MORPHOLOGY AND SURFACE ROUGHNESS ANALYSIS OF COATED FeCrAl FOIL FOR CATALYTIC CONVERTER APPLICATION

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ABSTRACT

Transportation sector contribute high air pollutant that mainly consists of three major pollutants such as Nitrogen Oxide (NO), Carbon Monoxide (CO) and Hydro Carbon (HC). One of the factors of ineffective pollutant conversion is coating quality of catalytic converter. Therefore, this study proposed coating technique by high speed bubbles ultrasonic bath approach. Ultrasonic Bath (UB) was carried out by various holding time of 1, 1.5, 2, 2.5 and 3 h with fixed frequency of 35 kHz. Meanwhile, for Ultrasonic Bath during Electroplating (UBdEL) was carried out by 15, 30, 45, 60 and 75 minutes holding time with voltage of 12 V and current of 1.28 A/dm^2, NiO as anode and FeCrAl as cathode material and fixed frequency of 35 kHz. The average of surface roughness analysis of UB samples of 0.154, 0.122 and 0.156 µm for measurement 1, 2 and 3, respectively. Surface roughness for UBdEL samples are 1.182, 2.442 and 1.808 µm for measurement 1, 2 and 3, respectively. It can be linked with microstructure analysis which shown that bonding mechanism of γ-Al_2O_3 adhesion into FeCrAl was increased with holding time increased as well. However, UB with ethanol solution was not fully effective as compared to UBdEL with sulphamate solution in imbedding γ-Al_2O_3 into FeCrAl.

Keyword: *Air pollution, Catalytic converter, Ultrasonic technique and morphology*

1. INTRODUCTION

Nowadays, high pollution which contributed by transportation has become main issues in creating healthy environment. According to the Department of Environment (DOE) Malaysia (2014) [1], that in the southern region of the West Coast of Peninsular Malaysia (Negeri sembilan, Melaka and Johor) generally air quality in between good and moderate level. However, there are some hazardous days in southern region of 12 days and unhealthy days of 94 days as well as very unhealthy days of 7 days. The improvement of air quality report on 2014 [1] as compared to air quality status on 2013 that the air quality is in good and moderate level but there are some unhealthy days of 63 days. It caused by high level of NO, CO, HC and Particulate Metter (PM_{10}) which produced by trans-boundary pollution of several resources such as transportation, industrial and home sectors [1]. Therefore, need to perform the improvement in exhaust system by catalytic converter as pollutants filtering process [2,3]. Currently, Metallic material (FeCrAl) become interesting material for catalytic converter because it have low specific heat capacity, excellent formability, high strength and oxidation resistance at high temperature around 1300 ^{0}C as compared to ceramic substrate [4,5]. For washcoat material commonly used Al_2O_3, SiO_2, TiO_2, or SiO_2-Al_2O_3 [6] but in this research, FeCrAl substrate is coated by γ-Al_2O_3 coating which typically 20-150 µm thick with a high surface area on the top of substrate and as the catalyst's carrier [6]. However, the most important factor is coating technique in order to improve the properties of metallic catalytic converter from converting pollutant and thermal stability as well as oxidation resistant. Therefore, in this research, coating process is conducted by ultrasonic technique which not fully explored yet even though it able to generate high speed bubbles of 100 m/sec (Fig -1) which can be applied as cleaning, removing impurities from spent catalyst, electroplating or surface treatment process [7-9], and predicted to catalyst activation after and during coating process. Therefore, FeCrAl substrate which coated by γ-Al_2O_3 using ultrasonic technique for catalytic converter believe can be achieved good coating quality which investigated by microstructure and surface roughness analysis. and it can effect to the effectiveness of catalytic converter for pollutant removal.

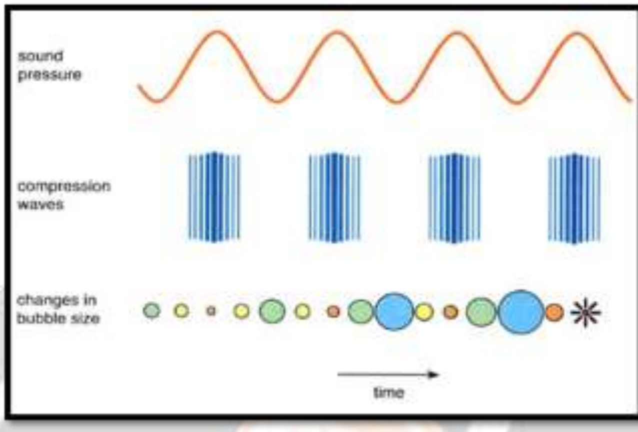


Fig -1: Principle of ultrasonic process [10].

2. METHODOLOGY

This research were carried out by FeCrAl substrate material and γ-Al_2O_3 coating material. Those material was performed by ultrasonic bath technique to embed the γ-Al_2O_3 into FeCrAl substrate. Ultrasonic bath was conducted to FeCrAl foil which cut in size of 40 mm x 20 mm and γ-Al_2O_3 powder. The samples were cleaned in water and then proceed in ethanol for 5 minutes. During ultrasonic process, the frequency of 35 kHz and various ultrasonic times of 1, 1.5, 2, 2.5 and 3 hours is imposed. The samples were immersed into the beaker with γ-Al_2O_3 powder and ethanol with the concentration of 20 g/l. The other methods will be conducted i.e. ultrasonic bath during electroplating which conducted by voltage of 12 V, current density of 1.28 A/dm^2, NiO as anode and FeCrAl as cathod material, frequency of 35 kHz, sulphamate types solution and holding time of 15, 30, 45, 60 and 75 minutes. In this process, the stirrer was replaced by ultrasonic sources. It conducted in order to achieve homogenizing of coating process or leveling the spread coating material.

Scanning Electron Microscope (SEM) was conducted for morphology characterization. In this research, High Vacuum (HV) mode is used in SEM process with Secondary-Electron Image (SEI) detector with the imaging mechanism with magnification of 300 times. Surface roughness machine is arranged by λ_c of 0.8 mm, λ_s of 2.5 µm, eva-L of 4 mm and Roughness range of 800.

3. RESULTS AND DISCUSSION

The results of this study was consists of three major analysis such as morphology analysis, composition analysis and surface roughness analysis.

3.1 Morphology analysis of UB and UBdEL samples

Surface morphology analysis of coated and uncoated FeCrAl substrate by γ-Al_2O_3 powder using two techniques which are ultrasonic bath and ultrasonic bath during electroplating like shown in Fig -2 (a) - (k). For raw material as uncoated substrate shows that it has even surface morphology with bit spallings. UB samples shows that higher ultrasonic holding time, produce higher number of γ-Al_2O_3 powder embedded into the FeCrAl substrate. It can be seen that UB 3 h shows fully embedded coated material as compared to UB 1, 1.5, 2 and 2.5 h. It approved by there are more particle of γ-Al_2O_3 that conduct the bonding activity on FeCrAl substrate. It caused by high speed bubbles which generated which cause the shock out wave into the liquid. When shock waves through a mass of particles, high speed inter-particle collisions are occurred with the right angle of the collision. Metal particles can be pushed together with a high speed to melt effectively at the point of collision [11,12].

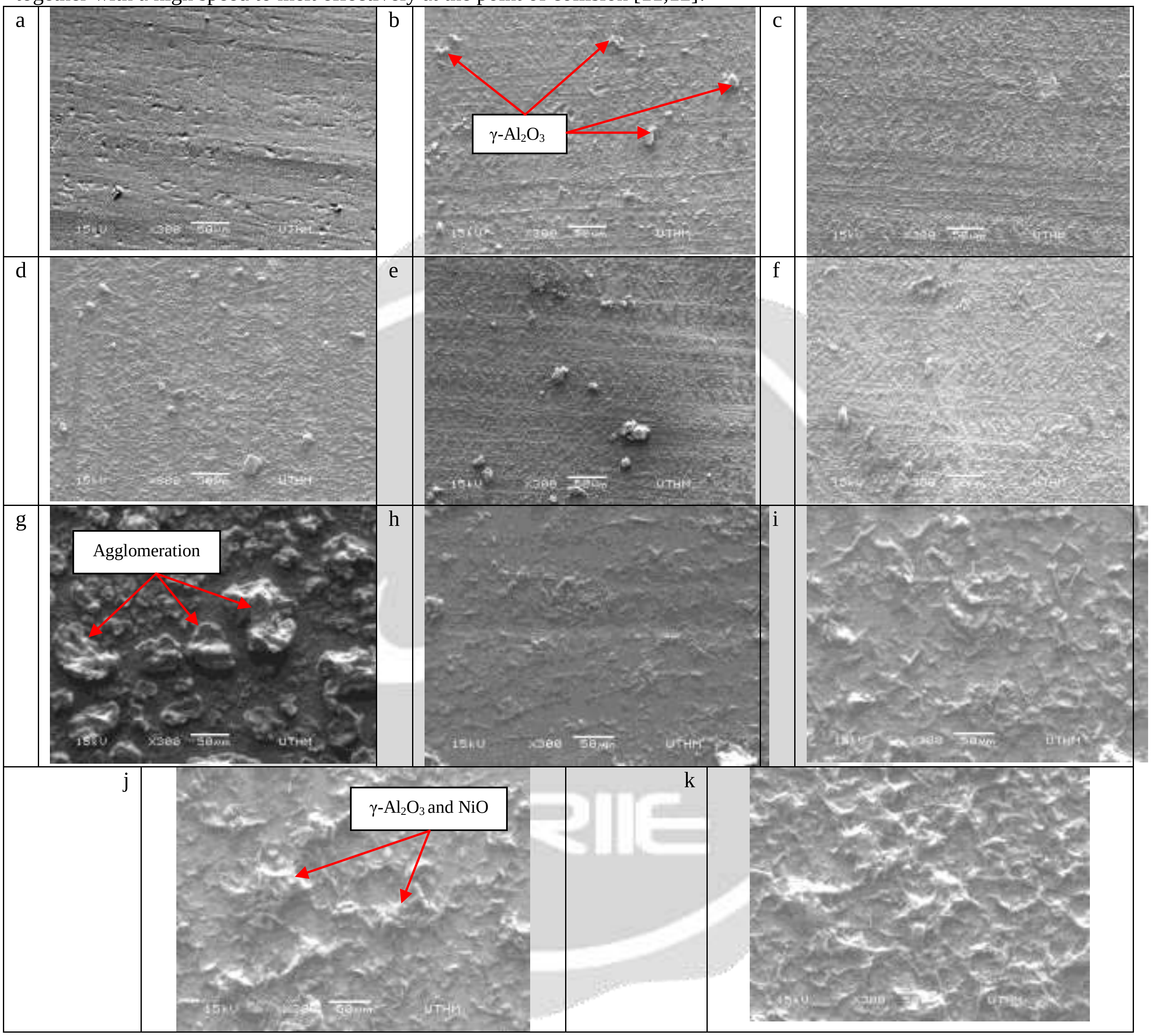


Fig -2: Morphology of (a) Raw material; (b) UB 1 h; (c) UB 1.5 h; (d) UB 2 h; (e) UB 2.5 h; (f) UB 3 h; (g) UBdEL 15 min; (h) UBdEL 30 min; (i) UBdEL 45 min; (j) UBdEL 60 min and (k) UBdEL 75 min

Fig -2 (g) - (k) shows the sample which treated by ultrasonic bath during electroplating with various times of 15, 30, 45, 60 and 75 minutes. for UBdEL 15 minutes the embedding process not fully occurred because low current density and voltage combined by low frequency still in early process for embedding material. Different morphology between UB and UBdEL was clearly imaging that γ-Al_2O_3 powder in UB sample still in powder form but in UBdEL samples show that γ-Al_2O_3 powder and NiO have been melted together and plated to the FeCrAl substrate. It caused by different electrolyte solution where UB used ethanol solution while UBdEL used suphamate types solution as well as UBdEL process is completed by low voltage and current with anode and cathode arrangement.

3.2 Composition analysis of UB samples

Composition analysis of FeCrAl substrate as raw material and coated FeCrAl by γ-Al_2O_3 powder using ultrasonic technique are shown in Fig -3. Raw material (Fig -3 (a)) has consists of C: 2.94 wt%, O:1.88 wt%, Al: 5.73wt%, Cr: 22.16wt% and Fe: 67.29 wt%. This material has high temperature range operation up to 1400 ^{0}C (according to material specification) because from that composition develop protective oxide compound such as Cr_2O_3, Al_2O_3 and FeO. Fig -3 (b) - (f) shows composition analysis of UB samples for 1, 1.5, 2, 2.5 and 3 hours, respectively. It shows that UB samples have consists of C: 8.48% - 16.82%; O: 34.31% - 37.98%; Al: 37.25% - 46.83%; Cr: 3.27% - 5.54% and Fe: 7.57% - 12.78%. Increasing of C content caused by heating process after ultrasonic process to drain the samples from ethanol as electrolyte. Oxygen content also increase which caused by oxygen cavitations on the γ-Al_2O_3 coating layer which can approved by surface morphology analysis. In addition, the increment of Al, Cr and Fe content because it activated by ultrasonic technique by collisions during the process and also because it has main components of FeCrAl fabrication.

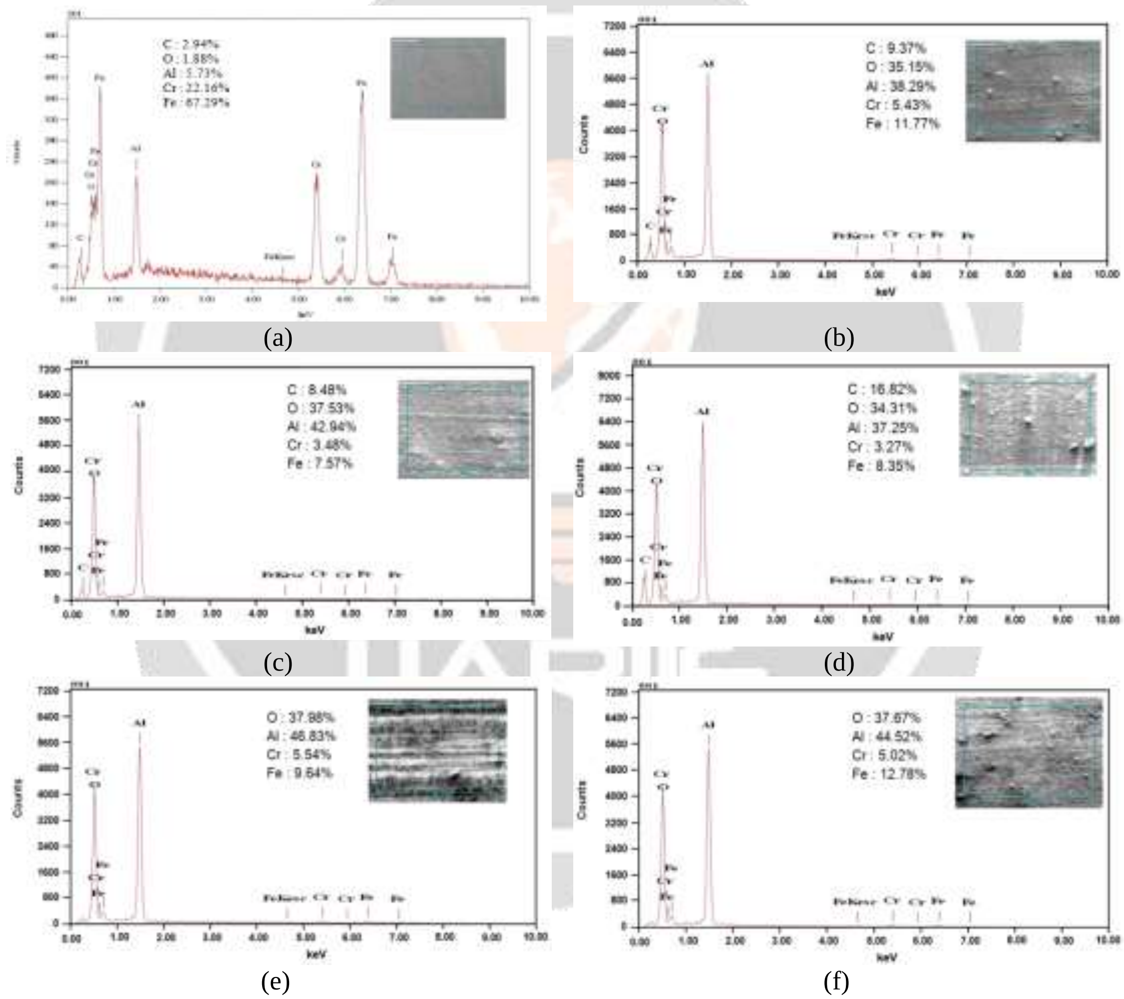
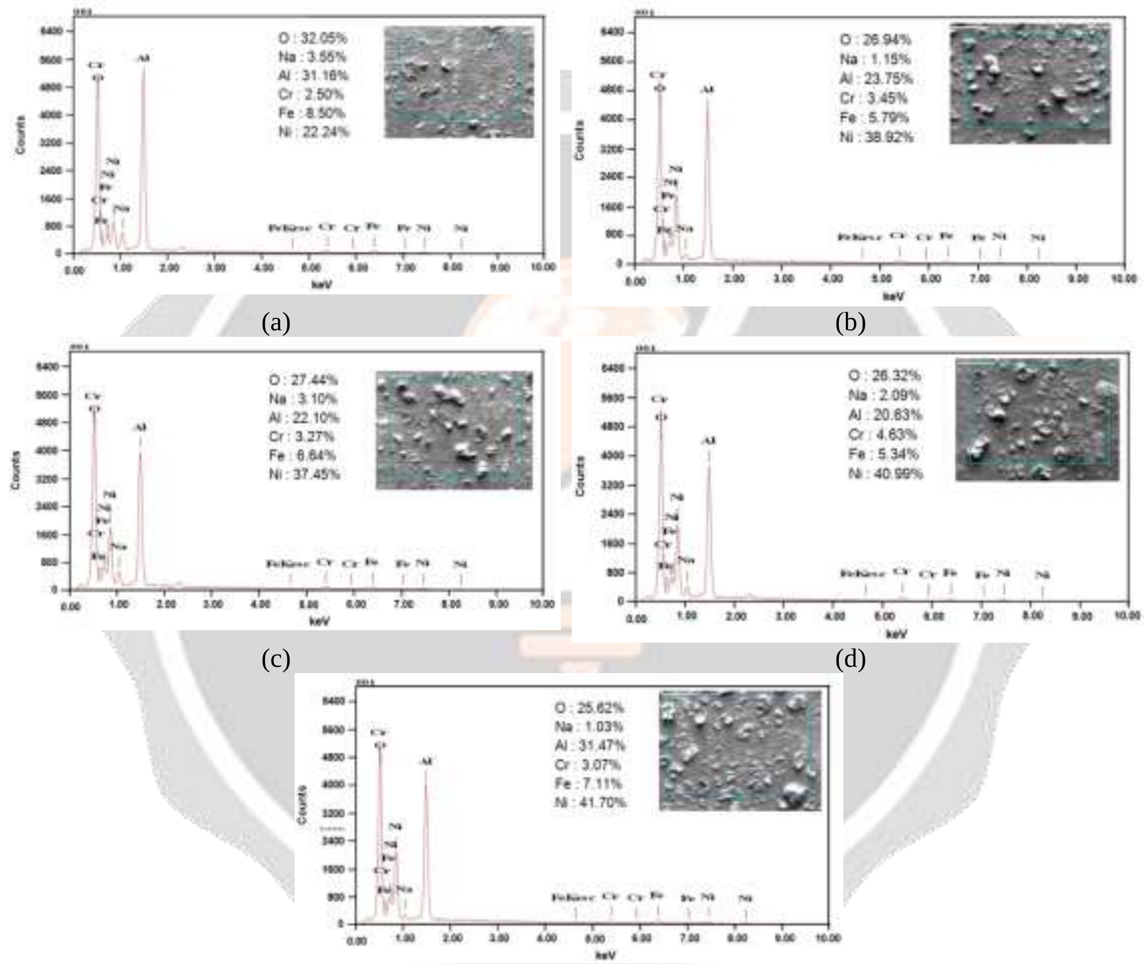


Fig -3: Composition analysis of (a) Raw material; (b) UB 1 hour; (c) UB 1.5 hour; (d) UB 2 hour; (e) UB 2.5 hour and (f) UB 3 hour

3.2 Composition analysis of UBdEL samples

EDS analysis of FeCrAl substrate coated by γ-Al_2O_3 powder using ultrasonic during electroplating with various times of 15, 30, 45, 60 and 75 minutes as shown in Fig -4. There are differences between composition of UB and UBdEL samples which located on Sodium (Na) chemical in small percentage of 1.03% - 3.10% that observed in UBdEL samples. It caused by sulphamate solution as electrolyte which consists of a lot of chemical agent including Na. Therefore, there are bonding activity between those chemical and FeCrAl substrate. Moreover, Ni content has been observed in UBdEL samples for 22.24% - 41.70% because Ni has used as anode material. Ni plays the important role in increasing protective oxide layer such as NiO form at high temperature condition. NiO form also prove that the UBdEL coating technique can be activate NiO active catalyst through oxidation technique. From the UBdEL samples can be seen that the bonding activity for surface γ-Al_2O_3 powder and electrolyte chemical in FeCrAl substrate is successfully achieved. Fully embedded of γ-Al_2O_3 in line with the time increment. It approved by surface roughness analysis that UBdEL 75 minute samples has highest surface roughness for 2.17 µm as compared to other UBdEL samples. Full bonding phenomena of UBdEL samples proof that a jet flush energy or high speed bubbles promote to the γ-Al_2O_3 powder to bond on the FeCrAl substrate [19]. Fully bonding activity is related to the high diffusion of γ-Al_2O_3 to the FeCrAl substrate since there is cation and anion transport which promote higher diffusion coefficient [20].



(e)

Fig -4: Composition analysis of (a) UBDEL 15 min; (b) UBDEL 30 min; (c) UBDEL 45 min; (d) UBDEL 60 min and (e) UBDEL 75 min

3.4 Surface roughness analysis

Chart -3 shows surface roughness (Ra) and surface roughness mean squared (Rq) of raw material, UB samples and UBdEL samples. Ra and Rq of raw material show that it in constant value of 0.02 and 0.03 µm, respectively. From the Ra UB samples can be calculated that the average of Ra in UB 1, 1.5, 2, 2.5 and 3 h are 0.12, 0.21, 0.12, 0.13 and 0.14 µm, respectively and Ra of UBdEL samples are 1.95, 1.28, 1.14, 1.84 and 2.84 µm, respectively. For Rq of UB samples are 0.19, 0.32, 0.17, 0.18 and 0.24 µm, respectively and for UBdEL are 2.56, 1.85, 1.63, 2.44 and 4.21 µm, respectively. It can be concluded that for UB samples highest Ra and Rq are located at UB 1.5 h and for UBdEL samples, highest Ra and Rq are located at UBdEL 75 minutes.

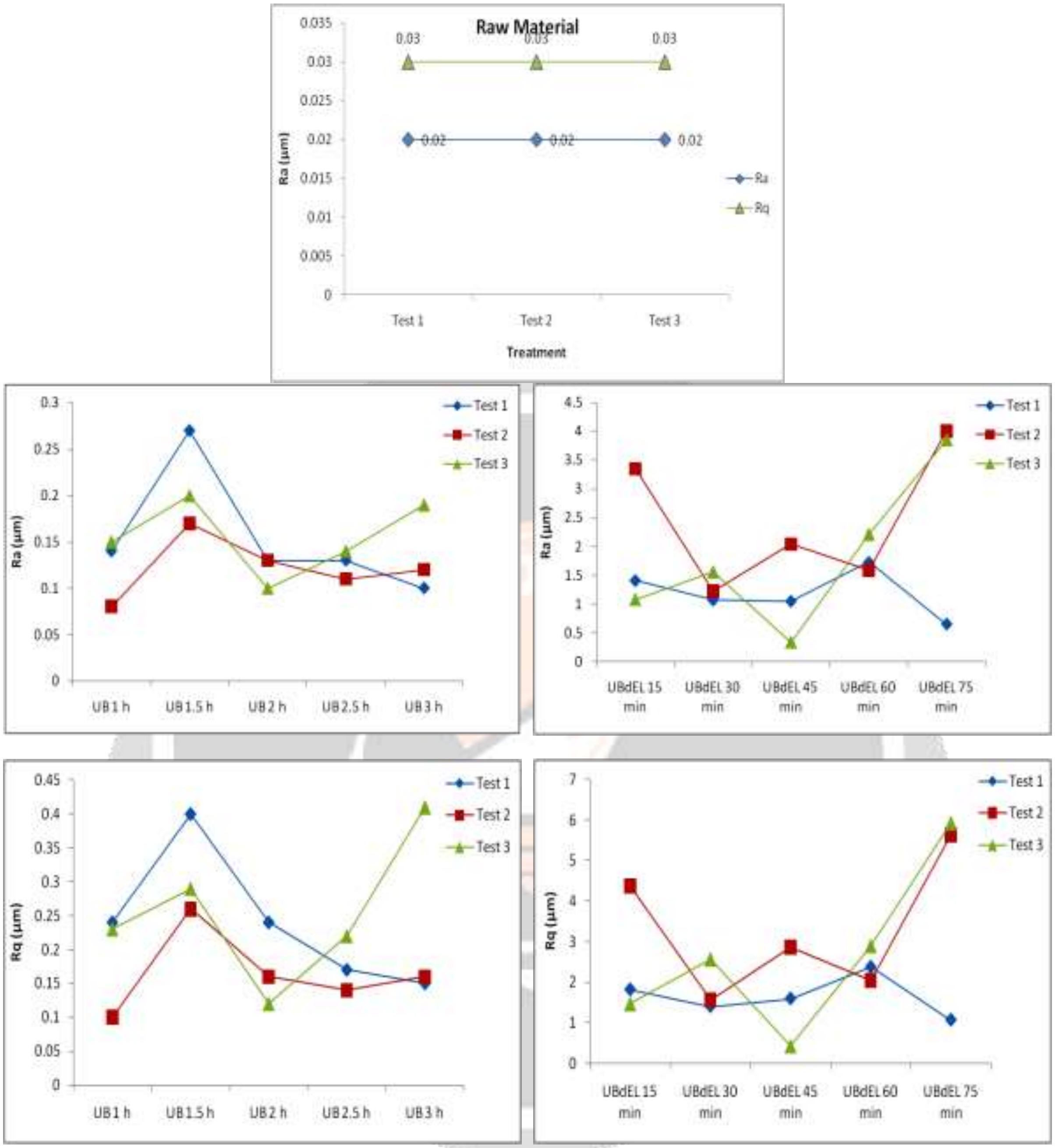


Chart -3: Ra and Rq of raw material, UB samples and UBdEL samples

Roughest Ra and Rq of UB samples is in UB 1.5 h and UBdEL samples are in UBdEL 75 minutes. It expressed to the wall thickness of the coated FeCrAl substrate where in modern scientific researches as well as engineering studies, rough surfaces have attracted more and more attention in a wide range of fields including, for example, tribology, geophysics, remote sensing and acoustics [13]. There are correlation of the surface roughness in catalytic converter regarding to the toxic emission flow through the catalytic converter. Surface roughness is can effect to the chemical reaction [13] which automatically effect to the result of exhaust emission of the catalytic converter. In this research will investigate which effective between low or high surface roughness in field of reducing emission.

4. CONCLUSIONS

Coating process of FeCrAl substrate by γ-Al_2O_3 powder have successfully conducted and it shows the correlation between surface morphology and surface roughness analysis. There are differences phenomena between morphology and Ra&Rq of UB samples that in morphology shows that longer ultrasonic time obtain more embedded γ-Al_2O_3 powder but in Ra analysis shows that highest Ra&Rq of UB samples was located at UB 1.5 h. However, it different with UBdEL samples that it shows in-line phenomena between morphology and Ra&Rq. full embedded γ-Al_2O_3 powder into FeCrAl at UBdEL 75 min and also highest Ra&Rq at UBdEL 75 minutes. Moreover, it can be concluded that the UBdEL technique was more effective for FeCrAl coating process and it will automatically effect to the exhaust emission system improvement in reducing the pollutant.

5. ACKNOWLEDGEMENT

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