Journal of Engineering and Development, Vol. 13, No. 2, June (2009) **ISSN 1813-7822**

An Investigation into the Railway Shoulder Manufacturing

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Abstract

Ductile cast iron is considered to be a recent member of the cast irons family. Because of the high cost that spent in producing ferritic ductile iron using heat treatment with long period of time. This work presents a brief picture to assess railway shoulder made from ferritic ductile iron in the as-cast condition without any post heat treatment. The manufacturing is achieved using RF induction furnace with the aid of instantaneous chemical analysis using optical emission spectrometer (OES) to control the chemical composition of the ferritic ductile iron. The results showed that the produced ferritic ductile iron has properties satisfy the required application.

التحقق في تصنيع كتف السكة الحديدية

الخلاصـــــة

يعد حديد الزهر المطيلي المكون الاحدث ضمن عائلة حديد الزهر. نتيجة للكلفة العالية الناتجة من عملية الحصول على الحديد المطيلي الفرايتي بسبب الفترة الزمنية الطويلة اللازمة لاجراء التعامل الحراري. لهذا فان هذا البحث يهدف الى اعطاء صورة مختصرة عن تقييم كتف السكة الحديدية المصنوع من الحديد المطيلي الفرايتي المنتج بدون اجراء اي تعامل حراري. اذ تم انتاج الحديد المطيلي الفرايتي باستخدام فرن الحث المترافق مع التحليل الكيميائي الدوري اثناء عملية الصهر باستخدام مطياف الانبعاث الضوئي (OES) للسيطرة على التركيب الكيميائي. اوضحت النتائج ان الحديد المطيلي الفرايتي المنتج في هذا البحث يمتلك خواص تكافيء التطبيق المطلوب.

1. Introduction

The term 'Cast Iron' identifies a large family of ferrous alloys which are different in chemical composition, microstructure and properties [1]. Cast iron is a cheap metallurgical material which is particularly useful where a casting requiring rigidity, resistance to wear or *high compressive strength* is necessary. Other useful properties of cast iron include [2]:

(i) good machinability when a suitable composition is selected;

(ii) high fluidity and the ability to make good casting impressions;

(iii) fairly low melting range (1130-1250 $^{\circ}$C) as compared with steel;

(iv) the availability of high strengths when additional treatment is given to suitable irons.

Ductile iron which is frequently referred to as nodular or spheroidal graphite cast iron has been known only since the late 1940s, but it has grown in relative importance and currently represents about 20 to 30% of the cast iron production of most industrial countries [3,4]. It consists of spheroidal graphite with specified matrix, depending on the melting and casting conditions and post heat treatment if required, through the addition of sheroidizing agent such as magnesium to the cast iron melt [5].

Because of the high strength, high toughness, good machinability, low cost and high reliability, ductile irons are widely used in the critical components such as crankshafts, front wheel spindle supports, complex shapes of steering knuckles, engine connecting rods, wheel hubs, truck axles, cylinder liners, etc. [6,7]. The mechanical and tribological properties of ductile irons are directly related to their matrix microstructure. The microstructure of ductile irons may be entirely ferritic, entirely pearlitic, or a combination of ferrite and pearlite, with spheroidal graphite distributed in the matrix. Kenawy *et al.* [8] found that the mechanical properties of ductile irons, with carbon equivalent percentage ranging between 4.5% and 4.76%, decrease with increasing size of casting module. They also showed that annealing reduces mechanical properties and hardness. While Rousiere and Aranzabal [9] could produce mixed structure consists of ferritic-austenite in ductile iron through ferritization treatment followed by an austenitization treatment in the domain (α-γ) and then a salt bath isothermal quenching.

The effect of melting and casting conditions on the ductile irons properties were investigated by Bockus and Dobrovolskis [10]. They found that the temperature, holding time and chemical composition of the melt in an induction furnace change the intensity of spheroidizing effect on the carbon and residual magnesium contents in the ductile iron castings.

High temperature wear behavior of ductile iron was studied by Celik *et al.* [11]. They found that ductile iron exhibited the highest resistance to abrasion at temperature ranging between 50 and 100 $^{\circ}$C. While Abdel Aal *et al.* [12] found that the electrodeposition of Ni-SiC composite material on the ductile iron improves the hardness and wear resistance in contrast with uncoated one.

In this work, some light will be thrown to assess railway shoulder that made from ferritic ductile iron by studying its microstructure and mechanical properties to guarantee the best chemical composition and processing that gives ferritic ductile iron according to the standard

ASTM A536 grade 65-45-12 from several experiments in the as-cast condition without post heat treatment.

2. Experimental Procedure

Several melts using pig iron, low carbon steel, graphite and ferrosilicon FeSi75 as starting materials were prepared using 50 kg capacity RF induction furnace type Elotherm. The chemical compositions of starting materials are illustrated in Tables 1-3. After adjusting the chemical composition, sampling of the melt was carried out for posterior chemical analysis using optical emission spectrometer (OES) type Thermo ARL 3460. All melts were transferred individually using traditional ladle into the special ladle named tundish cover reactor where the melt treated with spheroidizing agent which achieved using FeSiMg9. The chemical composition of spheroidizing agent is illustrated in Table 4. The spheroidization treated melt was then poured into the sand mould cavity which has the railway shoulder morphology through the gating system at temperature fixed about 1450 $^{\circ}$C. The gating system and railway shoulder are illustrated schematically as in Figures 1 and 2 respectively. The determination of pouring temperature was achieved using pyrometer type Zorelco. Inoculation was performed using inoculating agent (Table 5) in which in-mould inoculation was applied. During in-mould inoculation, the inoculating agent was placed in a specified chamber designed specially to be within the gating system of the sand mould where the reaction takes place between the spheroidization treated melt and the inoculating agent. The sand mould was covered with exothermic material in order to slow down the solidification and thereafter to prevent formation of pearlite and carbides. From the several experiments, the best chemical composition that gives ferritic ductile iron with mechanical properties coincide with the standard ASTM A536 grade 65-45-12 is tabulated in Table 6.

For metallographic examination, part of the cast was sectioned and then ground using 250, 500 and 1000 SiC emery papers respectively. Primary and final polishing was performed using alumina slurry with particle size of 50 µm and diamond paste with particle size of 1 µm respectively. Finally all polished samples were etched using 2%Nital etching solution.

The measurement of spheroidal graphite count, defined as the number of spheroidal graphite per squared millimeter, was achieved using an image J program. In this program, standard ruler picture was used to establish measurement scale. After setting the measurement scale, the microstructural picture of ferritic ductile iron was inserted to the program and spheroidal graphite count was measured.

The tensile test was performed using UTS apparatus (Thyson company, Germany) with 200 kN loading capacity in which three tensile test specimens have been tested and the average was determined. The tensile test specimen was sectioned from the direction perpendicular to the cast riser in which the gauge length section has the dimension of 12.5 mm diameter and 32 mm gauge length according to the ASTM designation: E 8M-87. The tensile test was achieved at room temperature in ambient air at a cross-head speed of 2 mm/min.

3. Results and Discussion

There are two steps must be carried out by foundarymen in order to produce desired microstructure and properties of ductile iron. If there is confusion between one of them, one can not obtain the required type of ductile iron. This may be related to the matrix phase(s) that evolved during solidification and/or related to graphite morphology [1]. The first step related to spheroidizing agent such as magnesium, as in this work, that must be added in sufficient amount in order to produce the required degree of spheroidization. If insufficient amount of magnesium is added, several morphologies of graphite are obtained depending on the magnesium amount. Compacted graphite structure with inferior properties may be produced if the magnesium amount is too low, while too high amount of magnesium may promote dross defect. The main purpose of spheroidizing agent is to create the condition for graphite to precipitate and grow in spheroidal shape. The second step that must be achieved carefully related to inoculation process. The inoculating agent is usually ferrosilicon that contains small amount of aluminum, as in this work, or may be contained other elements as in other types [5]. The main purpose of inoculating agent is to reduce undercooling during solidification and prevent formation of carbides in the structure. Furthermore, it increases the number of graphite spheroids. This leads to improve homogeneity, assist in the formation of ferrite and therefore promote ductility.

Figure 3-a shows the microstructure of ferritic ductile iron. It is clear from this figure that the matrix of ferritic ductile iron shows a divorced eutectic of well-shaped spheroids of graphite in austenite while has transformed to ferrite during slow solidification in sand mould. Figure 3-a also shows the potent effect of spheroidization on producing graphite with spheroidal shape. Furthermore, the results also showed that inoculation has a crucial role on increasing spheroidal graphite count approximately up to $180/mm^2$. The obtained graphite morphology with specified number and size of graphite spheroids in ferritic matrix of ductile iron guarantee good hardness (180 HB) and mechanical properties.

To produce ductile iron with ferritic matrix without post heat treatment, one must accomplish the above explained steps with controlled chemical composition, melting and casting. Any deviation in chemical composition that mentioned in experimental procedure will lead to change the size and morphology of graphite, and evolve other phases in the matrix. One of the failed ductile iron casts that was produced with 0.34%Mn and 2.3%Si can be shown in Figure 3-b. The microstructure that presented in Figure 3-b is known as Bull's eye which consists of graphite spheroids surrounded by ferrite shell and pearlite phase. Bull's eye structure leads to increase the strength and hardness but decreases the ductility to approximately zero. The same microstructure can be produced also by austenitizing ductile iron at 900 to 925 $^{\circ}$C, air cooling to room temperature, and then reheating and holding at 680 to 700 $^{\circ}$C for a sufficient time to form ferrite around the graphite spheroids in a Bull's eye structure [3].

Engineering stress-strain curve of ferritic ductile iron is shown in Figure 4. It is clear from this figure that the resulted 0.2%proof strength (380 MPa), tensile strength (570 MPa) and total elongation (12%) are greater than the minimum value that documented in standard ASTM A536 grade 65-45-12. This means that ferritic ductile iron produced in this work can satisfy the required application for railway shoulders. Kocatepe et al. [13] found that the main mechanism of failure in ferritic ductile iron in tensile test is related to the void formation in necked region of fractured specimen. They indicated that microvoid nucleation is initiated at the grain boundary junctions, and the interface between the graphite spheroids and the surrounding structure which is ferrite phase.

4. Conclusion

The important notices that concluded from analysis the manufacturing of railway shoulder made from ferritic ductile iron can be summarized as below:

1-Metallographic examination, tensile and hardness tests revealed that the produced ferritic ductile iron has characteristics and properties coincide with the required application properties according to the standard ASTM A536 grade 65-45-12.

2-The controlled chemical composition, melting and casting are very important factors that must be determined in order to produce ferritic ductile iron in the as-cast condition. Any variation in these determined factors lead to produce other types of ductile irons with different microstructures and properties.

5. References

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Table 1 Chemical Composition of Pig Iron.

C%	Mn%	Si%	P%	S%	Fe%
3.20	0.19	1.90	0.05	0.01	Residual

Table 2 Chemical Composition of Low Carbon Steel.

C%	Mn%	Si%	S%	P%	Cr%	Ni%	Mo%	Cu%
0.18	0.20	0.30	0.02	0.03	0.12	0.11	0.19	0.09

Table 3 Chemical Composition of Ferrosilicon.

Si (%)	Cr (%)	Mn (%)	Al (%)	C (%)	Ti (%)	P (%)	S (%)
75	0.5	0.7	2	0.1	0.1	0.05	0.04

Table 4 Chemical Composition of FeSiMg9.

Si%	Sr%	Ca%	Mg%	Fe%
14	0.3	1	9	Residual

Table 5 Chemical Composition of Inoculator.

Si (%)	Cr (%)	Mn (%)	Al (%)	C (%)	Ti (%)	P (%)	S (%)
75	0.5	0.7	2	0.1	0.1	0.05	0.04

Table 6 Chemical Composition of As-Cast Ferritic Ductile Iron Obtained from OES.

C%	Si%	Mn%	S%	P%	Cr%	Ni%	Mo%	Cu%	Mg%
3.72	2.92	0.24	0.021	0.06	0.03	0.01	0.02	0.1	0.02

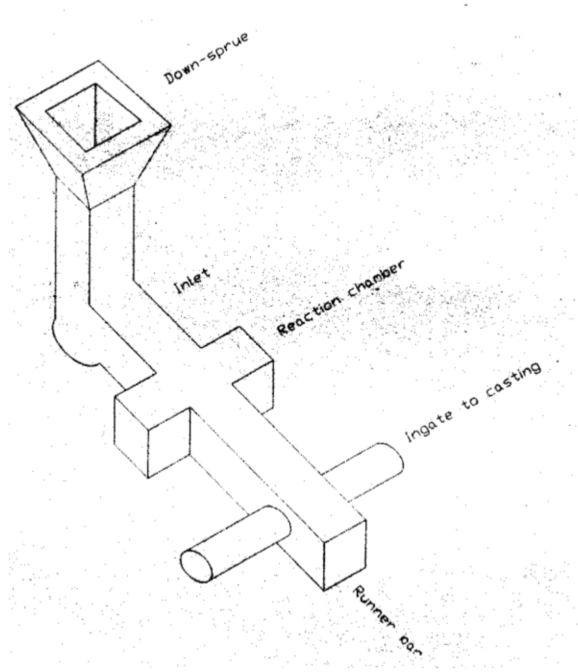


Figure 1 Schematic Illustration the Gating System.

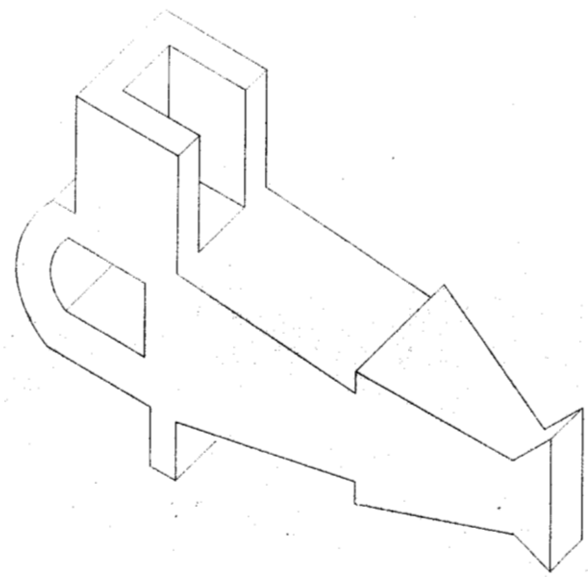
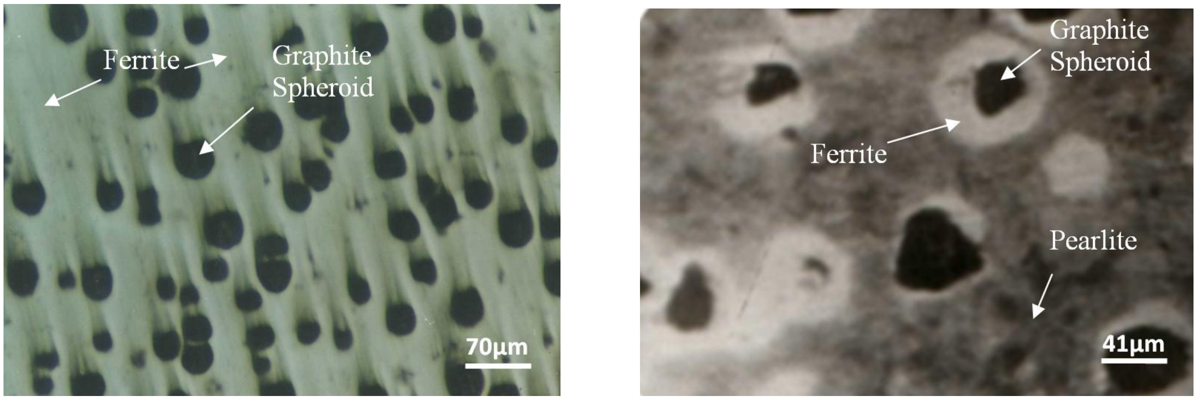


Figure 2 Schematic Illustration the Railway Shoulder Casting.



(a) (b)

Figure 3 Microstructure of Ductile Irons, (a) As-Cast Ferritic Structure, (b) Graphite Spheroids Surrounded by a Ferrite Shell and Pearlite Phase in Bull's Eye Structure.

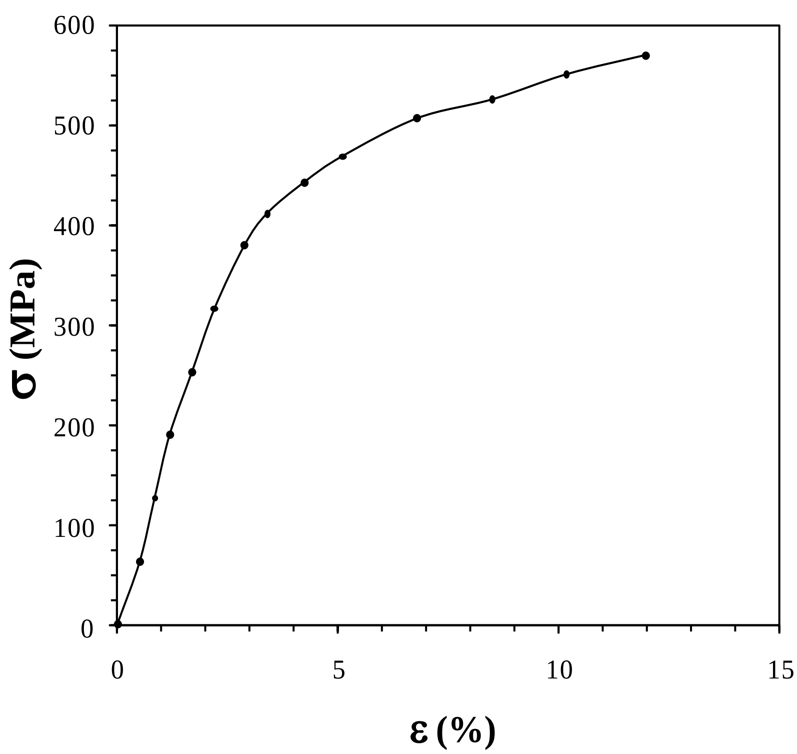


Figure 4 Engineering Stress-Strain Curve of As-Cast Ferritic Ductile Iron.