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EFFECT OF THE ELECTROPLATING DEPOSITION CONDITIONS ON THE WEAR RESISTANCE USING RESPONSE SURFACE METHODOLOGY (RSM)

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ABSTRACT

The present study represents an attempt to improve wet wear resistance through electroplating coating samples of low carbon steel. Minitab 18 program was used to precipitate a composite coating layer (Ni-SiC) because it is used in many industrial applications that require wear resistance. The samples were coated using different variables as inputs: SiC concentration, stirring velocity (r.p.m) and deposition time (min) for three levels using central composite design for design laboratory experiments. The factors of coating thickness (C.T), surface roughness (Ra) and Brinell hardness (HB) were adopted as outputs response and a complete analysis of variances (ANOVA) at constants significances levels of %5, was done to fully identify the most significant parameters. The surface response methodology (RSM) was used to give an optimal model with the best optimum properties such as Brinell hardness, surface roughness and coating thickness to improve wet wear resistance of low carbon steel samples. The results showed respectively that the SiC wt.% was the most effective on all the outputs response then deposition time (min) and stirring velocity (r.p.m).

Key words: Low Carbon Steel, Electroplating, Ni-SiC Composite Coating Layer, Wear Resistance, Response Surface Methodology (RSM), Central Composite Design (CCD).

تأثير ظروف ترسيب الطلاء الكهربائي على مقاومة البلى باستخدام منهجية الاستجابة السطحية

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الخلاصة

الدراسة الحالية تمثل محاولة لتحسين مقاومة البلى الرطب وذلك بطلاء عينات من الفولاذ واطئ الكربون بتقنية الطلاء الكهربائي. تم استخدام برنامج Minitabاصدار 18 لترسيب طبقة الطلاء المركبة (Ni – SiC)لكونها تدخل في العديد من التطبيقات الصناعية التي تتطلب مقاومة البلى. تم طلاء العينات باستخدام متغيرات مختلفة كمدخلات : هي تركيز كربيد السيلكون (SiC wt.%)وسرعة الخلط (r.p.m) وزمن الترسيب (t)لثلاث مستويات وذلك باستخدام التصميم المركب المركزي لتصميم التجارب المختبرية واعتمدت العوامل المتمثلة سمك طبقة الطلاء والخشونة السطحية وصلادة برينل كمخرجات عندها تم اعتماد التحليل الشامل للتباين (ANOVA)عند مستوى من الاهمية مقدار 5% لتحديد المعاملات الاكثر تأثيرا. تم استخدم منهجية الاستجابة السطحية (RSM)لإعطاء نموذج امثل بأفضل الخواص المثلى كالصلادة والخشونة السطحية وسمك طبقة الطلاء لتحسين مقاومة البلى الرطب لعينات من الفولاذ واطئ الكربون و بينت النتائج ان تركيز كربيد السيلكون هو المؤثر الاكبر على جميع المخرجات يليه زمن الترسيب و سرعة الخلط بالتعاقب

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INTRODUCTION

Corrosion is a natural phenomenon, which is unavoidable; instead it can be planner to a ratable extent. For this control to be proceed , certain checking are executed by putting the metal in the environment to which its usefulness is needed and accurate study of the metal is submit for a given time, depend on the monitoring and deduction drawn, the corrosion rate can be evaluate and a suitable measure can be made to control the average of corrosion. R.E. Lowental (2004).In the world today, low carbon steel is used in various engineering program for the creation of some motorcar components and sheets that are used in conduit, buildings, plants, viaduct and tin cans William et. al (2010). Low carbon steels are helped to show well mechanical characteristic and high aerial corrosion reluctant than traditional carbon steels Danijela (2011).The basic technology of surface coating used economically in this study to progress the rendering of components is called nickel electroplating. The layer of electroplating surface can remarkably increase the surface wear resistance, surface solution, corrosion resistance John (2001), D. Janke (2000) and Z.B. Wang et.al (2006). Composite coatings include the base metal such as (nickel, zinc ,copper, silver) or a metal alloy matrix containing a scattered stage of non-metallic (tiny) piece of oxides (e.g. Al_2O_3, TiO_2), or in the form of carbides (e.g. SiC, WC, TiC) Such coatings provide a clear improvement in the properties of the material about corrosion settlement, friction protection, wear resistance O. S. I. Fayomia et. al (2013).Response Surface Methodology (RSM): is a combination of mathematical and statistical techniques (a hybrid method), the main purpose is design experience , modeling and analyzing of input parameters influencing on output responses and improvement of these parameters by decrease the number of experiments needed to optimize the operation and give statistical deduction on the optimum conditions and also helps in limiting the relationship between the controllable input parameters and the progressing response roof. RSM is supposed an experimental strategy technique first described by Box and Wilson in 1951 for limiting the best conditions for multivariate systems V. Sridevi (2013), Demirel et. al (2012), Salam et. al (2014) and Q. Kong et. al (2004).In this study, the influence of the deposition coating conditions on the physical and mechanical properties using RSM method of low carbon steel samples is investigated. Also mathematical models for response surface methodology (RSM) is developed for the prediction of the surface roughness (Ra), coating thickness (C.T), Brinall hardness (HB) under various coating conditions.

EXPERIMENTAL METHODS

Alloy Substrate

In this study, the low carbon steel type (1018) was used as substrate. The nominal composition of low carbon steel in wt.% is shown in Table (1) ASTM international (2019).Whereas Table 2 illustrates Sepectrochemical analysis of low carbon steel alloy in wt. %.Low Carbon Steel samples have been cut with dimensions (20×15 × 5mm).These samples was cut from a sheet vertical to the rolling direction. All surfaces were grinding with silicon carbide papers in sequence of grit 180, 220, 320, 400, 600, 800, 1000, 1200, 1500, 2000, 2500, 3000 to obtain flat and scratch- free surface. These samples were polished using alumina solution with polishing cloth and cleaned with distilled water, Acetone degreasing and ultrasound cleaning for thirty minutes using ethanol as medium. After drying ,the samples are kept in a glass case.

ELECTROCHEMICAL CODEPOSITION COATING

The Steps Of The Work Of Electroplating

First Step:- Preparation Of Coating Solutions

These materials are added to distilled water to complete one liter. Initially it was added nickel sulfate to half the amount of water with heating to 55 C˚ and mixing until it dissolves. Secondly, the nickel chloride is dissolved by adding it to the previous solution. Thirdly, boric acid is also added to the previous solution to be completed one liter after which the solution is filtered to obtain of impurities and add silicon carbide (SiC) at the end of each stage after replacing the solution.

Second step:- Electroplating work

1.Cleaning the samples in alkaline after completing the grinding process with silicon carbide papers in sequence of grit 600 according to the American specifications meaning for 5 minutes.

2.Samples are washed with distilled water after alkaline solution and then immersed for 4 minutes in a dilute solution of HCl acid concentration before dilution 33% then washed with water 3 times and attached to the cathode wire and finally run the stirrer at the speed determined by the variables of each experiment and determine the current according to the voltage and sample area.

The electroplating coating process

It was tested by placing the solutions in plating bath and determining the positive electrodes and preferred plating samples materials. The bath was prepared with its current intensity and required voltages at the required temperature for coating process in order to avoid changes in concentricity of the achieved solution due to loss of evaporation as shown in Table 4 major processing parameters for a typical electrochemical deposition coating. Then add (2-5%) volume of solution within one day for the purpose of ensuring the continuity of the coating process on average. The time period for placement of the samples in plating bath and current density are determined by the thickness of the coating layer. After the required precipitation period process a certain thickness of the coating is carried out from the metal. Samples are extracted from the plating bath washed with distilled water, alcohol and dried with hot air. there after taking the weight measurement and then storing the samples in glass desiccator to get rid of the wetness which causes corrosion.

Brinell Hardness Test

This test was carried out at the Materials Eng. Labs./ University of Babylon. Brinell hardness device type (UH-250) of German origin has been tested to evaluate the hardness of composite coatings. This test consists of an indenter instrument which is a ball with a suitable holder that can carry a specific load on the surface of the test samples. As the indenter tool falls on to the sample surfaces with a (30 kgf) load for (10 Sec.), the steel ball diameter is (1mm). The hardness of all samples were recorded at an average of three hardness values at least taken from each coating surface of samples.

Coating Thickness Measurement

This test was carried out at the Materials Eng. Labs./ University of Babylon. Coating thickness gage was performed using a digital coating thickness gage type (TT 260) of Chinese origin, the accuracy of the device (10 μm). This test was done to determine the thickness of the coating layer on the surface samples by taking them in three places to provide average thickness.

Surface Roughness Test

This test was carried out at the Materials Eng. Labs./ University of Babylon. Surface roughness device type (TT 200) of Chinese origin has been tested to measure the surface

roughness of the sample by sensor that records the surface roughness of the sample and takes data directly from the device's screen and surface roughness measurements were taken in all three locations to provide an average surface roughness.

Wear Test

This test was carried out at the Materials Eng. Labs. / University of Babylon. The samples prepared in this study were weighted by baseline weight using a sensitive balance (±1) accuracy then it was put in the wear device type micro-tester (pin on disc) (TT 28021) of Spanish origin was adopted as shown in Figure (1)for different time periods. The samples were taken out and weighed then being replaced again in the device to complete the process. Wet wear test was performed for nine low carbon steel samples in the following conditions, the load is (5N), the rotational speed of the steel disc is (100 rpm), and four different time intervals (5,10,15 & 20 min) and sliding radius of 6mm, at room temperature (25ºC) in 3.5 wt.% NaCl solution.

Design of the experiments & mathematics models using RSM method

In this study experiments were conducted to evaluate the effects of the coating conditions: stirring time (t), SiC concentration (wt.%), stirring velocity (r.p.m) on the responses represented by surface roughness (Ra), coating thickness (C.T) and Brinall hardness (HB) for low carbon steel. Responses surfaces methodology's (RSM) was selected centrals composites designs (CCD) to design the present study experiments. In this study, three levels were taken for each input parameters effecting on the output parameters as shown in the Table 5.

RESULTS AND DISCUSSION

Experimental Results Of Coating Process

Central Composite Design (CCD) is used to design the current study experiments, which includes eight as corner points, six as axial points and six as central points, thus, a total of 20 trials in one blocks, were conducted for three factors input for two-level factorial. The results of these experiments were demonstrated clearly in Table 6.

Experimental Data Analysis Using RSM

The experiments work were designed using the RSM method. These experiments were conducted using Minitab statistical program,"Ver.18" to choose the right models. Regressions equations were developed using experimental data in Table 6 and it is plotted to discover the effect of precipitation conditions (input parameters) on parameters output properties responses. Finally, the results are analyzed statistically using the ANOVA approach. Table 7 illustrates the multiple regression coefficients associated with three responses (CT, HB and Ra) parameters. As for response prediction, the response parameters can be used, which are reliable tools for developing mathematical models. The Figures (2, 3and 4) illustrate the differences between the measured results and predicted based on the developed models. The equations (1, 2 & 3) were represented the final response models after backward elimination:

$$C.T = 34.4 + 0.794\,t - 1\,r.p.m + 6.16\,SiC\,wt.\% - 0.01680\,t^2 + 0.003200\,(r.p.m)^2 - 0.433\,(SiC\,wt.\%)^2 + 0.001550\,t \times r.p.m + 0.0657\,t \times SiC\,wt.\% + 0.00114\,r.p.m \times SiC\,wt.\% \quad (1)$$

$$HB = 146.2 + 1.846\,t - 0.408\,r.p.m - 5.88\,SiC\,wt.\% - 0.02164\,t^2 + 0.000638\,(r.p.m)^2 + 0.463\,(SiC\,wt.\%)^2 + 0.001813\,t \times r.p.m - 0.0162\,t \times SiC\,wt.\% + 0.01850\,r.p.m \times SiC\,wt.\% \quad (2)$$

$$Ra = -2.51 + 0.0317\,t - 0.029\,r.p.m + 1.088\,SiC\,wt.\% - 0.00093\,t^2 + 0.00007\,r.p.m^2 - 0.0798\,(SiC\,wt.\%)^2 + 0.000144\,t \times r.p.m + 0.00617\,t \times SiC\,wt.\%$$

$$+ 0.00077 \text{ r.p.m} \times \text{SiC wt.\%} \quad (3)$$

Parametric Analysis Of The Outputs Response

The effect of the input parameters [SiC wt.% , deposition time (t) and stirring velocity (r.p.m)] on the response of the output parameters [coating thickness (C.T), surface roughness (Ra) and Brinall hardness (HB)] were found out using the parametric analyses process. Three dimension surfaces plots were created using a technique RSM to know the changes in the outputs parameters and get relationships between the input and output parameters from these plots.

Parametric Analysis Of The Outputs Response

Figure(5)shows the main influence plot of three studied input parameters on the thickness of coating (C.T).The coating thickness (C.T) increased from (7.5 to 14.8 μm) with the time of deposition (t) of the factor increasing from 20 to 40 min. The reason for increasing the coating thickness with increasing deposition time is to give sufficient time for deposition of the largest amount of SiC particles on the nickel layer also the size of SiC particles is large, and it takes time for gravitate and adhesion to the nickel layer. But as time progresses, the coating layer becomes stable at 14.8 μm is due to several reasons:-

1. The concentration of SiC for the coating solution decreases.
2. The silicon carbide particles are large in size, and they leave pores between the SiC particles when deposited on the nickel layer, but when more time is available, this time it settles more particles on the nickel layer. These precipitates are deposited between the precipitated particles and fill all the pores that form by the initial precipitate which also reduces the porosity and roughness of the previous precipitate. The main effect of the parameter stirring velocity (r.p.m) shows the opposite slop. Increases in this parameter result in a decrease in the coating thickness (C.T) of about (12.5 to 11.5 μm) the amount of deficiency (1 μm) the reason for this decrease is that the high stirring velocity leads to a large movement of the coating solution and disruption in a silicon carbide particles movement , it is shifted from the center of the sample towards the edges. But sudden analyses show an increases in the stirring velocity with an increase coating thickness, which reaches up to (15.5 μm) at 200 r.p.m. The reason for the sudden increase in the thickness of the coating layer is due to for several reasons:-

1.The high stirring speed increases the coating thickness as it affects the random distribution or deposition of silicon carbide particles, thus increasing the porosity and roughness

2.The high stirring velocity causes the motion of the coating solution, after which it speeds up gravity and the ions are able to carry large silicon carbide particles and thus accelerates them randomly. the plot shows that high velocity creates great porosity to the fact that large silicon carbide particles are stabilize randomly compared to the little speed that provides particles to better arrange on the nickel layer and better adhere.

The analysis shows the significant effects of the concentration of SiC (wt.%) on a coating. Significant increases in the coating thickness from (5.5 to 18 μm) as the SiC concentration (wt.%) increases from (5 to 10 wt.%). The reason for this increase is that the more silicon carbide in the coating solution, the greater the ability of the ions to carry a greater amount of silicon carbide and deposited more on the nickel layer.

The combination plot shows in Figure(6) showings the effect of two different parameters r.p.m and stirring time (t) at (7.5wt.% SiC) on coating thickness (C.T) at a constant level (middle value).

Parametric Analysis of Brinell Hardness

Hardness is one of the most important property to be studied due to its vital effects on properties and the adhesion of the coating layer on the surface subtract, Figure(7) shows the main effect plot of each input parameter on Brinell hardness (HB).Increased

deposition time from (20 min to 40 min) leads to increase the Brinell hardness values from (136.5 to 148 HB). This is because the coating layer contains SiC particles is responsible for the high hardness of the coating layer, but with the progress deposition time, the Brinell hardness tends to be a very slight decrease from (148 to 147.5 HB), and the sudden decrease in hardness values is due to several reasons including:-

1.cylinder indenter is down from where the pores are due to the random deposition of large SiC particles in size.

2.presence of a movement of the coating solution for a long time period these conditions work to displace SiC particles to the end of the sample therefore the cylinder indenter records low values of hardness because these particles are responsible for the high hardness of the coating layer. The analysis shows an increase in the Brinell hardness values from (144.6 to 146 HB) with an increase in stirring velocity (r.p.m) from (100 to 150 r.p.m). With increasing velocity that lead to the movement of the coating solution ,this increase has the ability of ions to attract silicon carbide particles and sedimentation on a nickel layer that contains the silicon carbide particles that have a very high hardness therefor we note the increase of hardness value for nickel containing silicon carbide particles coating compared to the hardness value of nickel without the silicon carbide particles. Despite this increase in the hardness values is associated with a decrease from (146 to 143.3 HB) at 200 r.p.m. because of silicon carbide particles have high hardness value, they are the reason for the strengthening the nickel layer. Here we note a decrease in the hardness values due to the driftage of the SiC particles to the end of the sample. Finally, the plot analysis illustrate the main influence of a factor SiC (wt.%) that HB increase from (136.5 to 152.5 HB) with increase in SiC (wt.%). The higher the amount of silicon carbide causes the higher the hardness of the composite coating layer. This is due to the fact that the silicon carbide particles will have a very high hardness. The most influential factors on the hardness of the composite coatings are SiC concentration (wt.%), deposition time (t) after then stirring velocity (r.p.m). The combination plot illustrated in Figures(8 and 9) represents two different parameters with maintaining other process parameters at the central value, the effects of process parameters shows SiC wt.%, deposition time (t), stirring velocity (r.p.m) on Brinell hardness (HB).

Parametric Analysis Of Surface Roughness

Figure (10) shows the main effect plot of three studied input parameters on the surface roughness (Ra).The surface roughness (Ra) is increasing from (1.05 to 1.66 μm) with an increase of factor stirring velocity (r.p.m) from 100 min to 150 min .The reason behind the increase roughness for several reasons:-

1.The high speed leads to large precipitation of SiC particles on the nickel layer, but this high speed is not good because it precipitates SiC particles randomly.

2.The random deposition leads to increased porosity between the silicon carbide particles, thus increased roughness. Suddenly a slight decrease in surface roughness occurs from (1.66 to 1.5 μm) with increasing deposition time period, because SiC particles of large size lead to the formation of pores between particles when deposited on the nickel layer, but as the velocity increase, these pores are filled with the precipitated of new SiC particles.

The main effect of parameter deposition time (t) on the surface roughness. it shown large increases of the surface roughness from (0.59 to 1.68 μm) because the size of silicon carbide is large and there is enough time to deposition the largest amount of silicon carbide on the nickel layer and as a result of the large size of these particles, it causes the formation of pores and roughness with increasing time. The analysis shows the largest effects of SiC concentration (wt.%) on the surface roughness. it shown a large increase of the surface of roughness from (1.75 to 2.30 μm) with the increase of SiC concentration (wt.%) from (5 to 10 wt.%). Increased the size of SiC particles caused a significant increase in the values of roughness and the large of pores therefore greater roughness.

Figure (11) represents surface roughness (Ra) as a function of parameter r.p.m and parameter SiC wt.% at a constant level (middle value) of other parameters. It is observed that the Ra values be high when the parameters SiC wt.% and r.p.m are high. The combination effect of parameter r.p.m (stirring velocity) and parameter t (deposition time) shown in Figure (12), displays that the Ra values are higher when parameter r.p.m and parameter t are higher also.

Optimization of multiple response using the Desirability Function

Optimum manufacturing parameters have been determined using desirability function electroplating of mild steel for best of output parameters [C.T (μm), Ra (μm), HB]. In this study, it is desirable to has lower C.T and Ra, and the higher HB. Desirable function is represented in the mathematical formula as follows :-

Min: $F_1(x)$ = C.T (μm)

Min: $F_2(x)$ = Ra (μm)

Max: $F_3(x)$ = HB

Matrix as :- $5 \leq x_1 \leq 10$

$20 \leq x_2 \leq 60$

$100 \leq x_3 \leq 200$ (4)

Where, x_1, x_2 and x_3 represent input parameters of the process: SiC wt.%, deposition time (t) and stirring velocity (r.p.m). The desirability functions using an objective functions D(X). These functions translate a projected values into scale-frees values (di).The values of desirability differs from 0 to 1.0, a value close to 1.0 is preferred. If responses (Y) is at goals or target, then di =1. Responses externals the satisfactory regions is di=0, in this study Table 8 summarizes the key parameters set to finds global optimums settings. The Table 9 illustrates multiple response prediction for maximum of Brinell hardness (HB), minimum of both surface roughness (Ra μm) and the thickness of the coating (C.T μm).

Confirmation Test

Confirmation Testing: is a very important test that is used to verify the optimal conditions that arise from the surface response methodology. The Percentage error between the Predicted value and the experimental value of all response variables is calculated according to the formula (5) (Q. Kong et.al 2004)

$$\text{Percentage error (\%)} = \frac{\text{Experimental value} - \text{Predicted value}}{\text{Experimental value}} \times 100 \quad (5)$$

The Table 10 shows the errors rate within the ranges of (2 to 10) % Which were extracted by comparison of predicted models with laboratory experimental models of the optimal sample. Minitab program was used to develop predicted models can be successfully utilized to predict the optimal conditions for coating a laboratory model according to the optimum conditions (wt.% SiC, deposition time (t), stirring velocity (r.p.m)) for the response of the output parameters (Brinall hardness (HB), surface roughness (Ra), coating thickness (C.T) values within the ranges of the conducted experiments.

Scanning Electron Microscopy Analysis Of Optimum Sample

Scanning the electron microscope (SEM) investigate surface morphology and micro particles distribution of silicon carbide particles on low carbon steel substrate coated. Figurer (13) shows the morphology for surface composite coating layer Ni-SiC (optimum sample). Figure (14) shows the morphology for surface coating layer Ni without SiC particles sample. Figure(15) indicates the substrate surface without deposition of any coating layer. While Figure(16) represents EDS analysis results to illustrate the chemical composition for both coating layers Ni and Ni-SiC. In addition to Table(11) illuminate the mount of elements for EDS analysis of optimum sample.

Wet Wear Test

Three samples were subjected to wear test under load of 5N for different time periods (5,10,15 & 20) min accurate at room temperature with presence 3.5 NaCl solution as shown in Figure (17). The first sample is low carbon steel without any coating layer that appears in this test in continued weight loss. The Second sample is low carbon steel coated with Ni layer. It can be seen from this figure that a slight improvement in wear resistance has been obtained by the second sample in comparison with the first sample (without any coating layer), This is due to the difficult nature of the Ni layer, the hardness of the coating layer is 130 HB. The third sample (optimum sample) is low carbon steel coated with composite coating layer (Ni-SiC). The Figure (17) shows an improvement in wear resistance and it is noted little weight loss for coated layer compared with two previous samples. The reason of that, the presence of the SiC micro particles within nickel layer and the ceramic particles (SiC) is very hard resisting wear and also the composite coating layer have high hardness value is 160 HB.

CONCLUSIONS

According to these results of this study, the following can be concluded:-

1.The SiC concentration (wt.%) has a greater effect on the physical and mechanical properties (coating thickness (C.T), surface roughness (Ra) and Brinell hardness (HB)) of low carbon steel samples, followed by deposition time (min) and stirring velocity (r.p.m).

2.The samples coated with the coating layer reinforced with SiC particles gave the lowest wear rate compared with the base sample, nickel-coated samples without SiC particles.

3.The optimal settings of process parameters that can be used in coating process of responses surfaces methodology analysis results are: SiC concentration (5wt.% SiC), deposition time (59.1919 min), stirring velocity (100 r.p.m) to get maximum of Brinall hardness (142.395 HB), low surface roughness (0.3930 μm) and low coating thickness (3.7530 μm).

4.The confirmation test has verified that, the confirmation slop analysis that gave mathematical models for predicting response parameters with error ratios within panels of (2–10) % therefore, advanced predicted equations can be used successfully to predict surface hardness (Ra) ,coating thickness and Brinall hardness (HB) values for any groups of the deposition time (t), stirring velocity (r.p.m), SiC wt.% within the range of the experiments conducted.

Table **1**: Chemical composition of low carbon steel in wt.% according to ASTM **(2019)**

Metal	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Cu	Fe
Wt.%	<0.14-<0.20	0.166	0.60-0.90	≤0.040	≤0.050	-	<0.002	-	-	-	Bal.

Table 2: Sepectrochemical analysis of low carbon steel in wt.%

Metal	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Cu	Fe
Wt.%	0.13	0.16	0.56	0.013	0.004	0.0084	<0.002	0.020	0.032	0.012	Bal.

Table 3: Materials used to obtain coating solutions

Material	**Amount wt.%**	Supplier	Purity %
Nickel sulfate aqueous	300 g/l	BDH	99
Nickel chloride aqueous	40 g/l	BDH	99.9
Boric acid	20 g/l	Fluka	99.77

Table 4: Major processing parameters for a typical electrochemical deposition coating.

Plating Bath	**Nickel Sulfamate**
SiC particles size	23 μm
Temp.	42 C°
PH	4.0 – 4.1
Current Density	1.4 A/cm²
Voltage	2 V

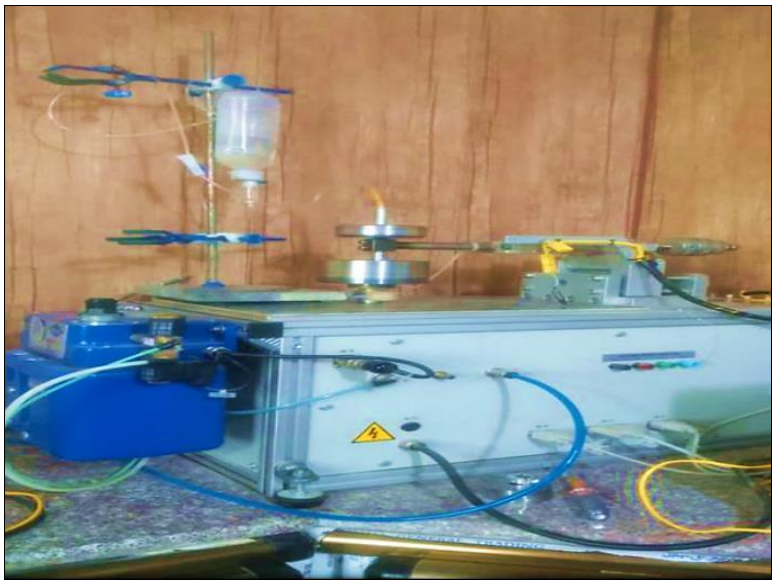

Fig. (1): Wear test device

Table 5: Input process parameters and their levels.

Actual-Factors	**Parameters**	**Units**	**Actuals levels**		
T	Deposition time	min.	20	40	60
r.p.m	Stirring velocity	rev./min	100	150	200
wt.% SiC	SiC Concentration	gram	5g	7.5g	10g

Table 6: Experimental data for input and output Parameters.

No. experiment	Deposition conditions (input parameters)			output parameters		
	Deposition time (min)	Stirring velocity(r.p.m)	Concentration SiC(wt.%)	Brinall hardness(HB)	Surface roughness(Ra)	Coating thickness(C.T)
1	40	150	5.0	144	0.555	3.760
2	60	200	10.0	160	3.038	27.633
3	40	150	7.5	148	2.025	12.40
4	60	100	5.0	141	0.164	4.500
5	20	200	10.0	148	1.490	9.400
6	60	150	7.5	146	1.480	9.500
7	40	150	7.5	149	1.950	12.27
8	60	200	5.0	142	1.248	9.400
9	40	150	10.0	156	1.413	21.233
10	40	150	7.5	150	1.901	12.400
11	40	150	7.5	151	2.011	12.300
12	20	100	10.0	145	0.594	10.133
13	40	200	7.5	148	1.680	26.100
14	60	100	10.0	154	2.356	21.533
15	20	100	5.0	133	0.425	5.600
16	40	100	7.5	150	1.666	20.300
17	40	150	7.5	149	2.100	12.060
18	40	150	7.5	148	1.980	12.700
19	20	150	7.5	136	0.735	7.460
20	20	200	5.0	127	0.146	4.930

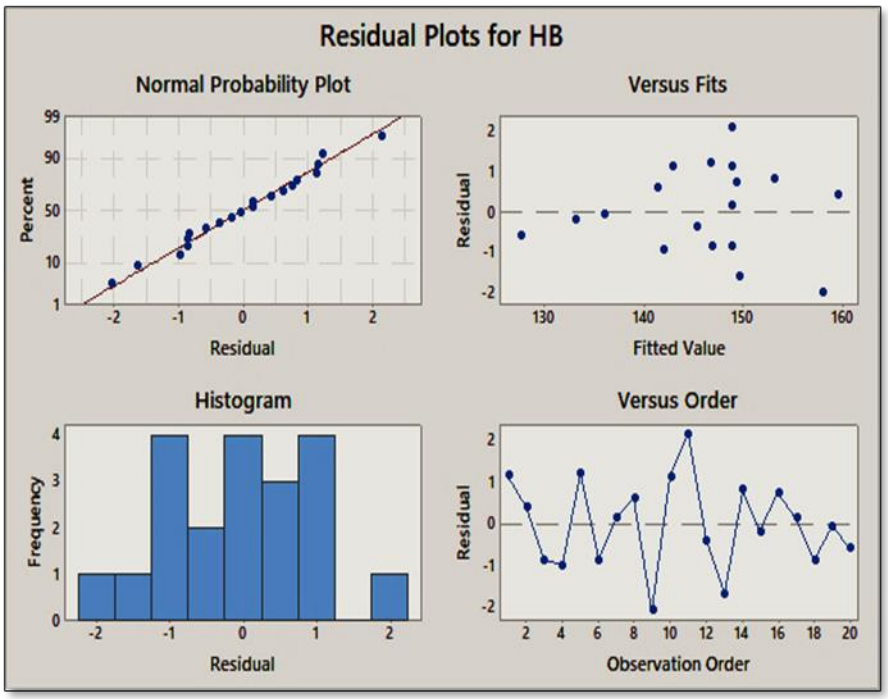

Fig. (2): Scatter Plot Diagram of HB.

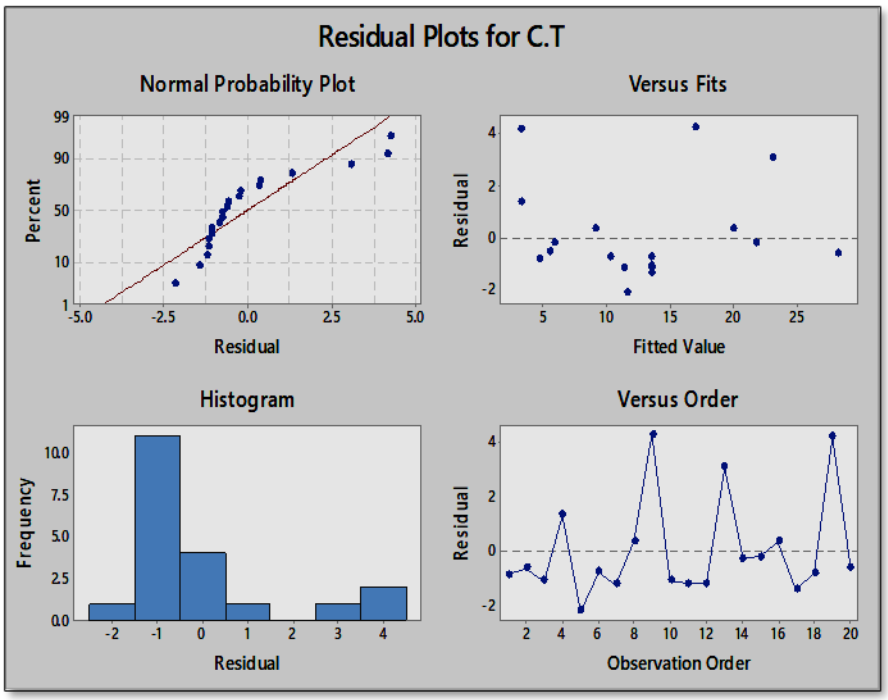

Fig. (3): Scatter Plot Diagram of Ra.

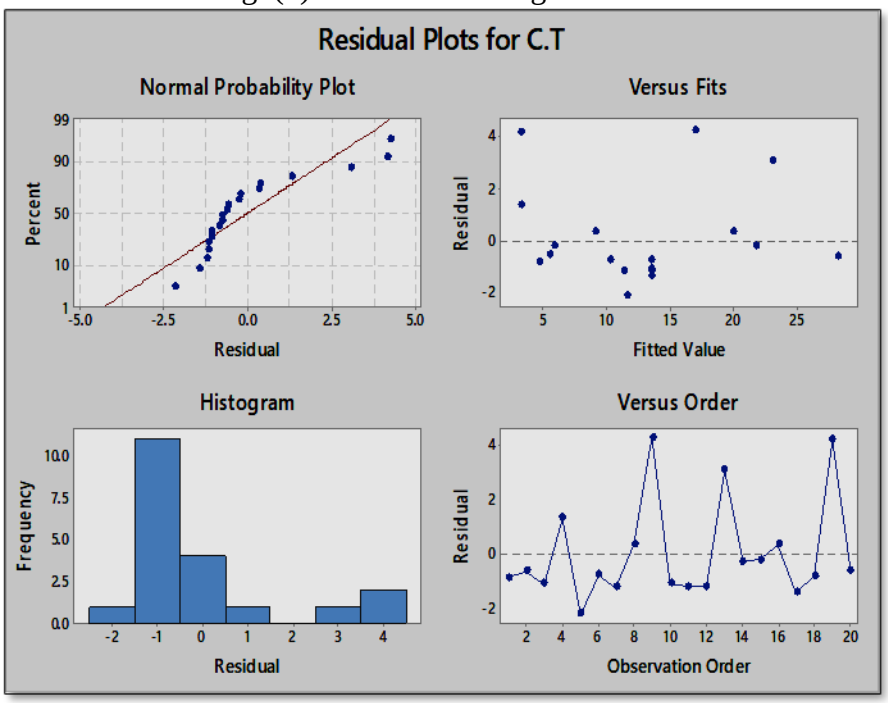

Fig. (4): Scatter Plot Diagram of C.T

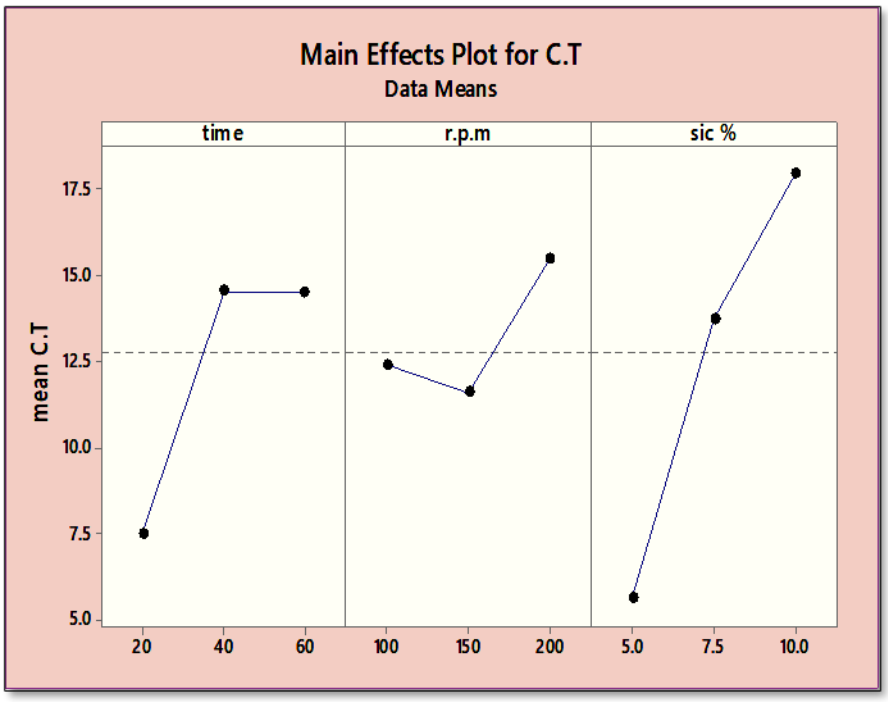

Fig.(5): Main effect plot for means of the coating thickness.

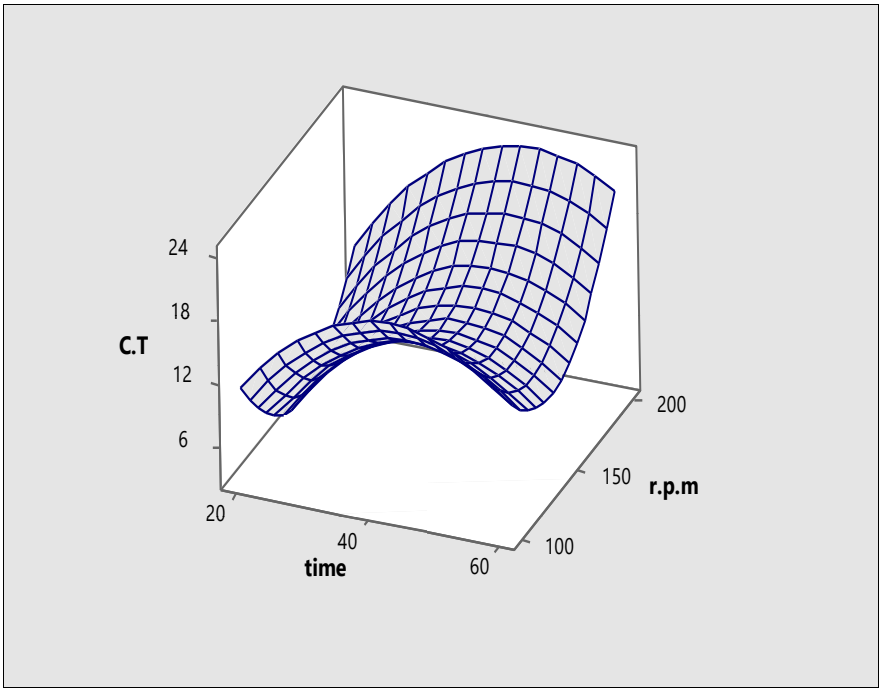

Fig. (6): Response surface plot of the coating thickness versus time (t) and stirring velocity (r.p.m)

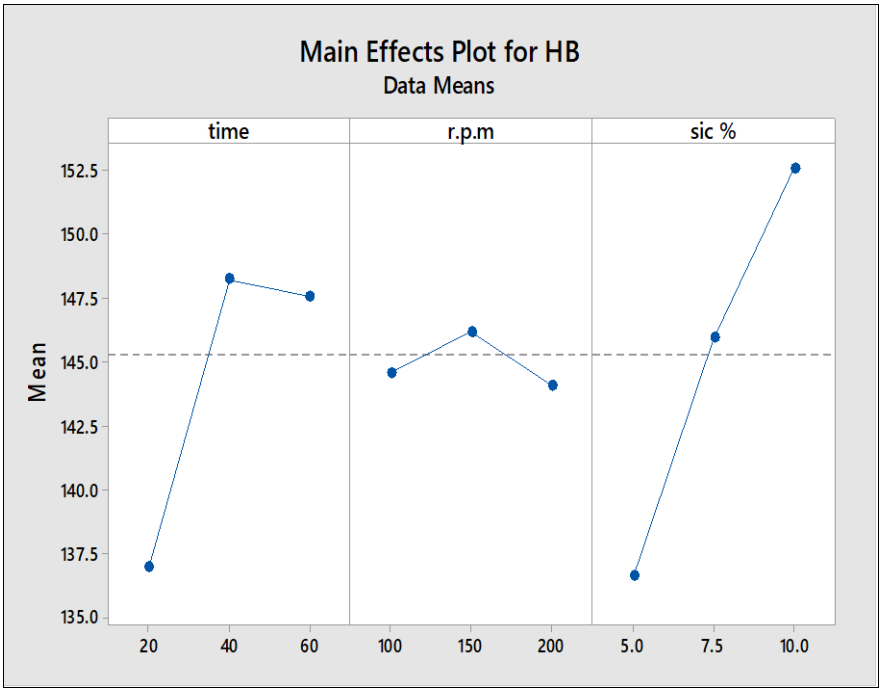

Fig. (7): Main Effect Plot for Means of HB.

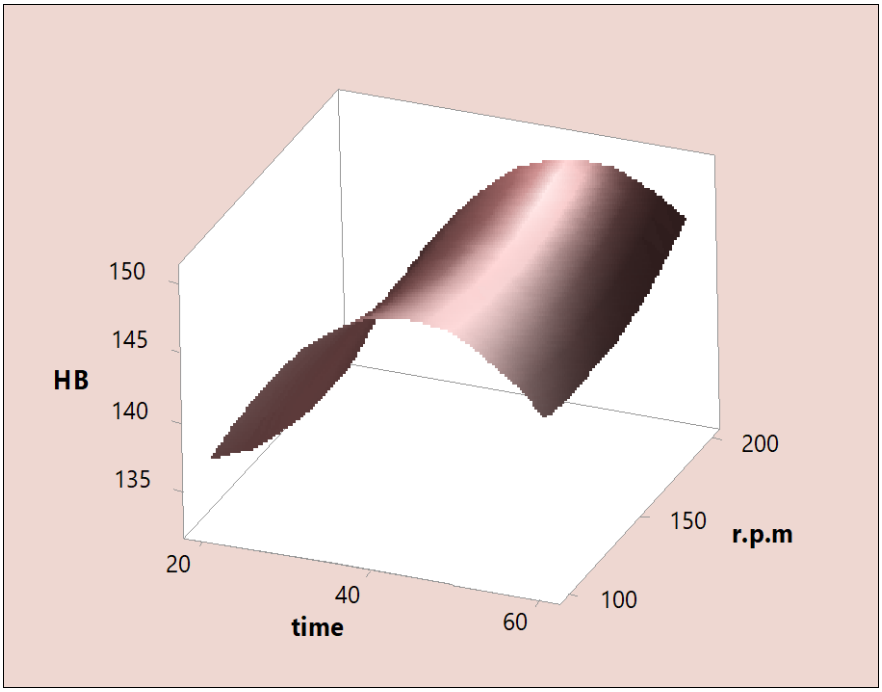

Fig. (8): Response surface plot of HB versus deposition time (t) and stirring velocity (r.p.m).

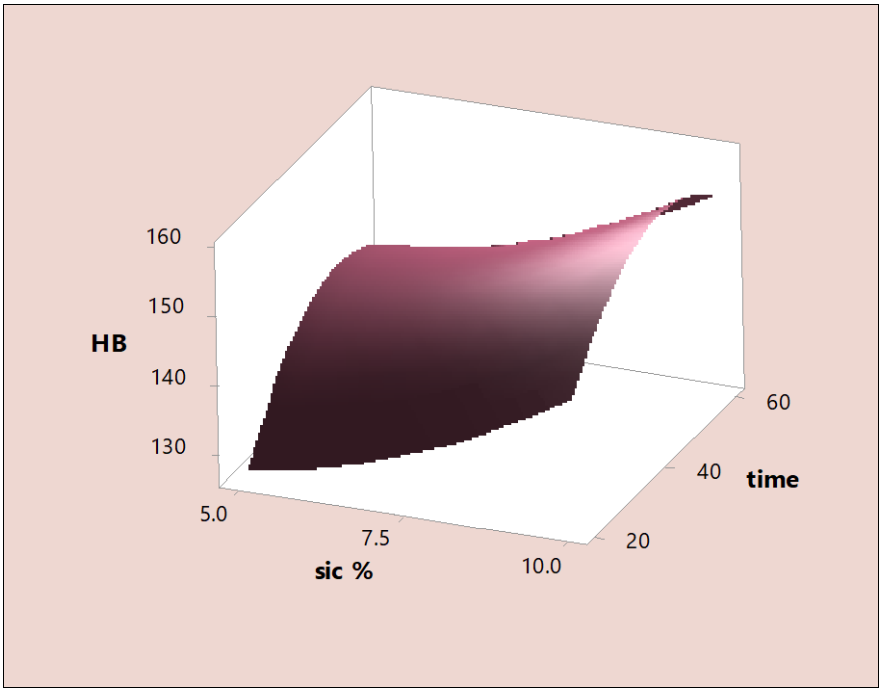

Fig. (9): Response surface plot of HB versus SiC wt. % and deposition time (t).

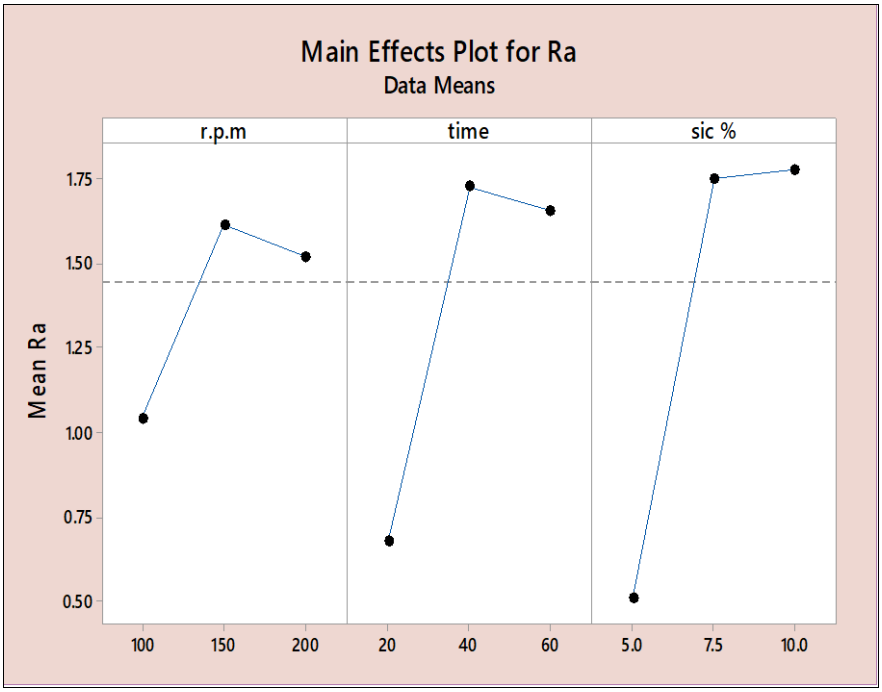

Fig. (10): Main Effect Plot for Means of Ra.

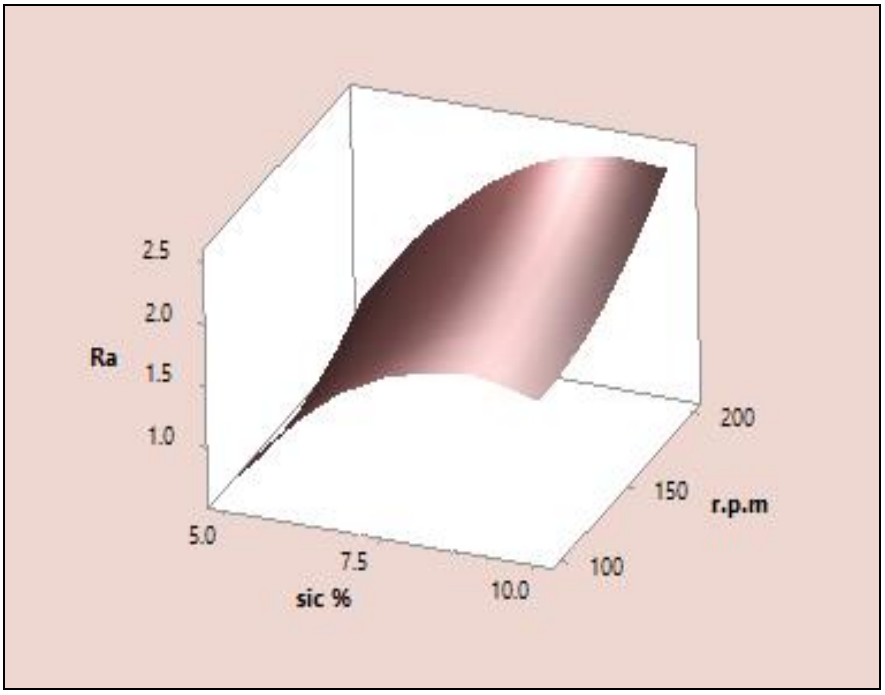

Fig. (11): Response surface plot of Ra versus SiC wt. % and stirring velocity.

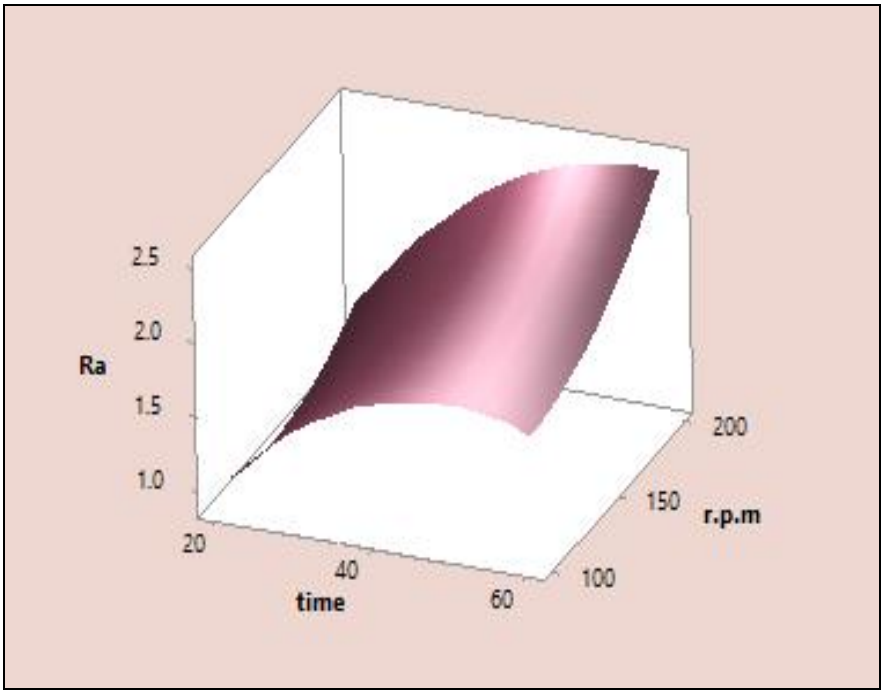

Fig. (12): Response surface plot of Ra versus deposition time (t) and stirring velocity.

Table 8: Summarizes the key parameters set to find Global optimum settings

Response	Goal	Target	Upper	Lower
HB .(ksp)	Max.	160	160	127
Ra (μm)	Min.	0.1460	3.038	0.1460
CT (μm)	Min.	3.7600	27.633	3.7600

Table 9: Multiple response prediction

Variables	Deposition time (min)	Stirring velocity(r.p.m)	SiC concentration (wt.%)
Setting	59.1919	100	5

Table 10: Confirmation results and percentage errors

Response	HB		Ra		C.T	
	Exp.	Pred.	Exp.	Pred.	Exp.	Pred.
	140	142.395	0.420	0.3930	4.153	3.7530
Error %	2		6		10	

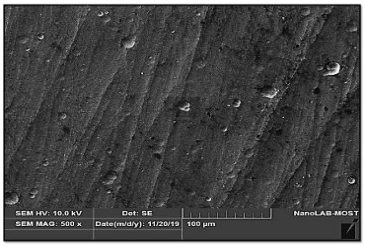

Fig. (13): SEM-Image Morphology for surface of the optimum sample (Ni-SiC).

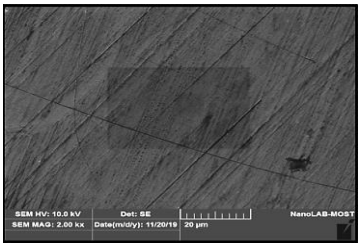

Fig. (14): SEM-Image Morphology for surface coating layer Ni only sample

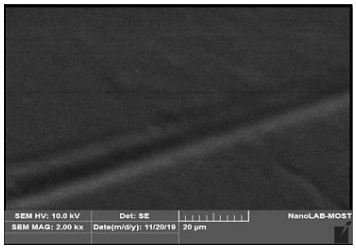

Fig. (15): SEM-Images Morphology of uncoated sample

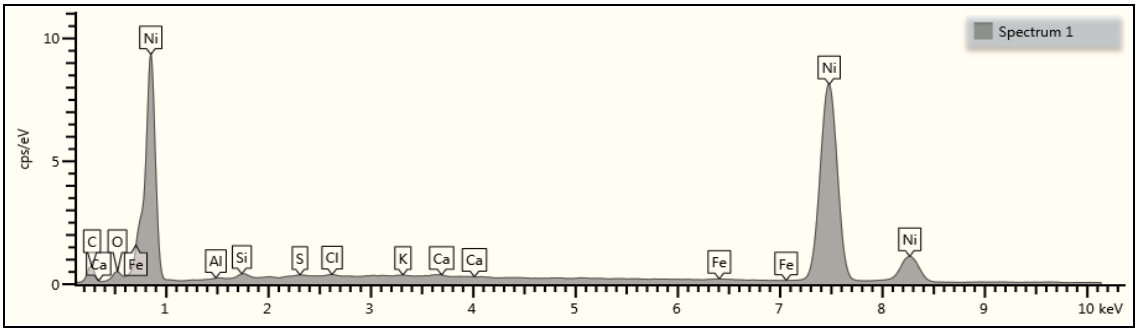

Fig. (16): EDS analysis of optimum sample (5wt.% SiC, 100 r.p.m, 60 min).

Table 11: Amount of elements for EDS analysis of optimum sample.

Element	C	O	Al	Si	S	Cl	K	Ga	Fe	Ni	Total
Wt.%	9.40	1.24	0.14	0.48	0.14	0.17	0.14	0.11	0.17	88.02	100
Wt.% sigma	1.59	0.16	0.09	0.09	0.07	0.07	0.07	0.08	0.10	1.57	

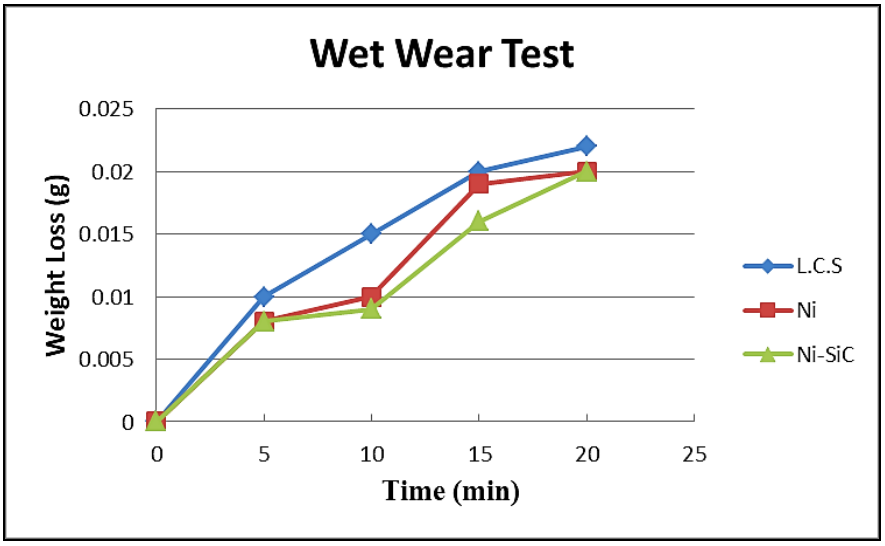

Fig.(17): Effect of time on weight loss during wet wear test of samples at conditions (load (5N), speed (100 r.p.m))

REFERENCES

ASTM international 2019.

R.E. Lowental, "Control of Corrosion and Aggression in Drinking Water Systems", Water Science and Technology, Vol.49, Iss.2,pp.9-18, 2004.

Danijela A. Skobir, "High-Strength Low-Alloy (HSLA) Steels", Institute of Metals and Technology, Lepi pot 11, 1000 Ljubljana, Slovenia, ISSN 1580-2949, MTAEC9, 45 (4) 295, 2011.

D. Janke, et al., "Scrap-Based Steel Production And Recycling Of Steel", Institute of Iron and Steel Technology, Freiberg University of Mining and Technology, Mater Tehnol. 34(6)387, ISSN 1580-2949, 2000.

Demirel M, Kayan B. "Application of response surface methodology and central composite design for the optimization of textile dye degradation by wet air oxidation". International Journal of Industrial Chemistry.;3(24):1–10, 2012.

John F. Papp, et al., "Recycling-Metals" , U.S. Geological Survey Minerals Yearbook, (703) 648-4974, 2001.

Mechanical Engineering, Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China Surface & Coatings Technology 201, 2006, 2796–2801.

O. S. I. Fayomia, M. abdulwahab and A. P. I. Popoola "Properties Evaluation of Ternary Surfactant-Induct Zn-Ni-Al_2O_3 Films on Mild Steel by Electrolytic Chemical Deposition", Journal of Ovonic Research , No. 5, Vol. 9, 2013 .

Q. Kong, G.Q., Q. H. Chen, F. Chen, "Optimization of medium composition for cultivating clostridium butyricum with response surface methodology", J. Food Sci. 69: M163-M168, 2004

Salam KK, Arinkoola AO, Oke EO, Adeleye JO. "Optimization of Operating Parameters Using Response Surface Methodology for Paraffin-Wax Deposition in Pipeline". Petroleum & Coal.;56 (1):19-28, 2014 .

V. Sridevi "Biosorption of methylene blue by spent biomass of aspergillus terreus using response surface methodology", International Journal of Pharm and Bio Sciences , Issue 4, Vol. 3, pp.317-325, 2013.

William D. Callister, Jr , David G. Rethwisch "Materials Science and Engineering" - 8th ed., (ISBN 978-0-47041997-7) , Printed in the United States of America, USA, 2010.

Z.B. Wang, J.Lu, K.Lu., "Wear and corrosion properties of a low carbon steel processed by means of SMAT followed by lower temperature chromizing treatment", Department of