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EFFECT OF MAGNESIUM TREATMENT PROCESS ON THE PRODUCING COMPACTED GRAPHITE CAST IRON WITH DIFFERENT CASTING THICKNESS

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ABSTRACT

Strength, toughness, machinability and damping capacity are properties of compacted graphite iron that distinguish the properties between flake graphite cast iron and spheroidal cast iron. The formation of compacted graphite can be set to achieve the required specification. The formation of compacted graphite is started from spheroidal to compacted cast iron. The residual magnesium after magnesium treatment and the solidification rate have a significant role in the formation of compacted graphite. The high content of residual magnesium can obstruct the graphite plane to grow during the transformation from spheroidal to compacted shape. In addition, the cooling rate of the casting can be controlled by varying the casting thickness. The compacted graphite in the cast iron are characterized according to shape, size and distribution. The optimum compacted graphite in the cast iron that can be produced has 30 mm of casting thickness with 0.017 % of residual magnesium.

Keywords: CGI, Magnesium, Graphite, Size.

ABSTRAK

Kekuatan, ketangguhan, kemampuan mesin dan kapasitas redaman merupakan sifat-sifat besi grafit padat yang membedakan sifat antara besi tuang grafit serpihan dan besi tuang spheroidal. Pembentukan grafit yang dipadatkan dapat diatur hingga mencapai spesifikasi yang dibutuhkan. Pembentukan grafit terpadatkan dimulai dari besi cor berbentuk bulat hingga besi cor terpadatkan. Residu magnesium setelah perlakuan magnesium dan laju pemadatan memiliki peran penting dalam pembentukan grafit padat. Kandungan sisa magnesium yang tinggi dapat menghalangi pertumbuhan bidang grafit selama transformasi dari bentuk bulat menjadi padat. Selain itu, laju pendinginan pengecoran dapat dikontrol dengan memvariasikan ketebalan pengecoran. Grafit yang dipadatkan dalam besi cor dikarakterisasi menurut bentuk, ukuran dan distribusinya. Grafit terpadatkan optimal pada besi tuang yang dapat dihasilkan mempunyai ketebalan tuang 30 mm dengan sisa magnesium 0,017 %.

Keywords: CGI, Magnesium, Grafit, Ukuran.

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1 Introduction

In a foundry process, cast iron is a well-known material that has excellent cast ability; hence, it is easy to obtain the desired geometry for the cast iron [1]. Almost all of the cast irons are used in as-cast condition to obtain the structure and geometry that are appropriate to the required specifications [2]. Cast iron is classified based on the morphology of the graphite such as flake, spheroidal, and compacted/vermicular [1]. The flake graphite is excellence in damping capacity, has good machinability, and it can uses as a chip breaker in lubricating the cutting tools. However, the flake graphite is a stress concentrator, so it has poor in toughness [3]. Spheroidal irons are inferior to flake irons in physical properties such as thermal conductivity but exhibit better in mechanical properties [1].

Compacted/vermicular graphite is developed to synergize the properties of flake graphite and spheroidal graphite such that it has high strength, toughness, thermal conductivity, cast ability, machinability, and good in damping capacity. It has a morphology that contain graphite precipitates with a short, stubby, compacted shape with round edges [4]. The compacted graphite cast irons are mainly used in the components for the automotive industry, like exhaust manifolds, brake components, cylinder heads, and cylinder blocks [5].

There are two factors that affect the formation of compacted graphite cast iron; (1) chemical composition including liquid metal treatment process (i.e. magnesium treatment) and (2) cooling rate during solidification [6]. The liquid metal treatment process for producing compacted graphite is carried out by adding magnesium into the liquid metal, which is known as magnesium treatment. Magnesium treatment is performed with Fe-Mg-Si alloy and followed by graphite compacting treatment [7].

The residual magnesium and fading time in magnesium treatment process will affect the percentage of compacted graphite in the cast iron, in which 0.006% of the residual magnesium is the lowest limit [8]. Because of the decrement in the active surface of magnesium in the spheroidal graphite, the fading time in magnesium treatment will cause the transformation of spheroidal graphite into compacted graphite. The slow cooling rate is needed to promote the formation of compacted graphite [8].

One of the difficulties in producing compacted graphite is to control the morphology of graphite [5]. The specification of compacted graphite is strictly controlled by ISO (16112:2006). It states the ratio of length to thickness in the compacted graphite needs to have a value of 2-10, and the maximum percentage of spheroidal graphite is 20% while the formation of flake graphite must be avoided [8]. According to ASM metals handbook volume 15, the formation of compacted graphite iron is only based on the percentage of residual Magnesium. However, the cooling rate plays also an important role in obtaining compacted graphite.

This study aims to investigate the effect of the residual magnesium and the cooling rate by varying the thickness of the cast iron to produce compacted graphite with specific length to thickness ratio. The maximum content of compacted graphite can be obtained in the maximum percentage of residual magnesium and the slowest cooling rate.

2 Experimental Methods

2.1 Material

Compacted graphite iron was manufactured using several materials including return material of spheroidal graphite cast iron, steel scrap, carburizer, ferro-silicon, ferro-manganese, inoculant, dan nodulizer. The range of Carbon Equivalent content was controlled within 3.7-4.7%. Inoculation process is essential in the formation of graphite in cast iron. The composition of inoculant was kept within 0.2-0.5% from the weight of the liquid metal [9].

Fe-Mg-Si was used as nodulizer in Magnesium treatment process which performed by sandwich ladle method. The amount of added magnesium during magnesium treatment was varied to obtain various amount of residual Mg in the cast iron (Table 1).

Table 1. Target percentage of residual magnesium

Sample	Added Magnesium (gr)	Residual Magnesium (%)
1	230	0.010
2	460	0.020
3	690	0.030

The pouring temperature during casting process was set according to the minimum thickness of the casting [10]. The minimum thickness of the casting in this study was 5 mm, while the pouring temperature was 1425°C [11]. The compacted graphite was formed during the fading process direct after the tapping step. The fading time was constantly set to 2 minutes which were chosen according to the previous study [12]. The tapping temperature was 1525°C which was then cooled down to 1325°C within 2 minutes of pouring.

The sample used in this study had a plate shape with a thickness of 5mm, 15mm, and 30 mm. the width of the samples were about 5 times or more of the thickness of the samples. So that the resulting dimensions of the sample are 35x35x5 mm (module 0.2 mm), 85x85x15 mm (module 0.6 mm) and 160x160x30 mm (module 1.1 cm).

2.2 Equipment

Induction furnace (Inductotherm, 500 Hz, 50 kW) was used for the melting process with a capacity of 250 kg. Ladle with lip pouring type was used during pouring. The chemical composition of compacted graphite iron was observed using optical emission spectroscopy (OES, ARL-3460). Shape, size, and distribution of graphite were observed with an optical spectroscopy (Olympus). Validation of graphite form (length to thickness ratio) and mechanism of formation compacted graphite were confirmed by scanning electron microscope (SEM, Hitachi SU-3500)..

3 Result And Discussion

3.1 Chemical composition of compacted graphite cast iron

Table 1 shows the chemical composition of compacted graphite iron sample 1, sample 2 and sample 3. The chemical composition of sample which was obtained using Optical Emission Spectroscopy and compared to chemical composition of the standard compacted graphite iron in the ASM reveals that the actual carbon content of sample 1 and 2 are smaller than the specified target (ASM) [13]. This is considerably caused by abnormal loses of carbon during the melting process which is around 10-14 %. However the carbon loses that occured in this study are about 17 %.

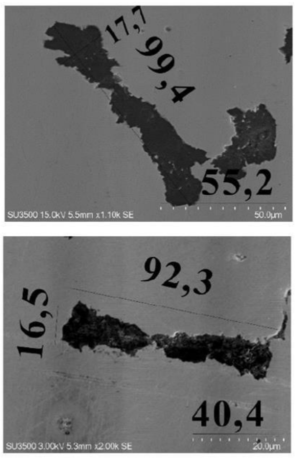
Table 2 Chemical composition of compacted graphite iron

Sample	Elements (weight %)					
	C	Si	Mn	P	S	Res. Mg
1	3.31	2.45	0.23	0.011	0.009	0.017
2	3.38	2.58	0.23	0.01	0.01	0.02
3	3.39	2.83	0.24	0.01	0.0065	0.028

The percentage of residual magnesium produced in samples 2 and 3 fit within the range of the previous target. meanwhile the percentage of residual magnesium in sample 1 is lower than the target. In this case, some of residual magnesium during magnesium treatment process evaporates and the non-condensable magnesium reacts with the active surface to produce MgS and MgO. According to ASM. The optimum percentage of magnesium residuals was obtained because the amount of magnesium that evaporates and the oxygen content was small. Compacted graphite can be obtained when the residual magnesium is controlled in the range of 0.013 to 0.022% [13]. According to Fowler et.al., by using regular Fe-Mg-Si alloy during magnesium treatment process, the compacted graphite iron can be achieved if the residual magnesium in the range of 0.015-0.020% [14]. Hence, all of sample in this study could achieve the compacted graphite in cast iron.

3.2 Shapes, size, distribution, and transformation mechanism of compacted graphite in cast iron

Shapes, sizes, and distributions of compacted graphite which were observed using optical microscopy with 200x magnification.are shown in figure 2. The study of graphite shape and size aim to determine the difference between compacted graphite and flake graphite. The difference between the morphology of the two graphite samples can be observed in the 2-dimensional view. Compacted graphite has ratio of length to thickness of 2-10 [15]. Figure 1 shows the measurement of length to thickness ratio using Scanning Electron Microscopy within 3 kV and 2000x of magnification. The ratio of length to thickness of compacted graphite in cast irons are 5.60 and 5.59. All casting thicknesses in this study have similar values of length to thickness ratio, but the size of the compacted graphite are varied. In this study, compacted graphite is achieved according to the specification [15].



$$\text{Length to thickness ratio} = \frac{\text{L max}}{\text{L min}}$$

L max = 99.40 mm
L min = 17.70 mm

$$\text{Length to thickness ratio} = \frac{99.40}{17.40}$$

Length to thickness ratio = 5.60

$$\text{Length to thickness ratio} = \frac{\text{L max}}{\text{L min}}$$

L max = 92.30 mm
L min = 16.50 mm

$$\text{Length to thickness ratio} = \frac{92.30}{16.50}$$

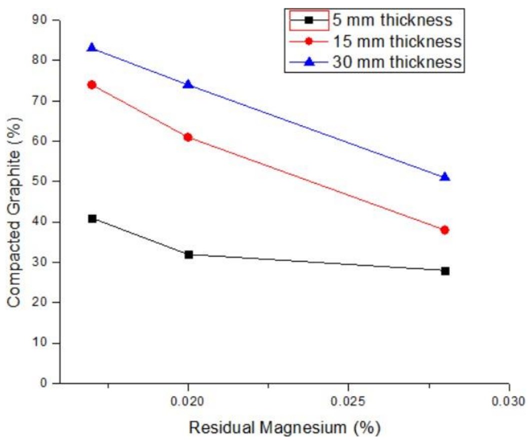
Length to thickness ratio = 5.59

Figure 1. The compacted graphite validation under Scanning Electron Microscope

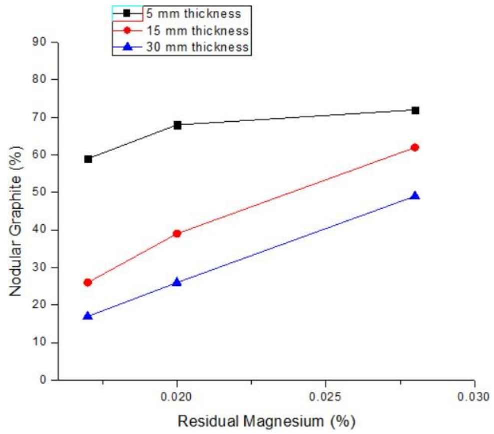
Residual magnesium shows a direct effect on the formation of compacted and nodular graphite in cast iron and its percentage accordingly. A Significant influence of casting thickness to the portion of compacted or nodular graphite can be found in almost all of residual magnesium percentage. Compacted graphite can be found in 0.006%-0.038% of residual magnesium [13]. The most significant formation of compacted graphite occurred in the percentage of residual magnesium of 0.017% as shown in figure 2.

Carlos et.al reported the range of the residual magnesium in the production of compacted graphite iron are 0.008-0.025% [16]. Therefore, the residual magnesium obtained in this study is within the range of the residual magnesium in the compacted graphite in the literature. The higher content of residual magnesium lead to the less formation of compacted graphite. This is in agreement with Kim et al., where the residual magnesium and section thickness of castings also reduce the percentage of spheroidal graphite [4].

This happens due to the differences within the cooling rate of the casting with various thicknesses. The lower castings thickness did not have sufficient time to form compacted graphite.In this study, the optimum percentage of the compacted graphite in cast iron is achieved within 0.017% of residual magnesium with casting thickness of 30 mm.



(a)



(b)

Figure 2. Effect of residual magnesium content and castings thickness on percentage of compacted graphite (a) and nodular graphite (b).

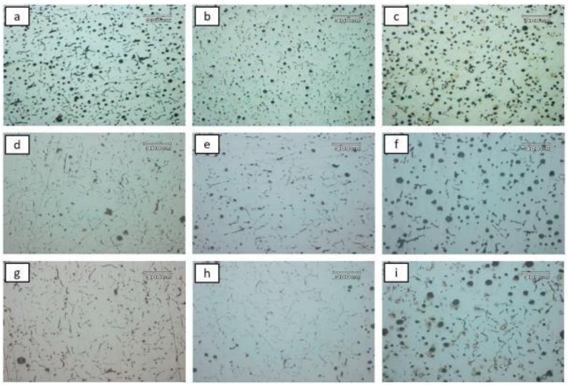


Figure 3. The shape, size, and distribution of graphite in cast iron within the residual magnesium content and casting thicknesses : (a) 5 mm 0.017%, (b) 5 mm 0.020 %, (c) 5mm 0.028%, (d) 15 mm 0.017%, (e) 15 mm 0.020%, (f) 15 mm 0.028%, (g) 30 mm 0.017%, (h) 30 mm 0.020%, (i) 30 mm 0.028%.

Cast irons can be classified according to the morphology of graphite: type I (spheroidal) and type IV (compacted). It can also be classified according to the distribution of graphite within the cast irons: type A, B, C and D. The type A distribution is the most desirable where the graphite has uniform distribution within the cast iron. In this case, the graphite distribution in our cast iron is confirmed to be a type A, which can be observed under an optical microscope [9]. The size of the graphite can be classified into type 1-8 which can be measured using optical microscope [9]. Figure 3 shows the micrograph of the sample and table 3 describes various sizes, shapes, and distributions of graphite in each castings

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thickness. The tendency of graphite to grow in the thicker casting is more significant than the thinner casting. The optimum shape, size and distribution of compacted graphite in cast iron is about 0.017% of residual magnesium and 30 mm of casting thickness.

Table 3. The shape, distribution and size of compacted graphite in the cast iron with various amount of residual Mg and casting thickness

		Casting thickness		
		5 mm	**15 mm**	**30 mm**
Residual Mg (0.017%)	**Graphite shape**	I & IV	I & IV	I & IV
	Graphite distribution	Type A	Type A	Type A
	Graphite size	4, 5, and 6	4 and 5	3, 4 and 5
Residual Mg (0.020%)	**Graphite shape**	I & IV	I & IV	I & IV
	Graphite distribution	Type A	Type A	Type A
	Graphite size	4, 5, and 6	4 and 5	3, 4 and 5
Residual Mg (0.028%)	**Graphite shape**	I & IV	I & IV	I & IV
	Graphite distribution	Type A	Type A	Type A
	Graphite size	4, 5, and 6	4 and 5	4 and 5

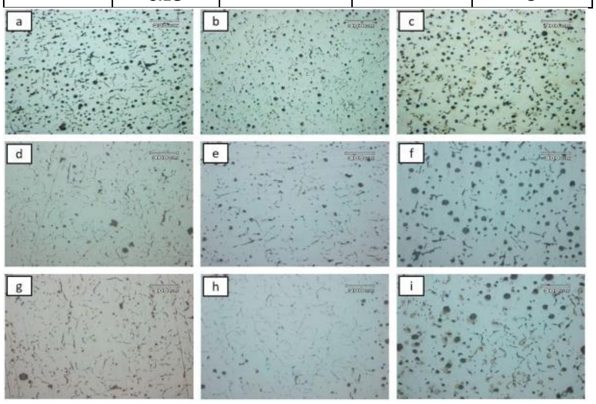
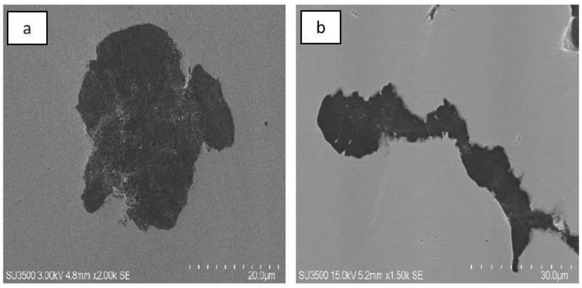


Figure 4. The shape, size, and distribution of graphite in cast iron within the residual magnesium content and casting thicknesses : (a) 5 mm 0.017%, (b) 5 mm 0.020 %, (c) 5mm 0.028%, (d) 15 mm 0.017%, (e) 15 mm 0.020%, (f) 15 mm 0.028%, (g) 30 mm 0.017%, (h) 30 mm 0.020%, (i) 30 mm 0.028%.

The transformation of nodular to compacted graphite as shown in the figure 4 was observed using a Scanning Electron Microscope after magnesium treatment.

The mechanism in the formation of compacted graphite is started from the spheroidal graphite shape. During the compacted graphite transformation, there are two growth directions: a-direction and c-direction [17]. Plane (0001) is the graphite plane where the transformation occurs from spheroidal into compacted graphite [17]. The higher content of residual magnesium can obstruct the growth mechanism and increase kinetic undercooling mechanism that cause the (0001) plane in graphite to be unstable [17]. In this study, the optimum content of residual magnesium is achieved at 0.017% where the transformation of spheroidal graphite into compacted graphite can be obtained.



(a) (b)

Figure 5. The transformation from nodular to compacted graphite (a) spheroidal graphite, (b) compacted graphite

4 Conclusion

Compacted graphite in cast iron was achieved by setting the optimum content of residual magnesium to 0.017% and the casting thickness of 30 mm. Various value of residual Magnesium and casting thickness produced two morphologies of graphite, which are type I (spheroidal) and type 4 (compacted) with a random distribution and a graphite size of 3,4 and 6. The specification of compacted graphite is determined according to the value of the length to thickness ratio (ISO:16112).

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