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Modification of ledeburite microstructure on impeller blades by mean of heat treatment

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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. The thin part undergoes consequently a very rapid cooling and promotes the formation of hard ledeburite. This study removes the already formed ledeburite ($(\alpha + \text{Fe}_3\text{C}) + \text{Fe}_3\text{C}$) by mean of heat treatment. By calculating the mass fraction of iron carbide at the level of 5%, heating the material at the austenite temperature, holding it for 2 hours and cooling it subsequently in the air, ledeburite changes to ferrite and graphite. Graphite is formed discrete along the grain boundaries of previous pearlite after the completion of heat treatment. The graphite resembles a randomly oriented eutectic undercooling type D and this is associated with a decrease of hardness to 115HV at the tip of the impeller blade.

1. Introduction

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

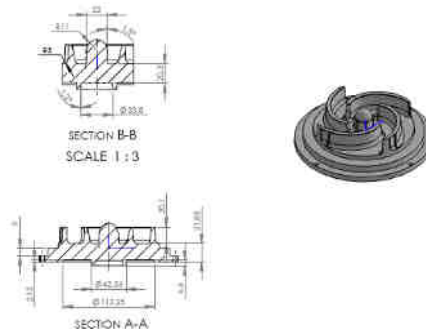


Figure 1. Water pump impeller.

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 sulphur (table 1), Grey Cast Iron belongs to the most cost effective material for the impeller and classified as 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 [1].

Appropriate manufacturing processes produce cast iron with microstructures consisting of eutectic lamellar graphite in the matrix of ferrite and pearlite (figure 2a). The most influencing parameters which

affect the properties of the material and its microstructures are the elemental compositions and the cooling rate [2].

Since the impeller blade shows variation in its wall thickness, the edge encounters very thin part. In this section, the metastable solidification takes place and produces a microstructure of ledeburite [3] (figure 2b).

In addition, the occurrence of this ledeburite can also be initiated by several potential causes, such as high content of carbon, less silicon content (Si) and lack of adequate diffusion time [4].

Table 1. Chemical composition of grey cast iron for several wall thickness [5].

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 can considerably be done to avoid the formation of ledeburite, however, this will affect the thicker part of the object, whereby graphite will not be formed. Silicone content is additionally put into the material to prevent white solidification, whereas it causes a decrease of the hardness due to the formation of a larger number of ferrite and bigger size of graphite [6]. Meanwhile, the biggest problem in the manufacturing process of a blade is the ununiform thickness of the blade itself. The microstructure is consequently not uniform. The solidification of metal liquid in the area of smaller wall thickness will form a ledeburite microstructure. The area accordingly becomes very hard, which is also associated with poor elastic and plastic behavior. Due to the hardness and low impact value, this part is not to be machined [7].

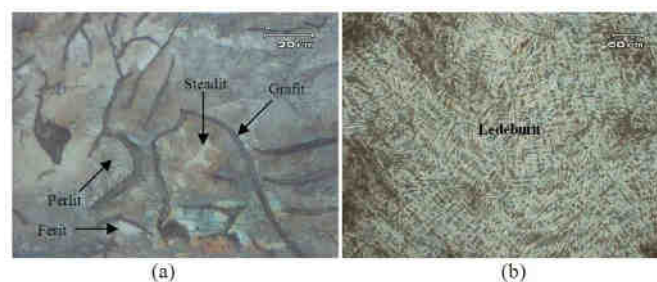


Figure 2. The microstructure of FC (A) and ledeburite (B), etched with Nital 3%.

Uniform wall thickness and appropriate chemical composition prevent a metastable solidification.

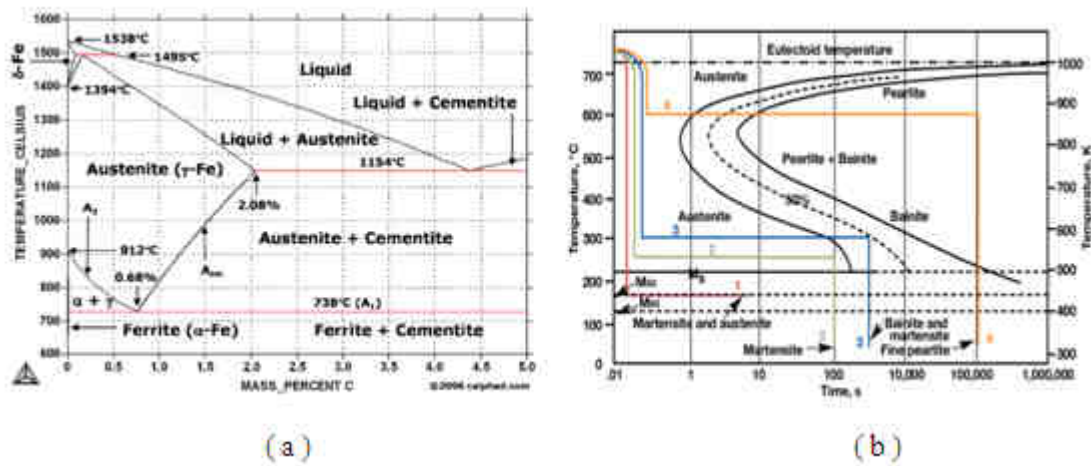


Figure 3. Binary diagram Fe-C (a) and CCT diagram (b).

Occasionally heat treatment process can be done 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 (figure 3b) [8].

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 the appropriate cooling rate, ledeburite can be transformed into Fe_3C which is dispersed at the grain boundary [9]. Ledeburite originally presented in the microstructure (figure 4a) can decompose to pearlite and ferrite (figure 4b). The heat treatment caused changes in the shape of pearlite and graphite size.

The decomposition of Fe_3C in the ledeburite is affected by several elements such as manganese (Mn). Manganese impedes the kinetics of graphitization of nodular graphite cast iron [10]. Manganese stabilizes the cementite and slows down the decomposition kinetics (in iron and graphite).

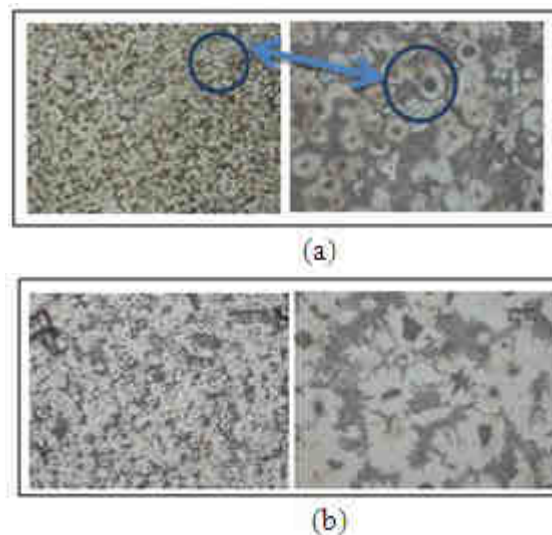


Figure 4. initial condition with ledeburite (A) and after heat treatment (B), etched with Nital 3%.

2. Design of experiment

2.1. 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 the 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 the 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- 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 ($\pm 830^\circ\text{C}$) and the maximum temperature is below solidus line ($\pm 1360^\circ\text{C}$).

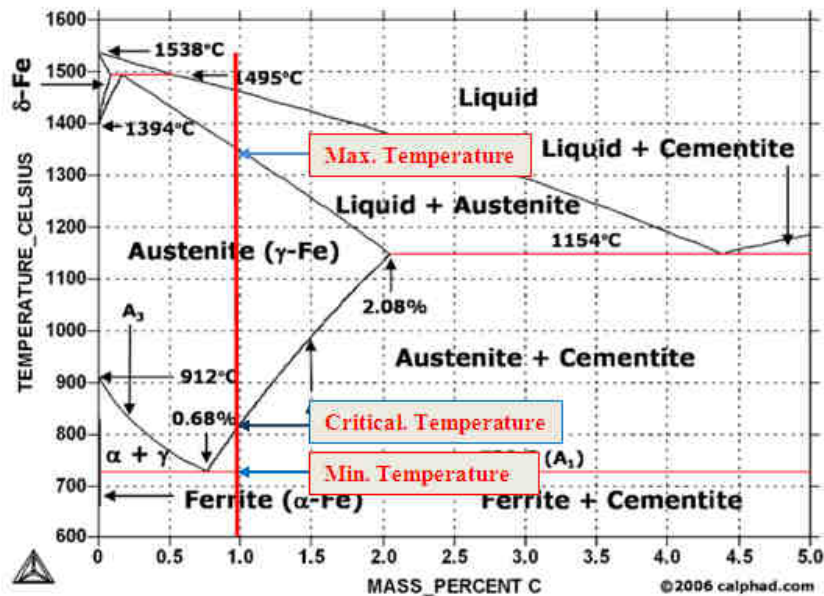


Figure 5. Diagram Fe-Fe₃C, decomposition of Fe₃C in ledeburite.

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 dissolve the ledeburite for a thickness of 5mm. The predetermined heating time can dissolve the ledeburite and the carbon from Fe₃C will subsequently diffuse into graphite or be present as Fe₃C at the grain boundary.

2.5. Testing

Tests were performed by applying metallographic analysis using an optical microscope and vickers hardness testing.

3. Result and Analysis

3.1. Initial microstructure

The impeller part having a thick wall (5 mm) shows a microstructure containing graphite with a dominant matrix of pearlite and a small amount of ferrite (figure 6a). Ferrite itself is formed around the graphite. The graphite that occurs has the shape type of A and random orientation [11]. At the edge of the impeller, the microstructure (figure 4b) shows a dominant fraction of the secondary ledeburite (pearlite + Fe₃C) [11]. 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), etched with Nital 3%.

3.2. Microstructure after heat treatment

Metallographic observation after the heat treatment process shows a complete change of the microstructure. Ledeburite decomposes completely into ferrite and graphite (figure 7a) [12]. The microstructure nevertheless shows nearly spherical primary phase, which is already transformed into ferrite. The cementite (Fe_3C) is not longer exist since all cementite is transformed into graphite and ferrite. Cementite (Fe_3C), which was originally located at the grain boundary, has been transformed into a group of graphite with random orientation. Figure 7b the formation of D-type graphite which is commonly identified as the undercooling eutectic graphite [13]. Conditions without etching.

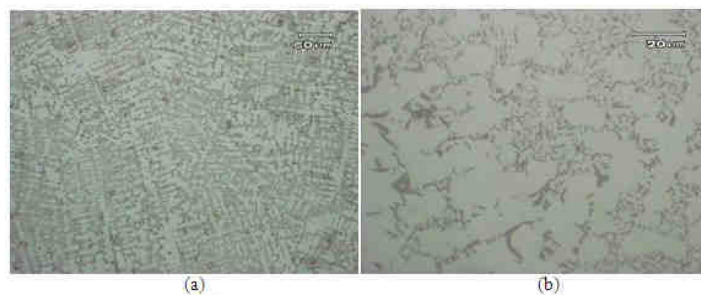


Figure 7. Micrograph after heat treatment process with graphite tip D (a) and graphite at the grain boundary with random orientation. (b), without etching.

Figure 8 shows the undissolved (Fe_3C) carbide in some particular location of the material, whereby the formation of graphite did not take place. The uneven distribution of manganese and silicon is considered to be the cause of it [14].

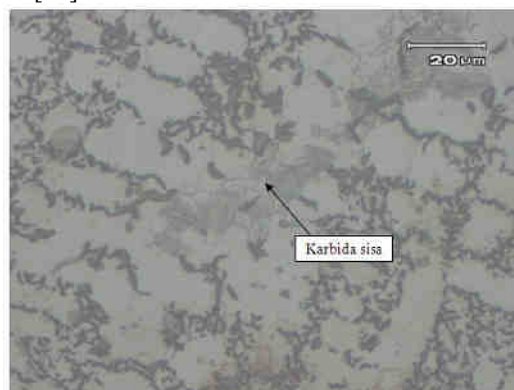


Figure 8. Retained iron carbide, etched with Nital 3%.

Related to the change of its microstructure the heat treated material undergoes changes in mechanical properties in term of hardness. The initial hardness of the material on the thick part prior to the heat treatment was 165 HV by a test load of 1 kg. The thin impeller blade portion shows a hardness value of up to 705 HV, which decreases up to 115 HV after completing the heat treatment process.

3.3. Analysis

By heating at the upper temperature limit carbide in the ledeburite decomposes into graphite and ferrite. The total decomposition is achieved due to the sufficient 2 hour holding time, the small wall thickness and the availability of silicon in the matrix which is also supported by relatively low levels of Manganese. Longer holding time 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 spherical shape does not change. Graphite that is formed from carbon diffusion has a random and discrete orientation. Finally, graphites resemble as D-type graphite which is commonly derived from a eutectic reaction and 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%.

4. Conclusion

The fully ledeburitic microstructure can be transformed into stable cast iron by applying heat treatment process. To determine the heating temperature, a number of cementite in the matrix is put as the basic value for the calculation of carbon content while using the binary diagram of Fe-Fe₃C. Ledeburite decomposes into ferrite and graphite. However the decomposition of ledeburite does not cause any increase of carbon content in the matrix, so that ferrite is still dominant in the matrix. The process results in a structure of D-type graphite without any change in the shape and dimension of the previous primary phase. The hardness decrease up to 115HV. Furthermore, the presence of Si and the low level of manganese are the requisites for the effective decomposition of cementite in the ledeburite.

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