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Using Alumina and Volcanic Ash in Producing Catalytic Converter Ceramics

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Abstract

This paper presents a study on the production and characterization of porous ceramic which is applied as an exhaust filter on a premium-fueled motor vehicle. The composition ratio of alumina-kaolin (1:4), volcanic ash and activated carbon: (50:50:0), (50:45:5), (50:40:10), (50:35:15), (50:30:20) weight percent. Alumina, kaolin, volcanic ash and activated carbon are sifted through 100 mesh respectively, mixed with homogenous mixtures, molded on a 5 ton pressure with dye pressing method, and burned at a temperature of 1100 ^{0}C for two hours. It was obtained that the characteristics of porous ceramics on 15%wt of activated carbon composition has the ceramic density of 1.76 gr/cm^3, porosity of 23.54%, mass loss of 22.33%, volume loss of 18.07% and compressive strength of 12.73 MPa and hardness of 56.85 MPa. The ceramic has Corundum (Al_2O_3) phase, Trigonal crystal structure and Mullite ($3Al_2O_3.2SiO_2$) phase, Orthorhombic crystal structure, and it was discovered that the ceramic pores are evenly distributed. CO and HC Gas emission absorption are 84.62% and 71.64% and an increase of 15% in CO_2 gas and 77% in O_2 gas. The increased absorption of CO and HC gases as well as the rise of CO_2 and O_2 gases suggests that the exhaust filter may effectively serve as a catalytic converter.

Keywords: absorbents, catalytic converter, porous ceramic, vehicle exhaust filter

INTRODUCTION

The number of motor vehicles in Indonesia has increased significantly year after year. The exhaust gas produced from those vehicles cause air pollution by 70-80%, while air pollution caused by industries is only 20-30% [1] [2].. Air pollution occurs everywhere and is caused by a number of things such as smoke from vehicles, smoke from factories, waste burning, and others. Smoke from vehicles is the major cause of air pollution due to recent technological advances in various fields particularly in the transportation industry, resulting in the increased number of different types and brands of motor vehicles [3][14][15].

The effect of motor vehicles on society and their environment is air pollution that damages health and environment, such as: carbon monoxide (CO), various hydrocarbon compounds (HC), various nitrogen oxides (NO_X) and sulphur oxides (SO_X), lead (Pb) [4],[13]. CO, NO_X, CO_2 dan HC gases generated from combustion engine have been associated as the cause of various diseases, such as: the emergence of various infectious diseases, decreased immune system, increased skin diseases and cataract [5],[13][16]. Where as health effects of lead exposure are hypertension, anemia, decreased brain function and inhibiting red blood formation.

One of the efforts to reduce the levels of hazardous gas emission is by using gas filter. The exhaust filter created under this study utilizes the volcanic ash of Mount Sinabung, alumina, kaolin and activated carbon as additives in the production of porous ceramic. The porous ceramic is molded using Dry Pressing Method and is heated to 1100 ^oC temperature for two hours. The volcanic ash of Mount Sinabung contains some compounds of Silicon Oxide (SiO_2) at 59.92%, Nitrogen (N) at 0.13%, Potassium (K_2O) at 0.55%, Carbon (C-Organic) at 0.54%, Phosphor (P_2O_5) at 0.55%, Sulphur (S) at 0.18% Iron (Fe) at 16.11% [6].

Activated carbon is carbon that has undergone changes in physical and chemical properties due to an activation treatment by chemical compounds activator or by heating up at a high temperature which results in open pores and greater carbon absorption capacity than the normal carbon. Activated carbon is widely used as absorbent materials [7]. Thus, this study attempted to produce porous ceramics by using volcanic ash of Mount Sinabung, alumina, kaolin and activated carbon as additives to exhaust filter application.

MATERIALS AND EQUIPMENTS

Alumina powder (Merck), kaolin powder, volcanic ash powder of Mount Sinabung taken from Berastepu village, Subdistrict of Simpang Empat, Karo District and activated carbon powder (Merck), a sieve of 100 mesh, Mixer, High Temperature Furnace, Sample Molds, Hydraulic Cold Press, Universal Testing Machine, UTM (Maekawa Testing Machine), X-Ray Diffraction, XRD (Shimadzu), Atomic Absorption Spectrophotometer AAS (Shimadzu), Vicker Hardness Testing (Matzuzawa Seiko), Gas Analyzer

(Sukyoung), Scanning Electron Microscope - Energy Dispersive Spectroscopy SEM- EDS (JED-2300 Jeol) and a unit of 2008 Toyota Rush.

RESEARCH METHODOLOGY

Alumina, kaolin, volcanic ash and activated carbon were sifted through 100 mesh respectively, and a ratio of alumina to kaolin is 1: 4. Afterwards, each material is placed on a scale and weighed, and the composition ratio of alumina, kaolin, volcanic ash and activated carbon is made as presented in table 1 below.

Table 1. The Ratio of Ceramic Material Composition

No.	Alumina: Kaolin 1 : 4 (%wt)	Volcanic Ash (%wt)	Activated Carbon (%wt)
1	50	50	0
2	50	45	5
3	50	40	10
4	50	35	15
5	50	30	20

Alumina, kaolin, volcanic ash and activated carbon powders are mixed evenly using a plastic container. Having been evenly mixed, the powders are taken out and are spread onto a plastic container and are sprayed with water evenly to get them moistened/tender. Next, they are placed onto dry pressing and inserted into two types of molds. The first mold is a hollow cylinder iron with an outside diameter of 3.9 cm, inside diameter of 1.6 cm and 6 cm tall, and is pressed under 2 tons for 5 minutes. Afterwards, the mold is opened and the sample is put in the open air outdoor for 6 days. 3 (three) samples are made in each of 5 composition types.
The second mold is pellet iron with the diameter of 3 cm and 4 cm tall, 2,3 cm thick and is pressed under 5 tons for 5 minutes. Then, the mold is opened and the sample is removed from the mold and put in open air outdoor for 6 days. 3 (three) samples are made in each of 5 types of composition.. All samples are then burned in a furnace at 1100 ºC temperature for two consecutive hours, and the furnace is turned off. After being turned off 24 hours, the samples are removed and set for a testing of their physical properties (density, porosity, mass loss, and burn loss), mechanical properties (hardness and compressive strength), crystal structure and phase using XRD, SEM-EDX analysis of microstructure and elements, and exhaust gas emission test using gas analyzer, analysis of elemental composition of volcanic ash using AAS. Shown below is the figure of hollow cylindrical and pellet samples:

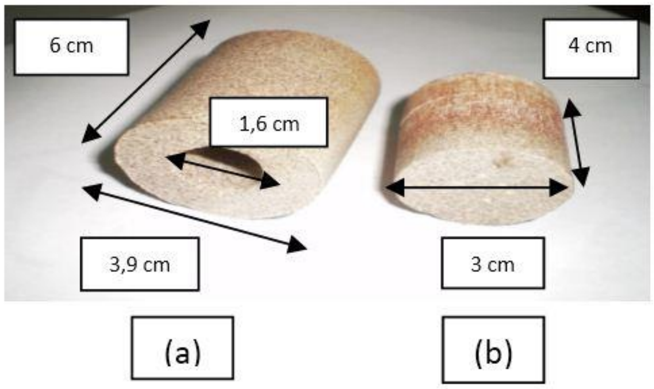


Figure 1. Samples of (a) hollow cylinder and (b) pellet cylinder.

RESULT AND DISCUSSION

A. Analysis of Volcanic Ash Compound

The chemical composition of Mount Sinabung volcanic ash erupted on 14 March 2016, originating from Berastepu village Karo District, 2 km away from Mount Sinabung, has been analyzed using AAS. The chemical composition of the volcanic ash has the following compounds: SiO_2 at 87.19%; Fe_2O_3 at 3.08%; Al_2O_3 at 6.67%; MgO at 0.13%; CaO at 2.83%; Na_2O at 0.02%. The compound composition can be classified into ceramic type so that the volcanic ash can be used as modern ceramic raw materials.

B. Testing of ceramic mechanical and physical properties

On the ratio of alumina-kaolin composition (1:4), volcanic ash and activated carbon (50:50:0), (50:45:5), (50:40:10), (50:35:15), (50:30:20)%wt, it was discovered that the characteristics of porous ceramics on 5-20%wt activated carbon composition: the ceramic density of 1.97-1.57 gr/cm^3 which decreases linearly. Silicon Nitride Si_3N_4 has the density of 0.91 gr/cm^3 [11][16]. Porosity of 13.18-31.24%, the highest ceramic porosity occurs at the composition of 15%wt activated carbon namely 31.24%, mass loss of 12.34-26.82% which increases linearly, volume loss of 15.41-20.21%, which increases linearly, and ceramic compressive strength of 30.68-8.63 MPa, which decreases linearly, hardness of 67.48-39.32 MPa, which also decreased linearly [8]. The coefficient of γ thermal expansion of porous ceramics is 5.6-7.8.10^6/ºC at 25-1100 ºC temperature with the ceramic melting point of 1500-1600 ºC [10][16]. These porous ceramics are classified as refractory ceramics and can be used at a high temperature [12]. Cordierite γ of 0.7-1.0.10^6/ºC [9][16].

C. Testing of Exhaust Gas Emission

The exhaust gas emission testing results in CO, HC, CO_2 and O_2 gases. The relation of absorption to activated carbon composition within ceramics is shown in figure 2.

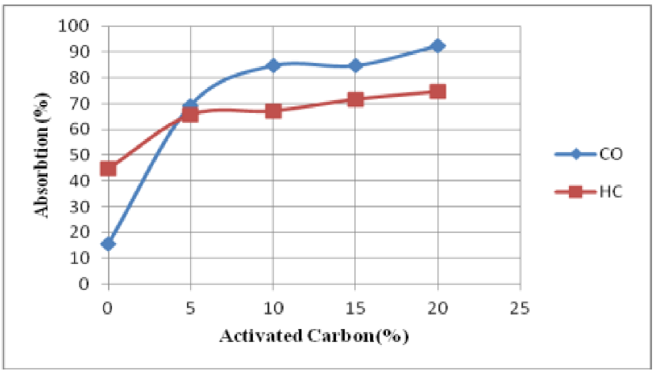


Figure 2. Absorption CO and HC gases vs activated carbon

Figure 2 above shows that CO and HC gases absorption levels decrease by 92.31% and 74.63% respectively at 15% activated carbon composition. The addition of activated carbon on porous ceramics may potentially decrease CO and HC gas emission. The result of CO_2 dan O_2 gas emission measurement using ceramic filter is presented in figure 3 below.

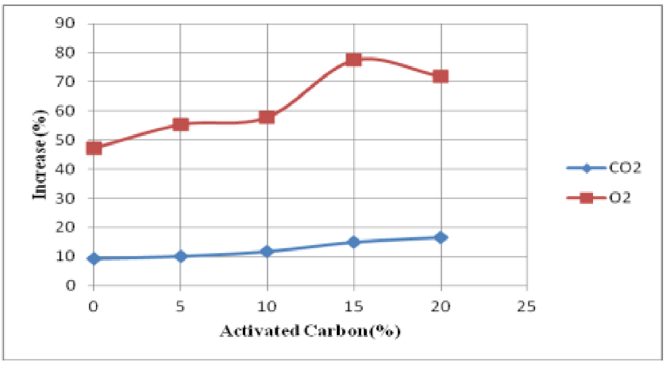


Figure 3. Increase of CO_2 dan O_2 gases vs activated carbon

Figure 3 above shows that the increase of 16.67% and 77.45% in CO_2 dan O_2 gases levels occurs at the 15% activated carbon composition after going through porous ceramic gas filter. Assessing from its ceramic strength, the compressive strength decreases from 12.73 MPa to 8.63 MPa, yet still met the standard of mechanical strength of catalytic converter ceramics [8],[11]. The imperfect reaction of premium gasoline is shown below:

$2C_8H_{18} + 28O_2 \rightarrow 4CO + 4CO_2 + 8HC + 14\ H_2O + 15O_2.$

The imperfect reaction forms CO gas which poses danger to human being if inhaled. The reaction occurs after the installation of ceramic filter as shown below:

$2CO + O_2 \rightarrow 2CO_2$ dan $2H_2O \rightarrow 2H_2 + O_2$

Then the above reaction leads to the following reaction:

$2C_8H_{18} + 28O_2 \rightarrow 2CO + 10CO_2 + 4HC + 16H_2 + 17O_2.$

The installation of ceramic filter would convert CO gas into CO_2 gas and might also increase O_2 gas. The increase of O_2 gas is due to the decomposition of vapor into H_2 dan O_2 gases. That would allow this designed porous ceramics to reduce CO gas emission by converting it to environmentally friendly CO_2 gas [4][16].

D. Testing of structure and phase

An XRD analysis has been carried out on ceramic structure and phase, as shown in the following figure 4.

Figure 4. X-ray diffraction pattern of ceramic on 15%wt activated carbon.

The result of ceramic analysis on 15%wt activated carbon composition burned at 1100°C temperature for two hours derived by using MATCH software version 2 shows that Corundum (Al_2O_3) using No, 46-1212 JCPDS standard with a lattice parameter of, a = 4.758 Å, c = 12.99 Å with Trigonal crystal structure and Mullite phase ($3Al_2O_3.2SiO_2$) using No. 15-776 JCPDS standard with a lattice parameter of, a = 7.5430 Å, b = 7.6872 Å dan c = 2.8842 Å with Orthorhombic crystal structure.

E. Testing of Microstructure and Analysis of Ceramic Elements

Ceramic microstructure on 15%wt activated carbon composition burned at 1100 °C for 2 hours is shown in Figure 5.

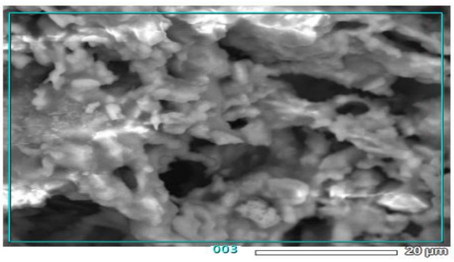
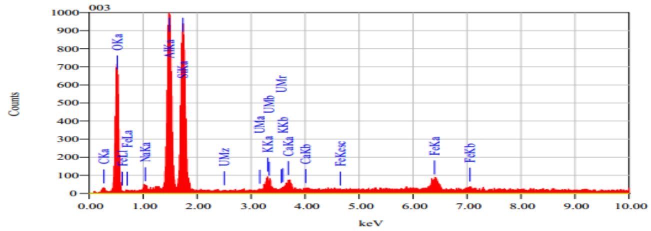


Figure 5. Ceramic microstructure on 15%wt activated carbon

The microstructure of porous ceramic has evenly distributed and similar pores and is proportional on the ceramic surface. Similar pores will proportionally have more optimum exhaust gas emission absorption .



ZAF Method Standardless Quantitative Analysis
Fitting Coefficient : 0.2490

Element	(keV)	Mass%	Error%	Atom%	Compound	Mass%	Cation	K
C K	0.277	5.95	0.23	9.97				0.9101
O K	0.525	45.37	0.19	57.06				50.8233
Na K	1.041	0.96	0.15	0.84				0.8639
Al K	1.486	18.76	0.10	13.99				18.1109
Si K	1.739	20.34	0.13	14.57				18.3999
K K	3.312	1.70	0.14	0.88				2.2280
Ca K	3.690	1.46	0.16	0.74				2.0351
Fe K	6.398	5.46	0.34	1.97				6.6286
U M*								
Total		100.00		100.00				

Figure 6. Analysis of ceramic elements on 15%wt activated carbon

The elements contained in porous ceramics on 15% activated carbon are oxygen (O) at 45.37 mass%, silika (Si) at 20.34 mass%, aluminium (Al) at 18.76 mass%, Carbon (C) at 5.95 mass%, Iron (Fe) at 5.46 mass%, Calsium (Ca) at 1.46 mass%, Natrium (Na) at 0.96 mass% dan Kalium (K) at 1.70 mass%.

CONCLUSIONS

Conclusions can be drawn from all ceramic characterization tests as follows:

1. The volcanic ash of Mount Sinabung is dominated by silica compounds (SiO_2) at 87.19% which means it can potentially be used to substitute for quartz material in ceramic production.
2. Ceramic composition on 15%wt activated carbon has similar and identical porous microstructures. Pore traces formed by the activated carbon will increase ceramic porosity by 31.24% and decrease ceramic density by 1.76 $gr/cm^{3.}$
3. Ceramic composition on 15%wt activated carbon has *Corundum* (Al_2O_3) phase through No. 46-1212 JCPDS standard with lattice parameter of, a = 4.758 Å, c = 12.99 Å with Trigonal crystal structure and Mullite ($3Al_2O_3.2SiO_2$) phase through No. 15-776 JCPDS standard with lattice parameter of, a = 7.5430 Å, b = 7.6872 Å dan c = 2.8842 Å with Orthorhombic crystal structure.
4. The testing of exhaust gas emission using porous ceramic with 15% activated carbon composition installed on premium-fueled car exhaust proves that it can potentially decrease CO gas emission level by 92.31% and HC particles by 74.63%. Those porous ceramics can be used as exhaust gas filter which is applied as catalytic converter. This can be seen from the increase of CO_2 gas emission level by 16.67% and O_2 gas level by 71.92%.

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