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EFFECTS OF INOCULATION ON VARYING WALL THICKNESSES IN GRAY CAST IRON RECYCLING

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Abstract: Cast irons are important engineering materials, which possess a wide range of attractive properties. Their properties are significantly dependent on the microstructure of the cast irons. A way of controlling the microstructure of cast iron is through the control of cooling rates during solidification. To control the cooling rate, inoculants are necessary mostly in the thin castings. This project presents the study of the effect of inoculants of fixed composition in the wall thickness ranges from 3.5–12.5mm of grey cast iron. The chemical compositions of both the inoculated and un-inoculated were determined. The eutectic cells, the graphite flakes in the microstructure and hardness of the varying wall thicknesses were also evaluated. From the results there were significant effects of inoculants on the section thickness unlike the un-inoculated sample. The eutectic cells were more in the 3.5, 4.5 and 5.0 mm thicknesses while the other thicknesses showed the reduction in the eutectic cells. There is evenly distribution of graphite flakes in the 11.5 and 12.5 mm thicknesses of type A, 7.0 and 8.0 mm sections contain graphite flakes of type B while 3.5 and 4.5 mm sections contain no graphite flakes due to rapid cooling of the samples.
Keywords: microstructure, inoculants, graphite flakes, wall thickness, grey cast iron

INTRODUCTION

Inoculation is a means of controlling the structure and properties of cast iron by minimizing undercooling and increasing the number of nucleation sites during solidification. An inoculant is a material added to the liquid iron just prior to casting that will provide a suitable phase for nucleation of graphite during the subsequent cooling. Traditionally, inoculants have been based on graphite, ferrosilicon or calcium silicide. Almost exclusively, inoculants today are ferrosilicon based containing small quantities of active elements such as Al, Ba, Ca, Sr, and Zr.

According to Woolley cast iron can be used to produce thin-wall iron castings if developed to its full potential'[1]. There are several reasons why chilled structures are normally undesirable. Chilled structures are hard and brittle and interfere with machining, necessitate additional heat treatment operations, resulting in nonconformance with specifications and, in general, increase the total cost of production [2]. Inoculation changes the structure of cast iron by altering the solidification process. Proper inoculation practice results in reduced shrinkage, improved fluidity, the reduction of residual stresses and better machinability [3].

However, automotive manufacturers have turned to new technologies to make cars lighter. There are several disadvantages to using Al over ferrous alloys. Aluminium alloys lose their strength at high temperatures, making them unsuitable for applications where higher engine temperatures are required to produce more efficient combustion. Aluminium also provides much less damping than ferrous alloys, resulting to increased levels of noise [4]. Finally, and perhaps most significantly, Al is much more expensive than ferrous alloys.

The biggest impediment to using cast iron instead of Al is that cast iron components are often thicker than necessary to carry an applied load, resulting in added weight and reduced energy efficiency [4]. There are two reasons responsible for this. First, cast iron has a minimum casting thickness necessary to maintain its structural integrity. Second, moulding technology is often inadequate to produce quality thin-wall castings.

The definition for thin-wall casting varies. Several authors refer to thin-wall castings are being anywhere from 3mm to 5mm, while Hornung defines thin-wall as anything less than 2.5mm [5]. This work majorly focuses on casting of grey iron of thickness ranges from 3.5mm to 12.5mm.

MATERIALS AND METHODS

Equipment and Materials

The equipment and tools are: Rotary furnace, sieve, moulding box, blower, strike-off bar, shovel, band saw, gating tools, grinding and polishing machine, mounting machine, bellow, and pyrometer. The major materials are: Engine-block scraps iron, graphite, fuel (diesel), green sand, 7 wooden pattern (block form) of dimensions 60mm x 40mm and varying thickness of 3.5-12.5mm, parting sand, facing sand, ferrosilicon (0.2 wt % inoculant).

Pattern Design

The patterns were made of wooden material in block form. The pattern comprises 7 sheets of plywood of different thickness of 3.5-12.5 mm. It is rectangular in shape with a very smooth surface. Good design was incorporated in the making of the pattern to ensure a perfect cast.

Making of Mould

The mould was prepared with green sand. The green sand have good permeability, good grain size, accurate moisture content and with a very good refractoriness. Bentonite was added to the green sand to increase its bonding strength. Suitable flask is first selected large enough to accommodate the pattern.

Facing sand was put into the drag and the content was well rammed. The drag was turned upside down on the mould board, the pattern as well as its accessories were placed on the board inside the flask in such a position that space is left for gate cutting. Parting sand was sprinkled over the top surface and the drag is turned upside down.

The cope was placed over the drag and top parts of the pattern assembled in position. Runners, risers were put in position and supported vertically by taking a small amount of moulding sand around them, therefore, the excess sand was cut off, runners, riser and pins removed, venting was done on the top surface of the mould. The pattern and its accessories were removed from both the drag and cope. The sprue well and in-gate was dressed to allow molten metal to flow freely into the mould cavity without turbulence.

Charged Materials

The materials charged in the furnace are 60kg of engine scraps iron, 40kg ferrosilicon, 2kg flux and 4kg graphite.

Melting and Casting Processes

The furnace is first preheated to about 1 hr. After melting of the scraps, the molten metal was tapped at a temperature of 1555ºC. The pouring temperature was 1520ºC, right from the pouring to the ladle; the inoculant (0.2% ferrosilicon of elemental compositions: Si-74.22%, Ca-2.44%, Al- 1.21% and Zr-1.21%) was added to the molten metal. The molten metal was quickly poured into the mould before the inoculants faded away.

Evaluation of the Parameters

After casting, the samples were cleared from unwanted particle that attached to the cast. Each of the samples was cut and various tests were performed on them. The operations performed on the samples were chemical analysis to determine the composition of various elements present in the sample, metallographic analysis to reveal the eutectic cells using Stead's reagent (8g of $MgCl_2$, 2g of $CuCl_2$, 4ml of HCl, 100ml of Grain Alcohol) and to reveal the types of flake graphites present using nicter etchant, Hardness test using Rockwell hardness tester.

Spectrographic Analysis

The chemical composition of each sample was analyzed to determine the variation of C, S, Si, Mn, P, in the samples.

Metallographic Examination

This was carried out to show how the flake graphite is distributed in the samples so as to know what effect the inoculant of fixed composition has on each sample due to their thickness. It was done by cutting parts of the cast products to represent each sample. The steps are shown below for each sample. After the micro-examination, the next stage was photomicrography. The observed microstructure was prepared for printing.

Hardness Measurement

Part of the cast product were cut, ground to ensure smooth surface and hardness test was performed on them using the Rockwell hardness of scale HRA.

RESULTS AND DISCUSSIONS

The following chemical compositions were obtained from the engine blocks (scraps).

Table 1: Elemental composition of scrap from auto parts

%C 3.97	%Si 1.94	%Mn 0.87	%P 0.088
%S 0.131	%Cr 0.163	%Ni 0.058	%Mo 0.0015
%Al 0.0058	%Cu 0.137	%Co 0.015	%Ti 0.0015
%Nb <0.0025	%V 0.0099	%W <0.010	%Pb 0.0083
%Mg 0.0033	%B <0.0005	%Sn 0.0083	%Zn 0.0081
%As 0.020	%Bi <0.0015	%Ce <0.0030	%Zr <0.0015
%La <0.0033	%Fe 92.5		

Chemical Equivalent Value

The carbon equivalent (CE) is a simplified method of evaluating the effect of composition on cast iron. One of the most common equations used is

$$CE = Tc + \frac{\%Si + \%P}{3} \tag{1}$$

where T_C is the total carbon, and %Si and %P are the silicon and phosphorus contents [6]

The value is important because it can be compared with the eutectic composition (4.3%) to indicate whether the cast iron will behave as a hypoeutectic iron or hypereutectic iron during solidification [6]

Effect of chemical composition on the eutectic cell in varying thickness

It can be shown from the table 2 and 3 that the chemical equivalent value is less than 4.3%, which is hypoeutectic cast iron in both the inoculated and un-inoculated grey cast iron. However, in the uninocculated, there is larger proportion of dendrites due to lower carbon equivalent value compare to the inoculated grey iron where the dendrites tend to reduce because of the increase in carbon equivalent value. With decrease of carbon equivalent, the length of primary austenite dendrite increases [7]. The reduction in the dendrites by the inoculants led to the increase in the eutectic cells. There is decrease in the eutectic cells as the thickness increases.

In figure 1 and 2 in which the wall thickness are 3.5 mm and 4.5 mm, the section sizes have higher eutectic cells. The sulphur content of 0.06%, Mn of 0.31% in the inoculated grey iron has effect on the eutectic cells and there is greater effect of inoculation. This is in accordance with what has been done by Zhou Jiyang, 2009 that "low sulphur content < 0.03%, the number of eutectic cells is significantly reduced and the inoculation effect is reduced".

The eutectic cells also increases in figure 3 with wall thickness 5.0 mm and figure 4 with wall thickness 7.0 mm but the grain boundaries begin to increase and eventually reduce the eutectic cells in figures. 5, 6, and 7 respectively with wall thickness 8.0 mm, 11.5 mm and 12.5 mm.

Table 2: Chemical Composition of Un-Inoculated Sample (control)

C	Si	Mn	P	S
2.354	2.450	0.234	0.088	0.135
Cr	Ni	Mo	CE	
0.090	0.059	0.007	3.200	

Table 3: Chemical composition of 0.2% inoculated sample

C	Si	Mn	P	S
2.78	3.25	0.31	0.16	0.06
Cr	Ni	Mo	CE	
0.11	0.05	0.01	3.92	

Microstructure of Eutectic cells

The following microstructures of the eutectic cells were obtained in different wall thicknesses using stead reagents.

Effect of microstructure in the varying thicknesses

With reference to the Figure 8, the results showed that in an uninoculated structure there is presence of globular graphite inclusions at low magnifications. The structure does not produce enough graphitization due to lack of inoculants and it will reduce the total amount of carbon formed. In this case, thin and fine graphite morphology of type D was noticed. In figure 9-14, the morphology of the inoculated iron shows the presence to some extent the evenly distribution of graphite flakes. There are more and longer bulky graphite inclusions than in the case of no addition of inoculant.

The microstructures revealed in the specimens show that there is presence of graphite flakes in a pearlitic matrix and very little ferrite was found. It shows that ferrite was more in 8.0 mm, 11.5 mm and 12.5 mm sections than in the 3.5 mm and 4.5 mm sections.

The 7.0 and 8.0 mm sections show that there is mixture of rosette graphite flakes of type B and type A while 11.5 and 12.5 mm sections have the graphite flakes of type A, that is, the graphite flakes are randomly distributed and oriented throughout the matrix.

The 5.0 and 7.0 mm specimens are dominated by type B due to the flake graphites that are not well distributed. The 3.5 and 4.5 mm have short graphite flakes and not as visible enough as compared to the 12.5 mm. Mostly, there is presence of cementite and small amount of graphite flakes in the 3.5 mm thickness due to greater undercooling.

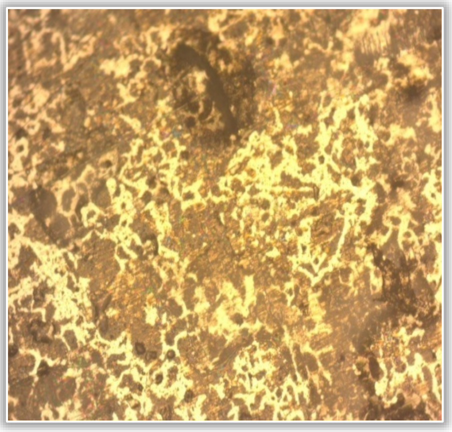

Figure 1: Eutectic cell 3.5 mm: x100

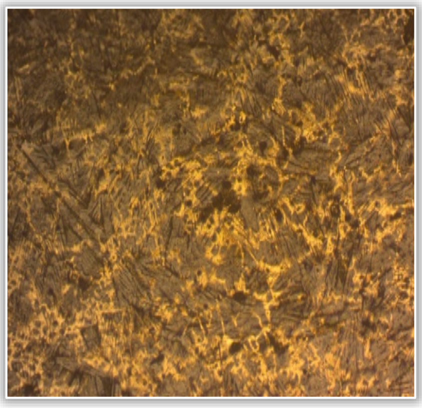

Figure 2: Eutectic cell 4.5 mm: x50

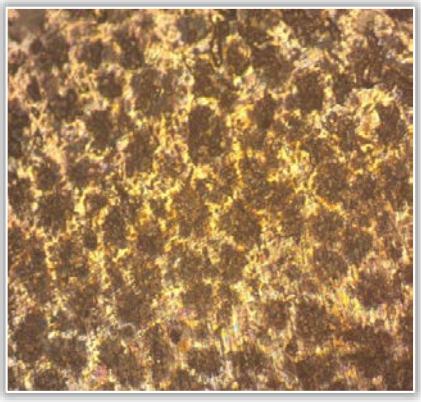

Figure 3: Eutectic cell 5.0 mm: x50

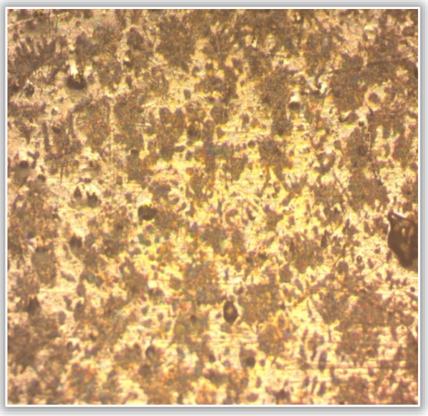

Figure 4: Eutectic cell 7.0 mm: x50

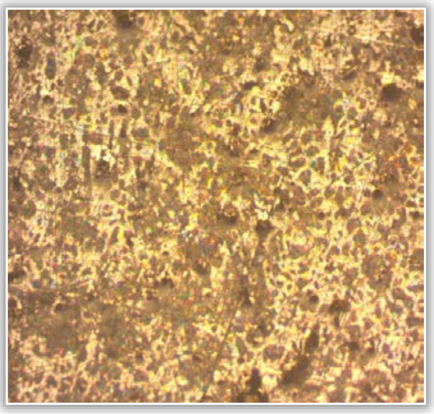

Figure 5: Eutectic cell 8.0mm thickness x100

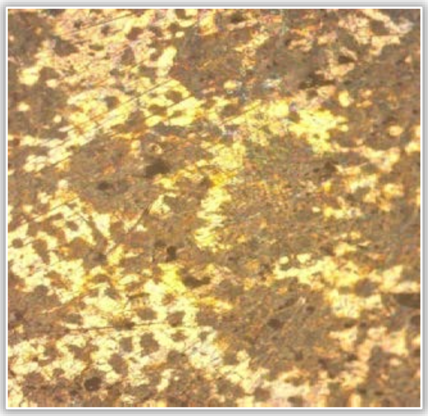

Figure 6: Eutectic cell 11.5 mm thickness x100

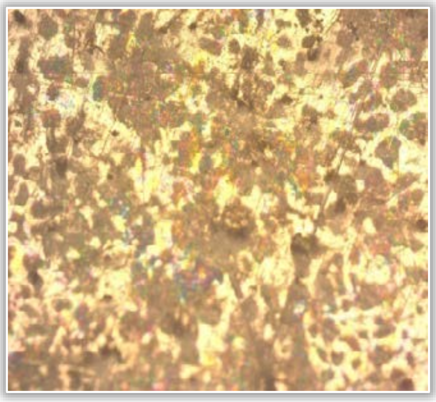

Figure 7: Eutectic cell of 12.5mm thickness x50

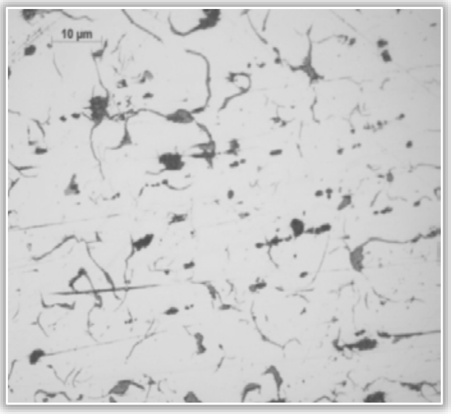

Figure 8: Microstructure of un-inoculated sample x50

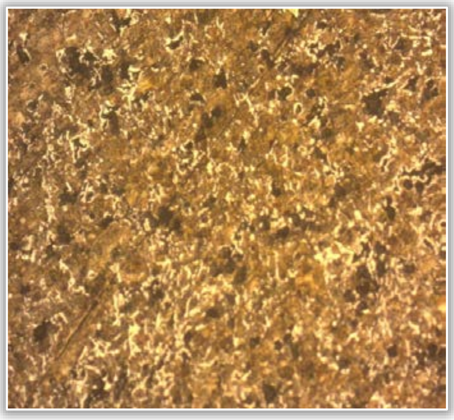

Figure 9: Microstructure of 3.5 mm thickness x100

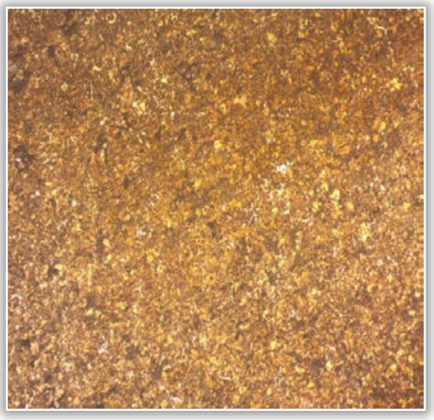

Figure 10: Microstructure of 4.5mm thickness x50

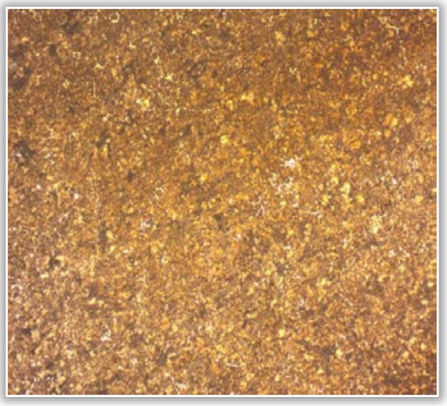

Figure 11: Microstructure of 5.0 mm thickness x100

Figure 12: Microstructure of 7.0 mm thickness x50

Figure 13: Microstructure of 8.0 mm x100

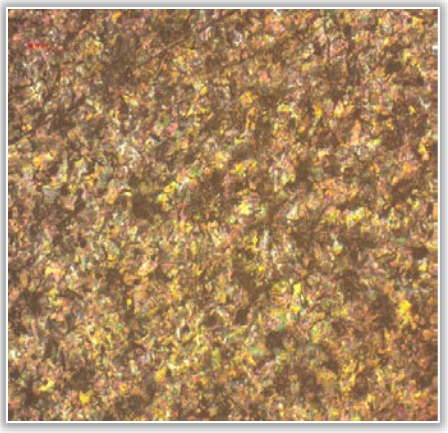

Figure 14: Microstructure of 11.50 mm thickness x100

Figure 15: Microstructure of 12.50 mm thickness x50

Table 4: The hardness values in different wall thicknesses

Thickness values (mm)	3.50	4.50	5.00	7.00	8.00	11.50	12.50
HRA	66.4	55.8	55.4	53.2	52.5	50.5	49.1

The effect of hardness values on the wall thicknesses

It was observed from the figure 16, when the thickness of the wall was 3.50 mm, the hardness value was 66.4 HRA, when the thickness of the wall was increased to 4.50 mm in figure 10, there was decrease in the hardness value to 55.8 HRA.

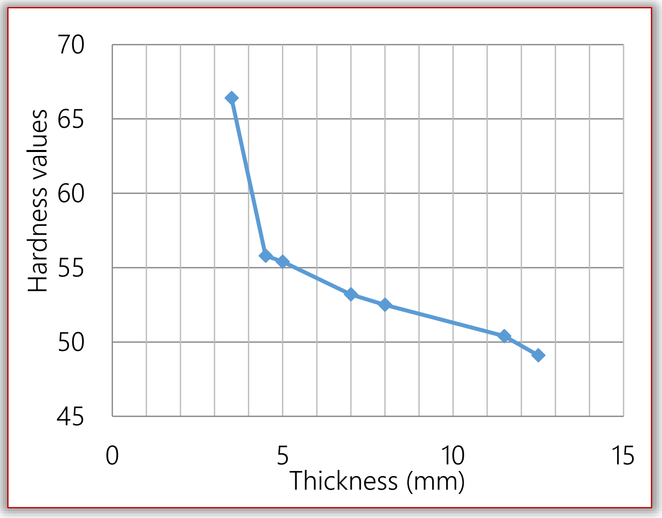

Figure 16: Graph of hardness values against wall-thickness

As the wall thickness increases, it was discovered that the hardness value decreases [8]. The cooling has to do with thickness, the lower the thickness, the faster the cooling rate. In wall thickness 3.50 mm as compared with thickness 4.5 mm, 5.0 mm, 7.0 mm, 8.0 mm, 11.5 mm and 12.5 mm, the cooling rate was faster and it follows that order, as a result carbon in it was found in the form of carbides which is responsible for the increase in hardness, as the wall thickness increases there is decrease in carbide formation and reduction in hardness.

CONCLUSIONS

The results discussed above showed that inoculant has greater influence on the different wall thicknesses. This was clearly shown in the eutectic cells and the graphite flakes exhibited in each microstructure. Based on this work the following main conclusions can be drawn:

- It was revealed that the eutectic cells in the 3.5 -5.0 mm section sizes were greater than the 7.0, 11.5 and 12.5mm section sizes. Therefore, the eutectic cells decreases as the wall thickness increases.
- The graphite flakes exhibited in 3.5 mm and 4.5 mm thickness were not revealed as much, due to greater undercooling and presence of cementite. The inoculant has a greater influence on the wall thickness. There is evidence of graphite flakes in 5.0 mm thickness and uniform distribution of graphite flakes are showed in 11.5 and 12.5 mm sections.
- The composition of 0.06%S and 3.25%Si are beneficial for graphite nucleation in inoculated grey irons with a lower incidence of carbides and undercooled graphite, compared to the 1.94%Si obtained from the scraps.
- Hardness increases with decreasing casting wall thicknesses due to structure refinement effect.

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