Erosion behaviour of alumina ceramic coating on mild steel by the modified composition of phosphate binder

by Rendi Reynaldi

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words per sentence

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Erosion behaviour of alumina ceramic coating on mild steel by the modified composition of phosphate binder

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Abstract. The Pulverizer pipe made of mild steel had erosion failure due to coal dust impacting, thus its service life also reduces. The ceramic coating overlay on the surface of mild steel is one of the appropiate ways to protect the mild steel from erosion. This research is aimed to perform a ceramic coating over the surface of the mild steel using a dipping method to improve its erosion resistance by using the alumina-phosphate ceramic coating. The coating layer is formed by the reaction between monoaluminum phosphate (MAP) as a binder and Al2O3 particles. It transforms into berlinite phase when heated at an elevated temperature. The observation is carried out with the variation of the MAP binder composition Al:P 25:75, 28:72, 30:70 and the Al2O3/MAP slurry is given at 40/60. Scanning electron microscopy is used to characterize the coating morphology. X-ray diffraction is applied to investigate the ceramic coating phases. The gas erosion jet measures erosion resistance of the ceramic coating. From the test result, it can be concluded that the binder composition influenced the erosion behaviour of alumina ceramic coating, the binder with Al:P (30:70) showed the erosion resistance increasing four times compared to the condition without coating.

1. Introduction

The pulverizer pipe is a part of the coal mill pulverizer system which has a function to deliver coal dust to a combustion chamber. Mild steel is commonly used for the pulverizer pipe material due to its mechanical strength, machinability, weldability, formability and reasonable cost. Many energy projects also rely on the amount of steel for pipelines and electric power turbine component [1]. Unfortunately mild steel does not have good erosion resistance against solid particles such as coal dust. During coal grinding at the working chamber of a coal mill pulverizer, the process releases a certain amount of heat which raises the temperatures to 300°C. Pulverizer pipe and inner cone which made of mild steel is impinged by coal dust particle and exposed to heat continuously, then the erosion takes place. The failure of the pulverizer pipe due to coal dust erosion demontrates in figure 1.

The erosion on mild steel is particularly induced by repeated plastic deformation of coal dust particle impact. Mbabazi et al [2] observed that the erosion rate of mild steel was affected by the impingement angle. The highest erosion rate of mild steel is 6.5 mg.Kg-1 the impingement angle reached an inclination between 25-30 deg. Ceramic coatings are widely used for the protection of base metal or cement components in chemical, power, and refractory industries against high temperature corrosion and oxidation and for the minimization of wear or erosion [3].

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Figure 1. Erosion failure of pulverizer pipe.

Alumina ceramic coated on steel is used to provide better performance and help in decreasing erosion that is caused by pressurized air containing entrained abrasive solid coal particles such as oxides and minerals. When the angle of impingement is less than 30 deg, wear produced is closely similar to abrasion but if the angle of impingement is greater than 30 deg to surface, wear produced is released by impact erosion [4]. Ścieszka et al [5] observed the erosion resistance of mild steel coated-alumina compared to high alumina ceramic by solid particle erosion test using pulverized coal dust from a power

plant. The result explained that the erosion resistance of alumina-coated mild steel is four times higher than the high alumina ceramic its self. Troczynski et al [6] have already investigated the behavior of alumina ceramic coating using phosphate binder for the variety of application, including high- temperature corrosion protection, wear resistance, dielectric properties, non-sticky surface, bioactive ceramic, thermal barrier ceramics, and others. Chen et al [7] expressed in their paper, phosphate inorganic binder plays a role in many applications i.e. repairing and joining of material.

This research focused on the use of alumina ceramic coating with phosphate binder on mild steel due to their superior properties and their suitability to the working conditions of pulverizer pipe. It is preferred over the sintering method which requires a process at an elevated temperature. The alumina phosphate ceramic coating consists of alumina particle in which aluminum phosphate used as a binder [8]. Aluminum phosphate binder is formed by reacting inorganic mineral or oxide with an acid-phosphate solution. It is a sort of inorganic binders used in refractory ceramic coating systems, which has been investigated and applied in the thermal spray coating systems. It is reported that refractories bonded with aluminum phosphate exhibit high strength, high-temperature stability, and abrasion resistance. Wang et al [9] reviewed that phosphate adhesive could be made in low temperature curing with high shear strength and excellent electrical properties. They observed the performance of phosphate adhesive which contains Al(HPO4)2 as the major constituent, has a heat-resistance of 1500°C. In this study, the variety of mole ratio Al/P as a phosphate binder for alumina ceramic that coated mild steel were observed. Furthermore, it was characterized using XRD, SEM-EDS and erosion testing then compared with mild steel without any protection. The results will be recommended for erosion

protection of pulverizer pipe.

2. Experiment Work

2.1. Materials and specimen preparation

The materials used for ceramic coating were alumina (Al2O3) as a filler and Al(OH)3 – H3PO4 as a raw material of binder. Alumina (Al2O3) that has a size of 50 – 60 μm was obtained from the local market. All materials that are used come up with a technical grade. It is consist of phosphoric acid (85%), aluminum hydroxide (Al(OH)3), methanol and aquades without further purification.

The specimen used in the investigation was mild steel of 5 mm thickness. The mild steel sheet was cut to a size of 25 mm x 25 mm for ceramic coating. Furthermore, the mild steel specimen was cleaned by methanol to remove scale, corrosion, and other contaminants.

IOP Conf. Series: Materials Science and Engineering 541 (2019) 012026
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2.2. Synthesis of binder

The phosphoric acid and aluminum hydroxide were synthesized to achieve monoaluminum phosphate
(MAP) binder as the equation (1).
3H3PO4 + Al(OH)3 → Al(H2PO4)3 + 3H2O (1) The mole ratio of Al/P was varied to find out the influence of the binder composition to the erosion
behavior of the coating material as shown in table 1.

Table 1. The mole ratio of Al/P in the synthesis of monoaluminum phosphate binder.

Materials
Vario
Al/P (25 : 75)
us moles of Al(OH) 3:
Al/P (28 : 72)
H3PO4
Al/P (30 : 70)
Al(OH)3
12 %
14 %
16 %
H3PO4
55 %
52 %
51 %
Aquades

33 %

34 %

33 %

This mixed solution was reacted at 100º - 120º Celcius to achieve the final product reaction of monoaluminum phosphate. Furthermore, the reaction was dried at the ambient temperature. Figure 2 showed the whole process of this reaction.

Figure 2. Synthesis of monoaluminum phosphate.

2.3. Synthesis of alumina phosphate ceramic coating

The alumina phosphate ceramic coating was synthesized from aluminum oxide particle and monoaluminum phosphate binder with 40:60 of the ratio [3] and applied to the mild steel which has already cleaned with methanol to remove the scale and grease, by dipping technique at the constant time. To gain the hardness of the aluminum coating, it was dried at the various temperature and illustrated in Figure 3.

IOP Conf. Series: Materials Science and Engineering 541 (2019) 012026
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Figure 3. Heat treatment of the aluminum-phosphate ceramic coating.

2.4. Characterization

Several tools were used[100] to characterize the coating. Optical microscope (OLYMPUS SZ61) was used[101] to figure the coating surface, Scanning Electron Microscope (Hitachi SU3500 at 5kV and 40% spot intensity) to[102] observe the microstructure of the coating and interface bonding between steel and coating[103]. Energy Dispersive Spectrometer (EDS) was applied to check the alumina particle composition as[104,105] depicted in figure 4. It showed the alumina was high purity.

Figure 4. Elemental analysis of alumina by EDS.

The density of the coating was counted[106] by Pycnometer (Pyrex, 5 mL). X-Ray Diffraction (SmartLab X-Ray Diffractometer) was used to characterize the binder and to operate at 30 kV and 30 mA scanning at 10° (2θ) to 60°. Erosion tester (TR-470) used to characterize the erosion properties of the coating. This

test according to ASTM G76-02 (standard test method for conducting erosion test by solid particle impingement using gas jets). After the test piece being placed at a jig, it will undergo impact load of alumina particle from the nozzle with speed of 30 m/s until 70 m/s, 90° angle and particle feed rate 2 gr/min for 10 minutes.

3. Result and Analysis

3.1. Monoaluminum phosphate binder

He et al [3], Emmerson et al and Wagh [10], reviewed that aluminum hydrogen phosphate or Al(H2PO4)3 is the phase being expected to be present on this binder which can be reacted with the aluminum oxide particle to form berlinite. The XRD result can be seen in figure 5.

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The peak shows other compound aluminum hydrogen phosphate hydrate Al(H2PO4) nH2O. This phase was detected because the binder aluminum still consists of water, due to the heating process before. The XRD result can be the basis of this research to continue the synthesized between binder and the aluminum oxide particles to achieve coating material. Aluminum hydrogen

phosphate hydrate was formed as much as aluminum hydrogen phosphate based on their height of intensity peaks.

Figure 5. XRD result of synthetic binder.

3.2. Characterizations of alumina-phosphate ceramic coating

Observation of the coating surface was conducted to find the agglomeration of the particle, crack, and the impurity from other material. This observation is important explained by Colonetti research [11]. Colonetti reviewed that crack and porosity influence to the mechanical properties of the coating.

(a) (b) (c)

Figure 6. SEM micrograph of surface morphology of the coating affected by mole ratio of Al/P

a. Al/P (25:75) b. Al/P (28 :72) c. Al/P (30:70).

As seen in figure 6, the surfaces of the coating has a uniform particle distribution, leak and fissures are observed in this coating. The mole ratio of Al/P leads the binder ability to form the compacted ceramic coating. The more the mole ratio of Al in Al/P the denser of the coating becomes.

Wagh et al [10] suggest that the bonding phase is a converted from a very small amount of alumina.

Al2O3 particles disperse in the Al2O3-berlinite system and the product is a thin coating of berlinite on the alumina. As depicted in figure 6 (a-c), the increase of P ratio (as H3PO4) creates the amount of porosity due to gas formation when the dipping process. This phenomenon relates with the increase of MAP acidity which will react with mild steel surface and then releases hydrogen gas.

IOP Conf. Series: Materials Science and Engineering 541 (2019) 012026
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Figure 7. XRD result of alumina-phosphate ceramic coating contained Al/P binder (28:72).

XRD test was used to characterize the compound of the coating with binder ratio Al/P (28:72). Figure 7 shows the main compound of this coating are aluminum oxide, cristobalite and little amount of berlinite in 20°-30°. Berlinite is described as a small peak in a diagram, since it serves only as a binder in the material. He et al [3], and Colonetti et al [11] also

detected berlinite at 20º - 30º with a small peak.

3.3. Effect of density to an alumina-phosphate ceramic coating

Characterization of coating morphology was conducted to prove the effectiveness of the binder to the alumina ceramic coating. Wagh et.al [10] observed the effect of binder density on the distance and compactness of the coating . Table 2 shows the various density of the binder with a different mole ratio of Al/P.

Table 2. The density of the alumina-phosphate ceramic coating.

Density (g/cm3) Al/P (25:75) 1.6704

Al/P (28 :72) 1.7029

Al/P (30:70) 1.7158

a Binder

b Binder

c Binder

Void

Particl[161]

Void

Particl[162]

 Void

Particl[163]

Figure 8. SEM micrograph a. Al/P (25:75) , b. Al/P (28:72) and c. Al/P (30:70).

Figure 8 shows in addition to the effect of the density, the void between the particle can also be caused by the distribution and size of the Al2O3 particle [10]. Void on aluminum ceramic coating was filled by the berlinite as synthesized between the binder and the Al2O3 particle. The reaction product will fill the space of the particle and make it compact. This condition occurrs when the product reaction has less density than the Al2O3 particle. Figure 8 (c) shows the product reaction of the binder with molar

IOP Conf. Series: Materials Science and Engineering 541 (2019) 012026
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ratio Al/P (30:70) has less density than Al2O3 particle and make the coating more compact compared to other molar ratios. The compactness of the coating is important which related to the mechanical properties of the coating.

3.4. Erosion behavior of the alumina-phosphate ceramic coating

Figure 9 shows the result of erosion test, as described in the diagram, it can be seen that coating with the molar ratio of Al/P (30:70) has 5mg/Kg loss material, compare to the steel without any protection that has only 20 mg/Kg loss material.

uncoated

Erosion rate (mg/Kg)

20

15

25 : 75

5

28 : 72

30 : 70

0

Mole ratio of Al : P

Figure 9. Erosion testing of alumina-phosphate ceramic coating and uncoated mild steel.

The result indicates that the erosion resistance of the coating steel is four-time than steel without any protection. This molar ratio also has a higher result than other ratios, it might be caused by the compactness of the coating and the void effect between the particle as the SEM test shows before. He et al [3] reviewed the abrasion resistance of the coating on their research which has two-time wear durability compared to steel without coating. The microstructure of the coating after erosion test can be seen in figure 9.

a b Micro Crack c

Micro Crack

Micro Crack

Creater Micro Crack

Micro Crack

Figure 10. SEM micrograph on magnification x850 after erosion testing a. Al/P (25:75) , b. Al/P (28:72) dan c. Al/P (30:70).

The microcrack was found on the coating after the erosion test, in which the crack can develop due to the impact from erosion particle and also an indication of mechanical properties of the binder. Mol ratio Al/P (30:70) has a less amount of crack, and it is related to the erosion test result of this mol ratio

IOP Conf. Series: Materials Science and Engineering 541 (2019) 012026
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which exibit less weight loss during the test compared to other ratios. A crater was observed in the mol ratio Al/P (28:72) this crater can happen through the test.

4. Conclusion

The mole ratio of Al/P in MAP binder influence the properties and erosion behavior of alumina ceramic coating. The aluminum phosphate ceramic coating was successfully coated to the steel and increase erosion resistance of the steel four times than steel without any protection. The best mole ratio of this aluminum phosphate ceramic coating was obtained in Al/P (30:70) and heated at 220°C to form

aluminum phosphate or berlinite as the binding phase of this coating in this research.

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1.	~~doi~~ → DOI	Misspelled Words	Correctness
2.	~~behaviour~~ → behavior	Mixed Dialects of English	Correctness
3.	E-mail :	Improper Formatting	Correctness
4.	~~, thus~~ → . Thus, ; thus	Punctuation in Compound/Complex Sentences	Correctness
5.	~~appropiate~~ → appropriate	Misspelled Words	Correctness
6.	*is aimed*	Passive Voice Misuse	Clarity
7.		Intricate Text	Clarity
8.	*is formed*	Passive Voice Misuse	Clarity
9.	the berlinite	Determiner Use (a/an/the/this, etc.)	Correctness
10.	*is carried*	Passive Voice Misuse	Clarity
11.	, and	Punctuation in Compound/Complex Sentences	Correctness
12.	*is given*	Passive Voice Misuse	Clarity
13.	*is used*	Passive Voice Misuse	Clarity
14.	*be concluded*	Passive Voice Misuse	Clarity
15.	~~behaviour~~ → behavior	Mixed Dialects of English	Correctness
16.	~~, the~~ → . The	Hard-to-read text	Clarity
17.	~~coating~~ → coat	Word Choice	Engagement
18.	, which	Punctuation in Compound/Complex	Correctness

		Sentences	
19.	*is commonly used*	Passive Voice Misuse	Clarity
20.	, and	Comma Misuse within Clauses	Correctness
21.	*Mild steel is commonly used for the pulverizer pipe material due to its mechanical strength, machinability, weldability, formability and reasonable cost.*	Hard-to-read text	Clarity
22.	~~also~~	Wordy Sentences	Clarity
23.	~~component~~ → components	Incorrect Noun Number	Correctness
24.	Unfortunately,	Comma Misuse within Clauses	Correctness
25.	~~good~~ → excellent	Word Choice	Engagement
26.	the coal	Determiner Use (a/an/the/this, etc.)	Correctness
27.	, which	Punctuation in Compound/Complex Sentences	Correctness
28.	, which	Punctuation in Compound/Complex Sentences	Correctness
29.	~~is~~ → are	Faulty Subject-Verb Agreement	Correctness
30.	~~particle~~ → particles	Incorrect Noun Number	Correctness
31.	~~, then~~ → ; then, , and then, . Then	Punctuation in Compound/Complex Sentences	Correctness
32.	~~demontrates~~ → demonstrates, demonstrated	Misspelled Words	Correctness

33.	~~on~~ → of	Wrong or Missing Prepositions	Correctness
34.	~~particularly~~ → mainly	Word Choice	Engagement
35.	*is particularly induced*	Passive Voice Misuse	Clarity
36.	~~et al~~ → et al.	Comma Misuse within Clauses	Correctness
37.	, the	Punctuation in Compound/Complex Sentences	Correctness
38.	*are widely used*	Passive Voice Misuse	Clarity
39.	~~against high~~ → against high	Improper Formatting	Correctness
40.	high-temperature	Misspelled Words	Correctness
41.	minimizes	Wordy Sentences	Clarity
42.	*be used*	Passive Voice Misuse	Clarity
43.	~~licence~~ → license	Mixed Dialects of English	Correctness
44.	, and	Comma Misuse within Clauses	Correctness
45.	~~licence~~ → license	Mixed Dialects of English	Correctness
46.	~~doi~~ → DOI	Misspelled Words	Correctness
47.	*is used*	Passive Voice Misuse	Clarity
48.	, but	Punctuation in Compound/Complex Sentences	Correctness
49.	~~et al~~ → et al.	Comma Misuse within Clauses	Correctness
50.	~~solid~~ → robust, substantial, reliable	Word Choice	Engagement
51.	~~its self~~ → itself	Wordy Sentences	Clarity

52.	~~et al~~ → et al.	Comma Misuse within Clauses	Correctness
53.	various applications	Wordy Sentences	Clarity
54.	~~application~~ → applications	Incorrect Noun Number	Correctness
55.	~~et al~~ → et al.	Comma Misuse within Clauses	Correctness
56.	i.e.,	Comma Misuse within Clauses	Correctness
57.		Intricate Text	Clarity
58.	the pulverizer	Determiner Use (a/an/the/this, etc.)	Correctness
59.		Intricate Text	Clarity
60.	*is preferred*	Passive Voice Misuse	Clarity
61.	, which	Punctuation in Compound/Complex Sentences	Correctness
62.	~~particle~~ → particles	Incorrect Noun Number	Correctness
63.	*is reported*	Passive Voice Misuse	Clarity
64.	~~et al~~ → et al.	Comma Misuse within Clauses	Correctness
65.	, which	Punctuation in Compound/Complex Sentences	Correctness
66.	~~major~~ → principal	Word Choice	Engagement
67.	*were observed*	Passive Voice Misuse	Clarity
68.	, and	Comma Misuse within Clauses	Correctness
69.	~~then~~	Wordy Sentences	Clarity
70.	~~compared with~~ → compared with	Improper Formatting	Correctness

71.	~~with mild~~ → with mild	Improper Formatting	Correctness
72.	~~mild steel~~ → mild steel	Improper Formatting	Correctness
73.	~~steel without~~ → steel without	Improper Formatting	Correctness
74.	~~without any~~ → without any	Improper Formatting	Correctness
75.	~~any protection~~ → any protection	Improper Formatting	Correctness
76.	*be recommended*	Passive Voice Misuse	Clarity
77.	the pulverizer	Determiner Use (a/an/the/this, etc.)	Correctness
78.	~~that has~~ → with	Wordy Sentences	Clarity
79.	*was obtained*	Passive Voice Misuse	Clarity
80.	*are used*	Passive Voice Misuse	Clarity
81.	~~consist~~ → consists	Faulty Subject-Verb Agreement	Correctness
82.	, and	Comma Misuse within Clauses	Correctness
83.	~~aquades~~ → equates	Misspelled Words	Correctness
84.	*was cut*	Passive Voice Misuse	Clarity
85.	~~mild~~ → calm, soft, sweet	Word Choice	Engagement
86.	~~doi~~ → DOI	Misspelled Words	Correctness
87.	*were synthesized*	Passive Voice Misuse	Clarity
88.	the behavior	Determiner Use (a/an/the/this, etc.)	Correctness
89.	, as	Punctuation in Compound/Complex	Correctness

		Sentences	
90.	25 :	Improper Formatting	Correctness
91.	28 :	Improper Formatting	Correctness
92.	30 :	Improper Formatting	Correctness
93.	*was reacted*	Passive Voice Misuse	Clarity
94.		Intricate Text	Clarity
95.	~~reaction~~ → result, response	Word Choice	Engagement
96.	*was dried*	Passive Voice Misuse	Clarity
97.	, which	Punctuation in Compound/Complex Sentences	Correctness
98.	*To gain the hardness of the aluminum coating*	Misplaced Words or Phrases	Correctness
99.	~~doi~~ → DOI	Misspelled Words	Correctness
100.	*were used*	Passive Voice Misuse	Clarity
101.	*was used*	Passive Voice Misuse	Clarity
102.	, to	Punctuation in Compound/Complex Sentences	Correctness
103.	~~coating~~ → sheet, cladding, layer	Word Choice	Engagement
104.	~~composition as~~ → composition as	Improper Formatting	Correctness
105.	, as	Punctuation in Compound/Complex Sentences	Correctness

106.	*was counted*	Passive Voice Misuse	Clarity
107.	, according	Punctuation in Compound/Complex Sentences	Correctness
108.	~~solid~~ → substantial	Word Choice	Engagement
109.	*being placed*	Passive Voice Misuse	Clarity
110.	an impact	Determiner Use (a/an/the/this, etc.)	Correctness
111.	the speed, or a speed	Determiner Use (a/an/the/this, etc.)	Correctness
112.	, and	Comma Misuse within Clauses	Correctness
113.	~~et al~~ → et al.	Comma Misuse within Clauses	Correctness
114.	~~et al~~ → et al.	Comma Misuse within Clauses	Correctness
115.	],	Comma Misuse within Clauses	Correctness
116.	*being expected*	Passive Voice Misuse	Clarity
117.	*be seen*	Passive Voice Misuse	Clarity
118.	~~doi~~ → DOI	Misspelled Words	Correctness
119.	*compound aluminum hydrogen phosphate hydrate*	Intricate Text	Clarity
120.	*was formed*	Passive Voice Misuse	Clarity
121.	the synthetic, or a synthetic	Determiner Use (a/an/the/this, etc.)	Correctness
122.	*was conducted*	Passive Voice Misuse	Clarity
123.		Intricate Text	Clarity

124.	~~important~~ → essential	Word Choice	Engagement
125.	important,	Punctuation in Compound/Complex Sentences	Correctness
126.	~~Colonetti~~ → Colonetti's	Incorrect Noun Number	Correctness
127.	~~Colonetti~~ → Coletti	Misspelled Words	Correctness
128.	~~to~~ → on	Wrong or Missing Prepositions	Correctness
129.	the mole	Determiner Use (a/an/the/this, etc.)	Correctness
130.	~~has~~ → have	Faulty Subject-Verb Agreement	Correctness
131.	, and	Comma Misuse within Clauses	Correctness
132.	*are observed*	Passive Voice Misuse	Clarity
133.	~~coating~~ → layer	Word Choice	Engagement
134.	, the	Punctuation in Compound/Complex Sentences	Correctness
135.	~~coating~~ → surface, layer, sheet	Word Choice	Engagement
136.	~~et al~~ → et al.	Comma Misuse within Clauses	Correctness
137.	~~a~~ converted	Determiner Use (a/an/the/this, etc.)	Correctness
138.	~~a very small~~ → a minimal, a tiny	Word Choice	Engagement
139.	, and	Punctuation in Compound/Complex Sentences	Correctness
140.	~~increase of~~	Wordy Sentences	Clarity

141.	~~with~~ → to	Wrong or Missing Prepositions	Correctness
142.	~~increase of~~ → rise in, rise of	Word Choice	Engagement
143.	, which	Punctuation in Compound/Complex Sentences	Correctness
144.	the mild	Determiner Use (a/an/the/this, etc.)	Correctness
145.	~~doi~~ → DOI	Misspelled Words	Correctness
146.	*was used*	Passive Voice Misuse	Clarity
147.	~~7~~ → Seven	Improper Formatting	Correctness
148.	~~compound~~ → mixture, synthesis	Word Choice	Engagement
149.	~~are~~ → is	Faulty Subject-Verb Agreement	Correctness
150.	, and	Comma Misuse within Clauses	Correctness
151.		Intricate Text	Clarity
152.	diagram,	Punctuation in Compound/Complex Sentences	Correctness
153.	~~et al~~ → et al.	Comma Misuse within Clauses	Correctness
154.	],	Punctuation in Compound/Complex Sentences	Correctness
155.	~~et al~~ → et al.	Comma Misuse within Clauses	Correctness
156.	*was conducted*	Passive Voice Misuse	Clarity
157.	~~et.al~~ → et al.	Comma Misuse within Clauses	Correctness

158.	~~coating~~ → surface, sheet, layer, coat	Word Choice	Engagement
159.		Intricate Text	Clarity
160.	~~density~~ → thickness, frequency	Word Choice	Engagement
161.	~~Particl~~ → Particle, Partial	Misspelled Words	Correctness
162.	~~Particl~~ → Particle, Partial	Misspelled Words	Correctness
163.	~~Particl~~ → Particle, Partial	Misspelled Words	Correctness
164.	*be caused*	Passive Voice Misuse	Clarity
165.	~~as synthesized~~ → as-synthesized	Misspelled Words	Correctness
166.	~~occurrs~~ → occurs	Misspelled Words	Correctness
167.	molar.	Closing Punctuation	Correctness
168.	~~doi~~ → DOI	Misspelled Words	Correctness
169.	~~ratio~~ → Ratio	Improper Formatting	Correctness
170.	~~make~~ → makes	Faulty Subject-Verb Agreement	Correctness
171.		Intricate Text	Clarity
172.	~~coating~~ → surface, layer, sheet	Word Choice	Engagement
173.	~~important~~ → essential	Word Choice	Engagement
174.	, which	Punctuation in Compound/Complex Sentences	Correctness
175.	~~coating~~ → surface, sheet	Word Choice	Engagement
176.	~~compare~~ → compared	Incorrect Verb Forms	Correctness
177.	25 :	Improper Formatting	Correctness

178.	28 :	Improper Formatting	Correctness
179.	30 :	Improper Formatting	Correctness
180.	The mole, or A mole	Determiner Use (a/an/the/this, etc.)	Correctness
181.	~~uncoated mild~~ → mild uncoated	Misplaced Words or Phrases	Correctness
182.	~~ratios~~ → rates	Word Choice	Engagement
183.	~~, it~~ → ; it, , and it, . It	Punctuation in Compound/Complex Sentences	Correctness
184.	*be caused*	Passive Voice Misuse	Clarity
185.	~~et al~~ → et al.	Comma Misuse within Clauses	Correctness
186.	~~coating~~ → surface, layer	Word Choice	Engagement
187.	, which	Punctuation in Compound/Complex Sentences	Correctness
188.	~~coating~~ → surface, sheet	Word Choice	Engagement
189.	the erosion	Determiner Use (a/an/the/this, etc.)	Correctness
190.	*be seen*	Passive Voice Misuse	Clarity
191.	~~Creator~~ → Creator, Create	Misspelled Words	Correctness
192.	*was found*	Passive Voice Misuse	Clarity
193.	ratio.	Closing Punctuation	Correctness
194.	~~doi~~ → DOI	Misspelled Words	Correctness

195.	~~which~~ → Which	Improper Formatting	Correctness
196.	~~exibit~~ → exhibit	Misspelled Words	Correctness
197.	*which exibit less weight loss during the test compared to other ratios.*	Incomplete Sentences	Correctness
198.	*was observed*	Passive Voice Misuse	Clarity
199.	the MAP	Determiner Use (a/an/the/this, etc.)	Correctness
200.	*For*	Inappropriate Colloquialisms	Delivery
201.	~~jiang~~ → Jiang	Misspelled Words	Correctness
202.	, and	Comma Misuse within Clauses	Correctness
203.	, and	Comma Misuse within Clauses	Correctness
204.	~~to~~	Wrong or Missing Prepositions	Correctness
205.	, which	Punctuation in Compound/Complex Sentences	Correctness
206.	the HIBAH	Determiner Use (a/an/the/this, etc.)	Correctness
207.	~~POLMAN~~ → Polman	Confused Words	Correctness
208.	~~sector~~ → sectors	Incorrect Noun Number	Correctness