EXPLORE IJET International Journal of Engineering & Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-3444

International Journal of Engineering and Technology Volume 3 No. 9, September, 2013

Influence of Heat Treatment on the Microstructure and Hardness Property of Inoculated Grey Cast Iron

Saliu Ojo Seidu[1], Bolarinwa Johnson Kutelu[2]

[1]Department of Metallurgical and Materials Engineering, Federal University of Technology, Akure, Nigeria
[2]Department of Mineral Resources Engineering, Federal Polytechnic Ado-Ekiti, Nigeria

ABSTRACT

Influence of heat treatments on the hardness property of inoculated grey cast iron was investigated in this study. To this end, some inoculated grey cast iron specimens with 0.2% ferrosilicon was produced from an automobile (as-cast) sample by casting, and the chemical compositions of both the automobile and inoculated specimen were determined. Thereafter, the specimens were subjected to annealing, normalising and tempering heat treatment processes. Microstructural characteristics and hardness property were investigated using standard procedures and equipment. Results of the findings revealed that the grain sizes and phases of the inoculated and non-inoculated specimens were influence by all the heat treatment processes considered. In addition, the average Rockwell hardness (HRA) values of the annealed, normalised and tempered specimens in inoculated and non inoculated conditions are in the respective order of 41.9 and 52.8; 43.1 and 54.6; 40.7 and 50.9, and when compared with the corresponding values of 45.9 and 58.9 for the as-cast sample, the hardness property of the inoculated and non- inoculated heat treated specimens are relatively lower.

Keywords: *inoculation; casting; annealing normalising; tempering; grain sizes; phases; hardness*

1. INTRODUCTION

Grey cast iron is an alloy of iron, carbon and silicon that has been melted and poured into a mould to form a shape. If molten iron is allowed to cool normally the carbon comes out of solution and forms flakes of graphite which run through the ferrite/pearlite matrix [3]. Grey cast iron has more carbon present than can be retained in solid solution in austenite at the eutectic temperature [2]. Major constituents of gray cast irons are carbon in the range of 1.7-4.5% and silicon in the range of 1-3%. The carbon precipitates as either graphite flake or carbide during solidification; the free graphite expands on solidifying, giving sharp, well defined castings, hence enhances maximum machinability, but reduces the strength of the grey cast iron. Also, graphite acts as a lubricant, improving wear resistance. On the other hand, the presence carbide in grey cast iron results in hardness and extreme brittleness. [5].

Grey cast iron is good under compression loading and has good corrosion resistance when compared to mild steel [2]. It works well under continual heating and cooling cycles, and has a range of tensile strength and hardness to suit different applications. Therefore, it is well suited for the production of low, medium and high quality castings, and are widely use in the production of spare parts and consumables in forges and rolling mills, brake disks and drums particularly where castings are subject to repeated heating and cooling cycles, valve and pump applications, motor housings, gearboxes, engine blocks and machinery components, architectural, decorative and sculptural castings. Apart from the properties of grey cast iron [3], its prefer choice for these applications relative to other alternative materials is as a result of its lower cost [4]. A common method of improving the mechanical properties of grey cast iron is inoculation [2]. Inoculation is the process of modification of cast structure by the addition of substance (inoculants) to the melt for the purpose of nuclei formation during crystallization. has been found to improve the micro-structural properties of the cast, and also offset the carbide stabilizing action of magnesium or cerium present in the casting in the production of nodular iron [5]. The mechanisms by which modifiers (inoculants) can influence crystallization are different. A group of modifiers can control the condition of growth of graphite and promote its crystallization in the form of compact or spherical inclusions, and another group can cause the formation of additional crystallization nuclei and thus, changes the degree of graphitization [3].

Despite the recorded improvement in engineering properties of grey cast iron through inoculation practice, its full ultilisation in applications requiring tension, bending or shock loading has not be adequately achieved, this may not be unconnected with its high hardness and[1], and poor weld ability[4] . Hence, if this material is to be well suited for such applications, concerted efforts must be made by researchers on how its properties can be further improved upon, and since it is well known that the properties of cast iron can be changed by heat treatment of castings [8]. Therefore, effort was made in this work to modify the microstructure of produced inoculated grey cast specimens via annealing, normalising, and tempering heat treatment routes. Consequently, the influence of the heat treatment processes on hardness property of inoculated as well as non inoculated specimens were considered, this is with a view to determining the optimum heat treatment route(s).

2. MATERIALS AND METHODS

2.1 Materials

The materials used for this research work were engine-block scraps (rich in grey iron), ferro-silicon, and graphite, and the equipment used include 100kg rotary diesel fired furnace, sledge hammer, bellow, optical pyrometer, weighing scale, electronic weighing scale, moulding box, vent wire, in and flat rammers, carbolite laboratory electric furnace, laboratory grinding and polishing machine, grinding papers, polishing cloth and diamond paste, and a wild heer-brugg microscope with attached camera.

2.2 Method

2.2 1 Scrap Sorting

The gray cast iron scraps from automobile were carefully selected and cleaned to avoid contamination that could lead to casting defects during melting. Thereafter, their sizes were reduced with the aid of a sledge hammer to allow for easy passage through the entrance of the rotary furnace and also to facilitate fast melting in the furnace.

2.2.2 Casting process

The furnace was pre- heated for about 35 minutes, thereafter the scraps were charged into it, melting of the scraps and tapping of the resulting liquid metal were achieved at temperatures of 1555^{0}C and 1520^{0}C respectively. Upon tapping into a ladle, 0.2% of ferrosilicon (inoculant) was added, and the melt was quickly poured into the prepared moulds to avoid gasification of the inoculant during cooling and solidification of the melt.

2.2.3 Sample Preparation

Specimens of dimensions 15 mm length and 10 mm breadth were cut out of the automobile scrap sample as well as the inoculated samples using hacksaw, and in a bid to prevent alteration in the structure of the samples that may result from overheating during cutting, they were continuously lubricated with water, twenty eight specimens were produced in the process with seven from the as cast sample, and 0.1%, 0.2% and 0.3% ferrosilicon inoculated samples. Thereafter, chemical analysis of the specimens were carried out, and the results are depicted in Table 2

2.3 Heat Treatment

The heat treatment **(**carbolite laboratory electrical) furnace was pre heated for 1 hour, thereafter; the specimens were heat treated using annealing, normalizing and tempering heat treatment processes. The procedures used are depicted in Table 1

Table I: Heat Treatment Procedure

Serial Number	**Heat Treatment Type**	**Procedure**
1	Annealing	The non-inoculated (control) and inoculated (0.2% ferrosilicon) samples were heat treated gradually from ambient temperature(25^{0}C) to 880^{0}C in the carbolite laboratory electrical furnace, and to ensure full austenisation, the samples were soaked for 1hour after which the furnace was turned off , and the samples were then allowed to cool gradually in the furnace.
2	Nomalizing	The non-inoculated (control) and inoculate (0.2% ferrosilicon) samples were heat treated gradually from ambient temperature (25^{0}C) to 880^{0}C in the carbolite laboratory electrical furnace, and to ensure full austenisation, the samples were soaked for 1hour. The samples were removed from the furnace, and were allowed to cool in air inside the laboratory.
3	Tempering	Four samples comprising two non- inoculated (control) and two inoculated (0.2% ferrosilicon) were heat treated gradually from ambient temperature (25^{0}C) to a temperature of 650^{0}C that is, below the critical temperature, and held for 1hour and 30 minutes. Thereafter, the furnace was turn off, and the first and second set of samples, one each from un-inoculated and inoculated were taken out and cooled in water and oil respectively.

2.4 Microstructure

Specimens for microscopy studies (un- inoculated and inoculated) samples were machined to dimensions of 10 mm length, 10 mm breadth and 8 mm thickness with lathe machine. They were mounted on thermosetting material known as Bakelite in order to make them convenient for handling. Thereafter, the surfaces of the specimens were then flattened by filing and grinding using laboratory grinding and polishing machines with a set of emery papers of 240, 320, 400, 600, 1000 and 1200 microns. The grinding was done in order of coarseness of the papers. As each specimen was changed from one emery papers to the other, it was turned through an angle of 90^o to remove the scratches sustained from the previous grinding. After grinding, the specimens were polished using rotary polishing machine, to give it mirror like surface, and in conformity with Bipin and Tewari, (2010) a polishing cloth was used to polish the surface of the specimens, and in order to make a coloured eutectic cell of the samples apparent when viewed under the microscope, the specimens were first etched in stead's reagent and later in 2% nital solution, thereafter their surfaces were rinsed with methylated spirit and dried in warm current of air using an electric dryer. The microstructures were then examined using metallurgical microscope Model- Axio at magnification of 100xx.

2.5 Hardness Test

Standard procedures and equipment were used to measure hardness property of the machined specimens. Surfaces of the (un- inoculated and inoculated) specimens with dimensions 15 mm length, 10 mm breadth and 8 mm thickness were properly ground to give it flat and stable surface using a hand grinder. Thereafter, hardness measurement was made using Digital Rockwell hardness (H_{RA}) Tester with 0.4064m indenter and 0.6N indenting load with a dwell time of 10s. The hardness measurement was taken in three different locations and the average values were considered (Olaniran et al.,2007). The results are shown in Table 3

3. RESULTS AND DISCUSSION

3.1 Microstructures

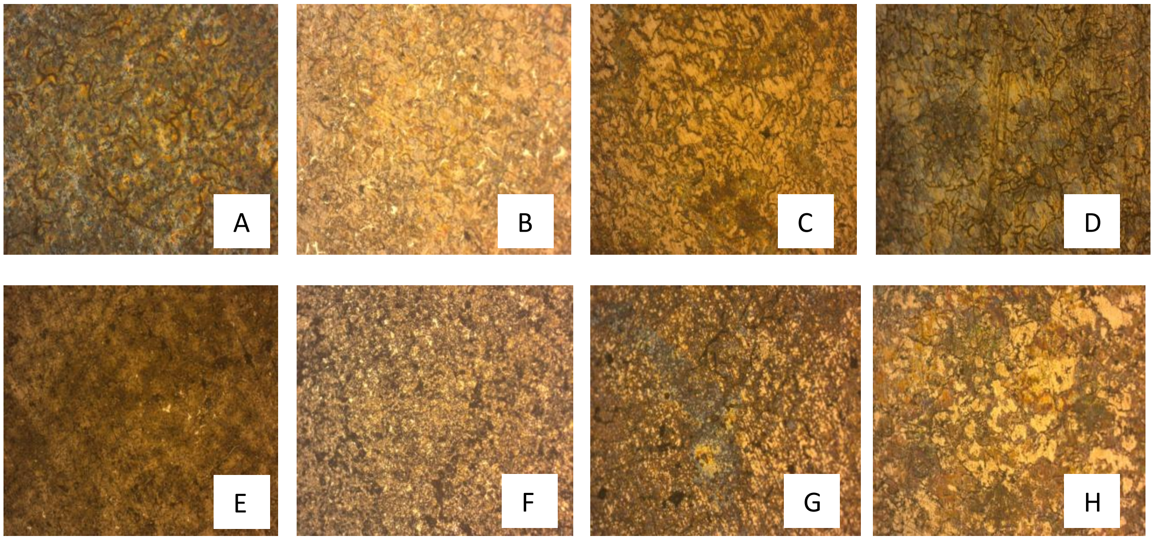

Figure 1 (A - un-inoculated, B-inoculated iron); (C- un-inoculated, D - inoculated annealed specimen); (E-un-inoculated, F-inoculated normalised specimen) and (un-inoculated and inoculated tempered specimen) respectively at magnification of 100xx.

Table **II: Percent Chemical Composition of the Non-Inoculate and Inoculated Specimens**

Element	C	Si	Mn	P	S	Cr	Ni	Mo	Fe	C.E
Scraps from automobile Sample	3.157	1.02	0.234	0.03	0.0801	0.090	0.003	0.002	94.90	3.507
Specimen inoculated with 0.2% ferrosilicon	2.950	2.980	0.313	0.03	0.063	0.110	0.050	0.011	93.04	3.953

Table III: Hardness Properties of the Heat Treated Un-Inoculate and Inoculated Specimens

S/N **A**	**Control Specimen**	**1st**	**2nd**	**3rd**	**Average Rockwell Hardness (HRA)**
1	Non-inoculated (control)	58.8	58.9	59.0	58.9
2	Inoculated with 0.2% ferrosilicon	46.0	45.8	45.9	45.9
B	**Annealed Specimen**				
1	Non-inoculated (control)	52.9	52.7	52.8	52.8
2	Inoculated with 0.2% ferrosilicon	41.9	42	41.8	41.9
C	**Normalised specimen**				
1	Non- inoculated	54.6	54.7	54.5	54.6
2	Inoculated with 0.2% ferrosilicon	43.2	43	43.1	43.1

D	**Tempered Specimen**				
1	**Non- inoculated**	50.9	51.0	50.8	50.9
2	**Inoculated**	40.8	40.6	40.7	40.7

3.2 Chemical Composition

The non-inoculated and inoculated experimental specimens are hypo-eutectic iron as revealed by the calculated carbon equivalent values of 3.507 and 3.953 respectively (Table 1), and the disparity seen in the specimens' chemical compositions may be due to such effects as the chemical composition of the inoculant and the resulting effects of its elements on graphitization, and losses due to volatilities of some of the elements during casting.

3.2.1 Effects of annealing, Normalising and Tempering on the Specimens' Microstructures

The observed uniform orientation of graphite flakes of type D with an inter-dendritic structure in a ferritic matrix as seen in the microstructures of the non-inoculated and inoculated annealed specimens (Fig.1c and 1d respectively) may have been due to slow cooling resulting from furnace cooling [6], and as a consequence, internal stresses resulting from the as-cast condition are relieved, while hard cementite of pearlite is decomposed to spheroidised cementite and ferrite in the process. And in comparison, the observed more graphite morphology in the microstructure of the inoculated annealed specimen over the corresponding non-inoculated specimen may have resulted from inoculation effects [5].

Microstructure of both the non-inoculated and inoculated normalised specimen with tiny flakes graphite of type A which are uniformly and completely distributed in cementite-rich pearlitic matrix as seen in Fig.1e and 1f respectively, may have resulted from air cooling, which is relatively faster than furnace cooling [6] [9]. Also, the observed more flakes in the graphite morphology of the inoculated normalized specimen as compared to the non-inoculated normalised specimen may be due to effects of the inoculant [5]. It was equally noticed that the non-inoculated tempered specimen which reveals flakes of graphite of type B (rosette) with random orientation of the graphite flakes in a tempered martensitic matrix as shown in Fig.1g, may have occurred as a result of slow cooling inside the furnace [6]; [1], while the observed increase distribution of graphite flakes in the matrix as seen in graphite morphology of the inoculated tempered specimen which shows increased distribution of graphite flake in the matrix as seen in Fig. 1h, may have resulted from the inoculation effect [5]

3.2.2 Effects of annealing, Normalising and Tempering on the Specimens' Hardness Property

The general reduction in hardness property of the inoculated heat treated specimens as compared to the non- inoculated heat treated specimen may have been due partly to graphitization resulting from inoculation [2]. Graphite has a strong effect on the principal properties of cast iron especially on the strength and ductility which are of value when the metal is used as structural material [2]. Also, graphite inclusion acts as stress concentrations in the metallic matrix, and internal stresses in the metal are higher where lines of force have higher density [4] and the negative effect of graphite is less pronounced when its concentration in the metal is low and its inclusions are fine and have a nearly spherical shape [3]. Graphite in cast iron decreases the ultimate and yield strength, ductility (relative elongation and impact strength [5],

The obtained relative improved hardness property of the non-inoculated and inoculated normalised specimens as compared to the corresponding annealed and tempered specimens respectively, may have resulted from dual effects of cooling rates and state of the melts. This effect, could have influenced the specimens' particle sizes and phases, and as a consequence, the normalised specimen with tiny flakes graphite of type A which are uniformly and completely distributed in cementite-rich pearlitic matrix are harder as compared to the annealed and tempered specimens with uniform orientation of graphite flakes of type D with an inter-dendritic structure in a ferritic matrix [6];[9]. Also, the decomposition of hard cementite of pearlite to spheroidised cementite and ferrite in the process of annealing heat treatment may equally have accounted for the relative reduction in hardness characteristic of the annealed and tempered specimens relative to the normalised specimen [8].

4. CONCLUSION

From the results of this work, annealing, normalising and tempering heat treatment processes were found to produce noticeable effects on the material's microstructural characteristics (phases and grain sizes) and hardness property in inoculated and non- inoculated conditions. However, due to variations in heat treatment effects, the resulting microstructures were found to be markedly different, and in addition, more graphite morphology were observed in the microstructure of the inoculated annealed specimens relative to the corresponding non-inoculated ones for all types of heat treatment considered.

Generally, the material's hardness was found to decrease in order of normalising, annealing and tempering heat treatment processes, and in relative to the non- inoculated specimens, hardness property of the inoculated ones were lower for all the processes of heat treatment considered. When compared to the as-cast sample, the heat treated specimens were found to reveal lower hardness values, and as a consequence, improvement in hardness property of the material has been achieved via the three heat treatment routes.

REFERENCES

[1]. Higgins, R.A (2004): Engineering Metallurgy: Applied Physical Metallurgy", 6th ed. Viva Books, New Delhi, pp.355-356.

[2]. John, R. B (1994): Foseco Foundryman's Handbook; 10th edition, pp 186; 188-189; 200; 211 and pp 215

[3]. Harvey, J.N and Noble, G.A (2007): Inoculation of Cast Irons- An Overview", 55th Indian Foundry Congress pp 344-360.

[4]. Chisamera, M; Riposan, I; Stan, S; White, D and G. Grasmo, (2008): Graphite Nucleation Control in Grey Cast Iron", International journal of cast metals research, W.S. Maney & son Ltd, Vol. 21 No. 1-4, pp 39-44.

[5]. Onsoien, M.I and Skaland, T (2001): Preconditioning of Grey Iron melts using Ferrosilicon or Silicon carbides", American Foundry Society.

[6]. Atanda, A. O and Oluwole, O. (2010): Microstructural Study of Heat Treated Chromium Alloyed Grey Cast Iron, Journal of Minerals & Materials Characterization & Engineering; Vol. 9, No.3, pp.263-274.

[7]. Elkem, A.S (2009): Foundry Products Division "Cast Iron Inoculation- The Technology of Graphite Shape Control, Oslo, Norway.

[8]. Sudsakorn Inthidech; Prasonk Sricharoenchai and Yasuhiro Matsubara (2006): Effect of Alloying Elements on Heat Treatment Behavior of Hypoeutectic High Chromium Cast Iron", Materials Transactions, Vol. 47, No. 1, pp. 72 to

[9]. Seidu S.O, Kutelu B.J (2013): Effect of heat treatment on corrosion of welded low-carbon steel in acid and salt environments, Journal of Minerals & Materials Characterization & Engineering*;* Vol. 1, No.3, pp.95-100