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Resistivity and Conductivity Analysis of Coated Metallic Catalytic Converter with Wavelenght Shape of Monolith

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Abstract

Removal of pollutants in the exhaust system was an interesting field and it was inspired by the invention of modern Catalytic Converter (CATCO). The problem is low emission conversion from CO, NO_x and HC to H_2O, CO_2 and NO_2 due to low CATCO material conductivity. Therefore, the objective of this research is to investigate the conductivity and resistivity of FeCrAl material for CATCO that coated by combined technique of electroplating and ultrasonic methods. Nickel (Ni) plate as anode and FeCrAl as cathode. The distance between anode and cathode was adjusted at 25 mm. Ultrasonic was carried out using frequency of 35 kHz. Ultrasonic and electroplating were conducted for several variation times of 15, 30, 45, 60 and 75 minutes. Drying process was performed after electroplating process at temperature of 60^0C for 12 hours. The conductivity and resistivity analysis will be conducted using 4 point probe machine. Resistivity and conductivity analysis show that the smallest resistivity and highest conductivity has been observed at UB+EL 30 minute for 2.67E+03 ohm-cm and 3.75E-04 S/cm, respectively. UB samples has lower resistivity and higher conductivity than EL, and UBdEL samples. It may cause by surface roughness of the FrCrAl material that embedded during the coating process.

Background, Motivation and Objective

Currently, metallic monolith became main CATCO material because of high frontal area up to 90%. Metallic monolith is the metallic substrate that supports a catalyst and commonly called by metallic substrate. The main advantage of metallic substrate in terms of wall thickness is limited by steel rolling mill's capabilities that typically automotive 400 cell/in^2 (Alahmer and Aladayleh 2016). Ceramic monolith has frontal flow are of 69% open and 31% closed. Meanwhile, metallic monolith has 91% open area and 9% is closed area. Therefore, ceramic monolith has higher wall thickness [0.007 in. (0.178 mm)] compared to metallic monolith of [0.002 in. (0.050 mm)] (Kaspar et al., 2003). Metallic monolith is provide higher geometric surface area while offering low resistant to flow i.e. back pressure, higher thermal conductivity which generate more uniform temperature distribution (Santos and Costa, 2008). Higher coefficient thermal expansion of metallic monolith potential to produce an adherent washcoat by special bonding technique. According to Heck at al., (2001) the suitable metallic monolith is FeCrAl alloy with composition of 73% Fe, 20% Cr, 5% Al and small amounts of Ni and Si which provide a melting temperature up to 1500^0C.

Metallic substrate such as FeCrAl foils become the most interesting material than ceramics as investigated by Zeng et al., (2011); Domínguez et al., (2014); Chandni and Arthur, (2014) and Masakuni and Kenichi, (2015). It is selected as the substrate since the higher thermal conductivity, lower heat capacity, greater thermal and mechanical shock resistant, thinner wall, lower pressure drop (Wu et al., 2005 and Leman et al., 2016), higher Coefficient of Thermal Expansion (CTE) (Zhao et al., 2003), high temperature oxidation resistance and achieve larger specific surface area (Putrasari et al., 2010) which influence to the effectiveness conversion. These advantages is provided that the metallic monolith enable to install closer to the engine (Wu et al., 2005). Different CTE of ceramic washcoat and metallic substrate is investigated by Zhao et al., (2003) and the result shows the CTE of γ- Al_2O_3 powder is 7.8-8.5 x $10^{-60}C^{-1}$ and CTE of FeCrAl substrate is 14-16 $10^{-60}C^{-1}$. γ- Al_2O_3 has lower CTE as compared to FeCrAl substrate which means that the ceramic material has lower size changing that effected by temperature performed. Therefore, ceramic material was suitable as protective layer of metallic material. According to Twigg and Webster (2006) that the function of the ferritic steel is can strongly adhering oxide film on their surface. The surface oxide film is developed by chromia rich when the material heated by 300 - 400^0C. Moreover, the alumina rich surface is developed when heated at 800^0C which is promoting the high temperature resistance (Dafit Feriyanto et al., 2021a and 2021b). It can be concluded that when ferritic steel will develop chromia rich during application process in exhaust emission system that operate in maximum temperature of 800 - 850^0C.

Methods

The research was performed using three different treatment which are Ultrasonic bath technique, Ni-electroplating technique, Ultrasnic bath during Ni-electroplating and combination between ultrasonic bath and Ni-electroplating technique. There are five sample name in this research which raw material called by Raw, Ultrasonic bath samples called by UB, Ni-electroplating sample called by EL, ultrasonic bath during electroplating sample called by UBdEL and combination technique samples called by UB+EL. The technique was consists of UB, UBdEL, EL and UB+EL technique. UB technique was conducted by frequency of 35 kHz, ethanol solution, temperature of 40^0C and various UB time of 1, 1.5, 2, 2.5 and 3 hours. For UBdEL technique was performed by using frequency of 35 kHz, sulphamate type solution (nickel sulphamate ($Ni(SO_3NH_2)_2\,4H_2O$), nickel chloride ($NiCl\,6H_2O$), boric acid (H_2BO_3) and sodium lauryal sulphate ($C_{12}H_{25}SO_4Na$)), temperature of 40^0C and various UBdEL time of 15, 30, 45, 60 and 75 minutes, NiO as anode and FeCrAl as cathode. For EL technique was carried out by sulphamate type solution, pH of 5, NiO as anode and FeCrAl as cathode and the distance between anode and cathode was adjusted by 25mm, current density of 8 A/dm^2, Voltage of 12 V and various EL time of 15, 30, 45, 60 and 75 minutes. For combination technique was performed by 2 deposition process which are UB technique for first deposition where the parameter was same with UB technique and the second deposition process was conducted by EL technique where same parameter with EL technique. Therefore, the combination technique was called by UB+EL technique.

The Conductivity and resistivity analysis was conducted using 4 point probe machine as shown in Figure 1. The coated and uncoated sample was selected five points on the each samples for electrical resistivity and conductivity measurement as shown in Figure 2. The average value from 5 points measured is selected as final conductivity and resistivity value of that material.

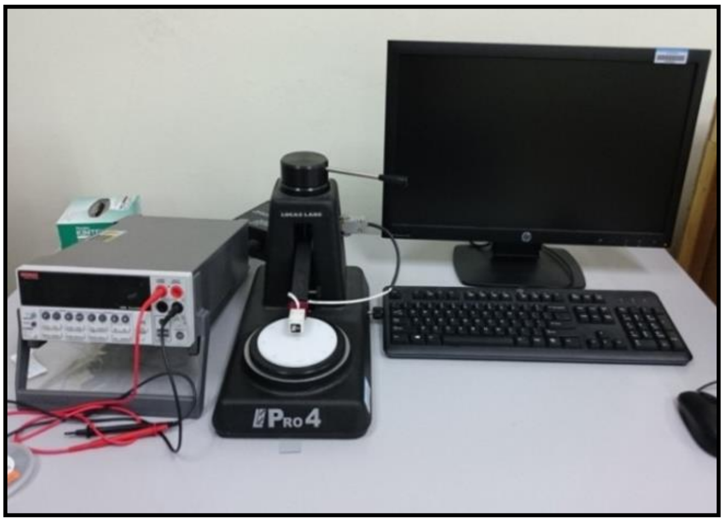

Figure 1. *4Point Probe machine*

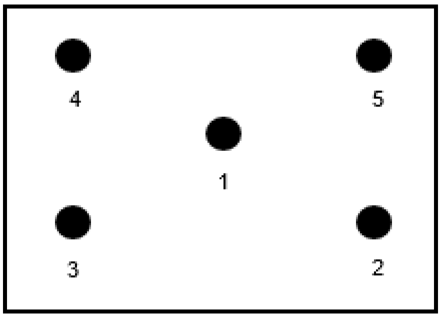

Figure 2. *Five points object for electrical resistivity measurement*

The electrical resistivity and conductivity also can measured using the formula as in Equation 1 and 2, respectively (Panta and Subedi, 2012).

$$\rho = (\pi / \ln 2)(V / I) x\ d$$
$$\rho \approx 4.532 (V / I) x\ d \quad (1)$$

$$\sigma = \frac{1}{\rho} \quad (2)$$

Where V = the drop potential measured among the internal electrodes

I = the current (mA)
d= Thickness of thin film

Results and Discussions

Resistivity and conductivity analysis

Resistivity and conductivity of coated and uncoated FeCrAl substrate was listed in Table 1. And illustrated in Figure 3. And 4. Resistivity was inversely proportional with conductivity value as mentioned in Equation 1 and 2. Therefore, higher or lower resistivity and conductivity are dependent on the surface roughness and thickness of coating material in FeCrAl substrate. Prior to resistivity analysis is conducted, annealing process was performed to eliminate other chemical agent which adhere in FeCrAl during coating process. Range of resistivity of coated and uncoated FeCrAl is 2.67E+03 ohm-cm to 1.19E+05 ohm-cm.

Table 1. *Resistivity and conductivity of coated and uncoated FeCrAl substrate*

Sample designation	Res. (ohm-cm)	conductivity (S/cm)
Raw	2.15E+04	4.65E-05
UB 1 h	6.42E+03	1.56E-04
UB 1.5 h	3.57E+03	2.80E-04
UB 2 h	4.17E+03	2.40E-04
UB 2.5 h	5.36E+03	1.87E-04
UB 3 h	6.52E+03	1.53E-04
UBdEL 15 min	1.19E+05	8.40E-06
UBdEL 30 min	9.90E+04	1.01E-05
UBdEL 45 min	4.39E+03	2.28E-04
UBdEL 60 min	5.30E+04	1.89E-05
UBdEL 75 min	6.01E+04	1.66E-05
UB+EL 15 min	6.80E+04	1.47E-05
UB+EL 30 min	2.67E+03	3.75E-04
UB+EL 45 min	3.01E+04	3.32E-05
UB+EL 60 min	4.04E+04	2.48E-05
UB+EL 75 min	1.12E+05	8.93E-06
EL 15 min	3.30E+04	3.03E-05
EL 30 min	7.96E+03	1.26E-04
EL 45 min	1.25E+04	8.00E-05
EL 60 min	1.43E+04	6.99E-05
EL 75 min	6.70E+04	1.49E-05

Lowest resistivity and highest conductivity in each treatment is shown by UB+EL 30 min for 2.67E+03 ohm-cm and 3.75E-04 S/cm respectively. The highest resistivity is located at UBdEL 15 min followed by UB+EL 75 min and EL 75 min for 1.19E+05 ohm-cm, 1.12E+05 ohm-cm and 6.70E+04 ohm-cm respectively as well as the rest value is lower than 8.00E+04 ohm-cm which indicated that the materials is unready condition to allow the flow of electric current. That phenomena caused by higher surface roughness which influenced by agglomeration of γ-Al_2O_3 into FeCrAl substrate. In over the optimum treatment time, the γ-Al_2O_3 leading to agglomerate and meet with plastic deformation of material (Panta and Subedi, 2012). Therefore, the increment of resistivity and decrement of conductivity are inevitable. Higher conductivity or lower resistivity caused by higher geometric surface area of γ-Al_2O_3 washcoat which led to more uniform temperature distribution (Feriyanto et al., 2020 and Santos and Costa, 2008).

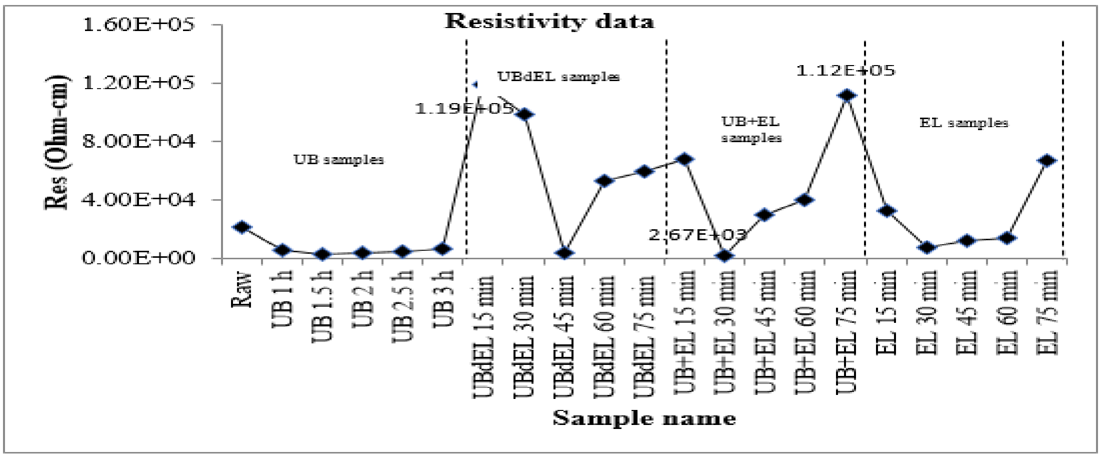

Figure 3. *Comparison of resistivity of coated and uncoated FeCrAl*

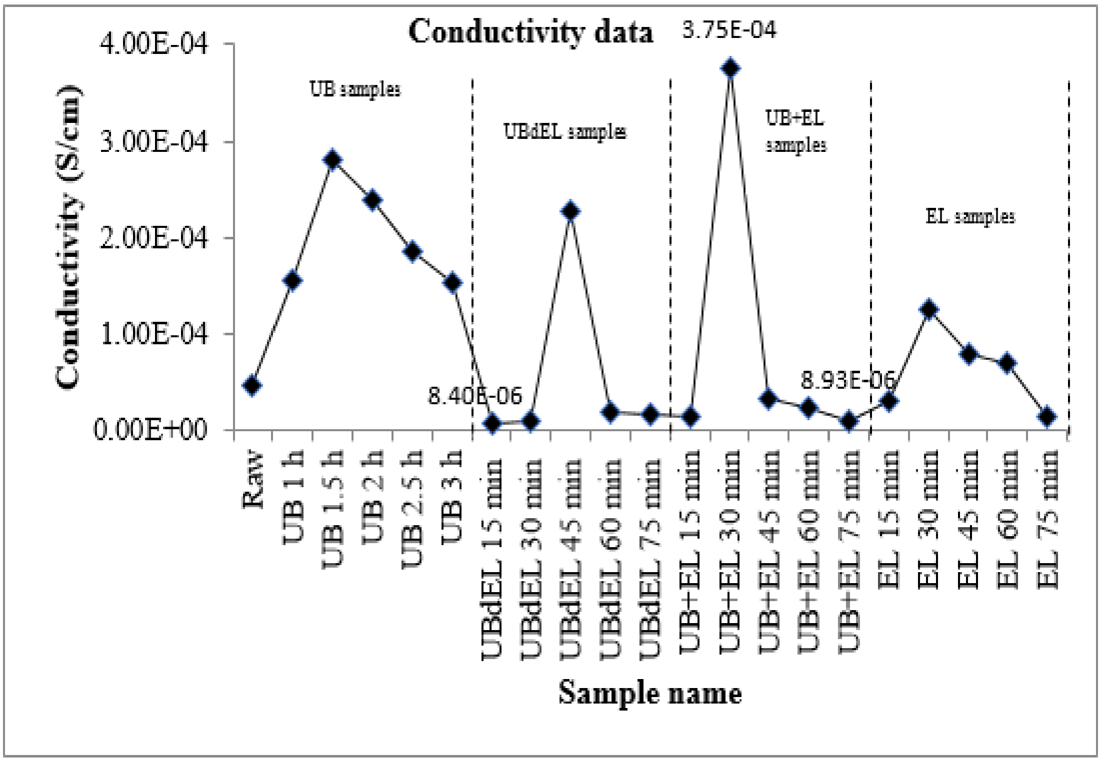

Figure 4. *Comparison of conductivity of coated and uncoated FeCrAl*

The resistivity and conductivity value was influenced by surface roughness data where surface roughness data increase, the resistivity increase as well and conductivity decrease which influenced by chemical that embedded on FeCrAl substrate during washcoat process. Where the other chemical able to increase the resistivity and decrease the conductivity.

Resistivity and conductivity in thin film is high dependent on several factors such as rate of deposition, temperature, surface roughness, grain boundaries and thickness. Γ-Al2O3 present when it exposed into atmospheric pressure and annealing process before resistivity and conductivity analysis will strengthened composition of γ-Al_2O_3. Higher electrical conductivity of metal as compared with ceramic material is caused by higher energy level to move the electron (Panta and Subedi, 2012). The data shows that UB+EL 30 min has highest conductivity value of 3.75E-04 S/cm. Higher electrical conductivity effect to the higher level of emission conversion from CO, NO_x and HC to H_2O, CO_2 and NO_2 which indicated that UB+EL 30 min is the appropriate parameter to coat FeCrAl substrate by γ-Al_2O_3 powder.

Method and parameter selection

An appropriate method and parameter was selected based on analysis that has been done in optimization stage. There are several methods that used in this study such as UB, UBdEL, and UB + EL and EL technique. The optimization process was select the best method and parameter in terms of resistivity and conductivity analysis. The conductivity and resistivity analysis shows that UB+EL 30 min has highest conductivity of 3.75E-04 S/cm and lowest resistivity of 2.67E+03 ohm-cm. Therefore, based on highest conductivity and lowest resistivity, UB+EL 30 min was selected for further application and fabrication of FeCrAl catalytic converter. The summary of selection process was listed in Table 2.

Table 2. *Method and parameter selection*

No.	Method and parameter	Analysis	Result
i.	Raw material	Resistivity Conductivity	High (Range 2.15E+04 to 1.19E+05 ohm-cm) Low (Range 8.40E-06 to 4.65E-05 S/cm)
ii.	UB 1h UB 1.5 h UB 2h UB 2.5h UB 3h	Resistivity Conductivity	Lower (3.57E+03ohm-cm) than raw material Higher (2.80E-04S/cm) than raw material
iii.	UBdEL 15 min UBdEL 30 min UBdEL 45 min UBdEL 60 min UBdEL 75 min	Resistivity Conductivity	Lower (4.39E+03ohm-cm) than raw material and EL Higher (2.28E-04S/cm) than raw material and EL
iv.	UB+EL 15 min UB+EL 30 min UB+EL 45 min UB+EL 60 min UB+EL 75 min	Resistivity Conductivity	Lower than UB, UBdEL and EL (lowest resistivity: 2.67E+03 ohm-cm) Higher than UB, UBdEL and EL (highest conductivity: 3.75E-04 S/cm)
v.	EL 15 min EL 30 min EL 45 min EL 60 min EL 75 min	Resistivity Conductivity	Lower (7.96E+03 ohm-cm) than Raw material Higher (1.26E-04 S/cm) than raw material

Conclusions

The conductivity and resistivity analysis of FeCrAl metallic CATCO material has been investigated by various treatment and the results shows that combination technique that called by UB+EL sample has highest conductivity and lowest resistivity as compared to raw material, UB, EL, and UBdEL samples about 3.75E-04 S/cm and 2.67E+03 ohm-cm, respectively. That properties was recommended to applied as CATCO coating technique to achieve an optimum performance of FeCrAl CATCO material.

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