Mechanical Characterization of Zinc Coated Mild Steel Plate Using L27 Taguchi Technique

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Abstract - *Metal coating is used to form a layer which changes the surface properties of the workpiece to those of metal being applied. Among all higher than techniques, electro deposition could be versatile vasoconstrictor method that is employed to fabricate purposeful coatings. In this study Zinc coating was prepared from the sulphate bath with the aid of electro deposition process over the mild steel substrate. The process parameters are the voltage, speed, and time of deposition were considered for the experiment work. The three levels of design of Taguchi method L27 orthogonal array have been chosen for the experiment design. The micro hardness test for the coated specimen was done under pay load of 300 gram force. The surface morphology of the coating was investigated under SEM and the influence of parameters on the micro hardness of zinc was investigated by S/N ratio (signal to noise ratio) and mean effect studies via Taguchi method and they were ranked by order. The voltage and the time of deposition has influence on the micro hardness of the Zinc coating and in order to confirm the ranks the ANOVA test was carried out which confirmed that the ranking were correct. The hardness value has increased from 86 HVN to 148.60 HVN and there are no flaws or cracks detected on the surface. The zinc coated mild steel plate is used in Transportation, piping, construction projects, etc.*

***Key Words*: Orthogonal Array, ANOVA, Electro deposition, S/N ratio, Micro hardness.**

1. INTRODUCTION

Electro deposition is a method of coating or depositing on a cathode by immersing each anode and cathode into an electrolytic bathtub connected to an external power source. Among all higher than techniques, electro deposition could be a versatile vasoconstrictor method that is employed to fabricate purposeful coatings in an exceedingly single step while not going any secondary treatment.
Various metals or alloys are electroplated with completely different properties are earned. Electroplating is well-suited with integrated circuits production because it is low temperature and high rate deposition technique [1].

Zinc metal incorporates a kind of uniqueness that makes it perfect to be utilized as plating for safeguarding iron and steel stock from rust. Its great erosion obstruction in many situations represents its fruitful use as a defensive covering on a spread of stock. Deposition has been called a possible and price effective technique for manufacturing of skinny film coating.

A Senthil Kumar et al [2] they have achieved the zinc plating and contemplated the conduct of added substances like thiourea, sulphosalicylic corrosive and β-alanin in zinc sulphate arrangement. These added substances were utilized in various fixations and the impact of these focuses on current effectiveness, tossing power, cathodic polarization and erosion conduct in 3.5% NaCl arrangement was examined and the sort of deposition was appeared by the filtering electron magnifying lens (SEM examination).

S Shivakumara et al [3] Their research work deals with the electroplating of Zn on steel using chloride bath and additives like 3,4,5-trimethoxy benzaldehyde and chitosan, which effects the plating depending on the pH, current density and temperature of the bath. Further good corrosion resistant properties where obtained the results between the cathode potential and current densities were plotted.

K.O. Nayana et al [4] have carried out the bright electroplating of zinc and studied the control of synergistic communication of additives on coating properties. The bright coating was obtained using cetyltrimethyl ammonium bromide (CTAB) and condensation product of valine and veratraldehyde (VV). These additives help in the improvement of the zinc coating corrosion resistance, and hardness value.

Benu Chatterjee [5] has mentioned new non conventional methods of zinc plating and these process include composite coating method, compositionally modulated multilayer coating method, pulse plating technique, thermal spraying of zinc, water-based coatings of zinc powder and zinc-rich painting. These processes have influence on the properties like tribology behavior – wear resistance, micro hardness value, and improved corrosion resistance.

K. De Wit et al [6] They explored the properties of the Zn-Co electro plating on car steel sheet by fluctuating the current magnitude, pH, and electrolyte stream rate. The Cobalt substance changing from 0.2 to 7 wt% was effectively gotten. The control of these strategy parameters on the attributes of the covering may well be related with the hydroxide concealment system for a typical co-deposition. The morphology of the coatings was resolved utilizing SEM and XRD examination.

So in this study, the deposition mechanism of Zn in alkaline sulphate electrolytes was investigated using a L27 orthogonal array techniques, and influence of parameters like voltage, speed, and time was studied which will be a guidance for zinc electroplating for corrosion resistance of steel substrate. In this work, three principal process parameters of electro deposition process such as voltage, time of deposition and speed of magnetic stirrer are considered on micro hardness of Zn thin film coatings. The Taguchi method of L27 orthogonal array has been employed to study the influences of process parameters on micro hardness of Zn thin film coating. With these, Analysis of Variance (ANOVA) techniques has been applied to determine the significance of these parameters.

2. TAGUCHI APPROACH

The ideas of a really prospering, leading quality adviser in Japan, Dr. Taguchi have been adopted by several yankee firms in each producing and scientific circumstances. The experimental styles developed by Taguchi referred to as orthogonal arrays, square measure basically incomplete factorials.
Eloquent the quantity of parameters thus the amount of levels, the tasteful symmetrical exhibit is assigned all through these works we've a bowed to assume control three plating parameters with three levels. Upheld on the prime of parameters and levels, L27 symmetrical cluster of Taguchi approach was completed for test vogue. The objective of the current work is to expand the micro hardness of the metallic component thin film coatings interim the bigger is best module. The higher is best agent of S/N quantitative connection is encircled as:

$$S/N = -10 \log \left(1/n \sum_{i=1}^{n} \frac{1}{y_{ij}^{2}}\right) \quad (1)$$

Where n is treasuring impersonation of the test work and y speaks to the yield of analysis. Moreover to mean impacts systems and ANOVA will be implemented to see the impact of the strategy parameters on the execution trademark.

3. MATERIALS AND METHODS

Electro deposition experiment was conducted in 1500 ml beaker. The electrolyte used is the sulphate bath. The mild steel plate of 70mmx40mmx1mm is used as cathode and the area of deposition is taken as 40mmx40mm. The zinc plate is made anode, ¾ of these two plates is than dipped in the sulphate bath containing ($MgSO_4.7H_2O$) Magnesium sulphate 126.66 gm and Zinc sulphate ($ZnSO_4.7H_2O$) 42.33 gm along with 3ml of concentrated sulphuric acid (H_2SO_4).

The degreasing agent Acetone is used to clean the mild steel surface. The distance between the cathode and anode is kept constant. A voltage of 1, 1.5 and 2 was supplied for different interval of time, the magnetic stirrer of size 25mmx8mm is placed in the solution and the speed of the stirrer is varied and the deposition is obtained. The plating conditions taken for these experimental tests are given in table I. The experiments were performed based on the run orders of L27 orthogonal array pattern and twenty seven samples were prepared from the bath.

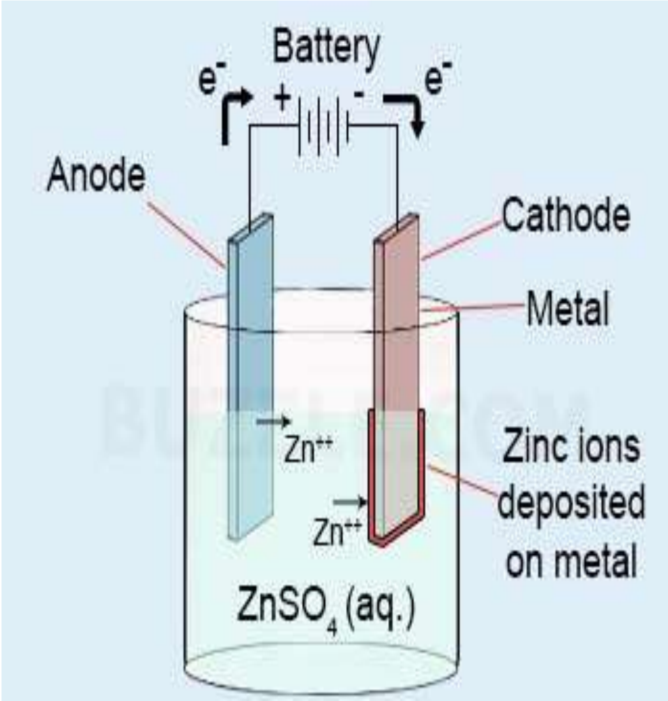

Fig-1: Schematic representation of zinc electroplating.

Table I- Process parameters and Levels

Sl.No.	Parameters	Levels		
		Level 1	Level 2	Level 3
A	Voltage-(V)	1	1.5	2
B	Stirrer Speed (RPM)	450	600	850
C	Time (Min)	10	15	20

4. RESULTS AND DISCUSSION

A. Micro Hardness Assessment

Table II- Micro hardness value of the experiment

Exp No	Control Parameters			Mass of deposit in mg	Micro Hardness H V
	V	S	T		
1	1	450	10	40	118.69
2	1	450	15	41	122.3
3	1	450	20	43	123.63
4	1	600	10	42	119.2

5	1	600	15	43	123.62
6	1	600	20	44	124.95
7	1	850	10	44	120.98
8	1	850	15	45	124.29
9	1	850	20	46	125.31
10	1.5	450	10	44	126.9
11	1.5	450	15	45	128.72
12	1.5	450	20	46	132.5
13	1.5	600	10	46	129.95
14	1.5	600	15	48	129.97
15	1.5	600	20	48	135.02
16	1.5	850	10	48	129.99
17	1.5	850	15	51	130.23
18	1.5	850	20	52	136.31
19	2	450	10	52	135
20	2	450	15	54	137.59
21	2	450	20	63	139.85
22	2	600	10	55	137.34
23	2	600	15	57	139.23
24	2	600	20	67	142.8
25	2	850	10	57	138.2
26	2	850	15	61	140.6
27	2	850	20	73	148.6

The micro hardness test was carried out on the Wilson's Vickers micro hardness tester, Wilson VH 1150 semi automated diamond indenter Vickers hardness tester load range 300gf to 50 kgf, the pay load of 300 gram force was applied on the coated specimen for 10 sec. Micro hardness of every sample was examined with three trials and also the average value was taken for final documentation.

B. Surface Morphology Assessment

The coated samples were organized for surface morphological examinations via metallographic procedures. The pattern of deposition of metallic element particles within the deposit was examined by scanning microscope at numerous magnifications. Before coating and after coating surface morphology for different specimens is observed and it was found that the coating of zinc on mild steel is uniform without any flaws or cracks.

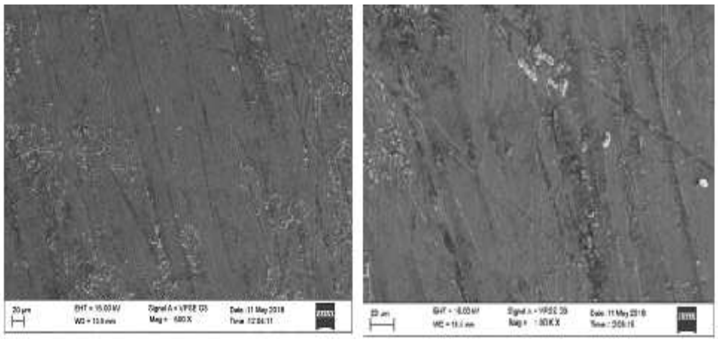

Fig-2: shows the surface morphology of the uncoated specimen under 500 X and 1.00 K X magnification.

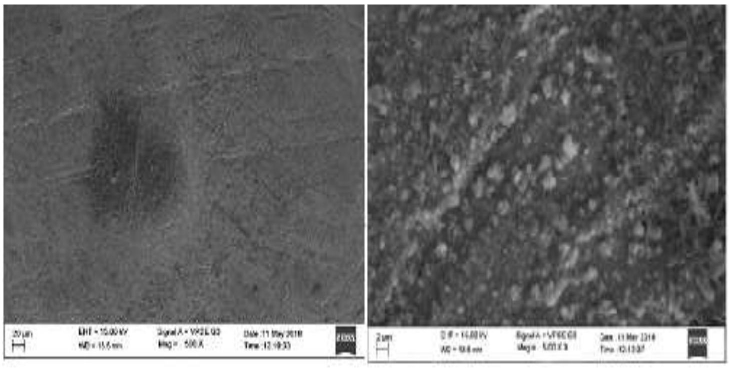

Fig-3: shows the surface morphology of the coated specimen no 2 under 500 X and 5.00 K X magnification having 13.5mm and area width 2 and 20µm.

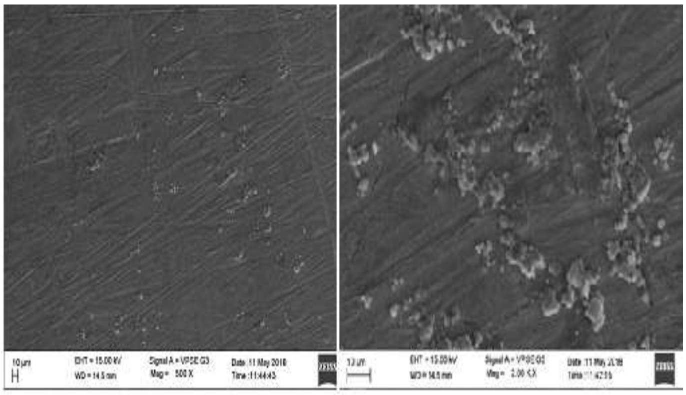

Fig-4: shows the surface morphology of the coated specimen no 12 under 500 X and 2.00 K X magnification having 14.5mm and area width 10 and 20µm.

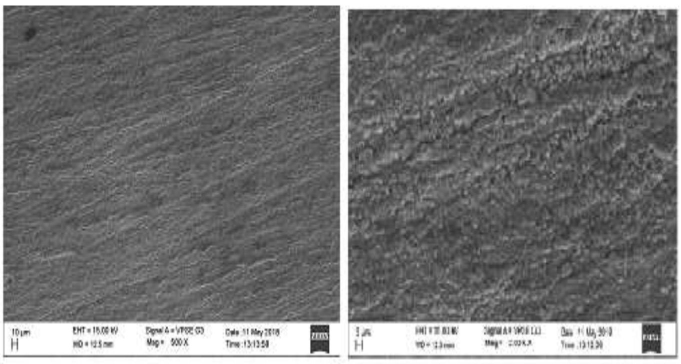

Fig-5: shows the surface morphology of the coated specimen no 17 under 500 X and 2.00 K X magnification having 12.5mm and area width 3 and 10µm.

C. Roughness Assessment

The surface roughness test for coated specimen was carried out on Tally Surf instrument the R_A, R_Y and R_Z values were noted down and then compared with theoretical calculated R_Y value. Table III shows the comparison of the surface roughness experimentally and theoretically. The theoretical maximum height R_Y is calculated by using the formula:

$$\mathbf{h} = \frac{\mathbf{V}}{\mathbf{a}} = \frac{\mathbf{w}}{\mathbf{a\,d}} \qquad (2)$$

Table III- Comparison of theoretical and experimented values of surface roughness.

SL.No	Tested Surface Roughness Value (µm)			Theoretical Maximum Height Value R_Y (µm)
	Avg Roughness	Maximum Height		
	R_A	R_Y	R_Z	
1	0.65	4.12	4.12	3.5
2	0.85	3.59	3.59	3.59
3	0.64	3.89	3.89	3.76
4	0.36	3.68	3.68	3.68
5	0.86	3.8	3.8	3.76
6	0.85	3.9	3.9	3.85
7	0.42	3.87	3.87	3.85
8	0.46	3.94	3.94	3.94
9	0.53	4.03	4.03	4.03
10	0.44	3.85	3.85	3.85
11	0.31	3.96	3.96	3.94
12	0.62	4.03	4.03	4.03
13	0.41	4.03	4.03	4.03
14	0.52	4.2	4.2	4.2
15	0.41	4.2	4.2	4.2
16	0.74	4.2	4.2	4.2
17	0.4	4.51	4.51	4.47
18	0.54	4.56	4.56	4.55
19	0.54	4.82	4.82	4.55
20	0.58	4.73	4.73	4.73
21	0.67	5.56	5.56	5.52
22	0.38	4.85	4.85	4.82
23	0.94	5.02	5.02	4.99
24	0.58	5.89	5.89	5.87
25	0.51	4.99	4.99	4.99
26	0.36	5.33	5.33	5.34
27	1.43	6.42	6.42	6.39

D. S/N Ratio Assessment

In Taguchi's outline technique the plan parameters factors that can be controlled by creators and commotion (factors that can't be controlled by architects, for example, ecological elements) are viewed as overwhelming on the item quality.

The Signal to Noise (S/N) proportion is utilized in this investigation which takes both the mean and the changeability of the test result into account. The S/N proportion relies upon the quality attributes of the procedure to be enhanced. Generally, there are 3 classifications of the execution attributes in the examination of the S/N proportion; that is, the lower the better, higher the better, and the ostensible the better.

The S/N proportion for every reaction is processed distinctively in view of the class of the execution attributes and subsequently paying little heed to the classification the bigger S/N proportion compares to a superior execution trademark. In the present investigation the coating mass and micro hardness are the higher the better execution qualities. When the majority of the S/N proportions have been processed for each kept running of a trial, Taguchi advocates a graphical way to deal with the information.

In the graphical methodology, the S/N proportions and normal reactions are plotted for each factor close by every one of its levels from the charts, higher the better the qualities were chosen and the verification tests were directed. This numerical hugeness of the variables can be accessed through the investigation of change (ANOVA).

A statistical ANOVA is performed to discover the installment of each factor for accomplishing the procedure end. Three process parameters considered for advancement of the examination are Voltage, Speed and Time.

In this study, the quality characteristic has larger-the-best formulation and therefore the equation for calculating S/N ratio is as follows:

$$\mathbf{S/N = -10 \log \left(1/n \sum_{i=1}^{n} \frac{1}{y_{ij}^{2}}\right)}$$

Where (y_{ij}) is the value of the micro hardness for the test in that trial and (n) is the number of tests in a trial, high signal-to-noise ratios are always preferred.

Table IV- Experiment response of Zinc thin coating

Exp No	Control Parameters			Mass of deposit in mg	Micro Hardness H V	S/N Ratio
	V	S	T			
1	1	450	10	40	118.69	41.48
2	1	450	15	41	122.3	41.74
3	1	450	20	43	123.63	41.84
4	1	600	10	42	119.2	41.52
5	1	600	15	43	123.62	41.84
6	1	600	20	44	124.95	41.93
7	1	850	10	44	120.98	41.65
8	1	850	15	45	124.29	41.84
9	1	850	20	46	125.31	41.95
10	1.5	450	10	44	126.9	42.06
11	1.5	450	15	45	128.72	42.19
12	1.5	450	20	46	132.5	42.44
13	1.5	600	10	46	129.95	42.27
14	1.5	600	15	48	129.97	42.27
15	1.5	600	20	48	135.02	42.6
16	1.5	850	10	48	129.99	42.27
17	1.5	850	15	51	130.23	42.29
18	1.5	850	20	52	136.31	42.69
19	2	450	10	52	135	42.6
20	2	450	15	54	137.59	42.77
21	2	450	20	63	139.85	42.91
22	2	600	10	55	137.34	42.75
23	2	600	15	57	139.23	42.87
24	2	600	20	67	142.8	43.09
25	2	850	10	57	138.2	42.81
26	2	850	15	61	140.6	42.94
27	2	850	20	73	148.6	43.44

Table V- Mean S/N ratio values of parameters for micro hardness

Level	V	S	T
1	41.76	42.23	42.16
2	42.35	42.35	42.32
3	42.91	42.44	42.55
Delta (Δ)	1.15	0.21	0.38
Rank	1	3	2

Table VI- Mean effects of parameters for micro hardness

Level	V	S	T
1	122.6	129.5	128.5
2	131.1	131.3	130.7
3	139.9	132.7	134.3
Delta (Δ)	17.4	3.3	5.9
Rank	1	3	2

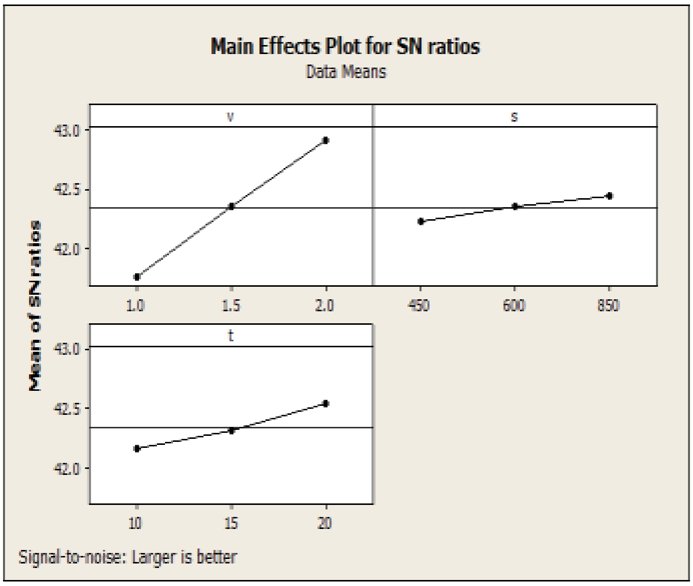

Fig-6: Mean Effect plots of S/N Ratio.

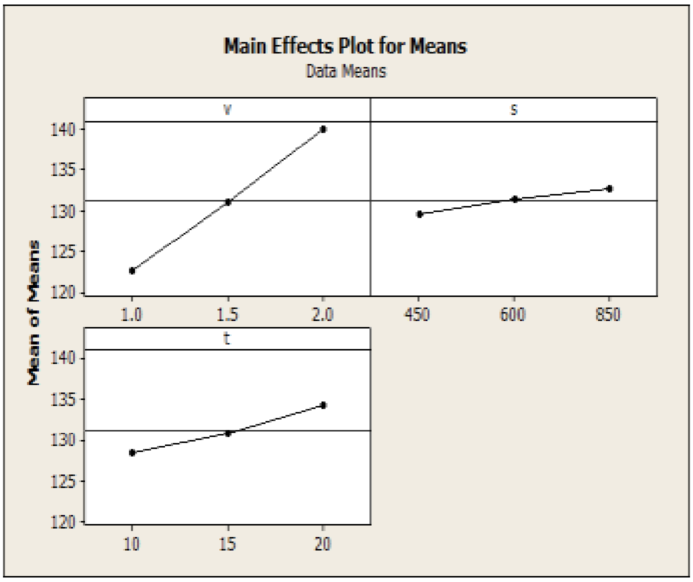

Fig-7: Mean Effect plots of mean.

The criticalness of S/N extent and mean impact response were appeared in Tables. These Tables in like manner consolidate the delta (Δ) which is the qualification among the most bewildering S/N extent and the slightest S/N extent regards. Positions for factors are doled out in light of the delta regard. The most raised delta regard is distributed to rank 1; rank 2 is consigned to next most significant delta regard and the rest. In light of the delta situating it is seen that the voltage has most surprising influencing variable on scaled down scale hardness in the zinc thin plate electro confirmation. With a particular true objective to assert the results of S/N extent and mean effects ponders, ANOVA approach was used to perceive the significances of process parameters on response variable.

E. Analysis of Variance (ANOVA)

The after effect of examination of change (ANOVA) is to test for critical contrasts between means. In this examination the ANOVA examinations for trial reaction were performed in ANOVA instrument offered in MINITAB 16 programming and the final products were classified.

Table VII- ANOVA table for micro hardness - conventional type deposition

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P	ρ%	Rank
V	2	1356	678.2	678.2	355	0	84.8	1
S	2	48.16	48.16	24.08	12.6	0	3.01	3
T	2	157.1	157.1	78.57	41.1	0	9.82	2
Error	20	38.26	38.26	1.91				
Total	26	1600					97.6	

Table VII shows the contribution levels (ρ %) of parameters on micro hardness investigated from ANOVA module for zinc thin film coating electro deposition. It was witnessed that, the contributions of parameters on micro hardness was about voltage, (ρ=84.8%); time of deposition, (ρ=9.82%); speed of magnetic stirrer, (ρ=3.01%). The above rank orders are worthy agreed with the rank orders of S-N ratio and mean effect studies. Thus, the influences and significances of process parameters on micro hardness of coating confirmed with three different schemes and authenticated.

5. CONCLUSION

The electro deposition of the Zinc thin coating has been produced by the sulphate bath. Stout experimental design methodology has been implemented for effect studies for above depositions using Taguchi approach with the objective of less experimental trails and cost effective experimentation. The following conclusions were established from the experimental and analytical studies.

- L27, symmetrical experimental array exhibit Taguchi methodology that was locked in to outline the test trails with slightest number of examinations. The investigations were proficient by changing the procedure parameters and levels in view of the run orders.
- The surface morphology of the uncoated and zinc coated specimen was analyzed under scanning electron microscope, and the experimental results such as mass of deposition, coating thickness, and micro hardness were examined methodically.
- The coating thickness was obtained by Tally surf as well as the theoretical calculations and only minute differences were observed for few specimens, 27th specimen has the highest roughness value due to high voltage ,speed and time.
- Form the above results of L27 it was observed that the voltage and the time of deposition are the most significant factor for the hardness of the zinc thin film coating.
- The hardness value of the mild steel specimen before coating was observed to be 86 HVN. Deposition of the coating mass was accomplished from 40 mg to 74 mg and the hardness value varies from118.69 - 148.60HVN, and it was observed that the 27th specimen has highest deposition of 74 mg and has higher hardness value of 148.60HVN with dark deposition, which concludes that the hardness value has increased up to 148.60 HVN.
- The impacts of process parameters (Voltage, Speed and Time) on the reaction micro hardness were analyzed by means of expository examinations, for example, mean impact studies and S/N proportion investigation. Keeping in mind the end goal to affirm the final products of above examination, the ANOVA test was carried out and it was found that the significances of process parameters were positioned by order.

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