International Journal of Family Medicine and Primary Care

Review Article
Published: 02 Oct, 2018

Physio-Mechanical Investigation of Austempered Ductile Iron

Dangtim DK[1], Ibrahim ME[2], Ajoge EO[3]* and Levi TI[4]

[1]Department of Mechanical Engineering, Plateau State Polytechnic, Nigeria

[2]Department of Mechanical Engineering, ModiboAdama University of Technology Yola, Nigeria

[3]Centre for Energy Research and Development, Obafemi Awolowo University, Nigeria

[4]Ministry of Works, Yola, Nigeria

Abstract

The results of experimental (physical and mechanical) study of Austempered Ductile Iron (ADI) are presented. The aim of the investigation is to locally produce ADI and to have a closer look into the mechanical properties of this very attractive cast material. The experiment was carried out with ASTM A536 Grade Ductile Cast Iron, which was first produced using a high frequency dual track induction furnace of 2500kg capacity by adding small quantities of magnesium alloy to a base cast iron with essentially the same analysis as grey cast iron, which produces graphite speroids instead of flakes. The ductile cast iron samples were subsequently subjected to a specific parameter of heat treatment - Austenitizing (930°C for 140 minutes) and Austempering (370°C for 10 minutes) in Potassium nitrate salt bath to give ADI. Mechanical test (Tensile) is conducted on the ductile iron and ADI specimen using Universal Testing Machine (Instron - Series 3369) to evaluate the basic mechanical properties (yield stress, tensile strength and elongation). Structure of the specimens was studied with conventional metallography. It followed from the study that ductile iron properties were significantly improved after heat treatment, elongation increased by 27.04% and tensile strength by 58.62%.

Keywords: Austempered ductile iron; A536 Grade ductile cast iron; Heat treatment; Tensile strength; Elongation; Metallography

OPEN ACCESS

Correspondence:
Dangtim DK, Centre for Energy Research and Development, Obafemi Awolowo University, Ile-Ife, Nigeria,
E-mail: emmanuelajoge@yahoo.com

Received Date: *22 Sep 2018*
Accepted Date: *25 Sep 2018*
Published Date: *02 Oct 2018*

Citation:
Dangtim DK, Ibrahim ME, Ajoge EO, Levi TI. Physio-Mechanical Investigation of Austempered Ductile Iron. Int J Fam Med Prim Care. 2018; 1(1): 1002.

Introduction

Even nowadays, in era of light alloys and composites, Ductile Cast Iron (DCI) still represents a structural material of choice for a wide range of demanding technical applications. Furthermore, the mechanical properties of DCI can be significantly improved by a special heat treatment known as austempering that was first commercially applied to DCI in 1970's. The conventional process consists of full austenitization of the casting in the temperature range of 815 – 950˚C followed by quenching to an intermediate temperature (austempering temperature) range of 235 - 400˚C to avoid formation of pearlite. The casting is maintained at the austempering temperature for 2 - 4hrs, depending on the section size and finally cooled in air to room temperature [1-5].

The mechanical properties of Austempered Ductile Iron (ADI) are closely related to the type of microstructure, which depends on a number of factors, the most important being the austempering temperature. High austempering temperatures result in improved ductility, fatigue and impact strengths and relatively low yield and tensile strengths. At low austempering temperature, ADI displays high yield and tensile strengths, high wear resistance, but reduced ductility and impact strength [6,7].

Alloying elements in ADI are normally required for harden ability purposes or the austemperability of DCI when section sizes are greater than 19mm. The alloying elements that are typically added for harden ability purposes are Cu, Ni and Mo [8,9].

The microstructure of ADI consists of acicular ferrite, that can be fine (characteristic for lower bainite produced at lower temperatures) or coarse (characteristic for upper bainite produced at higher temperature), high carbon austenite and nodules of graphite particles. European Norm (EN) specifies four grades of ADI in dependence of the ultimate tensile strength (Rm), while American Standard (ASTM) specifies five grades [10].

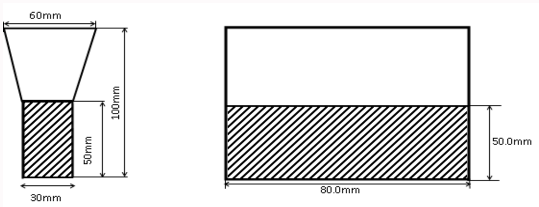

Figure 1: Y–block mould for the Ductile Iron Melts.

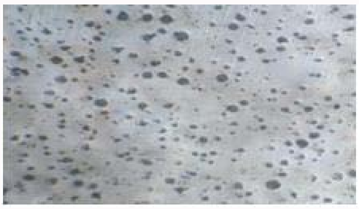

Figure 2a: Microstructure of the Ductile.

Figure 2b: Microstructure of the Cast Iron (X 200) Austempered Ductile Iron (X 400).

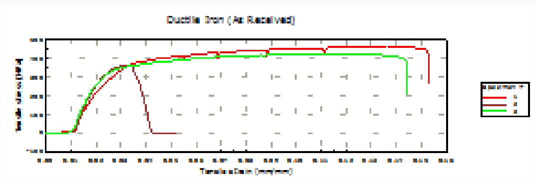

Figure 3a: Stress Strain Curve for DCI.

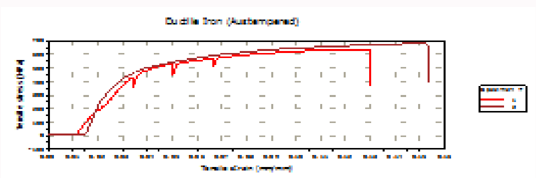

Figure 3b: Stress Strain Curve for ADI.

Combination of properties, such as strength, ductility, fatigue resistance and wear resistance, makes ADI not only an engineering material that may substitute cast, forged and/or heat treated steels, but even aluminum in applications, where high strength/weight ratio is important. The major applications of ADI include gears, crankshafts, connecting rods, camshafts, engine mounts, transmissions, suspension components, sprockets and many other parts used in automotive, railway, earth moving, excavating and agriculture equipment. The aim of this study is to find out how the specific heat treatment parameter been selected influences the mechanical properties of the DCI.

Experimental Procedure

The ASTM A536 grade ductile iron was produced at the Nigeria

Table 1: Composition of CRCA Steel Scraps used for the Production of the Ductile Cast Iron by weight %.

Carbon	Sulphur	Phosphorus	Manganese
0.05	Max 0.03	Max 0.03	0.3

Table 2: The Composition of Graphite used.

Carbon %	Ash %	Volatiles %	Sulphur %	Moisture %
69	30	<0.5	0.27	0.10

Table 3: Analysis of the Nodulizer, MgFeSi used for Treating Cast Iron Melt inthe Ladle.

Si%	Ca%	Mg%	RE%	Al%	Fe%
44.5	2.02	10%	0.8	<0.7	Bal.

Table 4: Permissible Range of Ductile Cast Iron Composition as per the ASTM A536-77 [65-45-12].

Grade	C	Si	Mn	S	P	Mg
ASTM A 536- 77 (65-45-12)	3.40-3.85	2.30-3.10	0.1-0.3	Max 0.03	Max 0.04	0.015-0.05

Machine Tools (NMT), Oshogbo Nigeria. The metal was melted in 2.5 tons high frequency dual track induction furnace. Table 1 shows the summary of charged materials used for the iron production. Graphite and CRCA steel scraps were weighed and charged into the furnace and completely melted at 1550°C, slags were removed from the melt. Table 1 and 2 show the composition of the graphite and CRCA steel scraps used for the investigation. Ferrosilicon 75% silicon grade was added as in the charge make up. A sample was taken for a chemical composition analysis using the optical emission spectrometry to ascertain the melt conformity as designated by ASTM A536 in Table 4. Two ladles were preheated such as the treatment and pouring ladle for about 40 minutes. The treatment ladle (1000kg) was taken to the treatment section which is closer to the moudling floor while the pouring ladle was taken to the furnace to tap out 600kg molten metal. The spheroidizing treatment was carried out with ferrosilicon magnesium alloy (analysis shown in Table 3) of 13kg using the sandwich method and it involves covering the alloy in a portion of the preheated treatment ladle with some mild steel fillings while the 600kg molten metal is poured unto the ladle and the reaction took place. Molten metal was inoculated with additional 3kg grounded ferrosilicon and then poured into an already prepared Y – block green sand mould (Figure 1) using sand recipe mixed in a 500kg capacity sand mixer in accordance to ASTM A536. From the time the molten metal touches the ferrosilicon magnesium inside the treatment ladle until the end of casting into mould must be done within 7 minutes that is, after 7 minutes, the melt gradually returns to a grey cast iron.

The molten metal obtained was measured using the optical Pyrometer. The tapping temperature of the melts is within 1550°C to 1530°C while the pouring temperature obtained ranges from 1490°C to 1470°C. The casting were allowed to cool to room temperature before been removed out of mould, the Spectro analysis of the ductile cast iron is shown in Table 7. From these Y - block castings, tensile specimens having 50mm total length, 19mm gauge length and 3mm gauge diameter were prepared.

The austempering was carried out at the foundry shop of National Metallurgical Development Centre (NMDC) Jos, Plateau State. The samples were charged into the 2804 Bremen Naberindustrieofenbau tubular heat treatment furnace and set to the austenitizing temperature 930°C for 140 minutes and autempering 370°C for 10 minutes in a potassium nitrate salt bath which was set up and positioned close to

Table 5: Charge Calculation for 2.5 Metric Tons Metals.

Charge material	Charge Mass kg	Carbon %	Carbon kg	Silicon % kg	Manganese % kg
CRCA steel scraps	2325	0.05	1.1625	- -	0.306.975
Graphite	129.84	69	89.7	- -	- -
(FeSi)	45.16	-	-	75 33.75	- -
Total	2500	-	90.8625	- 33.75	- 6.975
Charge %		$\left[\frac{90.8625}{2500}\times 100 = 3.6345\right]$		1.35	0.279

To balance Si

Silicon content increased during the batch treatment of 600 kg melt.

Si in FeSiMg =44.5%

Weight of FeSiMg =13 kg

Weight of ladle =600 kg

$$\text{Thus \% Si} = \left[\frac{44.5\times 13\ kg}{600\ kg} = 0.964\%\right]$$

Total Si after treatment = 0.964 + 1.35 =2.314%

3kg Ferrosilicon was used for inoculation

∴ 3kg FeSi is required to give

$$\frac{75\%\times 3\ \text{kg FeSi}}{613} = 0.32\%\ \text{Si}$$

Therefore gross % of Si in melt = (0.32 + 2.314)% =2.634%

Table 6: Summary of Charge Materials.

CHARGED MATERIALS	QUANTITY (kg)
CRCA steel scraps	2,325
Graphite	129.84
FeSi in furnace charge	45.16
Nodulizer (MgFeSi)	13
FeSi used as inoculants	3
TOTAL	2,516

the furnace. After final heat treatment, the specimens were tensile tested using Instron Machine Series 3369 to evaluate yield strength, tensile strength and elongation.

Microstructure observations were carried out using Olympus GX 51 Paxit Metallurgical Microscope with Magnification X 200 on metallurgraphic specimens prepared using conventional grinding and polishing. For etching Nital solution (2% nitric acid in 98% water) was used.

Charge calculation

The furnace was charged with metallic materials to give base iron with the following composition shown in Table 4. The charge consisted of CRCA steel scraps, graphite and ferrosilicon. Spectrometric determination of the composition are given above.

Results

Test materials

The Chemical composition of the Ductile Iron after casting is presented in Table 7.

Table 8: Percentage Increase in Tensile Properties for the as poduced ADI.

Sample/Property	UTS (MPa)	Yield Stress (MPa)	Elongation (%)
Ductile Cast Iron	415.98	363.12	11.65
Austempered Ductile Iron	659.84	478.14	14.80
% Increase in Property	58.62	31.68	27.04

Structural Investigation

Metallography

Figure 2a illustrate a typical microstructure of ASTM A536 grade ductile cast iron and Figure 2b the microstructure of the material after 10 minutes austempering at 370°C.

Mechanical testing

The results of the flow curves (stress-strain) obtained from the tension test conducted on the DCI and ADI are shown in Figures 3a and 3b below. Table 8 presents the percentage increase in tensile properties for the as produced ADI.

Discussion

In the austempering transformation as demonstrated by Kovac (1987), consists of full austenitization of the casting in the temperature range of 815 – 950°C followed by quenching to an intermediate (austempering temperature) range of 235 – 400°C to avoid formation of pearlite.

The as-cast ductile iron was austenitized at 930°C for 140 minutes and the transformation was formed at the upper end austempering temperature (370°C for 10 minutes) to give the ADI lower strength but higher elongation.

Typical microstructure of ADI as described by Polishetty (2011) consists of ferrite needles distributed in the autenite phase. According to Figure 2b on microstructure of the as produced ADI, the structure over the whole cross-section consisted of fine feathery ferrite and graphite nodules distributed in the austenite phase.

It is seen that, white background represents the austenite phase, dark feathery like structure constitute the ferrite and spherical modules represent the graphite.

The Mechanical properties of the as cast ductile iron was significantly improved after the heat treatment as presented in Table 8. It is shown that tensile strength and ductility of the ADI is more enhanced. The elongation increased by 27.04% and tensile strength by 58.62%.

Conclusion

On the basis of the experimental results including mechanical testing and structure investigations using conventional metallurgraphy observation, the following conclusions can be proposed:

1. The ADI has higher mechanical properties as compared to the conventional ASTM A536 grade ductile iron (65-45-12). ADI-UTS 660MPa, Yield Stress 478MPa and elongation 14.8%.

2. Microstructure of the as-cast ductile iron consists of

Table 7: Chemical composition in Percentage of the DCI in relation to the permissible range of composition as per the ASTM A536 – 77.

Grade	C	Si	Mn	S	P	Mg	Mo	Al	Cu	Ti	Nb	Fe
ASTM A536 – 77 (65-45-12)	3.40-3.85	2.30-3.10	0.1- 0.3	Max. 0.03	Max. 0.04	0.015 – 0.05	-	-	-	-	-	-
Sample Composition	3.65	2.04	0.096	0.006	0.015	0.028	0.026	0.013	0.077	0.023	0.01	Bal.

nodular graphite in Ferritic-Pearlitic matrix, while the as-produced ADI contains nodular graphite in a matrix of feathery ferrite and carbon enriched austenite called ausferrite and this explains its superiority in strength.

References

1. Aigbodion VS, Mohammed OY, Yakubu SI, Agunsoye JO. Corrosion characteristics of vanadium Alloyed Ductile Iron in Nitric Acid. Journal of Applied Sciences Research. 2007;4(10):1267 -71.
2. Alasoluyi JO, Omotoyinbo JA, Olusunle SO, Adewoye OO. Investigation of the Mechanical properties of Ductile iron produced for Hybrid inoculants using Rotary Furnace. International Journal of Science and Technology. 2013;2(5):12.
3. Gonzaga RA, Martinez L, Perez A, Villanueva P. Mechanical Properties dependency of the pearlite Content of Ductile Irons. Journal of Achievements in Materials and Manufacturing Engineering. 2009;33(2):157.
4. Hayrynen KL. The production of Austempered Ductile Iron (ADI), World Conference on ADI, Louisville, Kenturky, Cosponsored by Ductile Iron Society and the American Foundry Society. 2002.
5. Kaczorowski M, Krzyaska A. Mechanical properties and Structure of Austempered Ductile Iron. Archieves of Foundry Engineering. 2007;7(1):161-6.
6. Kaczorowski M, Myszka D. On the differences between Mechanical Properties of Structure of Ductile Iron Castings, Austempered using conventional and direct method. Journal for Manufacturing Science and Technology. 2005;7(1):33-9.
7. Lukas B, Radomila K, Gianni N. Fatigue Crack Propagation through Austempered Ductile Iron Microstructure. Material Engineering. 2010;17(3):84-73.
8. Lener YS. Overview of Ductile Iron Treatments, Foundry Trade Journal Metal Matters. 2003;19-21.
9. Oluwole OO, Olorunniwo OE, Ogundare OO, Atanda PO, Oridota OO. Effect of Magnetic and Calcium as spheroidizers on the graphite morphology in Ductile Cast Iron. Journal of Minerals and Materials Characterization and Engineering. 2007;6(1):25-37.
10. Polishetty A. Machineability and Microstructural studies on phase transformation in Austempered Ductile Iron. 2011;1-25.