I J C T A, 9(37) 2016, pp. 461-470

Performance Characteristic Analysis of ABB IRB 1410 Robot using Nano Paint

Thushar T[*] and S. Prabhu[**]

Abstract: This project which investigates the performance characteristics analysis of an ABB-IRB 1410 industrial robot for an automated painting process using nano paint with Taguchi Orthogonal array to optimize robot control factor. The nano paint was prepared through the ultrasonication process. The foremost objective of this experiment to identify the control parameters to which improve the quality of robot coating, measured regarding thickness variation. Using the statistical software Minitab to analyze the experimental data and explained how the control parameters affect the response and the level of significant factor considered. The graphical surface plot diagrams obtained from the experiment gives the idea of control factor effect in the through process. Paint booth was fabricated, and a special attachment for the spray gun and the substrate was arranged.

Index Terms: CNTs, MWCNTs, Taguchi Analysis, Image Analysis, Surface plots, Robot spray painting.

1. INTRODUCTION

Painting is a common process in automobile industries, manufacturing centers, home appliances and so on. The day by day it increasing productivity and their quality were expected from the customer side, where giving a new dimension to the field of the beauty of the products either in the way of its design or moreover an aesthetic power of the qualitative products. So this could be achieved in the era of the second century, but the current technical development and the scientific improvements in the field of painting application lead us to the most advanced way of spray painting using the factory made programmed robots with the ultimate power of shining and finishing. In the form of art, most of the customers were expected their needs in two way that are, the way it looks like and good finish. So this two were possible by the manipulation of the response variable that is thickness variation. If the products have a high surface quality, then it will be the one of versatile finishing product and that can be produced either the surface finish up to a micron level or a nano level.

Mathiazhagan et al. [1] studied the different types of coatings, various types of pigments used in paint formulation and a particular focus on the use of nanomaterials/fillers in coating application. The newly produced nano-sized particles and nanoscale system components have new properties, which are of importance for the development of new products and applications. Bhalamurugan and Prabhu [2] investigated the characteristics scrutiny of a robot ABB-IRB 1410 for an automated painting process with Taguchi Orthogonal Array and Grey Relational Method. The multi-response process is transformed into single objective and optimized using Grey Relational Analysis. This method established in this study combines both orthogonal array and gray relational analysis. Nalathambi et al. [3] reported the nano paints and the contribution of nano paints in the field of chemical engineering. In this, the nanotechnology helps to create the color which would act as the repellent for the many structures. Yan Cui et al. [4] established the particle size of polymers (100nm) measuring through the method of CENT. And make use of the nanometer polymer nanoemulsion as a film to form material development, average temperature self-crosslinking water dispersion, grinding of High-Performance Waterborne block type nanostructures paint for the exterior wall. Prabhu et al. [5] studied the Taguchi design of experiment techniques, demonstrated to be a

[*] M.Tech Robotics, Dept. of Mechanical Engineering, SRM University, Chennai, India. *Email: thusharkollam@gmail.com*
[**] Professor. Dept. of Mechanical Engineering, SRM University, Chennai, India. *Email: prabhume@yahoo.co.in*

dynamic tool for the development of neural networks which predict the surface roughness for the grinding process, where CNT mixed nanofluid is used as dielectric for machining AISI D3 Tool steel material. An empirical model for output parameters has been developed using regression analysis, and the results are correlated for with and without using CNT nanofluids. Keerthanaa et al. [6] developed a design mechanism and implemented Automatic Wall Painting Robot, which helps to achieve low-cost painting equipment. It offers the opportunity to decrease or eliminate human exposure to challenging and hazardous environments, which could solve most of the problems connected with critical when many activities happen at the same time. These factors motivate the advancement of an autonomous robotic painting system. Lindita Prendi et al. [7] investigated the effect of various factors like Film build and Dehydration on the solvent popping up when a clear coat applied over a waterborne base coat using Design of Experiments (DOE). The result depicts, the Coating quality regarding Popping alone affected by almost all factors considered, but not in an independent way. There is always a combination of the factors dependently varying the output results. Muzan et al. [8] utilized an industrial robot ABB IRB 1410 for painting applications by selecting a painting Spray gun was chosen as an end effector. The Robot was programmed to write alphabets in a suitably designed painting environment using robot studio and Solidworks. Shengrui and Ligang [9] established the paint deposition rate model according to with actual operating condition. Then, the paint deposition rate model is implemented by using the Bayesian normalization algorithm and genetic algorithm. SahirArikana and Tuna [10] Balkan developed a method and a computer program for the modeling of spray painting process, and the simulation of robotic spray painting, then off-line programming of industrial robots and paint thickness measurement for coating of arched faces. The computer program empowers the user to resolve the painting strategies, parameters, and paths. Pill Johan et al. [11] presented the experimental results of a new spray paint algorithm and confirmed this by implementing the algorithm on an ABB robot and found that the joint torques required to chase the trajectory are substantially lower than for the conventional approach. Peter Hertling et al. [12].reported the automatic generation of the center tool paths for the robot engaged in spray painting of arbitrary surfaces. The first phase consists of the proposed mathematical model for the paint flux field within the spray cone. Javad Jassbi et al. [13] studied the paint quality to reduce the defects using neural network techniques in auto industry production lines. The practical inputs factors in spray paint process identified for each thin layer on the sample plate. Two neural network models were constructed and with the application of statistical method (regression) to predict paint thickness. Atkar et al. [14] developed a procedure for automated trajectory generation for robotic spray painting applications and said the relationship between the spray gun path and the deposition uniformity, cycle time, and paint waste as the output properties by decomposes the coverage trajectory generation problem into three subproblems: selection of the start curve, choice of the speed profiles along each pass, and selection of the spacing between the passes.

In the current study, a modest attempt has been made to the dispersion of multiwall carbon nanotubes (MWCNT) into standard spray paint, and painting is carried out on CRCA steel surface using L9 orthogonal Taguchi design of experimental techniques. The source of the carbon nanotube is from the United Nanotech Pvt Ltd Bengaluru. The multi-walled carbon nanotube used in this study possess an excellent purity with 98%.

2. COATING

The coating is covering, which can be applied to the outer face of an object, usually referred to as the substrate. The purpose of the coating might be decorative or functional. The coating itself may be an all-over coating, completely covering the substrate, or it may only include parts of the substrate. The functional coating was usually applied to the protection surface from the features of the substrate, like adhesion, corrosion resistance, wettability and wear resistance. Different ways and types are used to coat the substrate, like organic, inorganic, metallic, nonmetallic, electroplating, electrolysis, etc.

A. Nano coating

Nano coatings are generally in micron sized inorganic fillers/particles which will have the nanopowder consists 40-60 nm with appropriate fillers of nanoparticle includes ZrO_2, AlOOH, TiO_2, and SiO_2. The nanoparticle will possess the homogeneous distribution that will provide more reliability and provide the resistance structure from the scratching. The nanoparticle has the alumina substances which will protect them from the ultraviolet radiations. Coatings may usually be applied in a multi-layered manner that is composed of primer and topcoat.

B. Properties of Carbon Nanotube (CNTs)

The high surface area and good electrical conductivity of the CNT make unique in the field of future. The Multiwall CNTs have double bonding structure, and they are 100 times stronger than iron materials also the weight ratio 1/6th weight of metal. Due to the high strength to weight ratio, CNTs are used in the application of painting, manufacturing and research field. The power of carbon particles makes the CNTs more convenient to make products with higher strength and good finish. Young's modulus of CNT's is over 1 Tpa versus 70 Gpa for aluminum, 200 Gpa for steel and 700 Gpa for C-fiber. The electrical conductivity of CNT's is 109 A/cm^2 and copper is 106 A/cm^2. A thermal conductivity of CNT is 3,320 W/mK in the axial direction with small values in the radial direction.

The MWCNTs are an excellent choice of nanoscale additives and can improve mechanical properties as well as the electrical and thermal conductivity of the products which add them into one. They are typically mix in 2-5 wt% loading ratios.

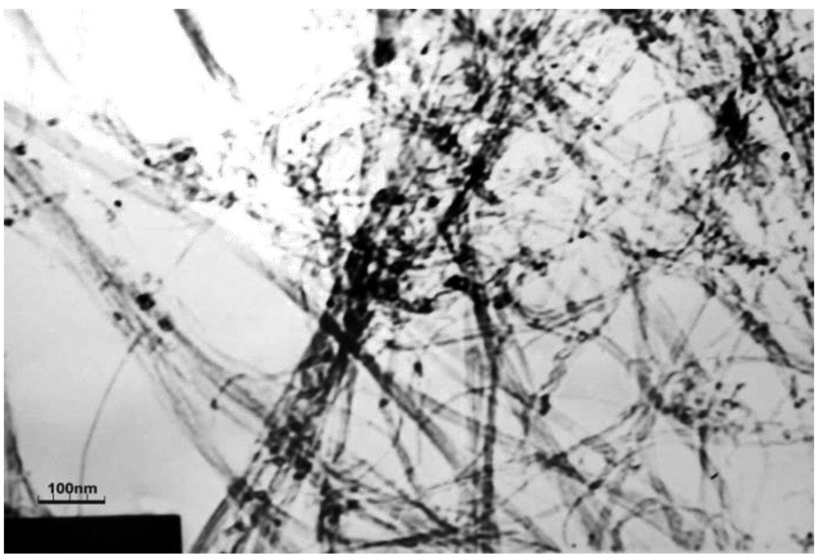

Figure 1: A TEM image of our MWNTs 98 wt%, <8 nm OD

Table 1
Specification of MWCNTS

Parameters	*Measure*
OD	10 – 20 nm
Length	10 – 30 μm
Purity	> 98 wt%
Ash	< 1.5 wt%
Specific Surface Area	> 233 m^2/g
Electrical Conductivity	> 10^{-2} S/cm

Masterbatcheshave 10, 15, or 20% Multi-walled carbon nanotubes loading. The structure of Multi-Walled Carbon Nanotubes are unique, they come in a composite array of fashion because every concentric nanotube has several structures, and there are a variety of sequential arrangements. The simplest sequence is when concentric layers are identical but different in diameter. These can have either proper layering or random layering. The structure of the carbon nanotubes influences its properties including electrical and thermal conductivity, density, and lattice structure.

3. ROBOT SPRAY PAINTING

The ABB IRB 1410 robot were used here for the real-time application of a coating. The robot provides consistent quality when maneuvering through detailed painting patterns. Compact, brushless, AC servo motors with absolute position encoders, and heavy-duty geared drive trains, servo drives for high speed, reliability in heavy-duty cycles are just some of the features of this robot. Available with six axes, the painting arm counterbalanced for smooth lead-through teaching.

4. EXPERIMENTAL SETUP

The experiments were carried out on ABB IRB 1410 robot with a specially designed end-effector with a spray gun. This is a Six-Axis articulated industrial manipulator. Each axis is servo-controlled with a resolver for feedback. The payload capacity of the manipulator is 5 kg, and the reach is 1.45 m. The robot is controlled through updated IRC5 controller. For this experiment, a gravity feed high volume low pressure (HVLP) spray gun was used which has an enhanced atomization capability for maximum transfer efficiency. The usual industrial automated robot painting method consists an automated HVLP spray gun including pressure pot and separate paint tank which acquire the initial cost, and the changing of paint type or color take much time and running cost. A spray gun is the main components of any paint finishing system. Here the same spray gun HVLP is used as the application of spray painting.

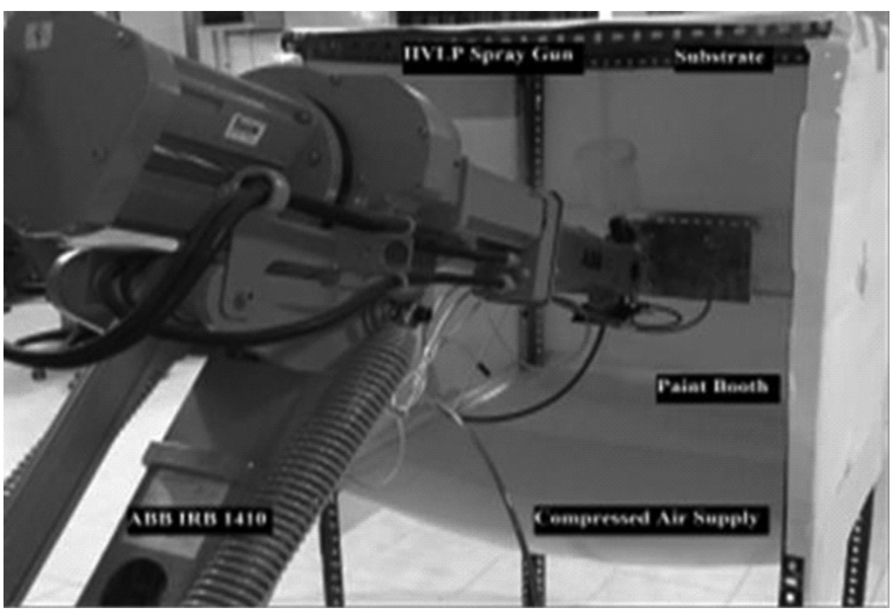

Figure 2: Experimental setup

For the consistency of pressure on the tip of the spray gun, a specially arranged end effector were fabricated and maintain a required pressure on the entire experiments. CRCA steel substrates with $250 \times 150 \times 1.5$ mm dimension taken as samples for painting. A painted substrate is are shown in Figure 8. To provide the increased adhesion properties, better coating in recessed areas, a layer of primer was first applied to the substrate as the pretreatment process.

A. High Volume Low Pressure (HVLP) Spray Gun

This is equal to a conventional spray gun using the compressor to supply air, but spray gun itself needs lower pressure (LP). And the higher volume (HV) of air is used to aerosolize and propel paint at lower pressure. The result is the higher proportion of paint to reach the target surface with reduced overspray, materials consumption, and air pollution.

The HVLP guns use 8 to 20 cfm (13.6–34 m^3/h), and also, an industrial compressor with least of 5 horsepower (3.7 kW) output is required. HVLP spray systems are used in the automotive, decorative, marine, architectural coating, furniture finishing, scenic painting and cosmetic industries. Same time the HVLP, spray guns also works at a lower pressure (LP), still they use a low volume (LV) of air when it compared to the conventional and HVLP equipment. And this is a further effort at increasing the transfer efficiency of spray guns while decreasing the amount of compressed air consumption, which is called LVLP spray guns.

5. METHODOLOGY

This project has an optimizing method, design of experiment using Taguchi method is that approach to the problem statement. For the optimization of the robot, the parameter was taken as distance, pressure and speed regarding selected response parameter thickness variation. According to the L9 orthogonal array technique, the parameters are designed and conducted an experiment with normal and nano paint-spray painting for nine different levels.

Further, the sample plate was tested for the quality checking of painting analyzed trough the microscopic image analysis tester.

A. Design of Experiments

In the present study, distance (mm), pressure (bar) and speed (mm/s), have been selected as design factors for robot coating while other parameters have been assumed to be constant over the experimental domain.

The dynamic range of design variables is taken as shown in Table 2 based on the limitations of the Robot specifications and other secondary devices. Orthogonal array testing is a black box testing technique which is a systematic, statistical way of software testing. And it is used when some inputs to the system are comparatively small but enormous to allow for exhaustive testing of possible input to the systems.

Table 2
Design Parameters

Run	*Design parameters*		
	Distance(mm)	*Pressure(bar)*	*Speed(mm/sec)*
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

It is particularly effective in obtaining errors associated with faulty logic within computer software systems. Orthogonal arrays can be implemented in user interface testing, regression testing, system testing, and performance testing. The permutations of factor levels including a single treatment are so chosen that their responses are uncorrelated, and hence, every treatment gives a unique piece of information. The net effect of organizing the experiment in such treatments is that the same information is gathered in the minimum number of experiments.

B. Result based on Taguchi Analysis

Taguchi design of experiments technique is used to carry out the modeling and analysis of' tile influence of process variables (design factors) on the response variables. The process variables (design factors) with their values on different levels are listed in Table 2. The selection of the values of the variables is limited by the capacity of the robot used in the coating process. Three levels within the operating range of the parameters have been selected for each of the factors. In the present investigation, L9 orthogonal array design has been considered for experimentation. Interaction effect of process parameters has been assumed negligible.

C. S/N Ratio

The S/N Ratio will be calculated based on the quality characteristics observed from the various quality testing. The objective function of this method is to improve the surface with good adhesion property of the paint, even thickness, and no micro cracks. So far the surface roughness and adhesion property, the larger the best S/N Ratio is considered. For thickness variations lesser is the better. The formula used for calculating the s/n ratio is given below,

S/N Ratio for smaller the better,

$$\frac{\text{S}}{\text{N}}\text{ Ratio }(\eta 2) = -10\log_{10}\frac{1}{n}\sum\nolimits_{i=1}^{n} y^2 \tag{1}$$

N = no of measurement y = no of responsive value

Table 3
Identifying Control Factors and Their Levels

Parameters	*Design factors*		
	Level 1	*Level 2*	*Level 3*
Distance (mm)	220	245	270
Pressure (bar)	3	3.5	4
Speed (mm/sec)	80	100	120

For thickness variation, smaller the better is used,

The predicted thickness variation by S/N Ratio (η') using the optimal level of the robot coating parameters could be calculated from equation,

$$\eta' = \eta m + \sum_{i=1}^{p}(\eta i - \eta m) \tag{2}$$

Where ηm-Total mean of S/N Ratio, ηi-Mean of S/N Ratio at the optimum level and p is the number of main machining parameters that significantly affect the performance of the robot.

6. RESULT AND DISCUSSION

The response from the experiment was measured by testing of its thickness variation. The TV is measured using microscopic image analysis. Using statistical software tool Minitab 17, the statistical analysis were carried out on the data collected from the experiments conducted based on the Taguchi method. The optimized factor levels were found using the exhaustive search method with the mathematical model constructed in Minitab. From the comparison of both normal and nano coat, we can predict the advantage of CNT mixed coating.

Here the thickness variation for the coating with and without CNTs was tabulated in the above table 4 & 5. From the data itself, it's clear that the variation of thickness in nano coating is very much reduced from the normal coat. The reaction of nanoparticle in the nano coat was reduced its thickness considerably to the normal coat. So we can prove the application of nano coat in the coating field will make a drastic change in the quality of coat and also the performance of the coating.

Table 4
Thickness Variation for Normal Coating

Distance (mm)	*Pressure (Bar)*	*Speed (mm/sec)*	*TV without CNT(μm)*
220	3	80	7.68
220	3.5	100	4.73
220	4	120	2.79
245	3	100	2.1
245	3.5	120	1.74
245	4	80	2.74
270	3	120	1.53
270	3.5	80	1.86
270	4	100	1.64

Table 5
Thickness Variation for Nano Coating

Distance (mm)	*Pressure (Bar)*	*Speed (mm/sec)*	*TV with CNT (μm)*
220	3	80	3.21
220	3.5	100	2.62
220	4	120	1.53
245	3	100	1.79
245	3.5	120	1.65
245	4	80	1.93
270	3	120	0.89
270	3.5	80	1.49
270	4	100	1.47

The normal painting and the nano painting make a difference in the sense of the optimization of the robot with mathematical analysis and this comparing with the manual coating, so it's very much understood the variance of the coating thickness.

The thickness variation for the both manual and robot coating was compared through the image analysis from the microscopic view. The variation of the coating thickness respect to the three level of parameters are shown in Table 4 & 5.

The effect of multi-walled carbon nanotube for nano coating is clearly visible through the microscopic pictures of the two samples shown in Figure 3. The strong bonding effect of the carbon molecules makes the coating particle stronger, which reduces the porosity in considerably. The micrograph for the both normal and nano coating thickness variation shown in Figure 3 with a Figure 4 of the coating after all methods. Thickness variation with respect to distance, pressure and speed is shown in Table 4 for the normal coating and the table 5 for the nano coating.

The thickness variation with the nano-thickness variation was tabulated in above table with the parameter and levels. From the two tables 4 & 5, the variation of thickness in the coat with both normal and nano have a change because of the strong molecular attraction of the nanoparticle the atoms combines them into place very closely packed more than a micro level normal coating. The both way of coating thickness and its control parameter are plotted on a surface graph using Minitab.

The nano coating parameters also plotted and shown in the Figure 3 from the graphical result its clear that the critical properties of multi-walled carbon nanoparticle are more reactive.

A. Confirmation Test

The confirmation of the experiment is the final step in the iteration of the design of experiment process. The purpose of the confirmation experiment is to validate the conclusion pinched during the Taguchi analysis. This is directed by optimized level getting from the main lot of Taguchi analysis, and the optimum level is $A_3B_3C_3$.

Table 6
Confirmation Test

Source	*Initial design*	*Optimum design*	
		Best trial	*Confirmation*
Setting level	A1B1C1	A2B2C3	$A_3B_3C_3$
TV without CNT	7.68	1.74	1.80
TV with CNT	3.21	1.65	1.71

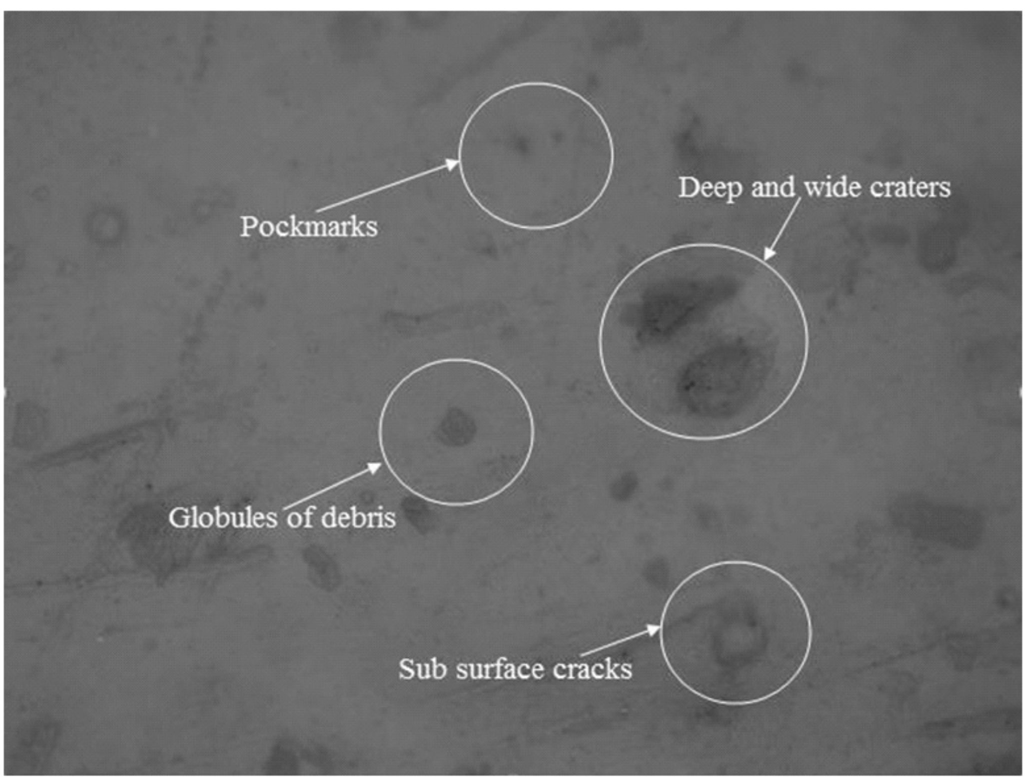

Figure 3: Micrograph of a nano coating

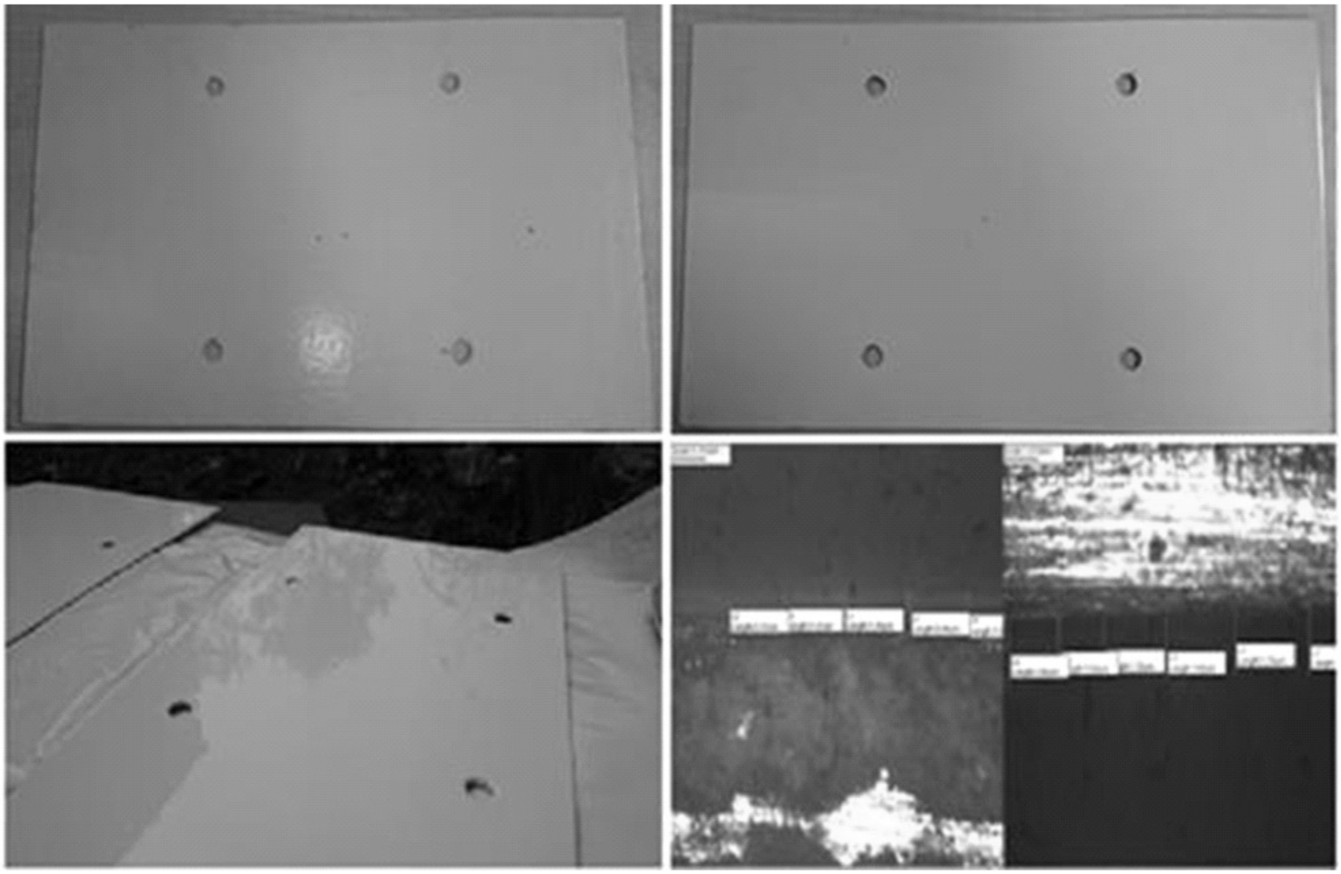

Figure 4: From the top left to right: (a) manual coating, (b) normal robot coating, (c) robot nano coating, (d) image analysis for thickness variation)

7. CONCLUSION

The design of experiment using Taguchi orthogonal array is a way to optimize the robot control parameter with an application nano paint.

- A model of the experiment have been successfully generated, and the various level of testing was carried out for the thickness variation.
- The optimized parameter from the design validated through the confirmation run.

Acknowledgement

The authors acknowledge to the Robotics Lab at SRM University for providing the facility to conduct the experiments.

References

1. Mathiazhagan, A. and Rani, Joseph. (2011) '*Nanotechnology-A new perspective in Organic coating*,' International Journal of Chemical Engineering and Applications, Vol. 2, No. 4, pp. 6-10.
2. Bhalamurugan, R. and Prabhu, S.(2014) '*Performance characteristics analysis of automated robot spray painting using Taguchi method and Grey relational analysis*', Arabian Journal of Science and Engineering, Vol. 5, No. 7-13, pp.
3. Nalathambi, V., and Suresh, G. (2014) '*Contribution of Nanotechnology in the Paints and Coatings*', SSRG International Journal of Chemical Engineering Research Vol. 1. No. 56-89, pp. 116-186.
4. Yan, Cui. And Jun, Xue. (2012) '*The Study of Friendly Nano-structured Wall Paint in the Water Dispersion Environment*', International journal on Optoelectronics and Microelectronics Vol. 12, No. 1 pp. 356-387.

5. Prabhu, S., Uma, M. and Vinayagam, B, K. (2014) '*Surface roughness prediction using Taguchi-fuzzy logic-neural network analysis for CNT nanofluids based grinding process*', Arabian Journal of Science and Engineering, Neural Computing and Applications, Vol. 25. No. 3-4, pp. 456-489.

6. Keerthanaa, P. and Jeevitha, K. (2013) '*Automatic wall painting robot*', International Journal of Innovative Research in Science, Engineering and Technology Vol. 2, No. 2, pp. 105-129.

7. Prendi. and Ali, A. (2008) '*Implementing DOE to study the effect of the Paint Application Parameters, Film Build, and Dehydration Temperature on solvent Pop*,' Journal of Coating Technology and Research, Vol. 5, No. 1, pp. 45-56.

8. Muzan, I.W. and Faisal, T. (2012) '*Implementation of the industrial robot for painting application*,' procedia Engineering, Vol. 41, No. 6 pp. 1329-1335.

9. Shengrui, C. And Yu, Ligang. (2011) '*Modelling and Prediction of Paint Film Deposition Rate for Robotic Spray Painting*,' International Journal on mechatronics and automation, Vol. 6, No. 8-9, pp. 445-450.

10. SahirArikan, M., and Balkan, T. (2001) '*Process simulation and paint thickness measurement for robotic spray painting*.' CIRP Annals-Manufacturing Technology, Vol. 50, No. 1, pp. 291-294.

11. Johan, J. and Pal Gunnar, J.T. (2011) '*Optimal paint gun orientation in spray paint application- Experimental results*,' IEEE Transactions on Automation Science and Engineering, Vol. 6, No. 2, pp. 438-442.

12. Hertling, P. and Hog, L. (1996) '*Task Curve Planning for Painting Robots. I. Process Modeling and Calibration*,' Robotics and Automation, No. 2, Vol. 12, pp. 324-330.

13. Jassbi, J. and Alborzi, M. (2011) '*Car Paint Thickness Control Using Artificial Neural Network and Regression Method*,' Journal of Industrial Engineering International, Vol. 14, No. 8, pp. b1-6.

14. Atkar, P. N. and Conner, D. C. (2005) '*Uniform Coverage of light surfaces embedded in R3 for Autobody Painting*,' Algorithmics Foundations of Robotics VI, Vol. 15, No. 2, pp. 27-42.