Modification of Ledeburite Microstructure on Impeller Blades by Mean of Heat Treatment

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Abstract. Water pump machine impeller is made of gray cast iron with some variation of wall thickness. According to it, the thin part undergoes a very rapid cooling so as to form a ledeburite. This study removes the formed ledeburite ((α + Fe_3C) + Fe_3C) by mean of heat treatment. The first step to remove the presence of ledeburite is by calculating the retained carbide at the level of 5%. Since the material consists only carbon as the main alloying element, the temperature of the heat treatment can be determined by using the Fe-Fe_3C diagram. After 2 hours of holding at 830 ° C ledeburite changes to ferrite and graphite. Based on the metallographical observation it is found that graphite forms discrete shape and is located at the grain boundary. The boundary of pearlite grain in the ledeburite itself does not change after the completion of heat treatment. The graphite resembles a randomly oriented eutectic undercooling type D and accompanied by a decrease of hardness to 115HV which occurs at the tip of the impeller blade

Keyword : impeller, ledeburite, gray cast iron

1. Introduction

1.1 Impeller

Impeller is a part of water pump machine that serves to produce water pressure. Figure 1 illustrates a water pump image having thin involute blades.

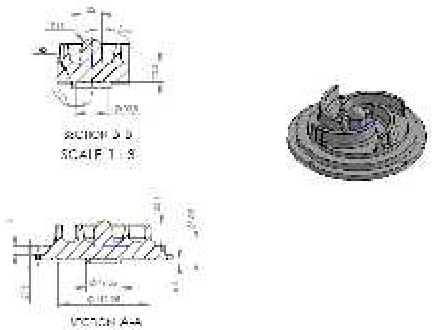

Figure 1. Water pump impeller

The impeller is made of gray cast iron with a material composition based on Fe with carbon, silicon, manganese alloy and some accompanying elements such as phosphorus and sulfur (table 1)
Appropriate inoculation and composition processes will produce materials with microstructures of eutectic lamellar graphite, ferrite and pearlite (Figure 2a). The gray cast iron is one of the stable types of cast iron, whose microstructure is characterized by the appearance of graphite, has a carbon content of above 2% and has good casting properties but low elongation value.
the most influencing parameters which affect the properties of the material and its microstructure are the alloy and the cooling rate.
The impeller blade shows differences in the thickness, so that the edge of the impeller blade encounters very thin part. In this section the solidification takes place metastably, so that graphite can not be formed since the material solidifies metastably and produces a microstructure of ledeburite (figure 2b). In addition, the occurrence of this ledeburite can also be initiated by several potential causes, such as too much carbon, lack of silicon content (Si) and lack of diffusion time.

Table 1. Chemical composition of grey cast iron for several wall thickness

Grade	Wall Thickness mm	C	Si	Mn	P max	S max
FC100	-	3.4-3.9	2.1-2.6	0.5-0.8	0.3	0.15
FC150	<30	3.3-3.5	2.0-2.4	0.5-0.8	0.2	0.12
	30-50	3.2-3.5	1.9-2.3	0.5-0.8	0.2	0.12
	>50	3.2-3.5	1.8-2.2	0.6-0.9	0.2	0.12
FC200	<30	3.2-3.5	1.6-2.0	0.7-0.9	0.15	0.12
	30-50	3.1-3.4	1.5-1.8	0.8-1.0	0.15	0.12
	>50	3.0-3.3	1.4-1.6	0.8-1.0	0.15	0.12
FC250	<30	3.0-3.3	1.4-1.7	0.8-1.0	0.15	0.12
	30-50	2.9-3.2	1.3-1.6	0.9-1.1	0.15	0.12
	>50	2.8-3.1	1.2-1.5	1.0-1.2	0.15	0.12
FC300	<30	2.9-3.2	1.4-1.7	0.8-1.0	0.15	0.10
	30-50	2.9-3.2	1.2-1.5	0.9-1.1	0.15	0.10
	>50	2.8-3.1	1.1-1.4	1.0-1.2	0.15	0.10

Reducing the carbon content to avoid the formation of ledeburite can be done but this at the other side will affect the thicker part of the object, since in the thick part graphite will not be formed. Silicone content can additionally be put into the material to avoid white solidification. The effect that will occur is a decrease of the hardness due to the larger number of ferrite and bigger size of graphite. Meanwhile the biggest problem in the manufacturing process of blade is the ununiform thickness of the blade itself since the micro structure is consequently not homogenuous. It should be noted that the liquid which is frozen in the area of small thickness will form a ledeburite micro structure. Hardness in this area accordingly becomes very hard and this is asociated with very low elastic area and small plastic area. This part cannot be manufactured by machining process and the impact value becomes low

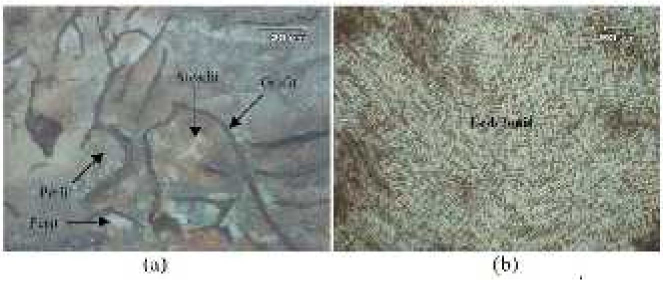

Figure 2. Microstructure of FC (A) and ledeburite (B)

1.2 Modification of the microstructure

Modifications can be carried out to produce a material that is free from ledeburite. In the early stages, the design of material can be focused on setting uniform thickness of the object.

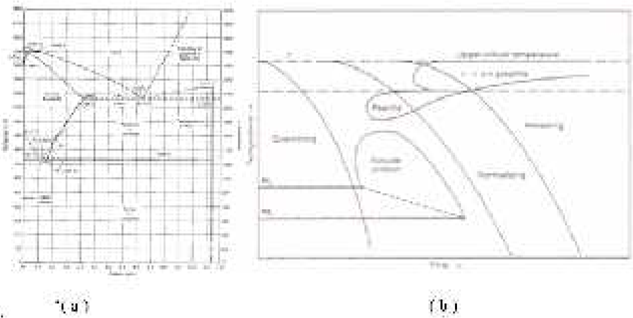

Figure 3. Binary diagram Fe-C (a) dan CCT diagram

If it still forms a ledeburite, heat treatment process can be done accordingly to eliminate the existing ledeburite. Heat-treatment to remove ledeburite is accomplished by heating the sample at the austenisation temperature, as shown in the binary diagram (Figure 3a). Cooling rate should be set by using CCT diagram (figure3b)

The decomposition of ledeburite in the FCD can be performed by calculating the fraction of ledeburite, calculating the composition / carbon content in the matrix, determining the decomposition temperature, determining the decomposition time and cooling at apropriate cooling rate[3]. In this study the ledeburite can be transformed into Fe_3C which is dispersed at the grain boundary. Ledeburite originally presented in the microstructure (Figure 4a) can decompose to pearlite and ferrite. (Figure. 4b). However this is accompanied by changes in the shape of pearlite and graphite size. Cooling is done in the oven after heating at 780 ° C for 2 hours.

The decomposition of cementite in the ledeburite is influenced by the presence of several elements such as manganese (Mn). Manganese exerts a retarding effect on the kinetics of graphitization of spheroidal graphite cast iron [4] With the increases of the content of manganese in cementite, it becomes more stable: therefore its decomposition kinetics (in iron and graphite) is slowed down. When the proportion of iron atoms substituted by manganese atoms increases, the Gibbs energy of formation of complex cementite decreases steadily

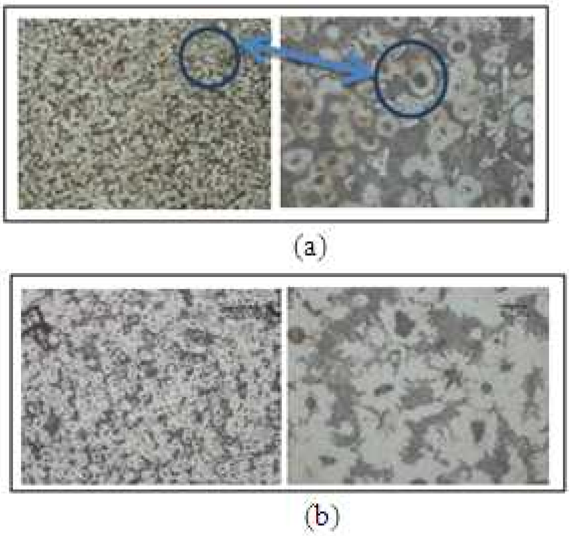

Figure 4. initial condition with ledeburite (A) and after heat treatment (B)

2. Design of experiment

1.1 Sampel (100% ledeburite)

The sample used is the tip of the impeller blade which has a 100% ledeburite micro structure. The calculation of the actual amount of C will be used for the formation of a new matrix after the decomposition of Fe_3C. The microstructure accordingly has a carbon content of 4.3%.

2.2 Solubility of Fe_3C in 5% Ledeburite

In this study, the maximum allowable level of ledeburite is set up at 5%. Ledeburite consists of a mixture of γ phase and cementite (Fe_3C). Calculation based on Fe-Fe_3C diagram (figure 3) and lever rule can be applied for dissolving Fe_3C in the ledeburite

Table 2. Percentage of ledeburite former

5% ledeburite in FCD		
Microstructure	Carbon content	Weight percent

Austenite (γ)	2.0 %	2.47 %
Fe_3C	6.67 %	2.53 %

Based on the data above it can be concluded that the austenite (γ) contained in the material of 5% ledeburite is 2.47%, while the cementite content (Fe_3C) is 2.53%. The removal of the ledeburite is done by decomposing Fe_3C into the matrix.

Table 3. Percentage of carbon in the decomposition of Fe_3c**.**

Microstructure	Max. Carbon content	Total carbon content
Fe_3C	6.67 %	0.977 %

The design of heat treatment process is accordingly based on the carbon content of 0.977% C

2.3 Determining the Heating Temperature

The carbon percentage is used as the initial reference of temperature determination for sample heating as it shown on the $Fe\text{-}Fe_3C$ diagram. In detail it can be described as follows: From this figure 5 the minimum temperature is at line A1 (727 ° C) and critical temperature at Acm line (± 830 ° C) and maximum temperature is below solidus line (± 1360 ° C).

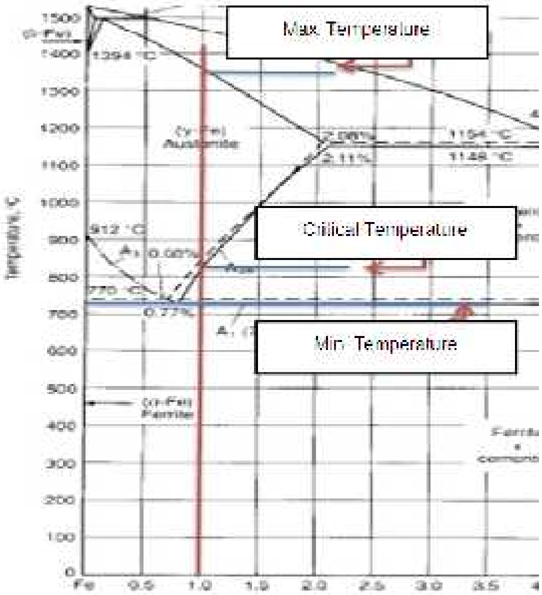

Figure 5. Diagram $Fe\text{-}Fe_3C$, decomposition of Fe_3C in ledeburite.

The heating is done exactly at the critical temperature of 830 ° C which is then followed by cooling in the open air.

2.4 Holding time

The heating time is set to 2 hours according to the minimum reaction time to disolve the ledeburite for a thickness of 5mm. The predetermined heating time can dissolve the ledeburite and the carbon from Fe_3C will subsequently diffuse into graphite or be present as Fe_3C at the grain boundary.

2.5 Testing

The test was performed by applying metallographic analysis using optical microscope and vickers hardness testing

3. Result and Analisis

3.1 Initial microstructure

The impeller part having a thick wall (5mm) shows a microstructure containing graphite with a dominant matrix of pearlite and small amount of ferrite. (Figure 6a). Ferrite itself is formed around the graphite. The graphite that occurs has the shape type of A and the arrangement of a 6. At the edge of the impeller, the micro structure (Figure 4b) shows a dominant fraction of the secondary ledeburite (pearlite + Fe_3C). In some other location assemblies of ferrite around the graphite are still to be found .

Figure 6. Micrograph at the thick wall (A) and at the tip (B)

3.2 Microstructure after heat treatment

Metallographic observation of the microstructure after the heat treatment process shows a complete change. Ledeburite decomposes completely into ferrite and graphite (figure 7a). The microstructure nevertheless still shows the almost spherical primary phase, which transforms into a brightly colored ferrite. In this material there is no indication of cementite (Fe_3C) to be observed. All Cementite are transformed into graphite and ferrite. Cementite (Fe3C), which was originally located at the grain boundary, has been transformed into a group of graphite with random orientation. The microstructure shows the formation of D-type graphite as commonly identified as the undercooling eutectic graphite (figure 7b).
Conditions without etching

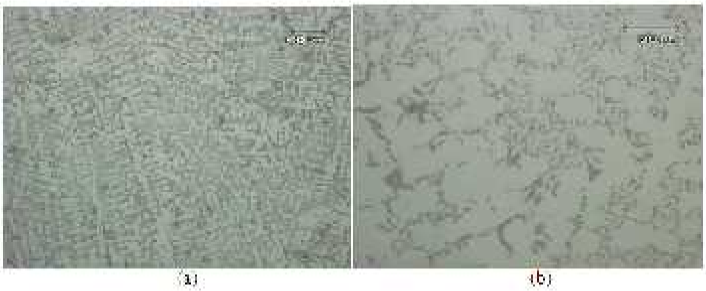

Figure 7. Micrograph after heat treatment process with graphite tipe D (A) and graphit at the grain boundary with random orientation. (B)

In some particular location of the material undesolved (Fe3C) carbide is still found (Figure 8). The formation of graphite in this area did not take place.

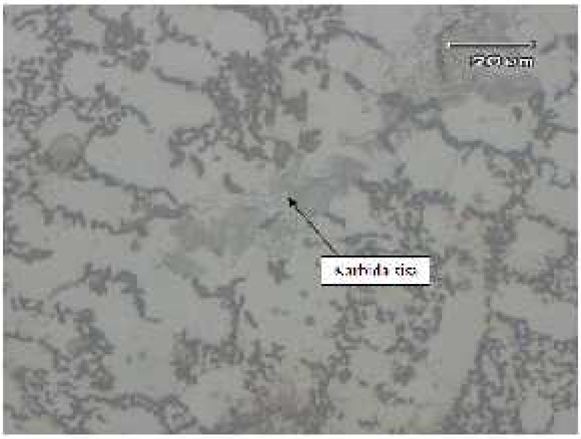

Figure 8. Retained iron carbide

The heat treated material undergoes changes in mechanical properties in term of hardness. The initial hardness of the material on the thick part before the heat treatment was 165 HV which was tested at 1 kg load. The thin impeller blade portion shows a hardness value of up to 705 HV and after experiencing the heat treatment process the hardness becomes 115 HV.

3.3 Analisis

By heating at the upper limit of temperature carbide in the ledeburite decomposes into graphite and ferrite. This can occur due to the sufficient 2 hour holding time, the small wall thickness and the availability of silicon in the matrix which is also accompanied by relatively low levels of Manganese. Longer heating results in not only the breakdown of carbides but also the diffusion of carbon out of the pearlite matrix. The iron carbide in the matrix of pearlite also breaks down into ferrite and graphite. During the decomposition process the basic form of pearlite in carbide that resembles a circle does not change. Graphite that is formed from carbon diffusion has a random and non-continuous orientation. The graphite resembles as D-type graphite which is derived from an eutectic graphite formation which is normaly associated with undercooling. The decrease of hardness occurs at the tip of the impeller drastically. This pattern of graphite deployment will result in a decrease in the value of tensile strength and impact. The remaining carbides can still be found because the initial setting of temperature calculations based on the remaining carbide is 5%

CONCLUSION

Fully ledeburitic microstructure can be transformed into stable cast iron by applying heat treatment process. It is to be noticed that the presence of Si and the lower level of manganese are the requisites for the effective decomposition of cementite in the ledeburite. However the graphite formation does not come along with the increase of carbon content in the matrix, so that ferrite is still dominant in the matrix. The process forms a structure of D graphite without any change on the shape and dimension of previous primary phase

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