

## STUDY ON PERFORMANCE OF CO<sub>2</sub> LASER IN PAINT REMOVAL OVER SELECTED NATIONAL CAR MODEL

Mohammad Khairul Azhar Abdul Razab<sup>a\*</sup>, Mohamad Suhaimi Jaafar<sup>b</sup>, Fatanah Mohamad Suhaimi<sup>c</sup>, Mohamad Najmi Masri<sup>a</sup>, Nor Hakimin Abdullah<sup>a</sup>, Mazlan Mohamed<sup>a</sup>, Mohamad Faiz Mohd Amin<sup>a</sup>, Muhammad Iqbal Ahmad<sup>a</sup>

<sup>a</sup>Advanced Material Research Cluster, Faculty of Earth Sciences, Universiti Malaysia Kelantan Jeli Campus, Locked Bag No. 100, 17600 Jeli, Kelantan, Malaysia

<sup>b</sup>School of Physics, Universiti Sains Malaysia Main Campus, 11800 Minden, Penang, Malaysia

<sup>c</sup>Advanced Medical & Dental Institute, Universiti Sains Malaysia, Bertam 13200 Kepala Batas, Penang, Malaysia

### Article history

Received

15 August 2015

Received in revised form

15 November 2015

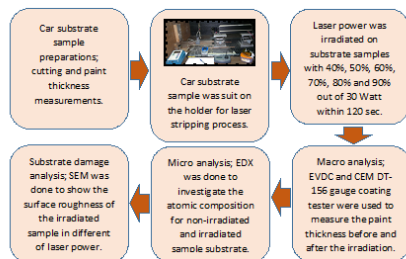
Accepted

30 December 2015

\*Corresponding author

azhar@umk.edu.my

### Graphical abstract



### Abstract

A technique to determine the optimum parameters of 30 Watt Continuous Wave (CW) CO<sub>2</sub> laser paint removal has been developed on national car coated substrate. This paper reports on the results of studies carried out on two different coating thicknesses; 196 µm and 201 µm using CW CO<sub>2</sub> lasers operating at 10, 600 nm wavelength and relatively high beam power from 40%, 50%, 60%, 70%, 80% and 90% out of 30 Watt. Empirical data were presented to demonstrate the optimum power required for paint stripping process. Macro analysis was done to prove the stripping process was in line with the increase of power percentage applied, whereas microanalysis using EDX and SEM revealed the atomic composition and surface roughness of the crater.

**Keywords:** CO<sub>2</sub> laser, Paint removal, Car coated substrate, Thermal decomposition

### Abstrak

Satu teknik untuk menentukan parameter optimum laser CO<sub>2</sub> gelombang berterusan (CW) 30 Watt dalam penanggalan cat telah dilaksanakan terhadap substrat kereta bercat. Kertas penyelidikan ini melaporkan hasil kajian dua perbezaan ketebalan cat; 196 µm dan 201 µm menggunakan laser CW CO<sub>2</sub> beroperasi pada 10, 600 nm panjang gelombang dan perbandingan kuasa alur bermula dari 40%, 50%, 60%, 70%, 80% dan 90% daripada 30 Watt. Data empirikal telah dibentangkan untuk menunjukkan kuasa optimum yang diperlukan bagi proses penanggalan cat. Analisis makro telah dilakukan untuk membuktikan proses penanggalan cat adalah selari dengan peningkatan peratus kuasa yang ditetapkan manakala analisis mikro menggunakan EDX dan SEM memberikan komposisi atom dan kekasaran permukaan kawah.

**Kata kunci:** CO<sub>2</sub> laser, Penanggalan cat, Substrat kereta bercat, Penguraian termal

© 2016 Penerbit UTM Press. All rights reserved

## 1.0 INTRODUCTION

Nowadays, chemical-based strippers and grit blasting are the core techniques practiced by Malaysian automotive industry in the process of repainting cars. However, neither of these techniques is ideal as both have resulted in environmental imbalance due to the generation of a large amount of waste and the process is unfavourable due to the high cost involved; especially the labour cost, [1-5]. Laser based paint removal processes can overcome these problems. The method is based on the removal of a thin layer of coating material from a metal surface under the action of the continuous wave (CW) laser beam, generally known as "laser thermal de-composition", [6-8].

The main advantages of this technique are; there is no direct mechanical contact to the substrate, in situ cleaning, less time cleaning, non-use of toxic solvents or chemical products, preventable damage to the substrate and controllable environment, [9, 10]. However, although benefits of this technique are highly feasible, laser cleaning of painted surfaces can only obtain a good result if the process is properly controlled, [10, 11].

This paper demonstrates the optimum power operation condition of Synrad J48-1 CO<sub>2</sub> laser 30 Watt applied to strip the paint of a national car body. This study aimed to introduce the fundamental of laser paint removal method as an alternative to conventional chemical stripping in Malaysian automotive industry and at the same time to prove its effectiveness and quality. The experiment was carried out at Medical Physics Laboratory, School of Physics, Universiti Sains Malaysia, Penang and Material Science Laboratory, Faculty of Earth Science, Universiti Malaysia Kelantan Jeli Campus.

## 2.0 EXPERIMENTAL

### 2.1 Laser Equipment and Substrate Samples Preparation

Before the experiment started, the laser power output was calibrated with PW-250 Power Meter in order to ensure the output power was constantly increasing to the power set-up using UC-2000 PWM controller.

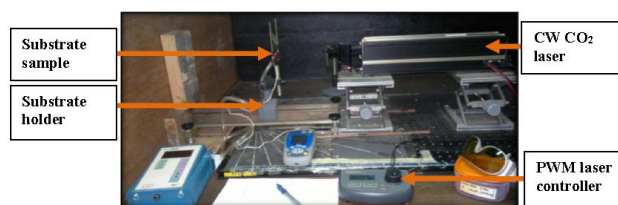
In this study, two substrate samples with black paint colour were prepared from the right front door of selected national car model obtained from car workshop and spare part centres in Kota Bharu. The door was cut into small rectangular substrate, approximately 4 x 4 cm<sup>2</sup> in size for SEM analysis availability. Before irradiation, both substrates provided were cleaned by running tap water to remove any contaminants and foreign particles.

The average coating thickness of substrate sample was measured by using CEM DT-156 Paint Coating Thickness Gauge Tester F/NF Probe. Five readings were taken from each side and the centre of the

square face of the sample substrate. Each substrate was marked by a unique number at the backside for sample identification. Moreover, one substrate sample was prepared for three different power parameters with three times laser irradiation required by each substrate. Hence, eighteen times of laser irradiation was utilized on two pieces of substrate samples in order to complete the six selected laser power parameters. Low power was applied at the bottom of the sample and the next high selected power was irradiated at the centre and top of the substrate respectively.

### 2.2 Operating Principle

Prior to irradiation, the sample substrate was fixed on the holder shown in Figure 1.



**Figure 1** Car substrate sample was fixed on the holder for laser stripping process

For this study, source to target distance (STD) was fixed at 10cm by locking the sample holder on the ruler track provided. With different densities of the laser power, the substrate samples were then irradiated based on the power level marked at the backside of the substrate. The laser power applied for the purpose of completing one cycle assessment were 40%, 50%, 60%, 70%, 80% and 90% out of 30 Watt. These selected laser power were emitted by fixing the irradiation time at 120 seconds.

During laser irradiation process, the sample was moved in horizontal line using the left-right mechanical controller equipped to the holder. This method enlarge the stripping area by continuously moving the substrate from left to right edge. The sample movement and laser irradiation will be stopped concurrently after 120 seconds. This process was repeated for three times with the same laser power in order to get the consistency and wide stripping area before proceeding with different selected laser power. Laser safety glass manufactured by Yamamoto was worn during the whole experiments for eyes protection from CO<sub>2</sub> laser irradiation.

### 2.3 Sample Analysis

The irradiated samples were cleaned by using plain water and dried in open air to remove any burning residue existed on the surface substrate. Cotton wool and tissue paper were used to swap the stripped area in order to ensure there were no more residues

left and at the same time to keep the originality of the structure and pattern of the crater before proceeding to sample analysis.

Macro analysis was done to find out the thickness of paint that has been removed in the laser stripping process. Electronic Vernier Digital Caliper (EVDC) and CEM DT-156 gauge coating tester were used to measure the paint thickness before and after the irradiation. In this case, EDCV measured the paint thickness together to the metal substrate, whereas CEM DT-156 only measured the paint thickness by applying magnetics resources. Hence, the depth of the paint that has been removed by different laser power will be revealed and analysed. In addition, each crater resulted from different laser power were viewed by using Meiji MT 7100 Metallurgy Microscope for micrograph comparison.

Both irradiated samples were sent for micro analysis by using scanning electron microscopy (SEM) for surface morphology. Energy dispersive x-ray (EDX)

technique was used for atomic composition study. The surface morphology was magnified to 500 times with the scale of 100 $\mu$ m for substrate damage and roughness analysis. In addition, 20kv penetration power was applied for EDX analysis in order to get the accurate percentage of atomic composition presence on the surface and subsurface of irradiated area.

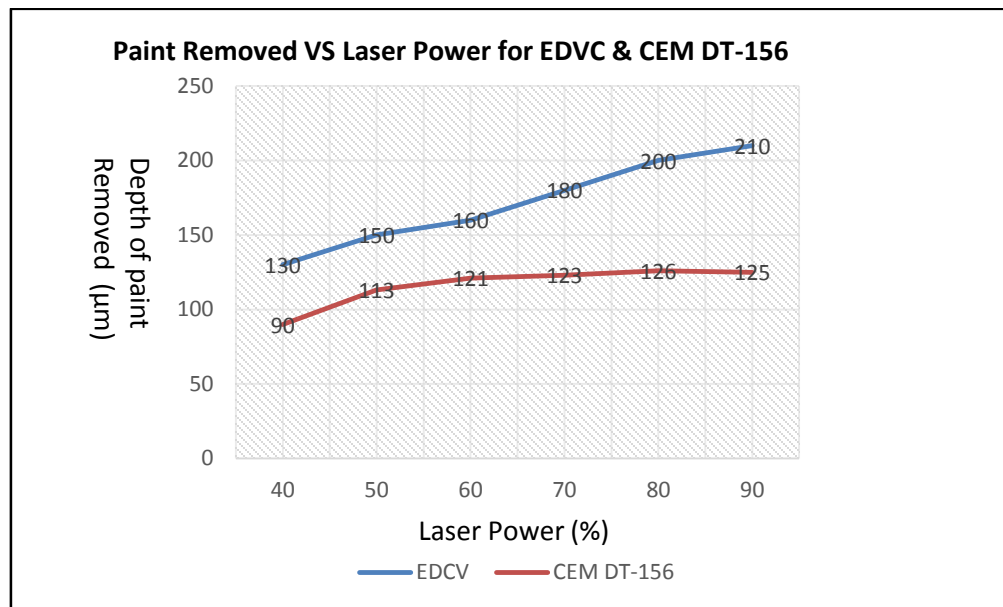
### 3.0 RESULTS AND DISCUSSION

#### 3.1 Macro Analysis

Macro analysis was carried out by using EVDC and CEM DT-156 gauge coating thickness tester to measure the depth of paint before and after the stripping process. The results produced by both instrument were compared and their relation to paint removal thickness were shown in Table 1.

**Table 1** The thickness of paint removed by varying laser power measured by EVDC and CEM DT-156 coating thickness tester.

Irradiation	Laser Parameters			Electronic Digital Caliper results ( $\mu$ m)			CEM DT-156 Coating Thickness Tester results ( $\mu$ m)		
	PWM (%)	Time (sec)	STD (cm)	Plate + Paint	Plate + Residue Paint	Paint Removed (depth)	Paint Thickness	Residue Paint	Paint Removed (depth)
-	-	-	-	950	-	-	196	-	-
1	40	120	10	-	820	130	-	106	90
2	50	120	10	-	800	150	-	83	113
3	60	120	10	-	790	160	-	75	121
-	-	-	-	930	-	-	201	-	-
4	70	120	10	-	750	180	-	78	123
5	80	120	10	-	730	200	-	75	126
6	90	120	10	-	720	210	-	76	125



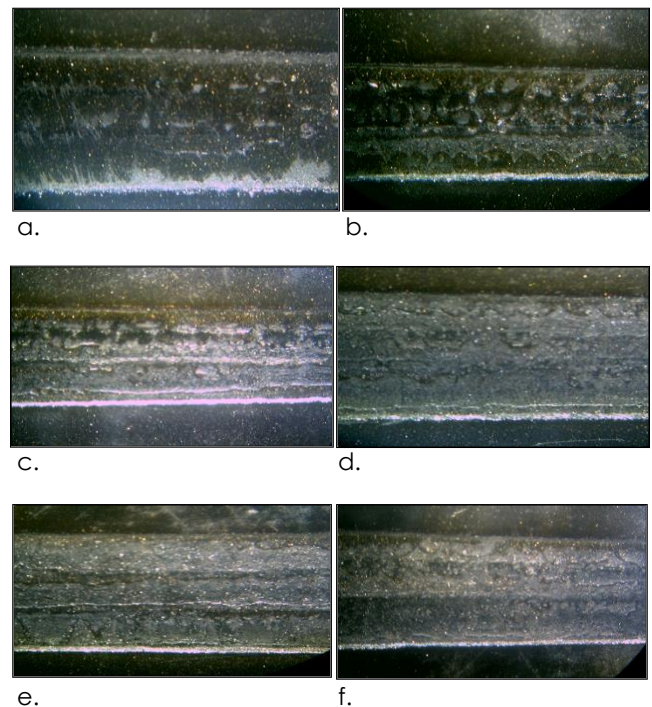
**Figure 2** Depth of paint removed for different laser power by using EDCV and CEM DT-156 techniques

Figure 2 shows the depth of paint removed which was in line with the increasing of laser power for both techniques, [12]. At 60% and next high-applied power, the paint thickness removed measured by CEM DT-156 was constant. This criterion might be due to the non-uniformity of the crater caused by high power laser irradiation which will lead to the fluctuation of the magnetic resources of the device. The non-uniformity surface morphology was proven by SEM micrograph as shown in Figure 6 (a) and (b).

Dissimilar for EDCV result, the thickness of paint removed were constantly raised in accordance with the laser power applied. Flat surface at the backside of the metal substrate was supporting the EDCV nozzle when the measurement was taken hence the reading is more stable.

The surface structure of the irradiated substrate samples were then viewed by using Meiji MT 7100 Metallurgy Microscope as shown in Figure 3 for initial surface morphology analysis.

In accordance to Figure 3 (a), (b) and (c), the applied laser power at 40%, 50% and 60% were unable to remove the topcoat of the coating system. However, this problem was overcome by increasing the laser power at 70%, 80% and 90% as shown in Figure 3 (d), (e) and (f). Surface morphology revealed that at low laser power application has caused the surface roughness to be more critical compared to higher laser power. The micrograph shows the depth of paint that has been removed which was almost the same as well as their roughness level started at 70% and above power applied, hence support the graph pattern produced by using CEM DT-156 in Figure 2.



**Figure 3** Meiji MT 7100 Metallurgy Microscope micrograph with 40x magnification lens for different laser power were applied in stripping process; (a) 40%, (b) 50%, (c) 60%, (d) 70%, (e) 80% and (f) 90%

### 3.2 Micro analysis

Microanalysis was conducted using Energy Dispersive X-ray (EDX) to investigate the atomic composition for

non-irradiated and irradiated sample substrate. Table 2 below shows the result of EDX analysis done from 40% to 90% of selected laser power applied for stripping process.

**Table 2** EDX results of atomic composition revealed (Wt %) for laser stripping process from 40%, 50%, 60%, 70%, 80% and 90% out of 30 Watt laser power

Element (Wt %)	Laser Power (%)						
	*N/A	40	50	60	70	80	90
C	73.11	61.87	74.6	78.03	-	-	-
N	-	-	-	-	14.6	-	-
O	26.89	33.83	23.5	20.9	59.81	60.75	53.79
Na	-	-	-	-	1.04	0.95	0.81
Mg	-	2.18	0.55	-	2.78	4.93	7.0
Al	-	-	-	-	9.39	7.34	13.42
Si	-	2.12	0.73	0.44	5.41	7.93	13.46
S	-	-	-	-	1.49	1.61	0.83
Cl	-	-	-	-	0.74	-	-
Ca	-	-	0.62	0.63	2.93	9.51	4.21
Ti	-	-	-	-	1.13	1.93	-
Fe	-	-	-	-	0.67	1.62	1.49
Ba	-	-	-	-	-	3.44	5.0
Total	100	100	100	100	100	100	100

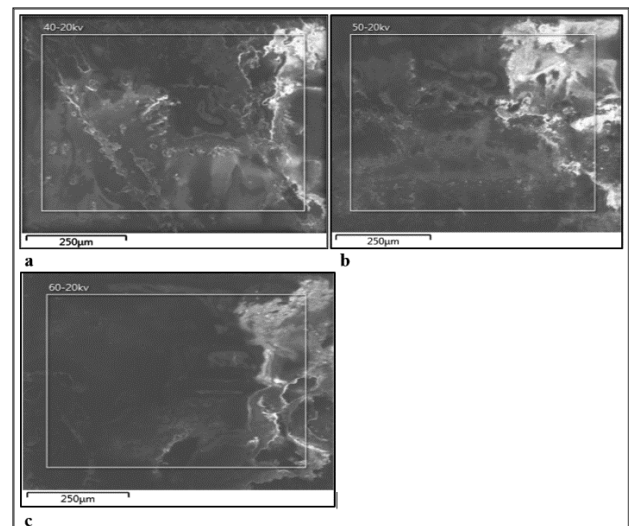
The basic composition existed at the painted surface or topcoat was carbon (C) and oxidized particle (O) which is typical for organic coatings, [13]. When the paint was removed, carbonization process occurred due to thermal decomposition [14]. This process started at 40% applied laser power where the exchange of C and O composition percentage can be seen in Table 2.

Absence of C at 70% of power level and above proved that the topcoat layer is already stripped. The most important element to be considered is Ferum (Fe) as the main composition of metal substrate, which is justified for all coated area, has been removed.

Since EDX result revealed the atomic composition at <2  $\mu\text{m}$  from the surface [15], 70% output power applied was able to remove the top coat of the coating system. However, the significant effect was seen at 80% laser power, which has exposed the Fe of about 1.62%, followed by maximum power applied at 90%, which is 1.49%. Hence, 80% laser power applied has given the best efficiency in paint removal process since the volume of paint removed over the power applied is very effective, [3, 16].

This phenomenon occurred probably due to the fact that almost all of the laser photon will have sudden reflect by the metal surface [13], at the highest power due to high penetration through the coating system.

Conversely, the laser photon is well absorbed by the coatings [17], at the optimum power 80% since the Time irradiation is quite enough for this photon to interact with the coatings system.



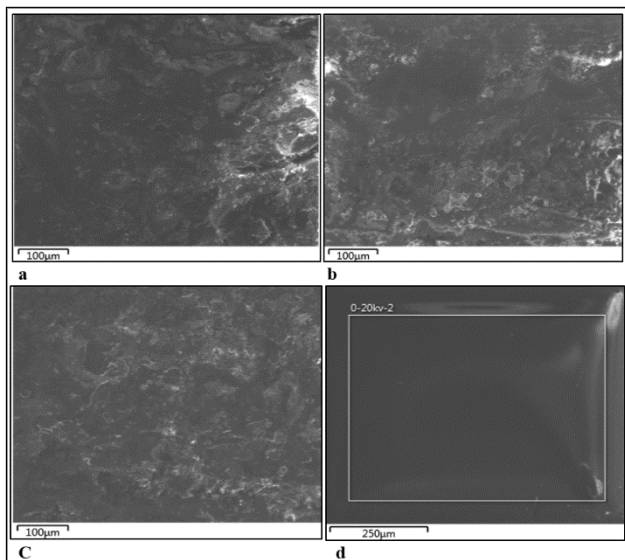
**Figure 4** Paint removed from car metal substrates using different laser power densities; (a) 40%, (b) 50%, and (c) 60% clearly show the coating surface rupture and roughened (bright area) resulted from laser heating-induced carbonization



### 3.3 Substrate Damage Analysis

At low power laser application, most of coating suffered the bond breaking of their main atomic composition known as photochemical, [18]. At this stage, C-O, C=O or even C single bonded to three O were exchanged and rearranged in their percentage composition due to thermal effects of laser irradiation, [13]. This photochemical interaction will rupture and toughen the coating surface. Furthermore, debris which mostly contains amorphous carbon, resulted from laser heating-induced carbonization of the coating was clearly seen by SEM micrographs in Figure 4 (a), (b), and (c), [2, 14].

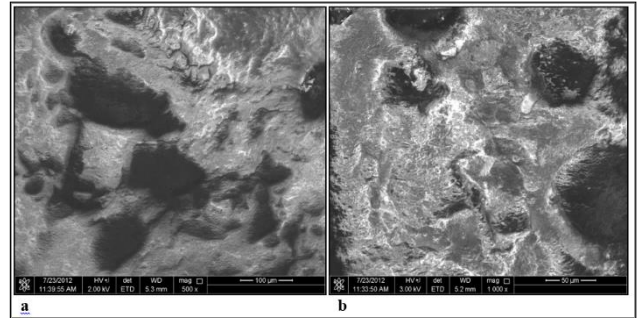
On the other hand, photo thermal interaction is dominant when middle and higher power were applied on the coating system, [18]. This interaction leaned to generate burr around the crater that consist of more oxidized particles as shown in Figure 5 (a), (b), and (c). This fact was proven by the increasing of O element percentage in line with its laser power as stated in Table 2. Photo thermal interaction has given major contribution on thermal decomposition process occurrence and hence removed the coating system, [6-8, 19]. This circumstance reduces the surface roughness due to oxidation particles solidification and the burr produced at the irradiated crater is less critical than the carbonization effects.



**Figure 5** Paint removed from car metal substrates using different laser power densities by SEM micrographs; (a) 70%, (b) 80%, (c) 90% and (d) non laser power applied. The oxidized particles existed at the whole of the irradiated area, (bright area)

Surface roughness or non-uniformity coating structure is inevitable in laser paint removal since it is dealing with the thermal decomposition process. The amorphous carbon and oxidized particles remaining

after the stripping process is very porous and rough as clearly shown in Figure 6 (a) and (b). This condition might be due to fast solidification of the residue paint after the removal process.



**Figure 6** Non-uniformity of paint removal surface morphology from SEM micrograph for 80% laser power; (a) 500x magnification, (b) 1000x magnification

### 4.0 CONCLUSION

Laser paint removal can be successfully done by selecting the proper parameters for the laser itself especially the power irradiation. In this study, EDCV and CEM DT-156 results show that the efficiency of paint removed was in line with the increasing of laser power, but there is an optimum power that must be considered based on the paint material, time irradiation and STD set-up. 80% laser power gives the best quality and effective result for paint removal using Synrad J48-1 CO<sub>2</sub> laser 30 Watt in term of paint removal efficiency. SEM results show the surface roughness of the irradiated sample in using different laser power. Surface roughness is inevitable in laser paint removal since it is dealing with the thermal decomposition process. Hence, high power laser followed by low power laser should be suggested to strip the coating system in order to ensure the roughness is less and does not affect the metal substrate.

### Acknowledgement

The authors acknowledge the support of the Short Term Research Grant Scheme (STRG) [Grant Number R/SGJP/A08.00/00451A/001/2015/000241] awarded by Universiti Malaysia Kelantan. Appreciation also goes to Mr. Yahya Ibrahim of the School of Physics, Universiti Sains Malaysia and Mr. Ahmad Fadli Ahmad Sanusi of the Faculty of Earth Science, Universiti Malaysia Kelantan Jeli Campus for their help in preparing the CW CO<sub>2</sub> laser and its accessories during the experiments.

## References

- [1] Walters, C. T., B. E. Campbell, and R. J. Hull. 1998. Laser Cleaning Of Metal Surfaces. *Conference on High-Power Laser Ablation, Santa Fe, New Mexico*. 3343(2): 859-865.
- [2] Razab, M. K. A. A., M. S. Jaafar, and A. A. Rahman. 2014. A Study of Temperature Effects on Car Coated Substrate in laser Paint Removal. *International Journal of Engineering & Technology*. 14(2): 39-48.
- [3] Razab, M. K. A. A., M. S. Jaafar, A. A. Rahman and Saidi, S. A. 2014. Determination of Average Coating Removal Efficiency for Nd: YAG Laser over Three Types of Car Coated Substrate. *Advances in Environmental Biology*. 8(1): 227-235.
- [4] Razab, M.K.A.A., M. S. Jaafar, A. A. Rahman, Mamat. S and Ahmad, M. I. 2014. Study of Health Implications Effects in Laser Paint Removal Process Based on PM<sub>1.0</sub> and PM<sub>10.0</sub> Measurements. *J. Trop. Resour. Sustain. Sci.* 2(1): 30-39.
- [5] Razab, M. K. A. A., M. Suhaimi Jaafar, and A. A. Rahman. 2014. A Study Of Particulate Matter Concentration Released During Laser Paint Removal Process On Car Coated Substrate. *IOSR Journal of Applied Physics (IOSR-JAP)*. 6(2): 40-48.
- [6] Mongelli, Gerard. 2005. *Portable Handheld Laser Small Area Supplemental Coatings Removal System*. (Final Technical Report). Headquarters Air Force Materiel Command Depot Modernization and Logistics Environmental Office: Dayton, Ohio, United States. 4-5.
- [7] Razab, M. K. A. A., M. S. Jaafar, A. A. Rahman and Saidi, S. A. 2014. Estimation of Threshold Fluence, Absorption Coefficient and Thermal Loading of Car Coated Substrate in Laser Paint Removal. *Applied Mechanics and Materials*. Trans Tech Publ. 554: 439-443.
- [8] Razab, M. K. A. A., M. S. Jaafar, A. A. Rahman., Mamat, S., Ahmad, M. I. and Suhaimi, F. M. 2015. Influenced Of Threshold Fluence, Absorption Coefficient And Thermal Loading In Laser Paint Removal Mechanisms. *Environment. Energy and Applied Technology*. CRC Press. 885-891.
- [9] Morais, P. J., Gouveia, H., Apostol, I., Damian, V., Garoi, F., Iordache, I., Bojan, M., Apostol, D., Campo, Jar, and Galli, R. 2010. Laser Beam In The Service Of Paintings Restoration. *Romanian Reports in Physics*. 62(3): 678-686.
- [10] Razab, M. K. A. A., M. S. Jaafar, A. A. Rahman and Saidi, S. A. 2014. Identification Of Optimum Operatives Parameters For Pulse Nd: YAG Laser In Paint Removal On Different Types Of Car Coated Substrate. *International Journal of Education and Research*. 2(2): 47-64.
- [11] Coutouly, Jean-Francois, Deprez, Pascal, Breaban, Florin, and Longuemard, Jean-Paul. 2009. Optimisation Of A Paint Coating Ablation Process By CO<sub>2</sub> TEA laser: Thermal Field Modelling And Real-Time Monitoring Of The Process. *Journal of Materials Processing Technology*. 209(17): 5730-5735.
- [12] Daurelio, G., G. Chita, and M. Cinquepalmi. 1999. Laser Surface Cleaning, De-Rusting, De-Painting And De-Oxidizing. *Applied Physics A*. 69(1): 543-546.
- [13] Cottam, C. A., Emmony, D. C., Cuesta, A., and Bradley, R. H. 1998. XPS Monitoring Of The Removal Of An Aged Polymer Coating From A Metal Substrate By TEA-CO<sub>2</sub> Laser Ablation. *Journal of Materials Science*. 33(13): 3245-3249.
- [14] Chen, G. X., Kwee, T. J., Tan, K. P., Choo, Y. S., and Hong, M.H. 2010. Laser Cleaning Of Steel For Paint Removal. *Applied Physics A*. 101(2): 249-253.
- [15] Tsunemi, A., Hagiwara, K., Saito, N., Nagasaka, K., Miyamoto, Y., Suto, O., and Tashiro, H. 1996. Complete Removal Of Paint From Metal Surface By Ablation With A TEA CO<sub>2</sub> Laser. *Applied Physics A: Materials Science & Processing*. 63(5): 435-439.
- [16] Roberts, D. E. 2004. Pulsed Laser Coating Removal By Detachment And Ejection. *Applied Physics A*. 79(4-6): 1067-1070.
- [17] Li, L., *Lasers in Technology*, in Physical Methods, Instruments and Measurements, Y.M.T. David A. Bradley, Editor. 2010. *Encyclopedia of Life Support Systems (EOLSS)*: Oxford. 4: 148-202.
- [18] Shin, B., J. Oh, and H. Sohn. 2007. Theoretical And Experimental Investigations Into Laser Ablation Of Polyimide And Copper Films With 355-nm Nd:YVO<sub>4</sub> Laser. *Journal of Materials Processing Technology*. 187: 260-263.
- [19] Zulkifli, N., Suhaimi, F. M., Razab, M. K. A. A., M. S. Jaafar and Mokhtar. N. 2015. The Use of Nd:YAG Laser for Ablation of Dental Material. *2015 5<sup>th</sup> International Conference on Biomedical Engineering and Technology (ICBET 2015)*. IACSIT Press, Singapore: Seoul, South Korea. 81(8): 40-47.