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Effect of Processing Parameters on the Microstructures and Properties of Automobile Brake Drum

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Abstract: In this study, the effect of processing parameters such as alloy composition and shake-out time on the microstructure and subsequently the mechanical properties of brake drums to the specification of an automobile company had been studied. The results show that processing parameters such as alloy composition (Silicon and Carbon contents) affect the quantity and morphology of the carbides formed while shakeout time affects the size of the carbide. When all other parameters are kept constant, shakeout time of a casting to obtain desired properties can be predicted using a relationship derived from multiple regression analysis in this study work. The relationship is: Shake-out time = -13.8+0.0799Si+6.954GS+0.0467 Hardness.

Key words: Brake drum, processing parameters, microstructure, shake-out time

INTRODUCTION

Automobile brake drum is part of the braking system that make contact with other parts for as many times as the brake is applied when the automobile is in motion. These contacts results in noise (squeals), frictional wear and fatigue failure of the drum. A lot of research and development have gone into the production of the brake drum in order to ensure that they perform optimally in service and that they not fail prematurely. Work is still going on in order to identify and reduce the noise level generated during braking (Lee *et al*., 2001; Fieldhouse *et al*. (2002a and b, 2003). Thermal fatigue cracks are also found to occur frequently on brake drums' surface, a phenomenon that leads to premature failure (Zhou *et al*., 2006; Heidrov, 2002; Burri *et al*., 2004; Cho *et al*., 2003).

The automobile brake drum is normally made from GL 250 cast iron on ASTM A-247 specification or the SAE standards. This specification is similar to DIN 1671 specification as presented in Table 1.

Under the standard charts available from American society for testing and materials (ASTM) specification A-247, the form of graphite should be I while the order and size should be A4-A7. Flake graphite. The graphite distribution should be uniform with an apparent random orientation. Type C is totally prohibited because of the coarse 'Kish' graphite (Walton and Opar, 1981), which is undesirable for auto-mechanical application.

It is also specified by Peugeot Automobile Nigeria Limited (PAN) that the matrix must be lamellar pearlite with ferrite content in the core be less or equal to 10% and the percentage of free carbide be less or equal to 2%.

Mechanical properties specifications for the brake Drum are

- Hardness 220±95 BHN
- Tensile strength greater or equal to 250 N/mm^2.
- Cracks of any sorts must be avoided.

Obtaining a brake drum conforming to above standards is however dependent on the following:

- Composition of the molten metal and hence on the scrap metals from which the melt is produced.
- Inoculating technique used during casting
- Mould material properties
- Shake-out time.
- Excellent casting practice.

Of highest importance in the composition of the molten metal are carbon and silicon. Silicon is necessary for the formation of graphite. It also imparts corrosion and elevated temperature oxidation resistance to the drum.

A large proportion of carbon in the automobile brake drum is present as graphite, which has little strength or hardness. The effect of carbon, silicon and phosphorus

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Table 1: Specification of brake drum (Courtesy of PAN*)

Grade	GL 250							
Component	Brake drum							
Chemical composition	CE.V 3.9-4.0	C 3.2-3.4	Si 2.1-2.3	Mn <0.8	P <0.15	S <0.12	Cu <0.8	Sn <0.8
Micrographic Structure	Graphite Matrix	1 A, Type C Prohibited Pearlite-ferrite <10% Free carbide <2%						
Mechanical Properties	Hardness (BHN)	220±25						

*PAN stands for peugeot automoblie of Nigeria

Table 2: Typical properties of moulding sand for casting brake drum (courtesy of PAN)

						Sand strength (kN m^{-2})	
AFS	Permeability	Mould strength (kN m^{-2})	Humidity (moisture content) (%)	Clay content (%)	Shatter index	Green compression	Green shear
58-70	100-140	75-95	3-5	<3	85-95	100-120	30-40

on the tensile properties of brake drum combined into a number called Carbon Equivalent Value (CEV). This CEV is expressed mathematically as:

$$C.E.V. = \text{total \% carbon}+(\text{Si \%}+\text{P \%})/3.$$

Inoculating reduces the size of the eutectic cell and the span of the graphite within each cell, thereby improving the strength of the casting (Krause, 1969). Rare earths, calcium, aluminum, barium and strontium are often used as active elements inoculants. Most commonly used is ferro-silicon. They have an important effect on the formation of nuclei of graphite during solidification, thus influencing the resulting structure (Ziegler, 1964) and strength of casting. Inoculating also promotes the formation of type A graphite. Mould material are also very important in obtaining the correct microstructure and hence the right properties in a casting. Mould materials affect the heat transfer characteristics during solidification. Sand composition requirements to produce defect-free casting of the brake drum as recommend by PAN are as shown in Table 2.

Shake-out time is of very great importance in determining the pearlite-ferrite distribution and carbide formation. The longer the shakeout time, the more the pearlite-ferrite distribution and the fewer the carbide formation (Jain, 1997). The shorter the shake-out time the finer the grain size for the grains will not have enough time to distribute themselves and consequently the harder the casting (Flinn, 1963).

The objective of this study is to develop a procedure for obtaining the properties in a brake drum (as specified by PAN) from grey cast iron using sand casting.

MATERIALS AND METHODS

Moulding sand preparation and testing: In order to meet PAN specification for sand mould properties (Table 2), sands from two sources were used. The sources of the sands and the proportion in which they were mixed are as shown in Table 3.

The proportion of 70% Igbokoda sand and 30% Bacita sand was found suitable and used throughout for the experiment. The choice of this mixture was based on the various test measured properties shown in the table.

Charge calculation and melting of charge: In order to meet the specified composition of metal from which automobile brake drum is produced, analysis of various charge materials were done using spectrometer and typical charge composition of charge materials is shown in Table 4.

Charge calculation was done based on the above composition. After melting, spectrometric analysis was done and the two results are nearly the same as shown in Table 5.

Melting is done in a coreless induction furnace of 250 kg capacity and power rating of 250 kw/1000 Hz.

Innoculating techniques: The inoculant used was ferrosilicon. This was introduced into the ladle just before tapping of the molten metal. One Hundred gram inoculant was used on every 250 kg ladle.

Post-casting treatment: The castings were left in the mould for various times before they were removed. These constituted the shake-out time. It varied from 12 min to 10 h.

Table 3: Sources of sand and their mixing proportion

Source sand	AFS80% Igbokoda +20% basita	Perme-ability	Mould strength N m^{-2}	Moisture content (%)	Clay content	Shatter index	Sand strength (kN m^{-2}) Green comp	Green shear	Dry comp	Dry shear
100% Igbokoda										
100% Basita	56	140	72	3.0	1.0	85	115	38	660	370
100% Basita	70	100	88	3.5	3.0	85	110	39	680	1360
90% Igbokoda										
+10% Basita	56	138	74	3.0	1.2	84	115	36	630	370
80% Igbokoda										
+20% Basita	57	122	78	3.5	1.4	85	114	38	640	320
70% Igbokoda										
+30% Basita	62	125	80	3.0	1.5	85	112	38	660	370
60% Igbokoda										
+40% Basita	65	120	85	4.0	4.0	84	110	32	620	300

Table 4: Specified composition of metals

Material	Composition C	Si	Mn	P	S	Cu	Sn
Pig irons	4.0	2.2	0.8	0.9	0.8	-	-
Cropped-end (OSRC)	0.23	0.2	0.5	-	-	0.30	-
Foundry Returns	2.90	2.90	0.9	-	-	0.3	0.04
Carburizer	99.3	0.1	-	-	-	-	-
Fe Si	0.1	75.0	-	-	-	-	-
Fe Mn	0.1	-	75	-	-	-	-
Copper	-	-	-	-	-	99.1	-
Tin	-	-	-	-	-	-	99.1

Table 5: Spectrometric analysis of charge

Charge	Composition C	Si	Mn	P	S	Cu	Sn
By Calculation	3.4	2.3	0.71	0.09	0.08	0.27	0.04
By Spectrometer	3.3	2.1	0.68	0.09	0.09	0.25	0.05

Metallographic examination: Specimens were prepared for micro-structural examination using standard method of preparation. Polished and etched specimens were observed under the microscope at x100 magnification to assess the following:

- The microstructure developed in the casting under various conditions.
- The type of carbide and graphite flakes formed.
- The grain size of the carbide. The linear intercept method of grain size measurement was used.

Mechanical properties: Hardness measurement were carried out on the specimens from which the tensile strength were calculated using Hardness conversion Table (DeGarmo *et al*., 1997).

RESULTS

The result of the experiment and various measurements carried out on the casting are as shown in Fig. 1 to 2.

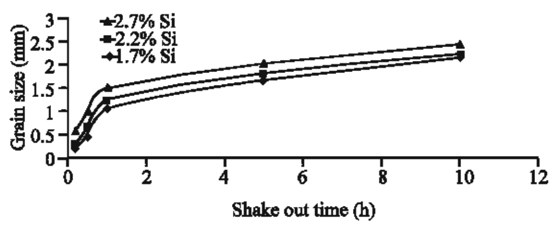

Fig. 1: Graph of shake-out time vs grain size of carbide

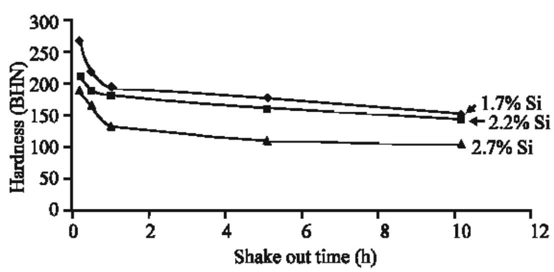

Fig. 2: Graph of shake-out time vs hardness

Multiple regression analysis was carried on the parameters that were varied (shake-out time and silicon content) and those measured (carbide grain size and hardness).

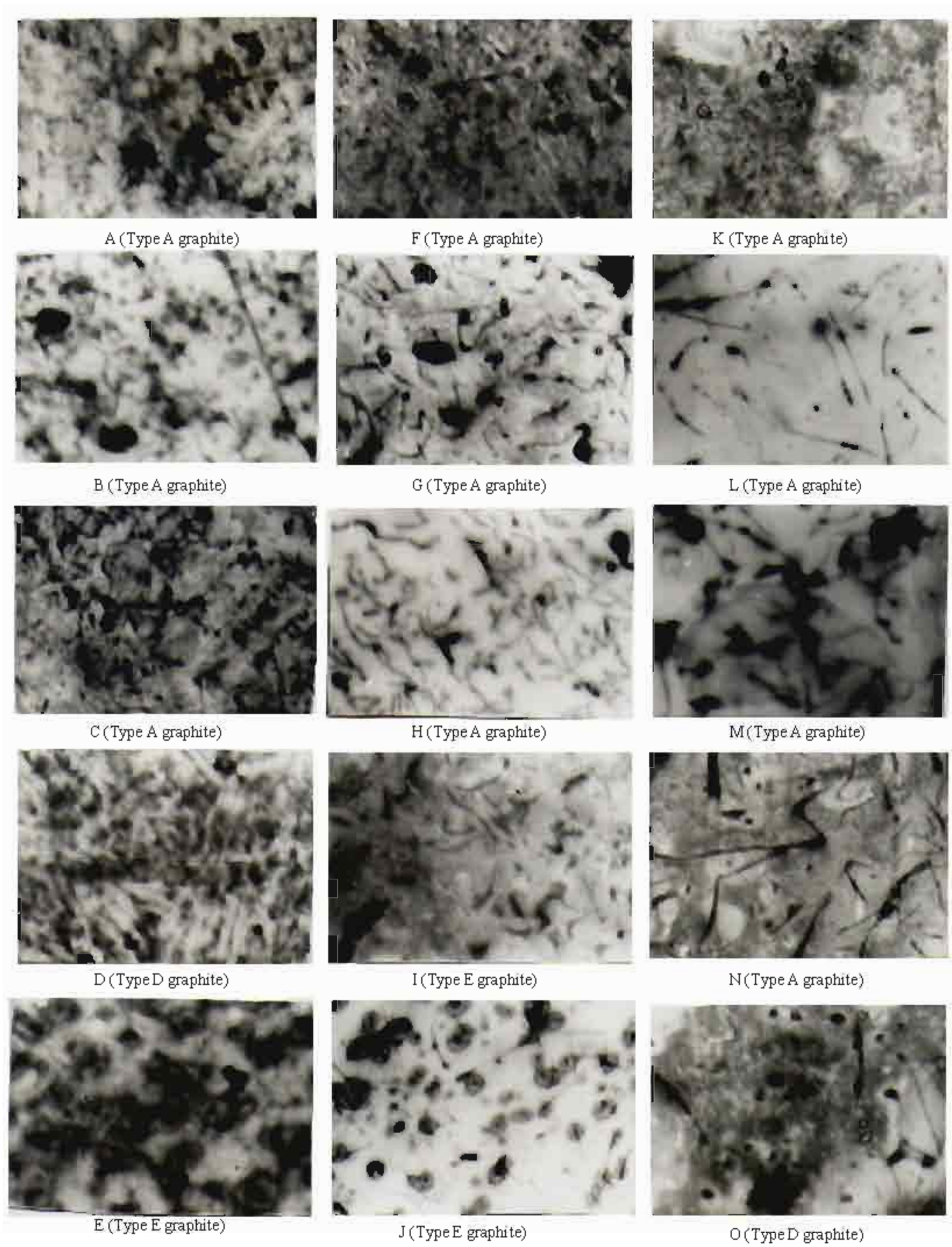

Fig. 3: Optical X 100 A-E: Optical micrographs of automobile brake drums cast in sand mould containing 1.7% Si, pouring temperature of 1400°C and shakeout times of (A = 12 min, B= 30 min, C =1 h, D = 5 h, E = 10 h), F-J: Optical micrographs of automobile brake drums cast in sand mould containing (2.2%) Si, pouring temperature of 1400°C and shakeout times of (F = 12 min, G = 30 min, H =1h, I = 5 h, J = 10 h), K-O: Optical micrographs of automobile brake drums cast in sand mould containing 2.7% Si, pouring temperature of 1400°C and shakeout times of (K = 12 min, L= 30 min, M = 1 h, N = 5 h, O = 10 h)

The result obtained with shake-out time as the dependent variable is given as:

$$\text{Shake-out time} = -13.8+0.0799\text{Si}+6.954\text{GS} +0.0467 \text{ Hardness}$$

Micrographs of the samples produced are shown in Fig. 3.

DISCUSSION

The parameters that have varied in this study are shake-out time and silicon content and those that were measured, which resulted from these variations are carbide grain size and hardness. As reported earlier in the results, multiple regression analysis has shown that:

$$\text{Shake-out-tine} = -13.895+0.799 \text{ Si}+6.954 \text{ GS} + 0.0467 \text{ Hardness}$$

Hence, shakeout time can be predicted and or specified using this equation. Also from the results of this work, grain size of carbide and hardness are both dependent on Silicon content of melt. Therefore, a particular shake-out time and silicon content can be chosen that will give the correct carbide grain size and hardness and hence the correct mechanical strength desired in the brake drum.

As the micrographs have also revealed (Fig. 3), choice of appropriate shake-out time is also necessary in order to develop the right microstructure. As shown in this figure, the finest microstructure are obtained in the shortest shakeout times at different levels of silicon (Fig. 3A, F and K). This also shows that the silicon levels are immaterial as long as the shakeout times are short. This is also evident in Fig. 1 and 2 where the hardness and grain size values almost coincide at short shake-out times.

It must be noted that the results which led to the above equation were obtained using a mould of known sand properties. Any change in the properties of the mould will definitely affect the microstructure of the brake drum, most especially the carbide grain size. It is mould properties that will determine the cooling rate of a casting and consequently how long the casting to remain in the mold before shake-out to develop the desired microstructure. It is therefore necessary in any foundry producing brake drums to determine their own relationship between shake-out time and other parameters based on their own mould properties and other raw materials for production of brake drum.

CONCLUSIONS

The control of processing parameters is of vital importance in the casting of automobile brake to required specifications and a predictive equation can be found linking all the processing parameters using multiple regression analysis. This equation can be used to predict shakeout time when all other parameters relating to mould properties are kept constant within a particular foundry.

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