INVESTIGATION OF DUCTILE IRON IN MOLD TREATMENT PROCESS PARAMETER

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project report and in my opinion, this project is adequate in terms of scopes and quality for the award of the degree of Bachelor of Mechanical Engineering with Manufacturing.

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STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotation and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ABSTRACT

Ductile iron was first developed in 1943 and it is widely used in automotive industry. The difference between cast iron and ductile iron is due to the presence of spheroid graphite in the matrix of ductile iron which is not found in brittle cast iron. Ductile iron possesses higher ductility and tensile strength than in cast iron. It is inexpensive and castability compared to steel. Magnesium is an effective nodularization agent and it is added into the molten iron to produce nodular shape of cast iron. This is happened through a mechanism called heterogeneous nucleation. In this project, it is divided into two stages, foundry laboratory and parameters investigation. Magnesium ferrosilicon is used as the nodularization agent for the nodularization process. “In mould” treatment is a method of late inoculation. A special reaction chamber is built and placed in the gating system. This is an effective technique to obtain highest magnesium recovery and eliminate fading problem. The production of ductile iron is obtained through sand casting process. It is controlled by using different amount of magnesium ferrosilicon and casting size. Then, the ductile iron casting is investigated to observe corresponding material behaviour and mechanical properties through hardness test and metal analysis. As a result, these parameters are significantly influence on the nodularization of ductile iron casting.

ABSTRAK

Besi mulur (Ductile iron) telah dihasilkan pada 1943 dan digunakan secara besar-besaran dalam industri automotif. Perbezaan antara "cast iron" dan besi mulur ialah besi mulur mempunyai "spheroid graphite" manakala "brittle cast iron" tiada komponen tersebut. Besi mulur mempunyai takat mulur dan "tensile strength" yang tinggi berbanding dengan "cast iron". Selain itu, besi mulur lebih murah daripada "steel". "Magnesium" merupakan "nodularization agent" yang baik. "Magnesium" ditambahkan ke dalam besi yang lebur untuk menghasilkan "nodular shape of cast iron" melalui process "heterogeneous nucleation." Projek ini dibahagikan kepada dua bahagian, iaitu "foundry laboratory" dan "parameters investigation". "Magnesium ferrosilicon" digunakan sebagai "nodularization agent" untuk process "nodularization." "In mould treatment", juga dikenali sebagai "late inoculation." Satu kebuk akan dibina khas dan diletakkan dalam "gating system." Ini merupakan teknik yang paling berkesan untuk membaiki pulih "magnesium" dengan cepat dan menghapuskan masalah "fading". Penghasilan besi mulur adalah melalui acuan pasir. Kuantiti "magnesium ferrosilicon" yang digunakan dan "casting size" akan dikawal untuk menghasilkan besi mulur. Kemudian, "ductile iron casting" akan dikaji dari segi "material behaviour" dan "mechanical properties" dengan menggunakan "hardness test" dan "metal analysis". Keputusan dari eksperimen mendapati bahawa parameter tersebut memberi kesan kepada "nodularization of ductile iron casting"

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INTRODUCTION

1.1 BACKGROUND

Discovery of ductile iron was first born in 1943. A young metallurgist named Keith Millis who work for International Nickel Company had facing the shortage of chromium to manufacture the wear resistant of iron. From his project research, he had found an alternative to overcome the crisis of chromium where the magnesium alloy was added into molten iron to produced spheroidal graphite structure of iron, namely as ductile iron.

Development of spheroidals graphite shape of iron had energized the production of ductile iron since 1949. The demand of ductile iron was steadily increased in the sector of automotive such as producing crankshaft, camshaft, piston, diesel engine parts and valves. This was due to the addition of magnesium into cast iron results a high strength to weight ratio of ductile iron. Besides, ductile iron is inexpensive and castability compared to steel.

The formation of ductile iron is due to the degeneration of brittle cast iron with flakes structure of graphite and turn into spheroidal graphite in structure. Compared to cast iron, ductile iron has higher ductility, tensile strength, resistance to elevated temperature oxidation, and machinability. Besides, ductile iron was continuously developed and become an alternative to steel due to its superior mechanical properties.

Magnesium is the most effective spheroidizing agent but it does not react individually with iron. Violence chemical reaction might take place when using magnesium alone to produce the nodular shape of graphite. This is due to lower boiling point of Magnesium (1090 ˚C) compare to ferrous melting point (1536 ˚C). Thus, magnesium ferrosilicon (MgFeSi) alloy was developed and made the iron treatment easily. Magnesium ferrosilicon also gives the highest reliability to the magnesium recovery.

The addition of magnesium ferrosilicon into the melt of iron is known as inoculation process. The mechanism of heterogeneous nucleation results the formation of small crystals in nodular shape. Low content of phosphorus and sulfur are very important in controlling the inoculation process in order to obtain higher number of nodules in structure.

There are two types of inoculation, early inoculation and late inoculation. In mould treatment is a method of late inoculation. A specific location called as reaction chamber is essential to build in the gating system for magnesium treatment. It is the most effective technique to obtain highest magnesium recovery and eliminate the fading problem compared to tundish process, sandwich treatment, and open ladle treatment. Besides, it consumes less inoculant agent during inoculation.

As a result, the formation of ductile iron is influence by the addition of magnesium and technique used for inoculation. These factors will directly give impact to the grain size, shape and distribution of graphite which tends to change the microstructure, physical properties and mechanical properties

1.2 IMPORTANCE OF RESEARCH

The interaction between percentage of magnesium ferrosilicon and casting size will enhance the understanding of inoculation efficiency in mould treatment method. The transformation of the flakes graphite in cast iron into spheroid graphite in ductile iron is crucial by controlling the parameters.

1.3 PROBLEM STATEMENT

The formation of ductile iron in mould treatment is dependent on the inoculation process. Generally, it is controlled by various parameters such as percentage of magnesium ferrosilicon and casting size. The efficiency of inoculation is observed and determined by investigate the relationships of the percentage of magnesium ferrosilicon used and the mass of casting in this project.

1.4 OBJECTIVES

The project is concentrate on:

i. The study of ductile iron in mould treatment casting.
ii. The investigation of the design parameter to the formation of ductile iron.
iii. The investigation of the material behaviour and mechanical properties of ductile iron.

1.5 SCOPES

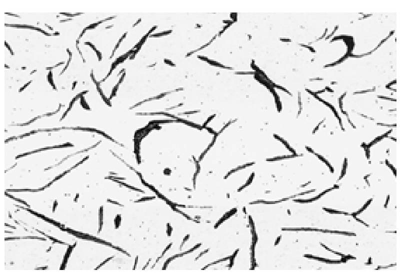
i. The sand casting process was used in casting of ductile iron.
ii. Inoculation was controlled in mould treatment method.
iii. Magnesium ferrosilicon was used as inoculant.
iv. Casting size was up to 1.5 kg in mass.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Ductile iron has been discovery since 1943 and becomes one of the most important engineering materials due to its low density. The application of ductile iron most used in automotive and machine tool industry. Difference of ductile iron from cast iron is the existing of nodular shape of graphite within its matrix as Figure 2.1. Nowadays, the use of ductile iron has increased in various industries due to its cost effective and superior mechanical properties compared to steel (Sheikh, 2008). It is also exhibit an excellent castability which is not found in steels.



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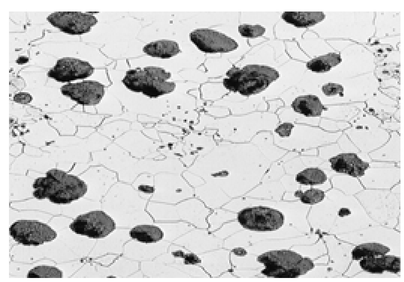

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Figure 2.1: Microstructure with magnification 100X. (a) cast iron with graphite flakes (b) ductile iron with graphite nodular form

Source: Kalpakjin and Schmid (2006)

2.2 IRON CARBON EQUILIBRIUM DIAGRAM

Based on iron-carbon equilibrium diagram, the carbon content for cast iron is in range of 2 % up to 6.67 % as Figure 2.2. For steel, it is less than 2 % of carbon content. From practices, cast iron usually contains 2 % to 4.5 % of carbon. The presence of cementite or known as iron carbide (Fe_3C) in cast iron results an extremely hard and brittle inter-metallic compound. Thus, some alloying elements are added to cast iron to improve its mechanical properties and material behaviour.

In general, 0.5 % to 3 % of silicon is used to decompose the cementite into ferrite and carbon. From several researches, an excess of silicon will inhibit the formation of hard carbides but it is saved energy (Schrader and Elshennawy, 2000). Low sulfur content must be kept and below than 0.01 % for the composition of cast iron especially in ductile iron. This is due to the decomposition of cementite after combines with iron to form iron sulfide and it tends to weaken the grain structure.

Manganese is used to combine with sulfur and form manganese sulfide. This will segregates as harmless inclusion but excess of manganese will make the iron harder after combine with carbide. 0.5 % to 0.8 % of manganese is sufficient for cast iron. Phosphorus in cast iron tends to increase the fluidity of cast iron and promote the formation of graphite (Schrader and Elshennawy, 2000). However, high content of phosphorus will form a brittle iron phosphate that has higher hardness and wearability but reduce the impact strength. Thus, less than 0.5 % of phosphorus is added to cast iron.

Accomplish with well manufactured of ductile iron, it has tensile strength varies from 350 Mpa to 900 Mpa, Brinell hardness varies from 150 to 320 BHN, high ductility, machinability and corrosion resistance (Ravi, 2005).

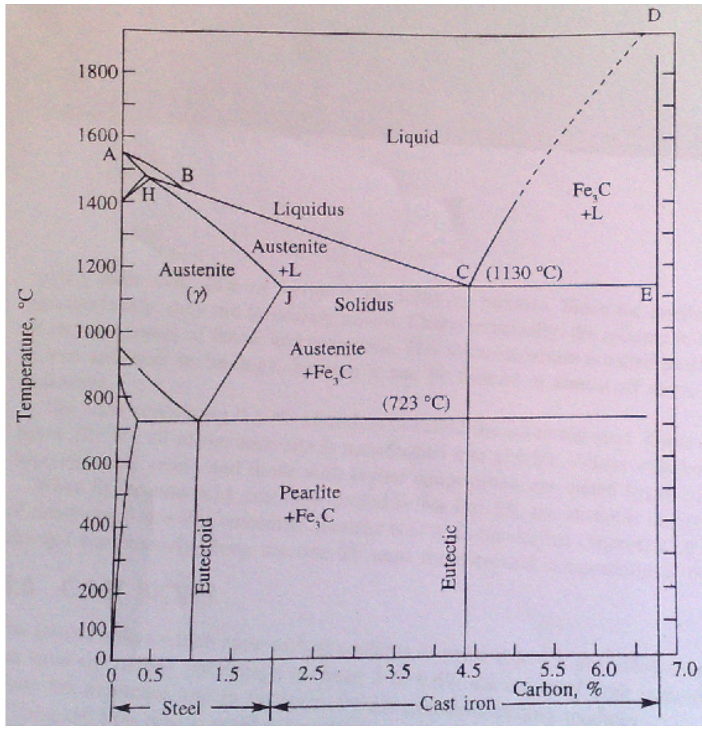


Figure 2.2: Iron carbon equilibrium diagram

Source: Rao (1998)

2.3 STRUCTURE AND DISTRIBUTION OF CARBON IN CAST IRON

Based on literature, cast iron was characterized by its colour of the fracture surface (Fredriksson and Akerlind, 2006). White iron has a reflecting surface which contains precipitated cementite. Grey iron has a greyish appearance and its matrix contains precipitated graphite. For grey iron, the shape and appearance of graphite are various. However, the main types are flake cast iron and nodular cast iron. The nodular cast iron also known as spheroidals graphite and it consists of spherical nodules and surrounded by austenite.

2.4 PRODUCTION OF NODULAR CAST IRON WITH MAGNESIUM TREATMENT

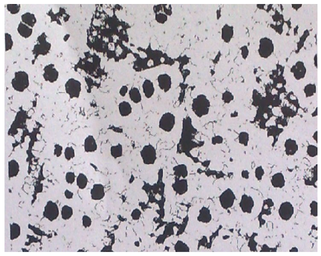
The production of nodular cast iron started in the middle of the 20th century and this improved the mechanical properties of cast iron like ductility and tensile strength. Nodular cast iron has superior mechanical properties especially ductility and thus well known as ductile cast iron. Metallurgical and metallographic control is very important to the production of ductile iron. The fundamental material is pure cast iron with low phosphorus content but free from impurities. The average composition of nodular cast iron is shown in Table 2.1.

Addition of magnesium to the melt of cast iron is the critical part of production process. It tends to precipitate the flake graphite in cast iron to from discrete nodules which is the spheroidals shape of graphite in ductile iron. Magnesium boils at about 1100 ˚C but cannot be added directly to molten cast iron due to the risk of explosion (Fredriksson and Akerlind, 2006). Thus, magnesium is necessary alloyed with nickel or silicon for safe condition. The magnesium treatment must be conducted immediately to resist oxidation and evaporation that may lead to magnesium fades away. This means the nodular structure in cast iron will partly disappears and yields unacceptable ductile iron with low nodular density as Figure 2.3.

Table 2.1: Alloying elements in nodular cast iron

Element	Content (%)
Carbon	3.3 – 3.8
Silicon	1.8 – 2.5
Manganese	0.1 – 0.7
Phosphorus	$\leq$ 0.1
Sulfur	$\leq$ 0.1

Source: Fredriksson and Akerlind (2006)



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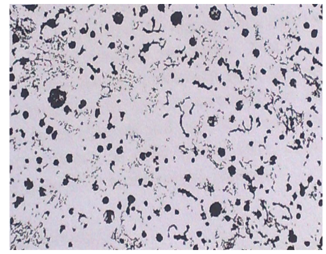

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Figure 2.3: Ductile iron (a) with high nodular density - successful product (b) with low nodular density - unacceptable product

Source: Fredriksson and Akerlind (2006)

2.5 PRODUCTION OF NODULAR CAST IRON WITH ALTERNATIVE TREATMENT

Cerium can be used as an alternative to magnesium to obtain nodular cast iron. It is either adding nickel cerium or silicon cerium to the melt of cast iron. Silicon cerium is cheaper than nickel cerium but encountered several practical problems such as floatation, rapid reaction, and heat generation (Fredriksson and Akerlind, 2006). Besides, cerium may react with carbon to form carbide although it reacts easily with both oxygen and sulfur. Therefore, nickel cerium is easier handling than silicon cerium.

2.6 INOCULATION PROCESS

Inoculation is the process of adding small amount elements to the molten metal and induced the formation of small crystals. The crystals are formed under a mechanism called heterogeneous nucleation which implies that the addition of particles act as nuclei in the molten metal for subsequence growth of new solid phase (Skaland, Grong, and Grong, 1993, and Ostberg, 2005). These elements are known as inoculants which used to control the grain size, shape and distribution of graphite (Sharma, 2004). Thus, it tends to change the microstructure, physical properties and mechanical properties of the metals. Some common inoculants are ferrosilicon, magnesium, calcium, aluminium, titanium, and zirconium.

Magnesium is the most effective nodulizing agent that used in foundry to produce a quality ductile iron castings and ferrosilicon alloy is the most common inoculant that used to treat cast iron. Inoculants can be supplied to the molten metal in an effective and controlled way. There are two methods for addition of inoculants to the melt during casting process, either in early inoculation or late inoculation (Fredriksson and Akerlind, 2006).

In early inoculation, the inoculants are added into the ladle. There are three alternatives ways to perform in casting process. First, inoculants are poured directly into the ladle which contains of molten metal. Second, air-blown small particles or inoculants are injected into the molten metal in the ladle. Third, a wire of inoculants is fed into the molten metal in the ladle. However, the disadvantage of using the early inoculation is only a small amount of inoculants will remain in the mould due to the inoculant fading problems.

However, fading problems are improved by using late inoculation method which is poured directly into the mould rather than ladle. There are three alternative methods for late inoculation, in stream inoculation, wire inoculation, and in mould inoculation (Lerner, 2003). In stream inoculation, inoculants are injected by mean of dry compressed air into the stream flow of molten iron when enter the mould (Riaboc, 1999). Usually, this process is involved with automated pouring. In wire inoculation, pouring siphon of the pressurized induction holding furnace is prepared for the injection of inoculants to the molten iron (Riaboc, 1999).

In mould inoculation, the inoculants are placed at a suitable point at the gating system (Fredriksson and Akerlind, 2006). Generally, a reaction chamber is built and placed in contact with the sprue and runner to dissolve inoculants gradually. An even and continuous treated of inoculants is reaches to the mould. Besides, it gives a high magnesium recovery which is 70 % to 80 % as in Table 2.2.

Table 2.2: Comparison of magnesium recovery

Technique	Magnesium recovery (%)
In mould treatment	70 to 80
Tundish cover process	up to 75
Open ladle treatment	50 to 70
Sandwich treatment	30 to 50

Source: Lerner (2003)

From Table 2.2, these are the common methods used to produce ductile iron. For tundish cover process, it has a special design cover for the ladle to improve magnesium recovery and eliminate glare and fume. Refractory is used and form an alloy pocket in the bottom of the ladle. For open ladle process, heavy magnesium content of alloys is used for treatment and it is placed at the bottom of the ladle. For sandwich treatment, it is needed a cover of steel scrap to be placed on top of the treatment alloys such as magnesium ferrosilicon. This method only suitable for the treatment less than 10 % of magnesium is used.

2.7 METAL CASTING

Sand casting is a traditional method of metal casting and it is widely used in automotive industry. The advantages of sand casting are capable to cast all types of metal which is regardless to the shape, size, and weight, and low tooling cost are used (Kalpakjin and Schmid, 2006). The basic steps in performing sand casting are making pattern, sand mould preparation, melting of metal, pouring of molten metal, fettling, and inspection.

2.7.1 Pattern

Pattern is the exact replica of the casting or part of interest and it is used to create the mould cavity. The pattern material is selected based on the size and shape of the casting, quantity of casting production, dimensional accuracy and moulding process. After the material selection, the pattern design becomes the critical portion in foundry process. The pattern dimensions are totally different from the final dimension due to shrinkage and further processing. Thus, some allowances are added during the stage of pattern design, such as metal shrinkage allowance and machining allowance. The shrinkage allowance and machining allowance can be summarized as Table 2.3 and Table 2.4.

Table 2.3: Shrinkage allowance

Material	**Pattern dimension, mm**	**Section thickness, mm**	**Shrinkage allowance, mm/m**
Grey cast iron	up to 600	-	10.5
Ductile iron	-	-	8.3 to 10.4

Source: Rao (1998)

Table 2.4: Machining allowance for cast iron

Dimension, mm	**Allowance, mm**		
	Bore	**Surface**	**Cope side**
up to 300	3.0	3.0	5.5
301 to 500	5.0	4.0	6.0
501 to 900	6.0	5.0	6.0

Source: Rao (1998)

2.7.2 Green Sand Mould

Green sand mould consists of silica grains, 15 % to 25 % of clay and 5 % to 7 % of moisture (Bawa, 2004). It is the cheapest mould and widely used in rapid production. High shear muller is used to mix both green sand moulds with binder like bentonite uniformly and to plasticize the clay. Then, green sand mould is mechanically compacted through ramming densely around the pattern to form the mould cavities. Permeability of green sand moulds should be well controlled to prevent occurrence of blow holes and gas inclusions. Molten metal is poured into the moisture green sand moulds within 4 to 6 hours after sand mould preparation to keep away from moisture evaporation that may results surface drying and friable mould surfaces (Totten, Funatani, and Xie, 2004). Once casting is solidified, it can be removed immediately by breaking the moulds.

2.7.3 Elements of Gating System

There are five main elements in gating system, pouring basin, sprue, runner, ingates and riser. These elements are designed to ensure the mould is filled completely within smallest time; flow of molten metal is smooth without turbulence to reduce formation of dross and mould erosion; casting is solidified without any shrinkage and distortions, and maximized the casting production.

For pouring basin, it acts as a reservoir for pouring of molten metal and allows molten metal to flow into the sprue smoothly without causes mould erosion and vortex formation. It is also capable to filter the slag and dirt from entering the mould cavity (Rao, 1998). For sprue, it is the channel that connected to runner and gates before reaches to the mould cavity. Two types of sprue are commonly used, straight sprue and tapered sprue. The straight cylindrical sprue will results a narrow metal flow at the bottom. This is due to the permeability of sand mould which tends to capture atmospheric air into the low pressure area of mould. Tapered sprue is designed to eliminate the obstacle of air aspiration.