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ANALYSIS OF EFFECTS OF HEAT TREATMENT PROCEDURES ON CHARACTERISTICS OF IRON

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ABSTRACT

The initial study was conducted on unalloyed ductile iron castings. The effect of austempering time was examined by varying austempering time in the range of 30 minutes to 90 minutes, while keeping austenitization temperature and austempering temperature constant. It was found that with the increase of austempering time, the tensile strength increased significantly. However, at 90 minutes the tensile strength decreased. The optimum temperature was found to be 60 minutes. The second variable was the effect of austenitization temperature on ductile iron. Based on the result of the first experiment, the austempering was carried out for 90 minutes. The austempering temperatures were kept at 270ºC and 370ºC. The austenitization temperature was varied from 850ºC to 925ºC. The study revealed that tensile strength increased at 900ºC but it decreased at 925ºC. The third major variable involving the effect of alloying additions on ductile iron, was studied by adding copper with three different values i.e. 0.5 wt. %, 1.0 wt. % and 1.5 wt. %. The fourth melt was without the addition of copper. It was found that with the increase of copper the tensile strength continued to increase up to 1.5 wt. %. The second alloying addition was nickel. One melt was made without nickel while the remaining three melts were made with the addition of 1.0 wt. %, 2.0 wt. % and 3.0% nickel. The tensile strength increased correspondingly with the increase in the addition of nickel to 3.0 wt. %. The effect of a combination of copper and nickel on ductile iron was also examined. The effect of the last alloying element which was studied was lanthanum. Four melts were made for this study. The first melt was without the addition of lanthanum while the remaining three had 0.006 wt.%, 0.02 wt.% and 0.03 wt.% lanthanum. The results indicated that the tensile strength increased with the increase of lanthanum content with and without austempering. Furthermore, the highest nodule count was obtained with 0.03 wt. % lanthanum while the nodularity remained almost unchanged.
Thus, it was observed that the addition of alloying elements results in an increase of tensile strength. The optimum austempering time was 90 minutes and the optimum austenitizing temperature was found to be 900ºC.

KEYWORDS: Austempering, austenitizing temperature, tensile strength and nodularity.

I. INTRODUCTION

The increasing interest in energy saving has led to the development of lightweight materials to reduce the weight of existing materials without compromising their properties. In the automotive industries, attempts have been made to replace cast iron and steel components with aluminum and austempered ductile iron.

Austempered ductile iron (ADI) is a ductile iron that has undergone a special isothermal heat treatment called austempering. Unlike conventional "as-cast" irons, its properties are achieved by specific heat treatment. Therefore, the only prerequisite for good ADI is a good quality ductile iron.

ADI offers superior combination of properties because it can be cast, like any other member of the ductile iron family. It offers all production advantages of conventional ductile iron castings. Subsequently it is subjected to the austempering process to produce mechanical properties that are superior to conventional ductile iron, many cast and forged steels.

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The mechanical properties of ductile iron and austempered ductile iron (ADI) are determined by the metal matrix. In conventional ductile iron it is controlled by the mixture of pearlite and ferrite. However the properties of ADI are due to its unique matrix of acicular ferrite and carbon stabilized austenite called ausferrite.

It is a well known that an appropriate amount of rare earth is often used in ductile iron production in order to counteract the deleterious effects of subversive elements, e.g. titanium, bismuth and others. It is believed that the rare earths combine chemically with the subversive elements to effectively remove them from the system although reactions between titanium and rare earths have not, as yet, been identified. However, an excessive amount of rare earth elements is known to promote the formation of chunky graphite.

The term, cast iron, identifies a large family of ferrous alloys. Cast irons are primarily alloys of iron that contain more than 2.0 wt. % carbon. It also contains 1.0 to 3.0 wt. % silicon. The different properties of castings can be achieved by changing carbon content, silicon content, by alloying with various elements, and by varying melting, casting and heat treatment practice. Cast irons, as the name implies, are indeed to be cast to shape rather than formed in solid state. Cast irons have low melting temperatures and are very fluid when molten and have undergone slight to moderate shrinkage during solidification. However, cast irons have relatively low impact resistance and ductility, which limits their use. This must be taken into account when designing castings to withstand service stresses. Irons of the composition given below in table 1.1 and table 1.2 satisfy a low and high grade specification of grey cast iron in a medium size, uniform sections sand castings.

Table 1. (G 150) Composition of Grey Iron for Low Grade

C%	Si %	Mn %	S%	P%
3.1-3.4	2.5-2.8	0.5-0.7	0.15	0.9

Table 2 (G 350) Composition of Grey Iron for High Grade

C%	Si %	Mn %	S%
3.1 max	1.4-1.6	0.6-0.75	0.12

The properties of flake iron depend on size, amount, distribution of graphite flakes and matrix structure.

II. OBJECTIVES

- To study the effect of alloying elements (copper, nickel, a combination of copper and nickel and lanthanum) on ductile iron.
- To study the effect of change of different parameters of heat treatment on ductile iron.

III. MATERIALS AND METHODOLOGY

During the present research an attempt was made to observe the tensile strength of ductile iron by the addition of copper, nickel, a combination of copper and nickel and lanthanum. Different heats with and without copper, nickel and a combination of copper and nickel were made to find out the effect of these alloying elements on ductile iron. Samples for this study consisted of tensile test bars having different compositions of ductile iron with and without the alloying additions. Test bars from one melt without lanthanum were produced in the Casting Laboratory of the University of Birmingham, UK. Test bars with varying composition of lanthanum from three melts were produced to observe the effect of the addition of lanthanum. Different experiments were conducted for studying the effect of alloying elements and effect of heat treatment on ductile iron.

- To find out the optimum austempering time, ductile iron samples were heat treated at fixed austenitizing temperature at 900ºC and austempering temperature at 270ºC and 370ºC. The austempering time was varied from half an hour, one hour and one and a half hour to determine the most suitable austempering time.
- To ascertain the suitable austenitizing temperature, the austempering temperature at 270ºC and 370ºC and austempering time for one hour was fixed. Austenitizing temperature of 850ºC, 900ºC and 925ºC was maintained for one hour to find out the best austenitizing temperature for these samples.
- Addition of Copper

Four heats were made to find out the effect of copper on the tensile strength of ductile iron. Copper content was varied from nil to 1.5 wt. %.

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- Addition of Nickel

Different heats were produced to examine the effect of nickel on ductile iron. The melts were made with the addition of 1.0 wt. %, 2.0 wt. % and 3.0 wt. % of nickel.

- Addition of a combination of Copper and Nickel

Different melts with a combination of copper and nickel were made to examine the effect of both of alloying elements together.

- Addition of Lanthanum

Four melts were made for this purpose. One melt was made without lanthanum while three melts with varying compositions of lanthanum were made. Three aspects of the composition of lanthanum were investigated i.e. nodule count, nodularity and tensile strength with and without heat treatment.

Different properties of ductile iron were studied taking into consideration the following:

- Change of tensile strength with the change of austempering time.
- The change of tensile strength with the change of austenitizing temperature.
- The change in nodule count and nodularity with the change in the amount of lanthanum.
- The change of tensile strength with the change of austempering temperature in low and high temperature ranges.
- The change of tensile strength with the change of lanthanum, copper and nickel content.

Ductile Iron without and with Copper, Nickel and Copper- Nickel Together

Ductile iron was made using local materials and local facilities. The melting was carried out in a commercial electro-induction foundry furnace. In order to get the required composition, ferro-alloys were added to the melt. After melting, the metal was poured into a ladle with two pockets at the bottom. In one pocket ferro-silicon-magnesium alloy and inoculant (ferro-silicon) were placed while the other was kept empty. The following raw materials for the production of ductile iron were used.

Pig Iron

Pig iron used for making ductile iron. The composition of the iron is given in table 3

Table 3 Chemical Composition of Pig iron in wt %

C	Si	Mn	P	S	Fe
4.1	0.83	0.6	0.025	0.021	Balance

Mild Steel

Mild steel with the following composition mentioned in table 4 was used.

Table 4 Chemical Composition of Mild Steel in wt %

C	Si	Mn	Fe
0.2	0.3	0.4	Balance

Ferro-silicon-magnesium

Ferro-silicon-magnesium used for the spheroidization with the composition shown in table 5

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Table 5 Chemical Composition of Ferro-silicon-magnesium in wt %

Si	Mg	Ca	Al	Fe
42	5.5	1.2	1.0	Balance

The melt was poured from about 1450ºC into a standard Y block sand mould. Tensile specimens of 15 mm diameter 250 mm long were machined from the castings.

Chemical Composition of Heats Produced

- The chemical analysis of ductile iron produced without and with copper addition is mentioned in the table 6. Four heats were made to find out the effect of copper on ductile iron. The details of heats are as follows:

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Table 6 Chemical Composition of Ductile Iron Produced with copper in wt %

Elements	Heat No C0	Heat No C5	Heat No C10	Heat No C15
C	3.6	3.5	3.7	3.9
Si	2.7	2.9	2.6	2.7
Mn	0.1	0.2	0.1	0.2
Cu	0.0	0.5	1.0	1.5
S	0.07	0.09	0.08	0.09
P	0.02	0.03	0.02	0.02

- The chemical analysis of ductile iron produced without nickel and with nickel addition is mentioned in the table 7. The details of heats prepared to find out the effect of nickel are mentioned below:

Table 7 Chemical Composition of Ductile Iron Produced with Nickel in wt %

Elements	Heat No N0	Heat No N1	Heat No N2	Heat No N3
C	3.6	3.7	3.7	3.8
Si	2.7	2.8	2.7	2.7
Mn	0.1	0.2	0.2	0.2
Ni	0.0	1.0	2.0	3.0
S	0.08	0.09	0.08	0.08
P	0.02	0.02	0.02	0.02

Ductile Iron Prepared without Lanthanum

Ductile iron samples were prepared at the University of Birmingham, U K. The furnace used was medium frequency induction furnace of capacity 28 kg. The material used was sorel metal, mild steel and ferroalloys. The investigation for optimum austempering time and austenitizing temperature was carried out on the samples of this melt. The composition of ductile iron produced is given in the table 8.

Table 8 Chemical Composition of Ductile Iron in wt. %

C	Si	Ni	S	P	Mg
3.5%	2.5%	0.019%	0.05%	0.005%	0.05%

Ductile Iron Produced with Lanthanum

Four melts were made with and without the addition of lanthanum i.e. 0.00 wt.%, 0.006 wt.%, 0.02 wt.% and 0.03 wt.% at the University of Birmingham, UK. For this purpose, the following charge materials were used. A good quality of charge was selected for the melting. The composition of the charge was as follows:

Sorel Metal

Sorel Metal of Grade RTF 10 was used. The composition is given the table 9.

Table 9 Chemical Composition of Sorel Metal in wt.%

C	Si	Mn	S	P
4.33	0.134	0.014	0.005%	0.017

Ferro-silicon 75(Base)

Ferro-silicon with 75 wt. % of silicon was used.

Ferro-silicon-magnesium

Ferro-silicon-magnesium with Si = 45.45 wt. % and Mg =4.72wt.% was used for graphitization

Swedish Iron

Swedish iron was used for the production of ductile iron. The composition of the iron is given the table 10.

Table 10 Chemical Composition of Swedish Iron in wt. %

C	Si	Mn	S	P
0.01	0.03	0.18	0.004	0.011

Chemical Analysis

Standard coin samples were chilled cast for chemical analysis for every melt. The samples were taken from the middle of casting. The chemical analysis of samples of ductile iron is given in the table 11.

Table 11 Chemical Analysis of Ductile Iron Alloyed with Lanthanum

Elements	Melt Number			
	MELT 1	MELT 2	MELT 3	MELT 4
C	3.71	3.45	3.40	3.41
Si	2.45	2.75	2.63	2.68
Mn	0.111	0.105	0.107	0.106
P	0.016	0.022	0.021	0.022
S	0.008	0.006	0.008	0.008
Cr	0.027	0.028	0.026	0.028
Mo	0.002	0.001	0.001	0.001
Ni	0.029	0.028	0.029	0.029
Al	0.019	0.018	0.017	0.016
Cu	0.016	0.015	0.016	0.015
Mg	0.064	0.071	0.058	0.060
Sn	0.001	0.001	0.001	0.001
Ti	0.005	0.005	0.005	0.006
V	0.008	0.008	0.007	0.008
La	0.000	0.006	0.020	0.030
Fe	Bal.	Bal.	Bal.	Bal.

IV. RESULTS AND DISCUSSIONS

Different variables have been studied during the present research. The first variable was the effect of austempering time on ductile iron. The second variable was the effect of austenitizing temperature on the ductile iron. The third major variable was the effect of alloying additions on the ductile iron. The alloying elements selected for this purpose were copper, nickel, a combination of copper and nickel and lanthanum.

Effect of Austempering Time on Ductile Iron

Table 12: Effect of Time on the Tensile Strength of Ductile Iron

No.	Austenitizing Temp °C	Austempering Temp °C	Austempering Time (Hours)	Elog. %	UTS N/mm^2
1	900	270	½	1.2	968.9
2	900	270	1	1.3	1360.9
3	900	270	1 ½	1.2	1312.3
4	900	370	½	2.5	811.8
5	900	370	1	2.7	925.2
6	900	370	1 ½	2.6	817.5
7	Without any treatment			4.0%	696.4

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Effect of Austenitizing Temperature on Ductile Iron

Table 13 Effect of Austenitizing Temperature on Tensile Strength of Ductile Iron

Sample No	Austenitizing Temperatures ºC	Austempering Temperatures ºC	Tensile Strength N/mm²
1	850	270	1142.47
2	900	270	1313.32
3	925	270	1205.95
4	850	370	991.19
5	900	370	1117.84
6	925	370	1010.46

Effect of Copper on the Tensile Strength of Ductile Iron

To find out effect of copper, four heats were made with 0.0 wt. %, 0.5 wt %, 1.0 wt. % and 1.5 wt. % by wt. in a commercial foundry. The tensile samples were machined from the castings. The samples were austenitized in a Carbolite muffle furnace at a temperature of 900ºC for one hour and austempered at 270ºC and 370ºC for one hour.

Table 14 Effect of Copper on Tensile Strength of Ductile Iron

Sample No	Austenitizing Temperatures C	Austempering Temperatures C	Tensile Strength N/mm²
1	850	270	1142.47
2	900	270	1313.32
3	925	270	1205.95
4	850	370	991.19
5	900	370	1117.84
6	925	370	1010.46

Effect of Nickel on Tensile Strength of Ductile

Table 15 Effect of Nickel on Tensile Strength of Ductile Iron

Nickel	UTS N/mm² 0.0 wt.%	UTS N/mm² 1.0 wt.%	UTS N/mm² 2.0 wt.%	UTS N/mm² 3.0 wt.%
Without heat-treatment	495.3	552.4	575.3	628.2
Austempered at 270ºC	938.8	970.5	979.7	1082.5
Austempered at 370˚C	698.0	721.18	732.8	917.7

Effect of a combination of Copper and Nickel on Ductile Iron

Table 16 Effect of Copper and Nickel together on Tensile Strength of Ductile Iron

Copper Nickel	UTS N/mm² 0.0 wt %	UTS N/mm² 0.5 wt %	UTS N/mm² 1.0 wt %	UTS N/mm² 1.5 wt %
Without heat-treatment	495.3	544.0	552.7	576.8
Austemperedat 270ºC	938.8	1034.3	1055.3	1164.1
Austemperedat 370ºC	698.0	715.7	738.7	787.3

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Effect of Lanthanum on Nodule Count and Nodularity of Ductile Iron

Table 17 Effect of Lanthanum on Nodule count and Nodularity on Ductile Iron

Melt No.	Lanthanum, %	Nodule Counts	Nodularity, %
MELT 1	0.000	377	81
MELT 2	0.006	444	83
MELT 3	0.020	448	81
MELT 4	0.030	467	82

Effect of Heat treatment on Microstructure of Ductile Iron

To find out the effect of heat treatment on the ductile iron the samples of ductile iron with lanthanum content of 0.006 wt %, 0.02 wt % and 0.03 wt % and without lanthanum were austenetized at 900ºC for one hour and austempered at 270ºC and 370ºC for one hour.

The micrographs taken from samples austempered at 270ºC are shown in figure 4.20. These micrographs clearly show the matrix of acicular bainite and distribution of graphite nodules. Figure 4.19 shows the micrographs of ductile iron austenitized at 900ºC and austempered at 370ºC for one hour.

V. CONCLUSION

1. An increase of austempering time upto one hour resulted in an increase in tensile strength; however, it decreased when the time was increased.
2. The maximum tensile strength achieved was 1313.3 N/mm² and 1117.8 N/mm² by austempering at 900ºC and austempered at 270ºC and 370ºC, respectively.
3. Austempering at 270ºC produced higher tensile strength in comparison with austempering at 370ºC which resulted in lower tensile strength in all samples.
4. With the application of austempering process, the tensile strength was doubled. The tensile strength without any heat treatment was 694.4 N/mm² and when the samples were subjected to austempering heat treatment at 270ºC for one hour; it increased to a value 1360.9 N/mm².
5. With the increase of copper content, the tensile strength of ductile iron went on increasing up to 1.5 wt % (705 N/mm²).
6. Nickel addition also increased the tensile strength of ductile iron. The highest tensile strength was obtained with 3.0 wt % nickel.
7. The tensile strength increased when ductile iron was alloyed with a combination of nickel and copper but there was no significant increase in the tensile strength.
8. The nodule count increased with the increase of lanthanum content in ductile iron thus improving its strength and ductility. The maximum nodule count was achieved with 0.03 wt. % lanthanum.
9. There was almost no effect of lanthanum on nodularity of the ductile iron. Good nodularity i.e. 81% to 83% was achieved with a good selection of charge and careful melting techniques.
10. It was observed that the nodule count of ductile iron increased with the increase of lanthanum when the ratio of lanthanum sulphur was as low as 1.0.
11. Tensile strength went on increasing with the increase of lanthanum addition when it was subjected to austempering treatment. The maximum tensile strength was achieved with the addition of 0.03 wt. % lanthanum.

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