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

by Rendi Reynaldi

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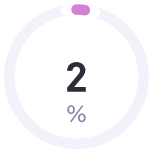

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116	**Correctness**	
24	Misspelled words	
28	Unknown words	
11	Determiner use (a/an/the/this, etc.)	
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3	Mixed dialects of english	
16	Improper formatting	
3	Comma misuse within clauses	
1	Text inconsistencies	
3	Confused words	
2	Incomplete sentences	
1	Incorrect verb forms	
1	Faulty subject-verb agreement	
1	Incorrect noun number	
1	Wrong or missing prepositions	
1	Misuse of quantifiers	
1	Pronoun use	
1	Closing punctuation	
47	**Clarity**	
25	Passive voice misuse	
3	Hard-to-read text	
11	Wordy sentences	
8	Intricate text	
16	**Engagement**	

16 Word choice

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22%

unique words

Rare Words

Measures depth of vocabulary by identifying words that are not among the 5,000 most common English words.

40%

rare words

Word Length

Measures average word length

4.2

characters per word

Sentence Length

Measures average sentence length

11.5

words per sentence

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

W Purwadi1 and D Idamayanti1

1Foundry Engineering Department, Politeknik Manufaktur Bandung, Indonesia

E-mail: wiwikpurwadi@yahoo.com

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 ((α + Fe3C) + Fe3C) 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

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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,[34] however,[35] this will affect the thicker part of the object, whereby graphite will not be formed.[36] Silicone content is additionally put into the material to prevent white solidification, whereas it[37] causes a decrease of the hardness due to the formation of a larger[38] number of ferrite and bigger[39] 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.

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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 apropriate cooling rate. ledeburite can be transformed into Fe3C 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 heattreatment caused changes in the shape of pearlite and graphite size.
The decomposition of Fe3C in the ledeburite is affected by several elements such as manganese (Mn). Manganese impedes the kinetics of graphitization of nodular graphite cast iron [10]. Manganeses 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%.

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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 Fe3C. The microstructure accordingly has a carbon content of 4.3%.

2.2 Solubility of Fe3C 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 (Fe3C). Calculation based on the Fe-Fe3C diagram (figure 3) and lever rule can be applied for dissolving Fe3C in the ledeburite.

Table 2. Percentage of ledeburite former

5% ledeburite in FCD

Microstructure Carbon content Weight percent

Austenite (γ) 2.0 % 2.47 % Fe3C 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 (Fe3C) is

2.53%. The removal of the ledeburite is done by decomposing Fe3C into the matrix.

Table 3. Percentage of carbon in the decomposition of Fe3C.

Microstructure Max. Carbon content

Total carbon content

Fe3C 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-Fe3C 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 the maximum temperature is below solidus line (± 1360°C).

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

The heating is done exactly at the critical temperature of 830ºC 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 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.

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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 (Fe3C) is not longer exist since all cementite is 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. 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 tipe D (a) and graphite at the grain boundary with random orientation. (b), without etching.

Figure 8 shows the undissolved (Fe3C) carbide in some particular location of the material, whereby the formation of graphite did not take place. The uneven distribution of manganeses and silicon is considered to be the cause of it [14].

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

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Related to the cange 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 [62]. 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 determined 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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1.	~~doi~~ → DOI	Misspelled Words	Correctness
2.	*ledeburite*	Unknown Words	Correctness
3.	The water	Determiner Use (a/an/the/this, etc.)	Correctness
4.	*is made*	Passive Voice Misuse	Clarity
5.	*ledeburite*	Unknown Words	Correctness
6.	~~, This~~ → ; This, , and This, . This	Punctuation in Compound/Complex Sentences	Correctness
7.	~~ledeburite~~ → Lefebure	Misspelled Words	Correctness
8.	*ledeburite*	Unknown Words	Correctness
9.	, and	Punctuation in Compound/Complex Sentences	Correctness
10.	~~sulphur~~ → sulfur	Mixed Dialects of English	Correctness
11.	~~table~~ → Table	Misspelled Words	Correctness
12.	~~cost effective~~ → cost-effective	Misspelled Words	Correctness
13.	~~effective~~ → useful, active	Word Choice	Engagement
14.	~~as is~~ → as is	Improper Formatting	Correctness
15.	~~good~~ → excellent	Word Choice	Engagement
16.	*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 ...*	Hard-to-read text	Clarity

17.	~~the matrix of~~	Wordy Sentences	Clarity
18.	*be used*	Passive Voice Misuse	Clarity
19.	~~licence~~ → license	Mixed Dialects of English	Correctness
20.	, and	Comma Misuse within Clauses	Correctness
21.	~~licence~~ → license	Mixed Dialects of English	Correctness
22.	~~doi~~ → DOI	Misspelled Words	Correctness
23.	~~affect~~ → Affect	Improper Formatting	Correctness
24.	, and	Punctuation in Compound/Complex Sentences	Correctness
25.	the variation, or a variation	Determiner Use (a/an/the/this, etc.)	Correctness
26.	a very	Determiner Use (a/an/the/this, etc.)	Correctness
27.	~~very thin~~ → fragile, skinny	Word Choice	Engagement
28.	*ledeburite*	Unknown Words	Correctness
29.	~~In addition~~ → Also, Besides	Wordy Sentences	Clarity
30.	~~the occurrence of~~	Wordy Sentences	Clarity
31.	*ledeburite*	Unknown Words	Correctness
32.	*be initiated*	Passive Voice Misuse	Clarity
33.	, and	Comma Misuse within Clauses	Correctness
34.	*ledeburite*	Unknown Words	Correctness
35.	~~, however~~ → . However, ; however	Punctuation in	Correctness

		Compound/Complex Sentences	
36.	*be formed*	Passive Voice Misuse	Clarity
37.	~~, whereas it~~ → . In contrast, it	Hard-to-read text	Clarity
38.	~~larger~~ → more significant	Word Choice	Engagement
39.	a bigger	Determiner Use (a/an/the/this, etc.)	Correctness
40.		Intricate Text	Clarity
41.	*ledeburite*	Unknown Words	Correctness
42.	*The solidification of metal liquid in the area of smaller wall thickness will form a ledeburite microstructure.*	Hard-to-read text	Clarity
43.	~~to be~~	Wordy Sentences	Clarity
44.	*ledeburite*	Unknown Words	Correctness
45.	~~doi~~ → DOI	Misspelled Words	Correctness
46.	*ledeburite*	Unknown Words	Correctness
47.	*ledeburite*	Unknown Words	Correctness
48.	*is accomplished*	Passive Voice Misuse	Clarity
49.	~~austenisation~~ → austenitization, customisation	Misspelled Words	Correctness
50.	The cooling	Determiner Use (a/an/the/this, etc.)	Correctness
51.	*be set*	Passive Voice Misuse	Clarity
52.	the CCT	Determiner Use (a/an/the/this, etc.)	Correctness

53.	*ledeburite*	Unknown Words	Correctness
54.	~~apropriate~~ → appropriate	Misspelled Words	Correctness
55.	*ledeburite*	Unknown Words	Correctness
56.	*be transformed*	Passive Voice Misuse	Clarity
57.	*is dispersed*	Passive Voice Misuse	Clarity
58.	initially presented, presented initially	Word Choice	Engagement
59.	~~heattreatment~~ → heat treatment, heat-treatment	Misspelled Words	Correctness
60.	*ledeburite*	Unknown Words	Correctness
61.	, such	Punctuation in Compound/Complex Sentences	Correctness
62.	*manganese; Manganese*	Text Inconsistencies	Correctness
63.	~~of nodular~~ → of nodular	Improper Formatting	Correctness
64.	~~down the~~ → down the	Improper Formatting	Correctness
65.	~~iron~~ → metal	Word Choice	Engagement
66.	*ledeburite*	Unknown Words	Correctness
67.	~~doi~~ → DOI	Misspelled Words	Correctness
68.	~~Sampel~~ → Sample	Misspelled Words	Correctness
69.	*ledeburite*	Unknown Words	Correctness
70.	, which	Punctuation in Compound/Complex Sentences	Correctness
71.	*ledeburite*	Unknown Words	Correctness

72.	~~micro structure~~ → microstructure	Confused Words	Correctness
73.	~~of the~~ → of the	Improper Formatting	Correctness
74.	*be used*	Passive Voice Misuse	Clarity
75.	~~matrix after~~ → matrix after	Improper Formatting	Correctness
76.	~~after the~~ → after the	Improper Formatting	Correctness
77.	*ledeburite*	Unknown Words	Correctness
78.	*is set*	Passive Voice Misuse	Clarity
79.	the y	Determiner Use (a/an/the/this, etc.)	Correctness
80.	*be applied*	Passive Voice Misuse	Clarity
81.	*ledeburite*	Unknown Words	Correctness
82.	*ledeburite*	Unknown Words	Correctness
83.	*ledeburite*	Unknown Words	Correctness
84.	*Microstructure Carbon content Weight percent*	Intricate Text	Clarity
85.	, it	Punctuation in Compound/Complex Sentences	Correctness
86.	*ledeburite*	Unknown Words	Correctness
87.		Intricate Text	Clarity
88.	*ledeburite*	Unknown Words	Correctness
89.	*Microstructure Max.*	Incomplete Sentences	Correctness
90.	*is accordingly based*	Passive Voice Misuse	Clarity
91.	*is used*	Passive Voice Misuse	Clarity

92.	heating,	Punctuation in Compound/Complex Sentences	Correctness
93.	~~shown~~ → is shown	Incorrect Verb Forms	Correctness
94.		Intricate Text	Clarity
95.	~~this~~ Figure	Determiner Use (a/an/the/this, etc.)	Correctness
96.	the minimum	Determiner Use (a/an/the/this, etc.)	Correctness
97.	, and	Punctuation in Compound/Complex Sentences	Correctness
98.	, and	Punctuation in Compound/Complex Sentences	Correctness
99.	the solidus	Determiner Use (a/an/the/this, etc.)	Correctness
100.	~~doi~~ → DOI	Misspelled Words	Correctness
101.	*ledeburite*	Unknown Words	Correctness
102.	~~exactly~~ → precisely	Word Choice	Engagement
103.	, which	Punctuation in Compound/Complex Sentences	Correctness
104.	*The heating time is set to 2 hours according to the minimum reaction time to disolve the ledeburite for a thickness of 5mm.*	Wordy Sentences	Clarity
105.	~~disolve~~ → dissolve	Misspelled Words	Correctness
106.	*ledeburite*	Unknown Words	Correctness
107.	~~ledeburite~~ → Lefebure	Misspelled Words	Correctness

108.	*were performed*	Passive Voice Misuse	Clarity
109.	~~vickers~~ → Vickers	Misspelled Words	Correctness
110.	*is formed*	Passive Voice Misuse	Clarity
111.	~~ledeburite~~ → Lefebure	Misspelled Words	Correctness
112.	, assemblies	Punctuation in Compound/Complex Sentences	Correctness
113.	~~doi~~ → DOI	Misspelled Words	Correctness
114.	~~at~~	Wordy Sentences	Clarity
115.	a spherical	Determiner Use (a/an/the/this, etc.)	Correctness
116.	*is already transformed*	Passive Voice Misuse	Clarity
117.	~~not~~ → no	Confused Words	Correctness
118.	~~exist~~ → exists	Faulty Subject-Verb Agreement	Correctness
119.	*is transformed*	Passive Voice Misuse	Clarity
120.	~~which was~~	Wordy Sentences	Clarity
121.	~~originally~~ → initially	Word Choice	Engagement
122.	*was originally located*	Passive Voice Misuse	Clarity
123.	, which	Punctuation in Compound/Complex Sentences	Correctness
124.	*is commonly identified*	Passive Voice Misuse	Clarity
125.	~~. Conditions~~ → —conditions	Incomplete Sentences	Correctness
126.	~~tipe~~ → type, tipi	Misspelled Words	Correctness

127.	*is considered*	Passive Voice Misuse	Clarity
128.	~~Retained iron~~ → Retained iron	Improper Formatting	Correctness
129.	~~iron carbide~~ → iron carbide	Improper Formatting	Correctness
130.	~~doi~~ → DOI	Misspelled Words	Correctness
131.	~~cange~~ → change	Misspelled Words	Correctness
132.	microstructure,	Punctuation in Compound/Complex Sentences	Correctness
133.	~~heat treated~~ → heat-treated	Misspelled Words	Correctness
134.	~~undergoes changes in~~ → changes	Wordy Sentences	Clarity
135.	~~term~~ → terms	Incorrect Noun Number	Correctness
136.	~~material~~ → content	Word Choice	Engagement
137.	~~prior to~~ → before	Wordy Sentences	Clarity
138.	~~up~~	Wordy Sentences	Clarity
139.	upper-temperature	Misspelled Words	Correctness
140.	, carbide	Punctuation in Compound/Complex Sentences	Correctness
141.	*ledeburite*	Unknown Words	Correctness
142.	*is achieved*	Passive Voice Misuse	Clarity
143.	, and	Comma Misuse within Clauses	Correctness
144.	~~and the~~ → and the	Improper Formatting	Correctness
145.	~~of silicon~~ → of silicon	Improper Formatting	Correctness

146.	~~silicon in~~ → silicon in	Improper Formatting	Correctness
147.	~~matrix which~~ → matrix which	Improper Formatting	Correctness
148.	, which	Punctuation in Compound/Complex Sentences	Correctness
149.	~~also supported~~ → also supported	Improper Formatting	Correctness
150.	~~supported by~~ → supported by	Improper Formatting	Correctness
151.		Intricate Text	Clarity
152.		Intricate Text	Clarity
153.	~~matrix~~ → model, pattern, array	Word Choice	Engagement
154.	~~basic~~ → primary	Word Choice	Engagement
155.	*is formed*	Passive Voice Misuse	Clarity
156.	~~as~~	Wrong or Missing Prepositions	Correctness
157.	, which	Punctuation in Compound/Complex Sentences	Correctness
158.	~~decrease in~~ → reduction of	Word Choice	Engagement
159.	*be found*	Passive Voice Misuse	Clarity
160.	*ledeburitic*	Unknown Words	Correctness
161.	*be transformed*	Passive Voice Misuse	Clarity
162.	~~a number of~~ → several, some, many	Wordy Sentences	Clarity
163.	*a number of cementite*	Misuse of Quantifiers	Correctness
164.	~~basic~~ → primary, underlying, fundamental, essential	Word Choice	Engagement

165.	However,	Punctuation in Compound/Complex Sentences	Correctness
166.	*ledeburite*	Unknown Words	Correctness
167.	~~matrix~~ → form, model, pattern, array	Word Choice	Engagement
168.		Intricate Text	Clarity
169.		Intricate Text	Clarity
170.	~~effective~~ → active, useful	Word Choice	Engagement
171.	*ledeburite*	Unknown Words	Correctness
172.	~~Cost effective~~ → Cost-effective	Misspelled Words	Correctness
173.	~~effective~~ → useful, active	Word Choice	Engagement
174.	~~and~~ → And	Improper Formatting	Correctness
175.	~~doi~~ → DOI	Misspelled Words	Correctness
176.	*was conducted*	Passive Voice Misuse	Clarity
177.	~~POLMAN~~ → Polman	Confused Words	Correctness
178.	you for	Pronoun Use	Correctness
179.	support.	Closing Punctuation	Correctness
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