Improvement of erosion resistance of alumina-phosphate ceramic coating on mild steel by SiC addition

by Rendi Reynaldi

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Improvement of erosion resistance of alumina-phosphate ceramic coating on mild steel by SiC addition

D Idamayanti1, I L Nurhakim1, B Bandanadjaja1, W Purwadi1, N Lilansa2

1 Foundry Engineering Department, Politeknik Manufaktur Bandung, Jl. Kanayakan no. 21 Bandung, Indonesia

2 Automation Engineering Department, Politeknik Manufaktur Bandung, Jl. Kanayakan no. 21 Bandung, Indonesia

E-mail :[2] idamayanti79@gmail.com

Abstract. This research is focused[3] on the application of the Al2O3-phosphate ceramic coating on mild[4] steel surface[5] to protect mild steel from erosion in coal[6] dust environment. Erosion resistance of mild steel could be improved by overlay[7] it with SiC in the Al2O3-phosphate ceramic coating. As a filler, Al2O3 was mixed[9] with 20%, 40%, and 60% SiC by using aluminium[10] phosphate as a binder and heated at 220 °C for 5 hours.[8] X-ray diffraction testing was conducted[11] to observe the phase of Al2O3-SiC phosphate ceramic coating. Meanwhile,[12] surface morphology and adhesion characteristic[13] of Al2O3-SiC phosphate ceramic coating were[14] analyzed by scanning electron microscope. To analyze[15] the erosion resistance quantitatively solid[16] particle impingement test by applying gas jets at the right angle (90°) against a sample surface has been conducted. The results showed that Al2O3-SiC phosphate ceramic coating is strongly[17] bound to the mild steel surface without the presence of[18] any void. The higher the SiC content can increase the ceramic coating density and its erosion resistance. The SiC 60% produces four times higher erosion resistance than

uncoated mild [19] steel. The material characterization of Al2O3-SiC phosphate ceramic coating proves that SiC gives [20] a significant impact on the enhancement of erosion resistance of the Al2O3- SiC phosphate ceramic coating.

1. Introduction

260 The purpose of this research is to improve the resistance of the inner cone [21] of a coal pulverizer against the erosion [22] [23] .
The inner cone as [24] shown in figure 1 [25] is part of the coal pulverizer. When observed [26] it has erosion failure due to coal dust scouring. The inner cone itself which [27] generally made of mild steel [28] serves to direct the coal dust to the classifier, therefore, [29] it should show excellent resistance against erosion caused by the flow of the coal dust. The mild steel is widely used as a structural material in some of the [30] engineering applications due to its good [31] machinability, high thermal conductivity, and superior mechanical strength [1]. Nevertheless, this material is highly [32] affected by corrosion and wear and last consequently [33] shorter service life.
Applying ceramic coating on the surface of the mild [34] steel is one of the most reliable erosion protection methods. [35] Ceramic coatings are widely applied [36] to protect some metal or cement machine components in power [37] and refractory industries against chemical corrosion, abrasive wear, and high-temperature oxidation environments [2,3].
The ceramic coating consists mainly of oxide particles such as Al2O3 (mostly used), CaO, MgO,Cr2O3, [38] etc., and binder. Several types of binder [39,40] can be applied for ceramic coatings such as polymers, inorganic materials, and chemically bonded ceramic. Polymer binder includes polyvinyl alcohol, Teflon, and acrylic [4] in the most cases

cannot withstand against high temperature above 200 °C, while the inorganic binders namely sodium silicate, and hydraulic cement show high strength at the room temperature but less resistant at elevated temperature [5]. Type

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of [47] binder used plays important [48] roles [49] in binding ceramic coating adhering to the substrate. The binder [50] does not only adhere between the coating [51] to the metal surface but also binds the ceramic particles together so that the ceramic particles is [52] not peeled [53] off the coating [54] [3]. An additional challenge applies to binders for making alumina ceramic coating that operates at high temperatures. According to previous studies by the authors, aluminium [55] phosphate is preferred [56] as a refractory and alumina ceramic coating binder due to its high strength, high-temperature stability, abrasion resistance [1,6,7], good[57] adhesion, and reduced risk of cracking under high heating rate after curing [8].

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Figure 1. The failure of inner cone coal mill pulverizer.

Also,[58] the aluminium[59] phosphate binder also[58] presents other interesting[60] properties, such as excellent mechanical properties, low-cost preparation, short setting time and[61] low-temperature ceramic "sol-gel like" coating which can be applied below 250°C [6,8]. The phosphate binder is firstly synthesized[62] by reacting aluminium[63] hydroxide and phosphoric acid to form monoaluminium phosphate (MAP). Subsequently, the MAP is mixed with ceramic particles such

as alumina, magnesia, and zirconia to result in a ceramic slurry system which[64] is known as chemically bonded phosphate ceramics (CBPC) [9]. Many researchers have observed CBPC and applied on metals to enhance corrosion and abrasion resistance of metals[65] [1–3,6,10]. They modified a kind of ceramic materials to improve the mechanical properties of the phosphate bonded Al2O3 ceramic coating. He et al[66] [5] has investigated the effect of SiC in the Al2O3-phosphate ceramic coating. It showed the improvement of wear[67] rate of phosphate bonded Al2O3-SiC ceramic coating due to the increasing[68] of SiC content. This
262 phenomenon is very logical due to the high hardness of SiC particles compared to Al2O3 particles [11]. This research has been conducted[69] to investigate the effect of SiC addition in phosphate bonded Al2O3 ceramic coatings as abrasive ceramic particles to enhance the erosion resistance of coated mild steel as representative materials for pulverizer inner[70] cone. The SiC particles were mixed with Al2O3 to form ceramic slurry using monoaluminium phosphate as a binder. The performance of phosphate bonded Al2O3-SiC ceramic coating on the mild steel was tested by alumina particle impingement using gas jets at the right angle (90°) against a specimen surface and was[71] then verified by surface morphology using a scanning electron microscope. The gas jet containing alumina particles is applied to simulate the real condition. The results can optionally be taken[72] for increasing the life of the inner cone pulverizer.

2. Experimental Work

2.1. Raw materials and specimen

The materials which are used[73] for phosphate bonded Al2O3-SiC ceramic coating were alumina (Al2O3) as a ceramic particle, SiC as a filler of ceramic[74] system, and Al(OH)3 – H3PO4 as raw materials of the monoaluminium phosphate (MAP) binder. Alumina (Al2O3) size was 50 – 60 µm with round shapes, obtained as technical grade material. The particle size of SiC was average[75] of 126,36 µm with irregular shapes. Both Al2O3 and SiC have different particles[76] morphology as[77] shown in figure 2. Phosphoric acid (85%), aluminium[78] hydroxide (Al(OH)3), methanol and aquadest[79] were used[80] as technical grade material

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without further purification.[82] The[83] specimen used in the experiment was mild steel with 5[84] mm thickness. The chemical composition is listed[85] in table 1. The specimen[86] was cut to a size of 25 mm x 25 mm for implementing the ceramic coating.[87] Furthermore, the specimen[88] was cleaned by methanol to remove scale, corrosion, and other contaminants.

Table 1. Chemical composition of specimen.[89]

C (%)

Si (%)

S (%)

P (%)

Mn (%)

Ni (%)

Cr (%)

Mo (%)

Cu (%)

Fe (%)

0,05

0,01

0,006

0,01

0,30

0,005

0,01

0,003

0,01

99,54

(a) (b)

Figure 2. The particles[90] morphology of Al2O3 (a) and SiC (b).

2.2. Synthesis of monoaluminium phosphate binder (MAP)

Monoaluminium phosphate (MAP) as a binder was synthesized[91] by reaction[92] of phosphoric acid (H3PO4) and aluminium[93] oxide [5]. The reaction between

263 phosphoric acid and aluminium[94] hydroxide was carried[95] out in deionized water at an Al/P (1/3) molar ratio. The mixture was stirred for 15 minutes at 100 °C to form MAP. Subsequently, the reaction product was dried at ambient temperature and was characterized[96] by X-Ray Diffraction (Rigaku SmartLab X-Ray Diffractometer). The design of the MAP molar ratio refers to the stoichiometry reaction that follows the equation (1).[97]

3H3PO4 + Al(OH)3 → Al(H2PO4)3 + 3H2O (1) The density of the MAP was measured using pycnometer to control its viscosity for coating application.

2.3. The formation of phosphate bonded Al2O3-SiC ceramic coating on mild steel

Recently, phosphate bonded Al2O3-SiC ceramic coating is widely used[98] because the process[99] can be carried[100] out at room temperature, easy to apply and[101] low-cost process [10]. It was applied to the prepared

mild steel using the brushing technique. To produce the Al2O3-SiC ceramic suspension[102], the MAP binder was slowly stirred[103] with Al2O3-SiC particles at a ratio of 1:1. The various amount of SiC in the Al2O3- SiC system studied were 20%, 40%, and 60%, respectively. He et al[104] [5] and Chen et al[105] [3] used SiC as an abrasive material to improve the mechanical properties of the Al2O3 phosphate ceramic coating. Phosphate bonded Al2O3-SiC that coated on the mild steel was hardened by following heat treatment processes:

Phosphate bonded Al2O3-SiC ceramic coating on the mild steel was dried at ambient temperature to evaporate water content for two hours. The heat treatment of phosphate bonded Al2O3-SiC ceramic

coating was continued at 80 °C for 2 hours, then was held at 220 °C for 5 hours to obtain the berlinite phase.[106]

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2.4. Characterization of phosphate bonded Al2O3-SiC ceramic coating

This research involved some instruments for the characterization process.

Optical Emission

Spectrometer (Spektris ARL 3460) was used to analyze the chemical composition of mild steel.

Macroscopic observation of phosphate bonded Al2O3-SiC ceramic coating was done by using the optical microscope (Olympus). Scanning Electron Microscope (Hitachi SU3500) was used to observe the surface morphology of the ceramic coating and its binding strength on the mild steel and the measuring of alumina or SiC particles size. Erosion characteristic of the mild steel and ceramic coatings were observed using SEM magnification at 200x. X-Ray Diffraction (Rigaku SmartLab Diffractometer) were carried out to observed phase identification of the binder and ceramic coating. Diamond cutting saw was used to a cross-sectional cutting of the ceramic coating. Erosion tester (Ducom triboinovator) was used to examine the erosion resistance of the ceramic coating according to ASTM G76-02 (standard test method for conducting erosion test by solid particle impingement using gas jets). The velocity of the testing is 30 m/s up to 70 m/s for 10 minutes with an impact angle at 90°. The solid particles selected were alumina particles close to the real conditions in coal[132] dust environment. The erosion resistance according[133] to erosion rate (mg/Kg) and was measured[134] as weight loss of the ceramic coating per weight of the erodent material (alumina).

3. Result and Analysis

3.1. Characterization of synthesized monoaluminium phosphate binder (MAP)

MAP binder has been successfully fabricated with its density of 1.71 g/cm3 as much as resulted by He et al[135] [5] for ceramic coating application. According to XRD patterns in figure 3, there is a mixture of several phases, namely[136] aluminium[137] hydrogen phosphate (known as a MAP) and aluminium[138] hydrogen phosphate hydrate (known as MAP monohydrate). The intensity of the MAP as a function of its content is almost proportional to the intensity[139] of MAP monohydrate.[140] Chen et al[141] observed initial dehydration of MAP trihydrate transforms to MAP as a dominant phase and MAP monohydrate as a secondary phase when the temperature is slightly elevated[142] to 105 °C [3,5].[143] MAP binder plays an important[144] role in binding between ceramic particles and also to bind the ceramic suspension to the mild steel surface. Chen et al[145] [3] stated that MAP is the most effective bonding phase which[146] fully formed when the temperature reaches 200 – 400 °C. A previous study concluded not only the concentration of MAP binder but also the reactivity and solubility of the selected oxide must be controlled[147] during the processing steps to attain an improved bonding of the fine[148] and coarse components [8].[149]

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30000

Intensity (counts)

20000

Meas. data:Mono alumunium Phosphat Aluminum Hydrogen Phosphate

Aluminum Hydrogen Phosphate Hydrate

10000

Aluminum Hydrogen Phosphate

Aluminum Hydrogen Phosphate Hydrate

10 20 30 40 50 60

2-theta (deg)

Figure 3. XRD pattern of the MAP binder consisting of monoaluminium phosphate (MAP) and monoaluminium phosphate hydrate (MAP hydrate). 155

3.2 Characterization of phosphate bonded Al2O3-SiC ceramic coating

Phosphate bonded alumina ceramic coatings are formed by slowly stirring alumina into a MAP binder solution. Alumina is a kind of amphoteric oxide that may slowly dissolve in aqueous MAP binder being weakly basic 156 cation with small radii for the formation of cold-setting ceramics known as a kind of chemically bonded phosphate ceramics (CBPCs). The kinetics of formation CBPCs are the dissolution of alumina, the formation of 157 aquosols 158 by hydrolyzes, acid-base reaction and 159 condensation into a CBPC, percolation and 160 gel formation, saturation then 161 the formation of crystallization into a monolithic solid of CBPC. 162 Thus, unreacted alumina is available to form a good 163 stable ceramic [12]. In this work, the addition of SiC in the Al2O3 ceramic system acts

as a filler which[164] enhances the mechanical properties of CBPC such as wear resistance, erosion resistance, and corrosion resistance [3,5]. The XRD patterns in Figure 4 show the composition of phosphate bonded Al2O3-SiC ceramic coating. The XRD peaks reveal the phases of residual aluminium[165] oxide (Al2O3), berlinite, and cristobalite. The reaction of alumina particles and MAP binder[166] produced aluminium[167] phosphate (AlPO4). As explained by Morris et al[168] [13], AlPO4 comes up as berlinite, tridymite cristobalite forms. Fully formed berlinite is obtained[169] by heating precipitated, amorphous, aluminium[170] phosphate to 450 °C with lithium fluoride, but berlinite inversion,[171] take[172] place[173] at lower temperatures (150 °C, [9]). Meanwhile, the cristobalite form can be obtained in[174] the presence of sodium chloride as promoters of crystallization or temperature stability relationship of berlinite phase [13].[175] As shown in figure 4, AlPO4 as cristobalite form is a dominant phase. Bandyopadhyay [14] stated that AlPO4 as cristobalite might be formed[176] when heated to 150 –
200°C.

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4000

3000

Meas. data:1,15 (20 h) 350 + SiC Aluminum Oxide

Berlinite

Cristobalite high temperature [178] form - from Ellor a Caves, India

2000

Intensity (counts)

1000

Aluminum Oxide

Berlinite

Cristobalite high temperature [179] form - from Ellora Caves, India

10 20 30 40 50 60

2-theta (deg)

Figure 4. XRD pattern of phosphate bonded Al2O3-SiC ceramic coating on the mild steel.

Berlinite (AlPO4) is the target phase compound of phosphate bonded Al2O3-SiC on the mild steel which[180] the kinetic transformation of berlinite is similar to the one in the conventional sol-gel process [12]. According to wagh[181] et al[182] [7][183] once aluminium[184] oxide dissolves, it will form intermediate[185] phase of AlH3(PO4)2.H2O which[186] will react with remaining oxide (Al2O3) on the surface of their particle to form berlinite and bind them. The reaction may be written[187] as the equation[188] (2). Al2O3 + 2AlH3(PO4)2.H2O → 4AlPO4 +4H2O (2) Wagh et al[189] [15] predict that a very small[190] amount of alumina must be converted[191] to form the bonding phase. In the Al2O3-berlinite system, Al2O3 particles disperse due to alumina sol-cluster and the Al2O3 surface[192] being highly electrostatically repulsive [16] and the product is mostly alumina with a thin coating of berlinite on the alumina [15]. In the case of the SiC-Al2O3 system, SiC particles absorb alumina sol- gel[193], resulting in a steric repulsive force between particles [16]. This phenomenon is essential to get complete[194] dispersion of ceramic particle[195] and preserve the final quality of the products. The solubility of alumina is very low (DH° -837.8 kJ/mol) so that dissolution of alumina and its hydrate phases may be enhanced[196] by elevating the temperature of the ceramic slurry. The heat treatment is also required for both [197] drying and transforming crystalline and amorphous phases of aluminium [198] phosphate [15].

Table 2. Parameters related to phosphate ceramic formulation for most common oxides [12].

Oxides

Reactions

DH (kJ/mol)

Al2O3

2Al2O3 + H3PO4 → 2AlPO4 + 3H2O

-45.75

FeO

FeO + H3PO4 → FeHPO43H2O

-136.7

Fe2O3

2Fe2O3 + 3H3PO4 → 2Fe(H2PO4)3 + 3H2O

-95.1

The ability to chemically bond Al2O3 and other ceramic particles like SiC on mild steel without complicated mild [199] steel preparation are technologically important. Table 2 shows FeO or Fe2O3 as

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corrosion[201] products which[202,203] commonly found on mild steel may easily[204] react with MAP binder due to highly exothermic enthalpy value. Mechanical adhesion due to surface roughness is also possible [13], and this can be increased[205] by elevated temperature.

Figure 5 illustrates that the Al2O3-SiC phosphate ceramic coating strongly[206] adheres to the mild steel. Thus, a good interface bonding between the mild steel and ceramic coating is created[207]. Along in the interface line, there is no void or other discontinuities. The thickness of the ceramic coating results in 352-460 μm.

Figure 5. SEM Micrograph of the cross-section view of Al2O3-SiC phosphate ceramic coating on steel. (a) 20% SiC, (b) 40% SiC, (c) 60% SiC.

3.3 Erosion resistance of phosphate bonded Al2O3-SiC ceramic coating

3.3.1 Effect ratio of SiC in the phosphate bonded Al2O3-SiC ceramic coating

The filler and its proportion in the compact affect both strength and thermal expansion [17]. Idamayanti[208]
et al[209] [18] applied phosphate bonded Al2O3 ceramic coatings (without SiC) on mild steel, then the ceramic coating shows the erosion rate of 5mg/Kg. Unfortunately, the Al2O3 phosphate ceramic coatings absorb the humidity in ambient temperature and also disintegrated[210] when placed in water [7,17,18]. Chen et al[211] [3] fabricated Al2O3-SiC ceramic coating on A3 steel which[212] its wear durability is about two times that of uncoated A3 steel. As mentioned above, SiC particle act both filler and ceramic slurry stabilizer due its[213] steric repulsive force. Considerable porosity was found in the phosphate bonded Al2O3-20%SiC ceramic coating (as seen in Figure 7A) caused by the releasing of hydrates when berlinite formed [7] and also by rapid evaporation of excess water in the slurry [15]. 20 % SiC in the ceramic system does not affect significantly to make dense[214] ceramic coating. Also, the[215] increase of SiC content 40 % to 60% generates compact and homogenous ceramic coating (figure 8A and 9A). In this work, an erosion testing was conducted[216] to measure the erosion resistance phosphate bonded Al2O3-SiC ceramic coating influenced by SiC content of 20%, 40%, and 40%, respectively, when compared[217] to that of uncoated mild[218] steel. Figure 6 shows that the erosion rate of mild steel is four times higher (20 mg/Kg) than the Al2O3-60% SiC phosphate ceramic coating (5 mg/kg).

These results show a relation between the hardness of material and erosion behavior (brittle or
ductile) [19,20]. Mohs hardness scale of each material used is alumina[219] of 9, SiC of 9-10, and berlinite of 6-7 [21]. According to the hardness levels, berlinite will erode first due to its the lowest[220] hardness.

When erodent materials impact both berlinite and Al2O3-SiC ceramic coatings, their resistance depends
on the most prominent phase in the impacted area.

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Figure 6. The effect of SiC addition on the erosion rate of phosphate bonded Al2O3-SiC ceramic coating.

3.3.2 Erosion behavior of the Al2O3-SiC phosphate ceramic coatings

The erosion behavior of materials was affected by its bonding strength to face the solid particle impingement then accelerated by the impact angle. According to Hutchings et al [22], the erosion rate
of ductile materials will be high at low impact angle (25-30°), while the erosion rate of brittle material will be high at high impact angle (90°). The phosphate bonded Al2O3-SiC ceramic coating as a kind of brittle material was tested at the high impact angle 90o to ensure its performance in severe erosion [19]. Figure 7-9 (B) shows the morphology after erosion testing. The surface morphology of phosphate

bonded Al2O3-20%SiC ceramic coating releases a lot of debris that comes from berlinite peel off, then a lot of cavities are formed. The result is comparable to the morphology of phosphate bonded Al2O3- SiC ceramic coating developed by Chen et al [226] [3]. Almost certainly, well-covered berlinite of Al2O3-60%SiC ceramic coating (figure 9B) is the most resistant toward particles [227] impingement.

Figure 7. SEM micrograph of the morphology of phosphate bonded Al2O3-20%SiC
ceramic coating, before erosion testing (A), after erosion testing (B).

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Figure 8. SEM micrograph of the morphology of phosphate bonded Al2O3-SiC ceramic coating before erosion testing (A), after erosion testing (B).

Figure 9. SEM micrograph of the morphology of phosphate bonded Al2O3-60%Si ceramic coating, before erosion testing (A), after erosion testing (B).

The higher the SiC content, the higher the particle density, the lower the porosity, and the lower debris releasing after erosion testing. The addition of 60% SiC in the Al2O3-SiC mixture showed the best performance against erosion.

4. Conclusion

A study of the SiC addition concerning the phosphate bonded Al2O3 ceramics system was carried out. It was found that SiC improves the erosion rate of phosphate bonded Al2O3-SiC ceramic coating. As high SiC was added in the ceramic coating, the erosion resistance of phosphate bonded Al2O3-SiC ceramic coatings increase. The addition of 60% SiC in the Al2O3-SiC ceramic coating produces four times erosion resistance if it compares respectively with uncoated mild steel. The Al2O3-SiC ceramic coating on mild steel results in good adhesion and produces 352-460 μm of the thickness.

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1.	~~doi~~ → DOI	Misspelled Words	Correctness
2.	E-mail :	Improper Formatting	Correctness
3.	*is focused*	Passive Voice Misuse	Clarity
4.	a mild	Determiner Use (a/an/the/this, etc.)	Correctness
5.	~~surface~~ → surfaces	Incorrect Noun Number	Correctness
6.	the coal	Determiner Use (a/an/the/this, etc.)	Correctness
7.	*by overlay*	Misplaced Words or Phrases	Correctness
8.	*As a filler, Al2O3 was mixed with 20%, 40%, and 60% SiC by using aluminium phosphate as a binder and heated at 220 °C for 5 hours.*	Intricate Text	Clarity
9.	*was mixed*	Passive Voice Misuse	Clarity
10.	~~aluminium~~ → aluminum	Mixed Dialects of English	Correctness
11.	*was conducted*	Passive Voice Misuse	Clarity
12.	~~Meanwhile~~ → ¶ Meanwhile	Intricate Text	Clarity
13.	~~characteristic~~ → characteristics	Incorrect Noun Number	Correctness
14.	~~were~~ → was	Faulty Subject-Verb Agreement	Correctness
15.	~~analyze~~ → investigate	Word Choice	Engagement
16.	~~solid~~ → stable, robust, substantial, reliable	Word Choice	Engagement
17.	~~strongly~~ → firmly	Word Choice	Engagement
18.	~~the presence of~~	Wordy Sentences	Clarity

19.	~~uncoated mild~~ → mild uncoated	Misplaced Words or Phrases	Correctness
20.	~~gives~~ → has	Incorrect Phrasing	Correctness
21.	~~cone~~ → core	Confused Words	Correctness
22.	~~the~~ erosion	Determiner Use (a/an/the/this, etc.)	Correctness
23.		Intricate Text	Clarity
24.	, as	Punctuation in Compound/Complex Sentences	Correctness
25.	1,	Punctuation in Compound/Complex Sentences	Correctness
26.	observed,	Punctuation in Compound/Complex Sentences	Correctness
27.	, which	Punctuation in Compound/Complex Sentences	Correctness
28.	steel,	Punctuation in Compound/Complex Sentences	Correctness
29.	~~, therefore~~ → . Therefore, ; therefore	Punctuation in Compound/Complex Sentences	Correctness
30.	~~of the~~	Wordy Sentences	Clarity
31.	~~good~~ → excellent	Word Choice	Engagement
32.	~~highly~~ → profoundly	Word Choice	Engagement
33.	, consequently	Punctuation in Compound/Complex Sentences	Correctness
34.	~~the~~ mild	Determiner Use (a/an/the/this, etc.)	Correctness

35.		Intricate Text	Clarity
36.	~~applied~~ → used	Word Choice	Engagement
37.	the power	Determiner Use (a/an/the/this, etc.)	Correctness
38.	, Cr2O3	Improper Formatting	Correctness
39.	~~binder~~ → wire, adhesive	Word Choice	Engagement
40.	~~binder~~ → binders	Incorrect Noun Number	Correctness
41.	*be applied*	Passive Voice Misuse	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.	~~of~~ → Of	Improper Formatting	Correctness
48.	~~important~~ → essential	Word Choice	Engagement
49.	~~roles~~ → role	Incorrect Noun Number	Correctness
50.	~~binder~~ → adhesive, wire, fastener	Word Choice	Engagement
51.	~~coating~~ → layer, sheet, lining	Word Choice	Engagement
52.	~~is~~ → are	Faulty Subject-Verb Agreement	Correctness
53.	*is not peeled*	Passive Voice Misuse	Clarity
54.	~~coating~~ → layer, sheet	Word Choice	Engagement
55.	~~aluminium~~ → aluminum	Mixed Dialects of English	Correctness

56.	*is preferred*	Passive Voice Misuse	Clarity
57.	~~good~~ → excellent	Word Choice	Engagement
58.	~~Also,~~ *the* or *binder* ~~also~~	Wordy Sentences	Clarity
59.	~~aluminium~~ → aluminum	Mixed Dialects of English	Correctness
60.	~~interesting~~ → exciting	Word Choice	Engagement
61.	, and	Comma Misuse within Clauses	Correctness
62.	*is firstly synthesized*	Passive Voice Misuse	Clarity
63.	~~aluminium~~ → aluminum	Mixed Dialects of English	Correctness
64.	, which	Punctuation in Compound/Complex Sentences	Correctness
65.	~~metals~~ → alloys	Word Choice	Engagement
66.	~~et al~~ → et al.	Comma Misuse within Clauses	Correctness
67.	the wear	Determiner Use (a/an/the/this, etc.)	Correctness
68.	~~increasing~~ → increase	Confused Words	Correctness
69.	*been conducted*	Passive Voice Misuse	Clarity
70.	inner pulverizer	Misplaced Words or Phrases	Correctness
71.	~~and was~~ → . It was	Hard-to-read text	Clarity
72.	*be taken*	Passive Voice Misuse	Clarity
73.	*are used*	Passive Voice Misuse	Clarity
74.	the ceramic	Determiner Use (a/an/the/this, etc.)	Correctness

75.	an average	Determiner Use (a/an/the/this, etc.)	Correctness
76.	~~particles~~ → particle	Incorrect Noun Number	Correctness
77.	, as	Punctuation in Compound/Complex Sentences	Correctness
78.	~~aluminium~~ → aluminum	Mixed Dialects of English	Correctness
79.	~~aquadest~~ → aqua dest	Misspelled Words	Correctness
80.	*were used*	Passive Voice Misuse	Clarity
81.	~~doi~~ → DOI	Misspelled Words	Correctness
82.	~~without~~ → Without	Improper Formatting	Correctness
83.	*without further purification.*	Incomplete Sentences	Correctness
84.	a 5	Determiner Use (a/an/the/this, etc.)	Correctness
85.	*is listed*	Passive Voice Misuse	Clarity
86.	~~specimen~~ → sample, example	Word Choice	Engagement
87.	*The specimen used in the experiment was mild steel with 5 mm thickness. The chemical composition is listed in table 1. The specimen was cut to a size of 25 mm x 25 mm for implementing the ceramic coating.*	Monotonous Sentences	Engagement
88.	~~specimen~~ → sample, example	Word Choice	Engagement
89.	the specimen	Determiner Use (a/an/the/this, etc.)	Correctness
90.	~~particles~~ → particle	Incorrect Noun Number	Correctness
91.	*was synthesized*	Passive Voice Misuse	Clarity

92.	the reaction	Determiner Use (a/an/the/this, etc.)	Correctness
93.	~~aluminium~~ → aluminum	Mixed Dialects of English	Correctness
94.	~~aluminium~~ → aluminum	Mixed Dialects of English	Correctness
95.	*was carried*	Passive Voice Misuse	Clarity
96.	*was characterized*	Passive Voice Misuse	Clarity
97.		Intricate Text	Clarity
98.	*is widely used*	Passive Voice Misuse	Clarity
99.	~~the process~~ → it	Wordy Sentences	Clarity
100.	*be carried*	Passive Voice Misuse	Clarity
101.	, and	Comma Misuse within Clauses	Correctness
102.	*To produce the Al2O3-SiC ceramic suspension*	Misplaced Words or Phrases	Correctness
103.	*was slowly stirred*	Passive Voice Misuse	Clarity
104.	~~et al~~ → et al.	Comma Misuse within Clauses	Correctness
105.	~~et al~~ → et al.	Comma Misuse within Clauses	Correctness
106.		Intricate Text	Clarity
107.	~~doi~~ → DOI	Misspelled Words	Correctness
108.	~~This research~~ → This research	Improper Formatting	Correctness
109.	research involved	Improper Formatting	Correctness
110.	~~involved some~~ → involved some	Improper Formatting	Correctness
111.	some instruments	Improper Formatting	Correctness

112.	instruments for	Improper Formatting	Correctness
113.	~~for the~~ → for the	Improper Formatting	Correctness
114.	the characterization	Improper Formatting	Correctness
115.	characterization process	Improper Formatting	Correctness
116.	*was used*	Passive Voice Misuse	Clarity
117.	~~used to~~ → used to	Improper Formatting	Correctness
118.	~~mild steel~~ → mild steel	Improper Formatting	Correctness
119.	*was done*	Passive Voice Misuse	Clarity
120.	~~particles~~ → particle	Incorrect Noun Number	Correctness
121.		Intricate Text	Clarity
122.	*were observed*	Passive Voice Misuse	Clarity
123.	~~were~~ → was	Faulty Subject-Verb Agreement	Correctness
124.	*were carried*	Passive Voice Misuse	Clarity
125.	~~to~~ → for	Wrong or Missing Prepositions	Correctness
126.	~~coating~~ → surface	Word Choice	Engagement
127.	*triboinovator*	Unknown Words	Correctness
128.	*was used*	Passive Voice Misuse	Clarity
129.	~~solid~~ → substantial	Word Choice	Engagement
130.	, with	Punctuation in Compound/Complex Sentences	Correctness
131.		Intricate Text	Clarity
132.	the coal	Determiner Use (a/an/the/this,	Correctness

		etc.)	
133.	, according	Punctuation in Compound/Complex Sentences	Correctness
134.	*was measured*	Passive Voice Misuse	Clarity
135.	~~et al~~ → et al.	Comma Misuse within Clauses	Correctness
136.	~~, namely~~ → :	Wordy Sentences	Clarity
137.	~~aluminium~~ → aluminum	Mixed Dialects of English	Correctness
138.	~~aluminium~~ → aluminum	Mixed Dialects of English	Correctness
139.	~~intensity~~ → power, concentration, strength, depth	Word Choice	Engagement
140.		Intricate Text	Clarity
141.	~~et al~~ → et al.	Comma Misuse within Clauses	Correctness
142.	*is slightly elevated*	Passive Voice Misuse	Clarity
143.		Intricate Text	Clarity
144.	~~an important~~ → a vital, an essential	Word Choice	Engagement
145.	~~et al~~ → et al.	Comma Misuse within Clauses	Correctness
146.	, which	Punctuation in Compound/Complex Sentences	Correctness
147.	*be controlled*	Passive Voice Misuse	Clarity
148.	~~fine~~ → beautiful	Word Choice	Engagement
149.		Intricate Text	Clarity
150.	~~doi~~ → DOI	Misspelled Words	Correctness
151.	: Mono	Improper Formatting	Correctness

152.	~~alumunium~~ → aluminum	Misspelled Words	Correctness
153.	~~Phosphat~~ → Phosphate	Misspelled Words	Correctness
154.	~~Aluminum Hydrogen Phosphate~~	Misspelled Words	Correctness
155.	*XRD pattern of the MAP binder consisting of monoaluminium phosphate (MAP) and monoaluminium phosphate hydrate (MAP hydrate).*	Hard-to-read text	Clarity
156.	~~basic~~ → essential, primary, necessary	Word Choice	Engagement
157.	~~formation~~ → structure, creation	Word Choice	Engagement
158.	~~aquosols~~ → aerosols	Misspelled Words	Correctness
159.	, and	Comma Misuse within Clauses	Correctness
160.	, and	Comma Misuse within Clauses	Correctness
161.	~~then~~ → than	Commonly Confused Words	Correctness
162.	*The kinetics of formation CBPCs are the dissolution of alumina, the formation of aquosols by hydrolyzes, acid-base reaction and condensation into a CBPC, percolation and gel formation, saturation then the formation of crystallization into a monolithic solid of CBPC.*	Hard-to-read text	Clarity
163.	~~a good~~ → an excellent	Word Choice	Engagement
164.	, which	Punctuation in Compound/Complex Sentences	Correctness
165.	~~aluminium~~ → aluminum	Mixed Dialects of English	Correctness
166.	~~binder~~ → binders	Incorrect Noun Number	Correctness

167.	~~aluminium~~ → aluminum	Mixed Dialects of English	Correctness
168.	~~et al~~ → et al.	Comma Misuse within Clauses	Correctness
169.	*is obtained*	Passive Voice Misuse	Clarity
170.	~~aluminium~~ → aluminum	Mixed Dialects of English	Correctness
171.	inversion,	Punctuation in Compound/Complex Sentences	Correctness
172.	~~take~~ → takes	Faulty Subject-Verb Agreement	Correctness
173.	~~, take place~~ → occurs	Wordy Sentences	Clarity
174.	*be obtained*	Passive Voice Misuse	Clarity
175.	*Meanwhile, the cristobalite form can be obtained in the presence of sodium chloride as promoters of crystallization or temperature stability relationship of berlinite phase [13].*	Hard-to-read text	Clarity
176.	*be formed*	Passive Voice Misuse	Clarity
177.	~~doi~~ → DOI	Misspelled Words	Correctness
178.	high-temperature	Misspelled Words	Correctness
179.	high-temperature	Misspelled Words	Correctness
180.	, which	Punctuation in Compound/Complex Sentences	Correctness
181.	*wagh*	Unknown Words	Correctness
182.	~~et al~~ → et al.	Comma Misuse within Clauses	Correctness
183.	7],	Comma Misuse within Clauses	Correctness
184.	~~aluminium~~ → aluminum	Mixed Dialects of English	Correctness

185.	an intermediate	Determiner Use (a/an/the/this, etc.)	Correctness
186.	, which	Punctuation in Compound/Complex Sentences	Correctness
187.	*be written*	Passive Voice Misuse	Clarity
188.	~~the~~ equation	Determiner Use (a/an/the/this, etc.)	Correctness
189.	~~et al~~ → et al.	Comma Misuse within Clauses	Correctness
190.	~~a very small~~ → a minimal, a tiny	Word Choice	Engagement
191.	*be converted*	Passive Voice Misuse	Clarity
192.	the surface	Determiner Use (a/an/the/this, etc.)	Correctness
193.	~~sol- gel~~ → sol-gel	Misspelled Words	Correctness
194.	a complete, or the complete	Determiner Use (a/an/the/this, etc.)	Correctness
195.	~~particle~~ → particles	Incorrect Noun Number	Correctness
196.	*be enhanced*	Passive Voice Misuse	Clarity
197.	~~both~~	Wordy Sentences	Clarity
198.	~~aluminium~~ → aluminum	Mixed Dialects of English	Correctness
199.	~~mild~~ → gentle, sweet	Word Choice	Engagement
200.	~~doi~~ → DOI	Misspelled Words	Correctness
201.	~~corrosion~~ → Corrosion	Improper Formatting	Correctness
202.	~~which~~	Pronoun Use	Correctness

203.	~~which~~	Wordy Sentences	Clarity
204.	~~easily~~ → readily, efficiently, quickly	Word Choice	Engagement
205.	*be increased*	Passive Voice Misuse	Clarity
206.	~~strongly~~ → firmly	Word Choice	Engagement
207.	*is created*	Passive Voice Misuse	Clarity
208.	~~Idamayanti~~ → Damayanti	Misspelled Words	Correctness
209.	~~et al~~ → et al.	Comma Misuse within Clauses	Correctness
210.	~~also disintegrated~~ → disintegrate	Wordy Sentences	Clarity
211.	~~et al~~ → et al.	Comma Misuse within Clauses	Correctness
212.	, which	Punctuation in Compound/Complex Sentences	Correctness
213.	to its	Wrong or Missing Prepositions	Correctness
214.	the dense, or a dense	Determiner Use (a/an/the/this, etc.)	Correctness
215.	~~Also, the~~ → The	Wordy Sentences	Clarity
216.	*was conducted*	Passive Voice Misuse	Clarity
217.	~~, when compared~~	Wordy Sentences	Clarity
218.	~~uncoated mild~~ → mild uncoated	Misplaced Words or Phrases	Correctness
219.	an alumina	Determiner Use (a/an/the/this, etc.)	Correctness
220.	~~the~~ lowest	Determiner Use (a/an/the/this, etc.)	Correctness

221.	~~doi~~ → DOI	Misspelled Words	Correctness
222.	~~solid~~ → substantial	Word Choice	Engagement
223.	~~et al~~ → et al.	Comma Misuse within Clauses	Correctness
224.	~~ductile~~ → plastic	Word Choice	Clarity
225.	a low	Determiner Use (a/an/the/this, etc.)	Correctness
226.	~~et al~~ → et al.	Comma Misuse within Clauses	Correctness
227.	~~particles~~ → particle	Incorrect Noun Number	Correctness
228.	~~doi~~ → DOI	Misspelled Words	Correctness
229.	~~micrograph of~~ → micrograph of	Improper Formatting	Correctness
230.	~~of the~~ → of the	Improper Formatting	Correctness
231.	~~the morphology~~ → the morphology	Improper Formatting	Correctness
232.	~~morphology of~~ → morphology of	Improper Formatting	Correctness
233.	~~of phosphate~~ → of phosphate	Improper Formatting	Correctness
234.	phosphate bonded	Improper Formatting	Correctness
235.	~~lower~~ → smaller, more moderate	Word Choice	Engagement
236.	*was carried*	Passive Voice Misuse	Clarity
237.	*was found*	Passive Voice Misuse	Clarity
238.	*was added*	Passive Voice Misuse	Clarity
239.	~~uncoated mild~~ → mild uncoated	Misplaced Words or Phrases	Correctness
240.	~~good~~ → excellent	Word Choice	Engagement

241.	, and	Comma Misuse within Clauses	Correctness
242.	, and	Comma Misuse within Clauses	Correctness
243.	, and	Comma Misuse within Clauses	Correctness
244.	, and	Comma Misuse within Clauses	Correctness
245.	~~doi~~ → DOI	Misspelled Words	Correctness
246.	~~Sebastain~~ → Sebastian	Misspelled Words	Correctness
247.	, and	Comma Misuse within Clauses	Correctness
248.	~~P G~~ → PG	Confused Words	Correctness
249.	, and	Comma Misuse within Clauses	Correctness
250.	~~Silion~~ → Silicon	Misspelled Words	Correctness
251.	~~P G~~ → PG	Confused Words	Correctness
252.	, and	Comma Misuse within Clauses	Correctness
253.	~~behaviour~~ → behavior	Mixed Dialects of English	Correctness
254.	, and	Comma Misuse within Clauses	Correctness
255.	~~to~~	Wrong or Missing Prepositions	Correctness
256.	, which	Punctuation in Compound/Complex Sentences	Correctness
257.	~~acknowledge~~ → accept	Word Choice	Engagement
258.	~~POLMAN~~ → Polman	Confused Words	Correctness
259.	facilities.	Closing Punctuation	Correctness
260.	*The purpose of this research is to improve*	Munition Demilitarization: Maintenance Program	Originality

		Improvement	
261.	*Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI. Published under licence by IOP Publishing Ltd 1*	Design and Development of an Automaic Tool Changer for an ... https://iopscience.iop.org/article/10.1088/1757-899X/65/1/012023/pdf	Originality
262.	*This research has been conducted to investigate the*	20 Research Methodology This research has been conducted ... https://www.coursehero.com/file/p3ci126/20-Research-Methodology-This-research-has-been-conducted-to-investigate-the/	Originality
263.	*The mixture was stirred for 15 minutes at*	Catalysis Weakly Coordinating Anion Probed in ... https://pubs.acs.org/doi/suppl/10.1021/acs.organomet.9b00332/suppl_file/om9b00332_si_001.pdf	Originality