abrasers. Model ISE-AO16. Taber tests involve mounting a flat round specimen approximately 100 mm² to a turntable platform that rotates on a vertical axis at a fixed speed. The volume of the loss material is taken with the force applied, velocity of the revolution and the time taken for the wear is recorded.

$$W = K \times F \times V \times T \quad (1)$$

whereW is wear volume (mm³); F is force (N); K is wear factor (mm³/Nm) 10^{-8}; V is velocity (m/s)and T is time (s)

Heat Treatment

The 25 as- cast samples were subjected to heat treatment by heating the samples in a muffle furnace after which they could be examined mechanically by hardness, wear and tensile tests and microscopically.

Normalizing temperatures, which were used for the samples were 885°C, 893°C, 901°C, 909°C and 917°C respectively and cooled in air to room temperature [12].

Metallographic Test

The specimens are prepared for metallographic test, using the following procedures. The as-cast and heat treatment already cut with power hack saw into specimens were subjected to grinding process. The microstructural examination was performed using Optical Metallurgical Microscope model AXIA. The specimen for the optical microscopy were polished using series of emery paper of grit sizes ranging from 60-1200, while fine polishing was performed using polycrystalline diamond suspension of particle sizes ranging from 10 - 0.5μ. The specimens were etched using 2% nitric to 98% alcohol (Nital).

RESULTS AND DISCUSSIONS

All the mechanical and micro structural analysis were carried out at room temperature and the following results were obtained. The spark analysis of the produced grey cast iron were carried out with the aid of spectrometer analyzer and the results are shown in Table 1.

Table 1: Chemical composition of the produced grey cast iron

%C	%Si	%S	%C	%P	%Mn
2.92	2.75	0.06	0.18	0.17	0.11
%Cr	%Mo	%V	%Cu	%W	%Ti
0.1576	0.0206	0.0113	0.1517	0.00027	0.0082
%Sn	%Co	%Al	%Nb	%Mg	%Fe
0.0215	0.0085	0.0031	0.00001	0.0026	93.4092

Effects of Normalizing on the Mechanical Properties

There were variations in the hardness property of the various samples as a result of different normalizing temperature. Sample with normalizing temperature 885°C had hardness value of 54.6 HRC, sample with normalizing temperature 901°C had hardness value of 49.5 HRC, sample with normalizing temperature 909°C had hardness value of 37.6 HRC and sample with normalizing temperature 917°C had hardness value of 34.7 HRC.

From the figure 8, as the normalizing temperature increases, the hardness values decreases, the microhardness value of the cast iron decreases as a result of decrease in pearlite. Also the lower the normalizing temperature, the faster the cooling rate which aid the refinement of the grain structure. When cast iron cooled at a faster rate, the resulting pearlite is fine [12].

There were also variation in the tensile strength values, at normalizing temperature 885°C, the tensile strength value was 1952 N/mm² and at normalizing temperature 893°C, the tensile strength value was 1644 N/mm², it was then observed from figure 9 that as the normalizing temperature increases, the tensile strength value decreases.

It was observed from figure 10, that as the normalizing temperature increases, the wear rate increases.

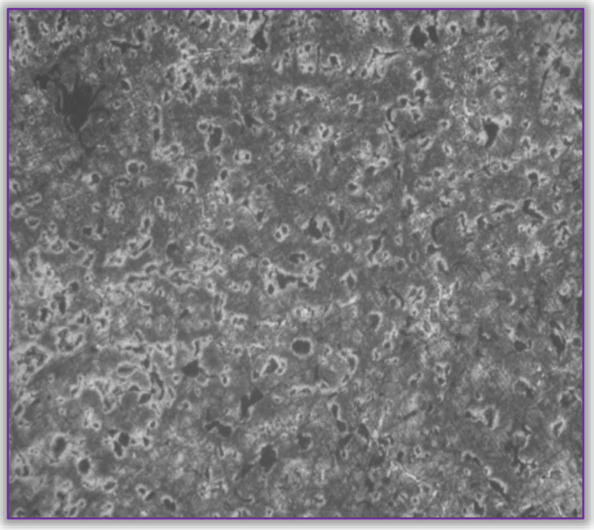

Figure 3: Microstructure of Normalized sample at 885°C

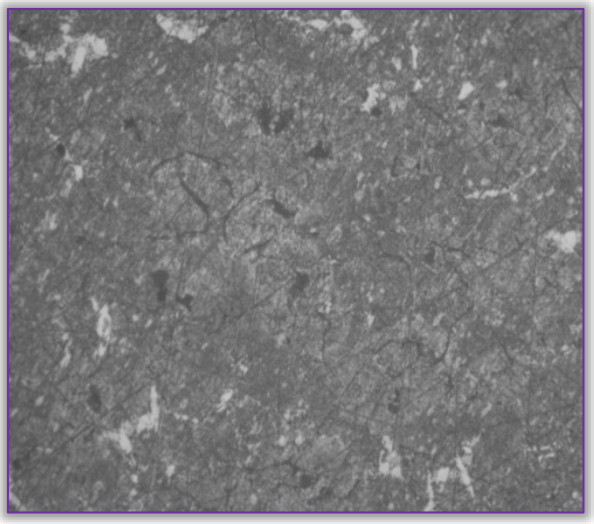

Figure 4: Microstructure of Normalized sample at 893°C

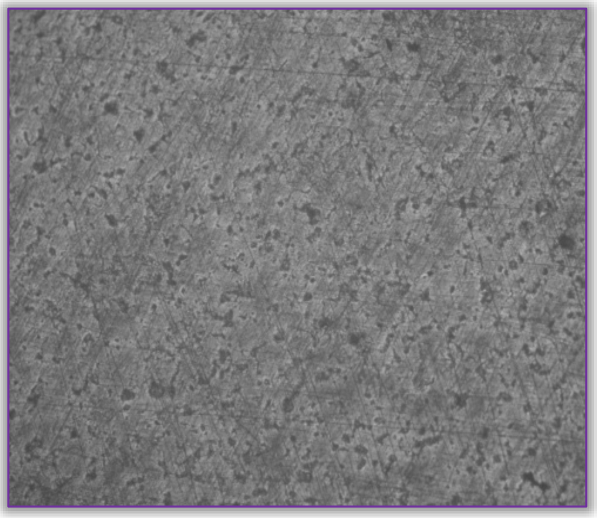

Figure 5: Microstructure of Normalized sample at 901°C

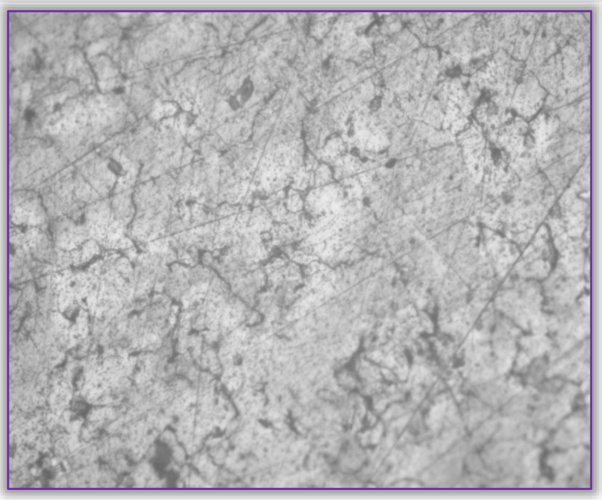

Figure 6: Microstructure of Normalized sample at 909°C

Figure 7: Microstructure of Normalized sample at 917°C

Microstructure

Usingthemetallurgicalmicroscope,the micrographs of each sample were shown in such a way that the graphite flakes morphologies could be easily analyzed. The figures 3-7 show an important view of the distribution of the graphite flakes and also the effects of the different normalizing heat treatment temperatures on the mechanical properties of gray cast iron.

Effects of Normalizing on the Microstructure

Microstructure of the normalized specimen with tiny flakes graphite of type A which are uniformly and completely distributed in cementite-rich pearlitic matrix as shown in figure 3, may have resulted from air cooling. Coarser carbide were observed in the normalized samples because of the higher normalizing temperatures [13].

However the area adjacent to the graphite flake experienced carbon decomposition and ferrite will result around the flakes. It is clear from the microstructures in figures 3-7, that the normalizing process will give more pearlite which is stronger than ferrite because of cementite layers inhibited in it [13].

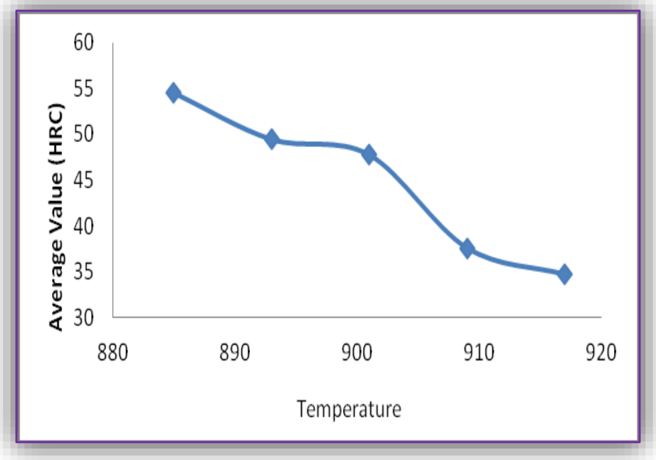

Figure 8: Variation of hardness with normalizing temperature

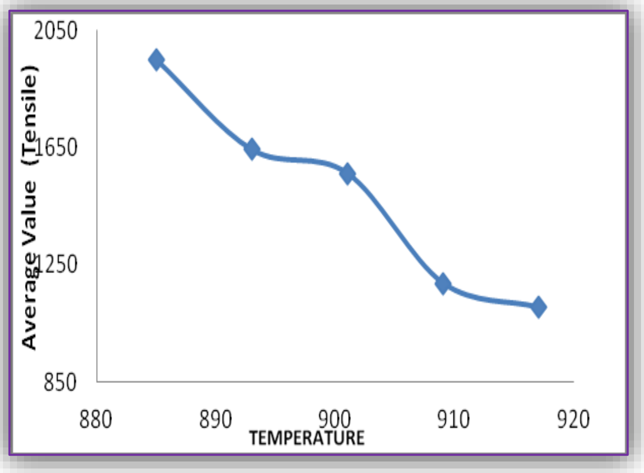

Figure 9: Variation of tensile with normalizing temperature

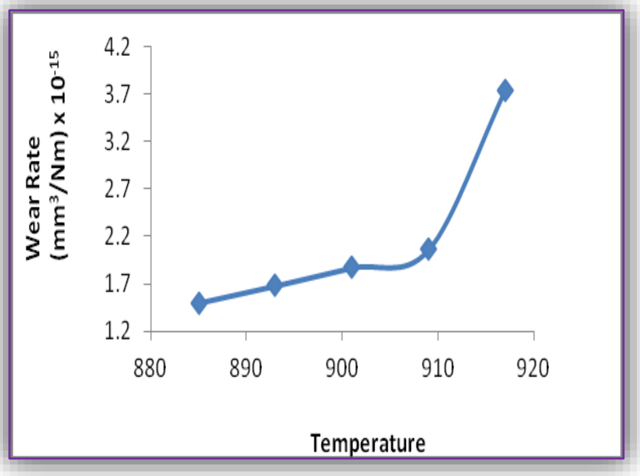

Figure 10: Variation of wear resistance with normalizing temperature

CONCLUSIONS

From the results of this work, normalizing heat treatment process was found to produce noticeable effects on the material's micro structural characteristics and mechanical properties. Hence the following conclusions were drawn;

i. The mechanical properties such as hardness and tensile showed appreciable decrease corresponding with increased normalizing temperatures of the grey cast iron.
ii. Tensile properties of the grey cast iron also increased with decrease in the heat treatment temperatures.
iii. Normalized samples showed higher hardness properties which continued to increase as operating the temperatures increased.
iv. Graphite flakes breaking the continuity of ferrite matrix results into an increase in hardness and tensile strength of the grey cast iron.

References

[1.] Bocus S. and Zaldarys G.: "Production of Ductile Iron Casting with Different Matrix Structure", Materials Science (Medziagotyra) 11(4), 307-310, 2010.
[2.] Zhou W., Zhu H., Zhang D, Zheng H., Hua Q. and Zhai Q. Niobium Alloying Effect in High Carbon Equivalent Grey Cast iron China Foundry, 8(1), 36-40, 2012.
[3.] Agbu S. "The Iron and Steel industry and Nigeria's Industrialization" Exploring Cooperation with Japan, 418, 1-146, 2007.
[4.] Whitney B., Sessler, and Peter C.: Ultimate American V-8 Engine Data Book. MBI Publishing, ISBN 978-0-7603-3681-6, 2010.
[5.] Jezerki J. and Bartocha D. Properties of Cast Iron Modifying with Inoculants, Journal of Achieving in Materials and Manufacturing Engineering, 22 (1), 25-28, 2007.
[6.] Ibhadode, A. O. Introduction to Manufacturing Technology, Ambik Press: Nig, 2001.
[7.] Talabi H.K., Adewuyi B.O., Oyetunji A. and Daramola O.O. Effects of Selected Casting Methods on Mechanical Behaviour of Al-Mg-Si Alloy- Leonardo Electronic Journal of Practices and Technology (LEJPT) 25, 109-117, 2014.
[8.] Oyetunji, A. Effect of Foundary Cast-size Distribution on the Mechanical and Structural properties of Grey Cast Iron. Nigerian Journal of Engineering Research, 1 (3), 1-18, 2010.
[9.] Ajayi J.A. and Adeleke O.A. Failure Analysis of Railway Brake Blocks, Engineering Failure Analysis, Vol. 4,(3), 205-213, 1997.
[10.] Oaikhinan, E.P. Introduction to Materials testing part 1, 45-47, 2005.
[11.] Pavlina, E. J., and Van-Tyne, C. J. Correlation of Yield Strength, Journal of Materials

Engineering and performance, 17(6) 123-126, 2008.
[12.] Krause, D. E. Gray iron-A Unique Engineering Material. PWS publishing, Boston, 3-28, 1969.
[13.] Atanda, P., Fatudimu, A., Oluwole, O. Sensitization Study of Normalized 316L Stainless Steel,Journal of Minerals & Materials Characterization & Engineering, 9,(1) 13-23, 2010.

ACTA Technica CORVINIENSIS
BULLETIN OF ENGINEERING
ISSN:2067-3809