Engineering and Technology Journal, Vol. 38, Part A (2020), No. 04, Pages 530-544

Engineering and Technology Journal
Journal homepage: engtechjournal.org

Optimizing of Coating Layers Parameters of (Nano Hydroxyapatite/TiO_2 NPs) on Nitinol SMAs by Electrophoretic Deposition

Riyam R. Rawdan [a*], **Makarim H. Abdulkareem** [b], **Ali M. Mustafa** [c]

[a*] Production Eng. and metallurgy. Dept, University of Technology, Baghdad, Iraq reamraad9@gmail.com

[b] Production Eng. and metallurgy. Dept, University of Technology, Baghdad, Iraq, engmak03@gmail.com.

[c] Production Eng. and metallurgy. Dept, University of Technology, Baghdad, Iraq. engalimmd75@gmail.com.

*Corresponding author.

Submitted : 12/09/2019 Accepted: 04/02/2020 Published: 25/04/2020

KEYWORDS

Coating, Electrophoretic deposition, Hydroxyapatite, Chitosan; Taguchi approach

ABSTRACT

This study aims to obtain the optimal variable for depositing (HA, TiO_2 and Composite) Nanomaterial on NiTi SMAs. Taguchi approach (with L9 array) was used to obtain the optimal conditions for coating produced by Electrophoretic deposition (EPD) techniques. The deposition process was done in different conditions (voltage, time, concentration and degree of grinding). Voltages were used (20, 40 and 60) volts, the time is (2, 4 and 6) min, the degree of the surface roughness (180, 500 and 1200) µm while the concentration of HA and TiO_2 are (2, 4, and 6) g/L for each one. Chitosan (biopolymer) was used as binder material to the ceramic materials. The result of the Taguchi approach detected that the best conditions of HA layer are (20 V, 4 min, 2%C and the degree of surface 180), TiO_2 is (20 V, 4 min, 4%C and the degree of surface 180) and composite layer is (60 V, 4 min, 4%C and the degree of surface 180). Solutions stability was measured by utilizing Zeta potential tests; which clarified good stability for all of them. Optical microscope and scanning electron microscopy were used to characterize and study the surface of the coating layers. The bonding adhesion was measured using a tape test in order to evaluate the adhesion bonding between the coating and substrate. It found that the percentage of removal coating area for samples were (8.8%for HA, 4.9% for TiO_2 and 6.9% of the composite layer.

How to cite this article: R. R. Rawdan, M. H. Abdulkareem and A. M. Mustafa, “Optimizing of coating layers parameters of (nano hydroxyapatite/TiO2 NPs) on nitinol SMAs by electrophoretic deposition,” Engineering and Technology Journal, Vol. 38, Part A, No. 04, pp. 530-544, 2020.
DOI: https://doi.org/10.30684/etj.v38i4A.577

1. Introduction

The request to an orthopedic prosthesis and artificial implants has dramatically increased in the last years. Where it is expected in 2020 that the number of aged people over 50 years old with bone diseases will be doubled. Most of these conditions will need surgeries to implant devices inside the body, such as total joint replacement or bone fracture fixation. Stainless steel, CoCr alloys, titanium, and its alloys are the most used implant materials because of their good mechanical performance and biocompatibility [1, 2]. Using metallic implants is limited due to their bio-inert nature and weak mechanical interlocking with the surrounding tissues. Secondly, due to the corrosive body fluid, the corrosion and detachment of metal implants happen with time. From different bimetallic materials, the alloys of NiTi have been chosen for use in various biological applications due to their excellent mechanical behavior [3, 4]. But in spite of their superior mechanical properties, this alloy could not meet, covers and support all clinical requirements of implants owing to the bio-inert surface and toxic ions releasing from the alloys. So, it was at the same with other bioinert metallic implants, titanium gives poor bioactivity characteristics. So, it was used with other types of biomaterials. Hydroxyapatite (HA) coatings on the metallic implants have shown good fixation to host bone and enhanced bone ingrowth into the implant. HA promoted biocompatibility, bioactivity, and osteoconductivity coatings due to its similarity in morphology and composition in organic constitute with human bone and hard tissues both [5, 6, 7].

A variety of available processes for surface modification techniques have been developed to promote the stability and also the corrosion resistance of the alloys in the human body, such as plasma spraying, centrifugal casting, common powder metallurgy, PVD, CVD, sol-gel, thermal and plasma spray and colloidal processing [8, 9, 10]. EPD is an effective method for deposit thick and thin layer coating, it has many advantages such as simple setup, need for low cost equipment, low formation times, ability to deposit even coatings on the complex-shaped objects and controlling the microstructure of deposits by simple adjustment of EPD parameters like voltage and time. HA-coated implants giving better pinning to the bone compared with that of the adhesion between the coating and the implant, which will ultimately lead to loosening and failure of the implant". To overcome these problems, bioactive TiO_2 powders were added to HA for improving bioactivity and adherence of the coating to the implant [11]. The addition of nano TiO_2 to nano HA is found to increase the adhesion of the coating to the substrate and also with the bone that has been shown by Webster et al. [12]. Koike et al. also have shown that the plasma spraying technique led to the increased corrosion resistance of TiO_2/HA composite coatings on Ti-6Al-4V alloy [13].

Mohan et al. were reported that adding TiO_2 to HA have been exhibited good passive potential and rate lower corrosion [14]. H. Farnoush et al. were studied nanoparticles and HA/TiO_2 nanocomposite coatings on Ti–6Al–4V, the results showed an increase in corrosion resistance of substrate [15].

The current study aims to find the optimum parameters to deposit nano-coating of HA and TiO_2 on NiTi shape memory alloy by using Taguchi approach design experiments with electrophoretic deposition technique.

2. Experimental Procedures

The NiTi shape memory alloy has the chemical composition (Ni 50.9% and 49%Ti) was used as substrates with dimensions (20 X 10 X 1) mm, Nano-powders of Titania powder (25 nm), purchased from Sigma Aldrich a medium molecular weight of Chitosan (with a degree of deacetylation of about 85%) and hydroxyapatite (reagent grade, powder, synthetic). Three types of surface grinding (1200, 500, and 180) grit sic grind were used by using emery papers to obtain the best surface rough to enhance the bonding with the substrate. Chitosan was dissolved in 1% acetic acid for all solutions with 0.5g/L and then a mixture of 94% ethanol with 5% deionized water was added to the solution of Chitosan. To deposit HA, and composite layers, different concentrations (2, 4, and 6) g/L of HA and TiO_2 were used. All solutions were fitted at 4 pH values. The final solutions were stirred for 24 hours, followed by sonication for 30 min to obtain the best dispersion and good stability.

Anode from 316L stainless steel was used with dimensions similar to the cathode for the substrate. The electrodes anode and cathode were centered with a distance between them at 1 cm. Acetone was used to wash the electrodes and then dried for several hours at room temperature before it's used in all experiments. As the main aim of this work is to identify the near values of parameters controlling the EPD process, the Taguchi design of experiments with L9 array was performed for this purpose. The parameters used in the current study have been shown in Table 1.

An accomplished accurate design for variability and their levels of deposition both layers of pure HA, TiO_2 and Composite were done. Depending on the philosophy of Taguchi design of experiments and the experience of the author.
The optimum condition for the deposition of HA, TiO_2, and Composites layers are based on the maximum thickness and roughness. Optical microscopy was used to characterize the surface layers. The features of the deposited layers from the upper surface views were analysed in detail. Optical microscopes were used to analyse the surface without any surface metallography preparation and the depths of deposition thickness were determined from transverse sections.

3. Results and Discussion

I. Analysis of HA deposition

From Table 2, it was noticed a wide range of thickness values were produced with different levels of variability. The SNs ratio theory (larger is the better) shows that the experiment has the highest value of SNs ratio implicit the better quality. The thickness of HA coating layers were obtained from the Taguchi approach as listed. It can be seen from Table 2 that sample 2 has higher values of thickness and SN_S ratio. The largest thickness (55μm) was obtained in experiment (2) with 20V, 4 min, 4 % C and 500 grit sic grind. But the best condition for deposit HA layer is (20V, 4min, 2%C, and 0.19 μm roughness which corresponded to 180 emery paper SiC) as shown in Figure 2. In order to verify that the conditions give the thickness and the roughness required, the experiments were performed at these conditions, it was found the value of thickness is (49.8μm), so it was sufficient to obtain reliable HA thickness. Optimum conditions of the solution stability were obtained by Measurements from the zeta potential; it was (31 mv) with a good mobility value of particles is (0.62) [16]. A test of zeta potential was performed to determine the stability of the solution and the result was a high zeta potential value That was the reason for solution stability confirming the increase of thickness and the homogenization of the coating layer under these conditions.
Figure 2 shows the good dispersion of particles in the solution. It was noticed from Table 3 that the more variables affected on the deposit HA layer is the time (39.87%) and then concentration (32.583%), voltage (27.082%) and degree of grinding (0.425%) respectively as shown in Tables 3 and 4. Figure 3 showed the cross-section for nine samples of HA coatings and Figure 4, showing the cross-section of the HA layer at optimum condition (20V, 4min, 2%C, and 0.19 μm).

Table 1: Taguchi approach parameters for HA and TiO_2 composites layer deposition

Experiments	Voltage V	Time min	Compositions %	degree of grinding
1	20	2	2	1200
2	20	4	4	500
3	20	6	6	180
4	40	2	4	180
5	40	4	6	1200
6	40	6	2	500
7	60	2	6	500
8	60	4	2	180
9	60	6	4	1200

Table 2: Signal-to-noise ratio of Taguchi design of (L9) for thickness HA coating layer

Experiments	Voltage V	Time min	Concentration %	degree of grinding	Thickness μm	SNRAI	MEANI
1	20	2	2	1200	50	33.0586	45.3333
2	20	4	4	500	55	34.2504	51.6667
3	20	6	6	180	43	32.9697	45.0000
4	40	2	4	180	34	30.7017	35.0000
5	40	4	6	1200	37	31.4399	37.3333
6	40	6	2	500	46	33.0292	46.0000
7	60	2	6	500	32	30.1740	32.3333
8	60	4	2	180	50	34.1644	51.6667
9	60	6	4	1200	50	32.6919	43.3333

Table 3: Rank of controlled factors for thickness of the HA layer

Level	Voltage V	Time min	Concentration %	degree of grinding
1	33.43	31.31	33.42	32.40
2	31.72	33.26	32.55	32.48
3	32.34	32.90	31.53	32.61
Delta	1.70	1.79	1.89	0.22
Rank	3	1	2	4

Table 4: ANOVA for the thickness of the HA layer

Variable	Degree of grinding	Sum of squares ss	Variance, MS	Contribution
V	2	4.4557	2.22785	27.082
T	2	6.5591	3.27956	39.87
C%	2	5.3669	2.68343	32.583
D	2	0.0702	0.03511	0.425
Errors	0			
Total	8	16.4519		99.96

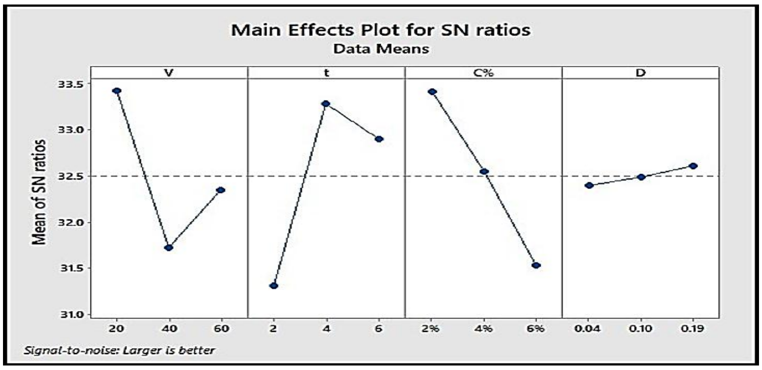
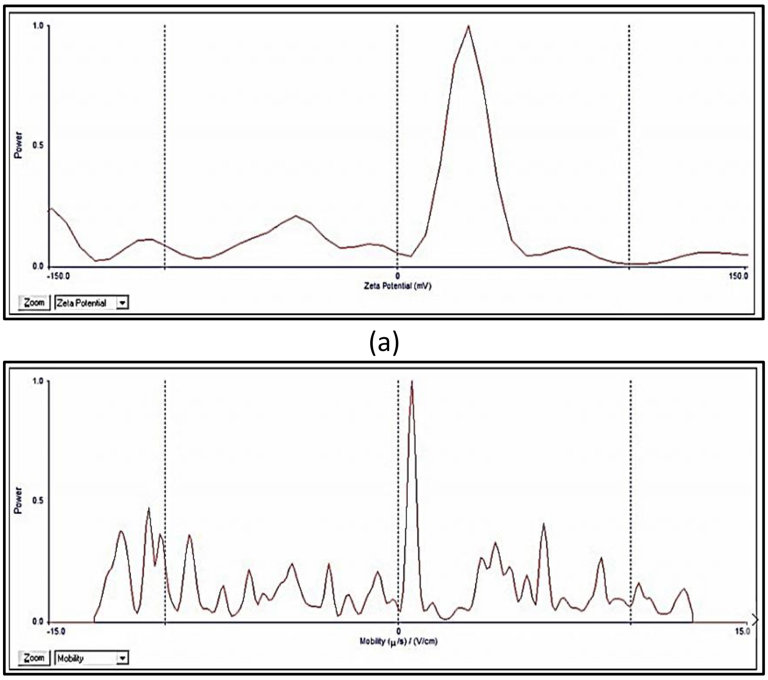


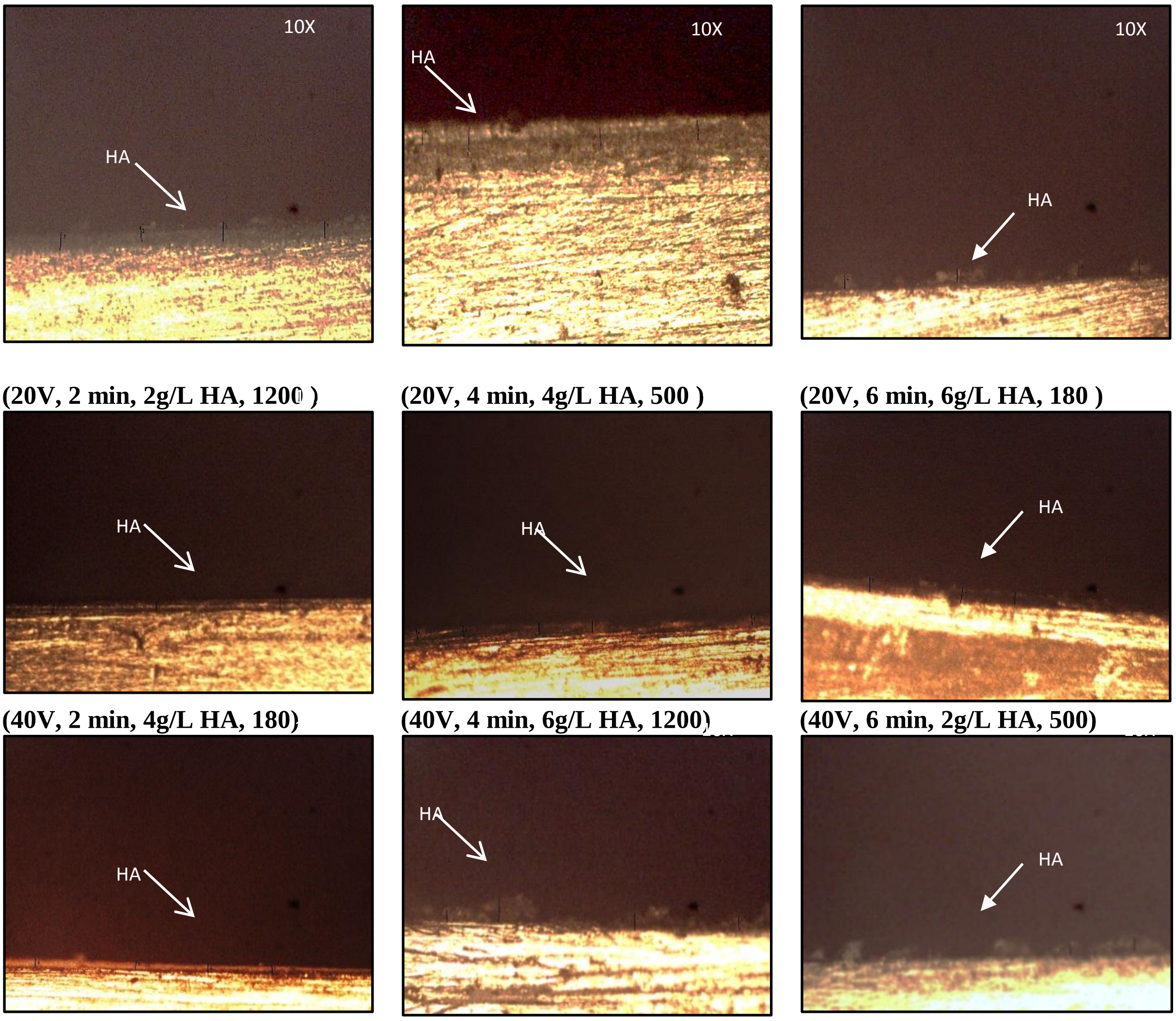
Figure 1: Mean of SNs response for HA thickness for different variables and levels



(a)

(b)

Figure 2 : (a) The value of zeta potential for HA solution, (b) The value of Mobility for HA solution



(20V, 2 min, 2g/L HA, 1200) **(20V, 4 min, 4g/L HA, 500)** **(20V, 6 min, 6g/L HA, 180)**

(40V, 2 min, 4g/L HA, 180) **(40V, 4 min, 6g/L HA, 1200)** **(40V, 6 min, 2g/L HA, 500)**

(60V, 2min, 6g/L HA, 500) **(60V, 4min, 2g/L HA, 180)** **(60V, 6min, 4g/L HA, 1200)**

Figure 3: Optical images for the cross-section of hydroxyapatite coating layers

Figure 4: Optical images for the sample of hydroxyapatite coating layers at optimal condition

From table 5 it was noticed that the higher value of roughness was 0.49 μm at (40v, 4 min, 6%C and polish degree of grinding) experiment 5. From SNs ratio Figure 5 it was noticed that the optimum conditions are (40 V, 6 min, 4%C and 0.19μm that corresponded to 180 degrees of grinding). The value of roughness at optimum condition is (0.34) Which is considered appropriate in the application [17].

The most parameter that affected micro-roughness is the concentration (51.354), degree of grinding (41.244), voltage (4.787) and time (2.216) respectively as shown in Tables 6 and 7.

Table 5: Signal-to-noise ratio of Taguchi design of (L9) for thickness TiO_2 coating layer

Experiments	Voltage V	Time min	Compositios %	degree of grinding	Thickness μ m	SNRAI	MEANI
1	20	2	2	1200	30	29.6254	30.3333
2	20	4	4	500	27	29.8456	31.6667
3	20	6	6	180	29	29.2844	29.3333
4	40	2	4	180	31	29.7113	30.6667
5	40	4	6	1200	29	29.2065	29.0000
6	40	6	2	500	22	26.5021	21.6667
7	60	2	6	500	14	22.6844	14.3333
8	60	4	2	180	29	29.3015	29.3333
9	60	6	4	1200	28	29.0311	28.3333

Table 6: Rank of controlled factors for thickness of the TiO_2 layer

Level	Voltage, V	Time, min	Compositions, %	degree of grinding
1	29.59	28.48	27.34	29.29
2	28.47	29.45	29.53	26.34
3	27.01	28.27	27.06	29.43
Delta	2.58	2.11	2.47	3.09
Rank	2	4	3	1

Table 7: ANOVA for the thickness of the TiO2 layer

Variable	D F	Sum of squares ss	Variance MS	Contribution
V	2	10.044	5.022	22.7
T	2	6.714	3.357	15.1
C%	2	9.225	4.612	20.8
D	2	18.224	9.112	41.2
Errors	0			
Total	8	44.207		99.9

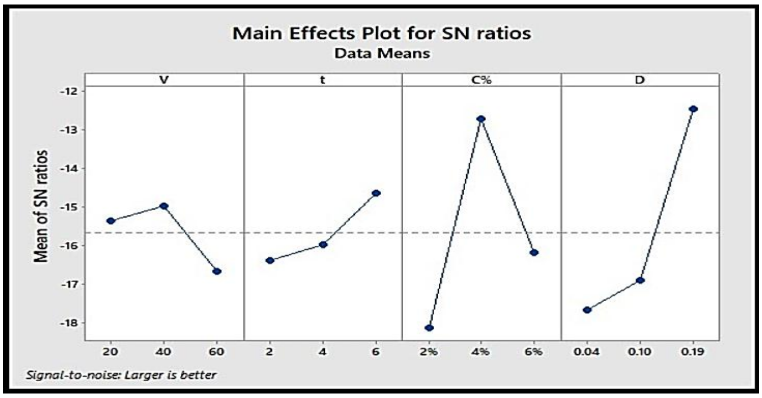


Figure 5: Mean response for HA roughness for different variables and levels

II. Optimum parameters for the TiO_2

The same parameters were taken to obtain the best conditions for deposit TiO_2 layer, it was found that the higher thickness (31μm) with a higher SNs ratio (29.7113) was obtained at (40V, 2 min, 4 % and 180 degrees of grinding) at experiment 4 as shown in Table 8. the more variables affected on the deposit TiO_2 layer is the degree of grinding (41.2%) and then the voltage (22.7%), concentration (20.8%) and time (15.1%) respectively (table 9 and 10). From the figure of the SNs ratio, it was shown that the best condition for deposit TiO_2 is (20V, 4 min, 4 % and 0.19 μm which obtains from 180 degree of grinding) as shown in Figure 6. The cross-section for nine samples of TiO_2 coatings were shown in Figures 7 and 8. It was shown that the cross-section of the TiO_2 layer at optimum condition (20V, 4min, 4%C, and 0.19 μm) with (30.7) μm thickness.

Table 8: Signal-to-noise ratio of Taguchi design of (L9) for thickness TiO_2 coating layer

Experiments	Voltage V	Time min	Compositions %	degree of grinding	Thickness μ m	SNRAI	MEANI
1	20	2	2	1200	30	29.6254	30.3333
2	20	4	4	500	27	29.8456	31.6667
3	20	6	6	180	29	29.2844	29.3333
4	40	2	4	180	31	29.7113	30.6667
5	40	4	6	1200	29	29.2065	29.0000
6	40	6	2	500	22	26.5021	21.6667
7	60	2	6	500	14	22.6844	14.3333
8	60	4	2	180	29	29.3015	29.3333
9	60	6	4	1200	28	29.0311	28.3333

Table 9: Rank of controlled factors for thickness of the TiO_2 layer

Level	Voltage, V	Time, min	Compositions, %	degree of grinding
1	29.59	28.48	27.34	29.29
2	28.47	29.45	29.53	26.34
3	27.01	28.27	27.06	29.43
Delta	2.58	2.11	2.47	3.09
Rank	2	4	3	1

Table 10: ANOVA for the layer thickness of TiO_2

Variable	DF	Sum of squares ss	Variance MS	Contribution%
V	2	4.374	2.187	4.787
T	2	2.387	1.194	2.612
C%	2	46.924	23.462	51.354
D	2	37.686	18.843	41.244
Errors	0			
Total	8	91.372		99.99

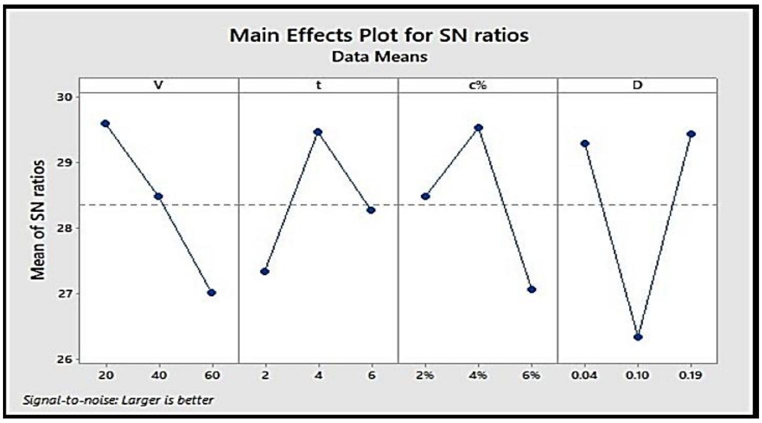
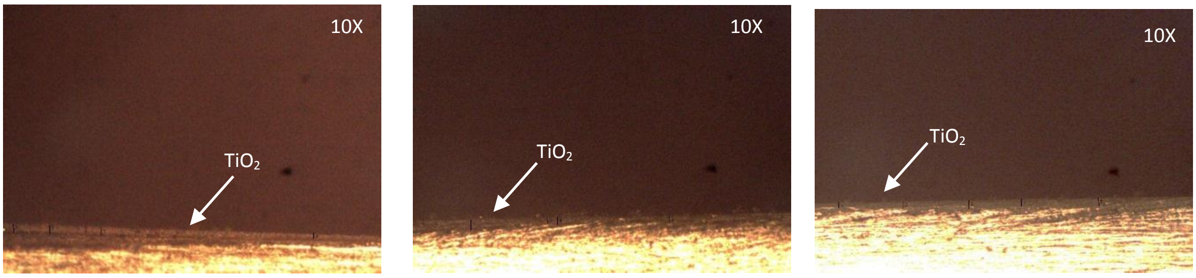
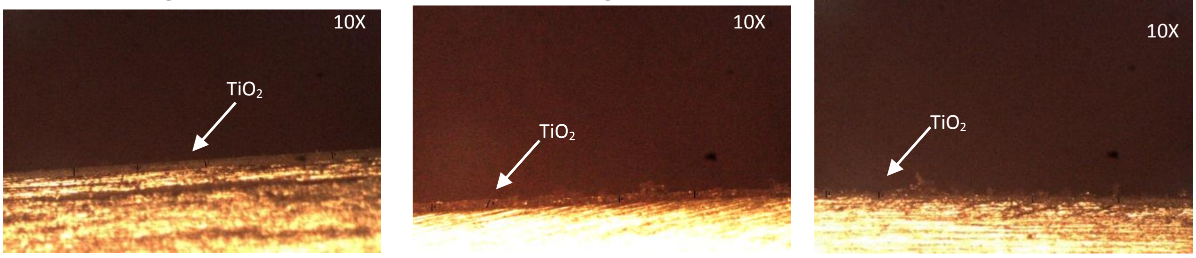


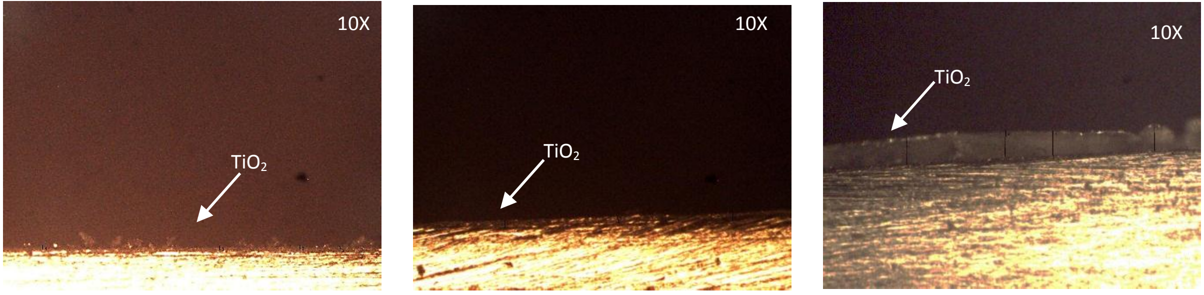
Figure 6: Mean of SNs response for TiO_2 thickness for different variables and levels



(20V, 2 min, 2g/L TiO2, 1200) **(20V, 4 min, 4g/L TiO2, 500)** **(20V, 6 min, 6g/L TiO2, 180)**



(40V, 2 min, 4g/L TiO2, 180) **(40V, 4 min, 6g/L TiO2, 1200)** **(40V, 6 min, 2g/L TiO2, 500)**



(60V, 2 min, 6g/L TiO2, 500) **(60V, 4 min, 2g/L TiO2, 180)** **(60V, 6 min, 4g/L TiO2, 1200)**

Figure 7: Cross-section of Optical images for TiO_2 coating layer

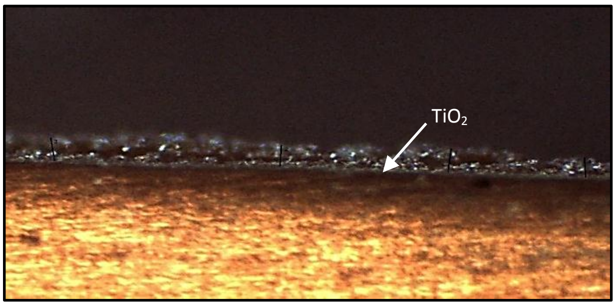
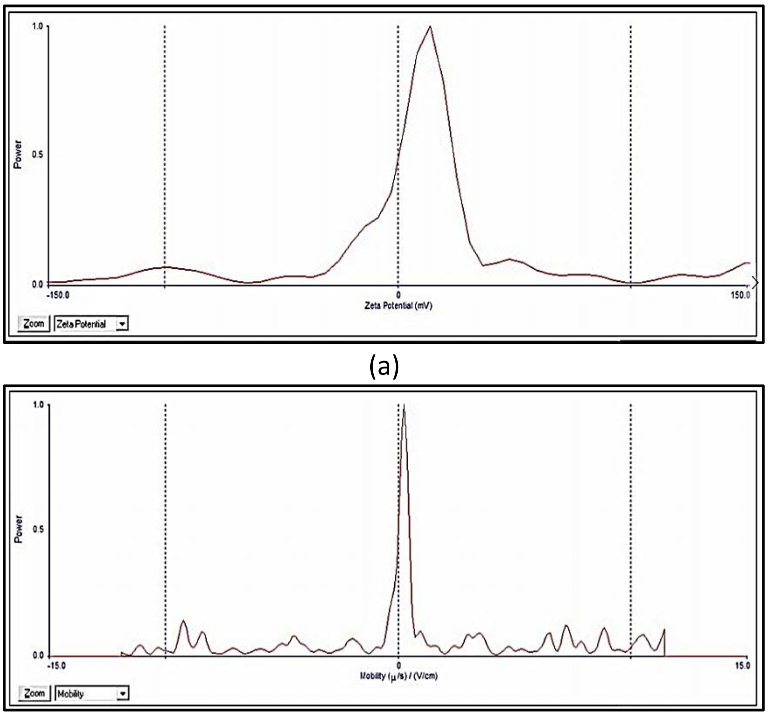


Figure 8: Optical images for optimal conditions of TiO2 coating layers

Optimum condition measurements of the solution stability were obtained by “zeta potential”; (14.7 mv) with good mobility value of the particles is (0.28) as shown in Figure 9.



(a)

(b)

Figure 9: (a) The value of zeta potential for TiO_2 solution, (b) The value of Mobility for TiO_2 solution

Taguchi approach was confirmed to obtain the higher roughness of the coating layers (0.9), it was found (60 V, 2min, 6 %C, 500 degrees of grinding). Experiment 7 as shown in Table 11. And the more parameters that affected this proceed are the degree of grinding (60.1%) and then followed by voltage (15.2%), time (15.07) and concentration (9.58%) (Tables 12 and 13). But the optimum condition obtained from the SNs ratio is (60 V, 6min, 4 %C, 180 degrees of grinding) as shown in Figure 1. Since the thickness is the main output feature, it was depended on optimum conditions of thickness experiment which also gave suitable roughness (32μm).

Table 11: Signal-to-noise ratio of Taguchi design of (L9) for thickness TiO_2 coating layer

Experiments	Voltage V	Time min	Compositions %	degree of grinding	Thickness μ m	SNRAI	MEANI
1	20	2	2	1200	30	29.6254	30.3333
2	20	4	4	500	27	29.8456	31.6667
3	20	6	6	180	29	29.2844	29.3333
4	40	2	4	180	31	29.7113	30.6667
5	40	4	6	1200	29	29.2065	29.0000
6	40	6	2	500	22	26.5021	21.6667
7	60	2	6	500	14	22.6844	14.3333
8	60	4	2	180	29	29.3015	29.3333
9	60	6	4	1200	28	29.0311	28.3333

Table 12: Rank of controlled factors for Roughness in TIO_2 layer

Level	Voltage V	Time min	Compositions %	degree of grinding
1	-15.84	-16.85	-16.21	-19.01
2	-17.65	-16.97	-14.72	-16.1
3	-14.59	-14.26	-17.14	-12.89
Delta	3.06	2.71	2.42	6.12
Rank	2	3	4	1

Table 13: ANOVA for Roughness of TiO_2 layer

Variable	D F	Sum of squares ss	Variance MS	Contribution%
V	2	14.231	7.116	15.2
T	2	14.116	7.058	15.07
C%	2	8.973	4.487	9.58
D	2	56.259	28.130	60.1
Errors	0			
Total	8	93.580		99.95

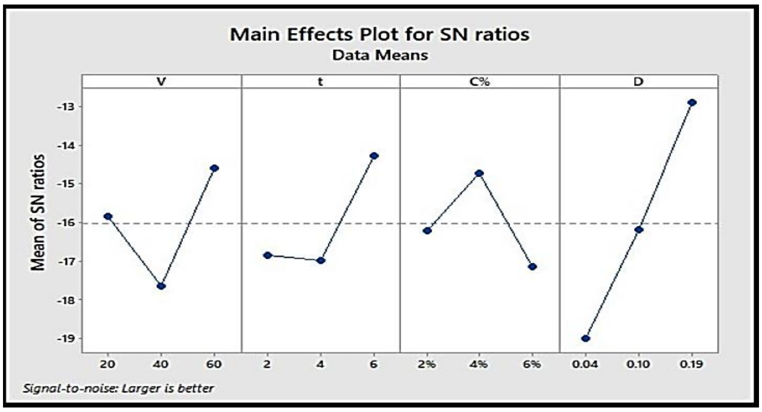


Figure 10: Mean of SNs Response for TiO_2 Roughness for Different Variables and Levels

Optimum parameters of the composite coating (HA/TiO_2)

The results that obtained about the best conditions for deposit Composite layer was found that the higher thickness (42µm) with a higher SNs ratio (32.217) was obtained at (60V, 4 min, 2 % and 180 degrees of grinding) at experiment 8 as shown in Table 14. The more variance affected on the deposit Composite layer is the Voltage (40.5%) and then Time, (31.3%), degree of grinding (15.06%) and concentration (13.04%) respectively (Tables 15 and 16). From Figure 11 of SNs ratio, it was shown that the best condition for deposit Composite is (60V, 4 min,4 % and 0.19 µm which obtain from 180 degree of grinding). The cross-section for nine samples of Composite coatings were shown in Figures 12 and 13. It was shown the cross-section of the Composite layer at optimum condition (60V, 4min, 4 %C and 0.19 µm) with 40 µm thickness.

Table 14: Signal-to-noise ratio of (L9) Taguchi design for thickness Composite coating layers

Experiments	Voltage V	Time min	Concentration %	degree of grinding	Thickness µ m	SNRAI	MEANI
1	20	2	2	1200	21	25.7020	20.6667
2	20	4	4	500	28	30.7958	34.6667
3	20	6	6	180	31	29.4341	31.0000
4	40	2	4	180	31	29.7113	30.6667
5	40	4	6	1200	34	30.5258	33.6667
6	40	6	2	500	30	29.2370	29.6667
7	60	2	6	500	36	31.0511	36.0000
8	60	4	2	180	42	32.2179	41.0000
9	60	6	4	1200	35	30.7330	35.0000

Table 15: Rank of controlled factors for thickness in Composite layer

Level	Voltage V	Time min	Compositions %	degree of grinding
1	28.	28.82	29.05	28.99
2	29.82	31.18	30.41	30.36
3	31.33	29.80	30.34	30.45
Delta	2.69	2.36	1.36	1.47
Rank	1	2	4	3

Table 16: ANOVA for the thickness of the Combination layer

Variable	D F	Sum of squares ss	Variance MS	Contribution
V	2	10.908	5.454	40.5
T	2	8.422	4.211	31.3
C%	2	3.509	1.754	13.04
D	2	4.051	2.026	15.06
Errors	0			
Total	8	26.891		99.99

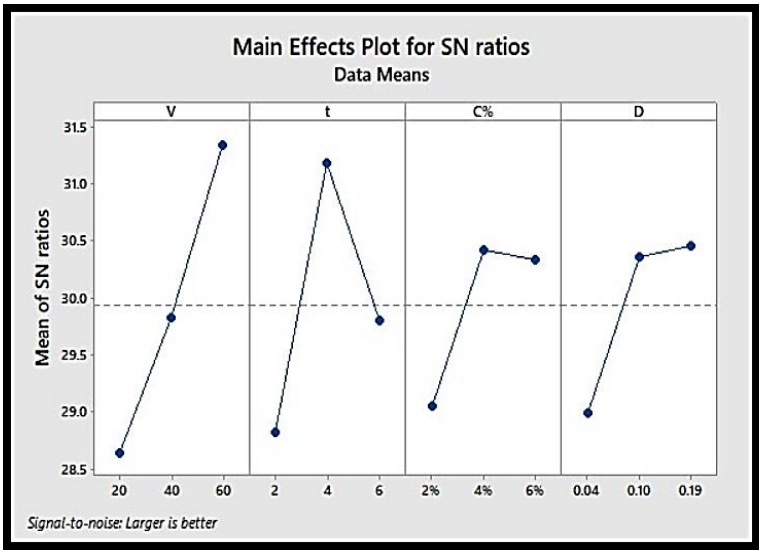
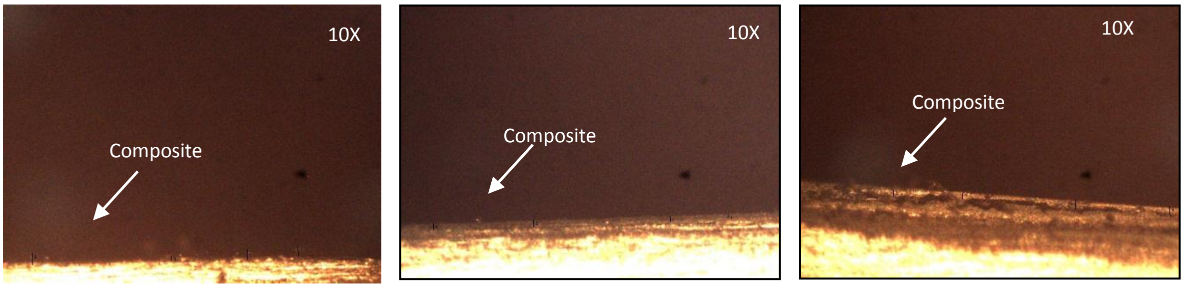
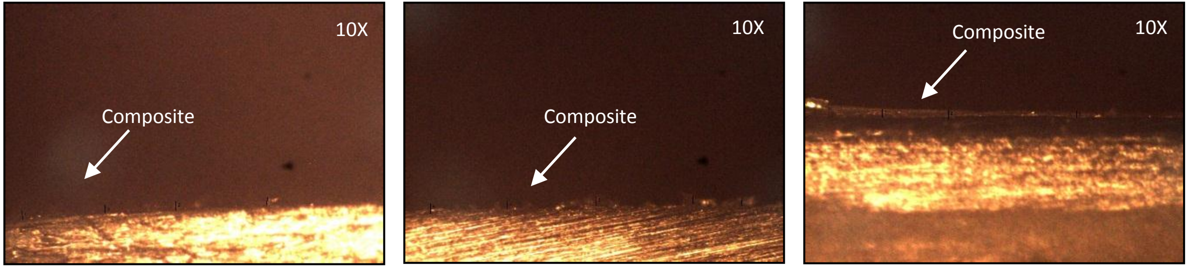


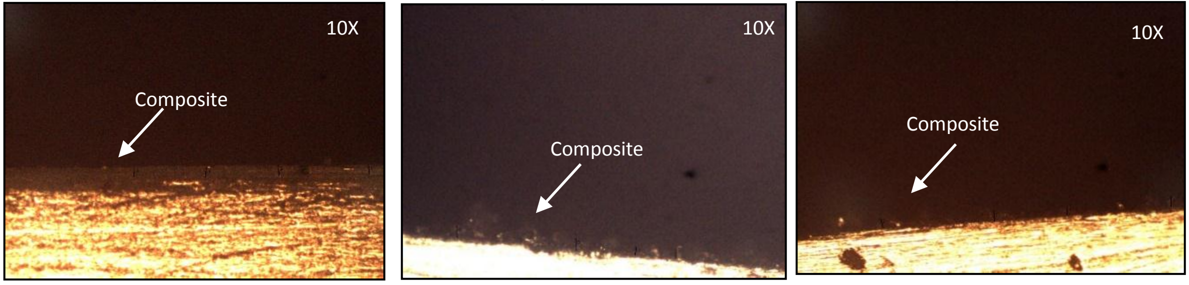
Figure 11: Mean of SNs Response for TiO_2 Roughness for Different Variables and Levels



(20V, 2 min, 2g/L composite, 1200) (20V, 4 min, 4g/L composite, 500) (20V, 6 min, 6g/L composite, 180)



(40V, 2 min, 4g/L composite, 180) (40V, 4 min, 6g/L composite, 1200) (40V, 6 min, 2g/L composite, 500)



(60V, 2 min, 6g/L composite, 500) (60V, 4 min, 2g/L composite, 180) (60V, 6 min, 4g/L composite, 1200)

Figure 12: Shows the Optical microstructure for Composite coating layers

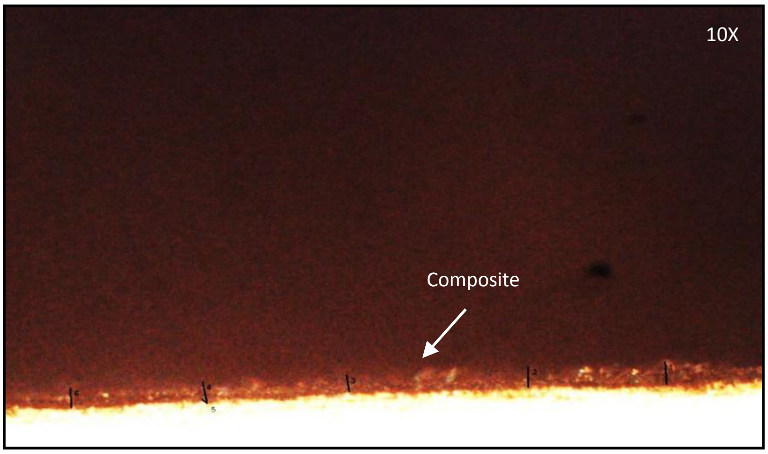
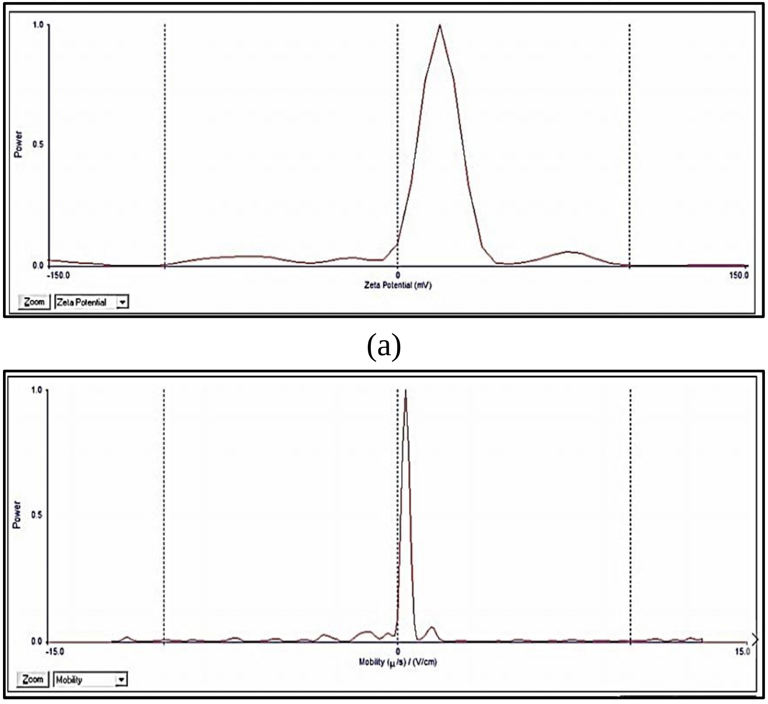


Figure 13: Optical images for the sample of composite coating layers at optimal conditions

Optimum conditions Measurements of the solution stability were obtained by “zeta potential”; (18.29 mv) with good mobility value of the particles is (0.36) as shown in Figure 14.



(a)

(b)

Figure 14: (a) The value of zeta potential for the composite solution (b) The value of Mobility for the composite solution

Taguchi approach was confirmed to obtain the higher roughness of the coating layers, it was found (60 V, 2min, 6 %C, 500 degrees of grinding). Experiment 7 as shown in Table 17. And the more parameters that affected this proceed Time (43.9%) and then followed by the degree of grinding (28.8%), voltage (17.3) and concentration (11.5%) (Tables 18 and 19). But the optimum condition obtained from the SNs ratio is (40 V, 6min, 6%C, 0.19 degrees of grinding) as shown in Figure 15. Since the thickness is the main output feature, it was depended on optimum conditions of thickness experiment which also gave suitable roughness (0.48μm).

Table 17: Signal-to-noise ratio of (L9) Taguchi design for Roughness Composite coating layer

Experiments	Voltage V	Time min	Concentrate %	Degree OF Grinding	Roughness μ m	SNRAI	MEANI
1	20	2	2%	1200	0.3	-30.4576	0.030000
2	20	4	4%	500	0.12	-18.1968	0.123333
3	20	6	6%	180	0.34	-9.6887	0.330000
4	40	2	4%	180	0.26	-16.5708	0.156667
5	40	4	6%	1200	0.15	-15.4893	0.173333
6	40	6	2%	500	0.41	-10.5970	0.316667
7	60	2	6%	500	0.9	-16.3632	0.383333
8	60	4	2%	180	0.41	-14.3265	0.193333
9	60	6	4%	1200	0.17	-15.7472	0.176667

Table 18: Rank of controlled factors for Roughness in the composite layer

Level	Voltage, V	Time, min	Compositions, %	degree of grinding
1	-19.45	-21.13	-18.46	-20.56
2	-14.22	-16.00	-16.84	-15.05
3	-15.48	-12.01	-13.85	-13.53
Delta	5.23	9.12	4.61	7.04
Rank	3	1	4	2

Table 19: ANOVA for Roughness of combination layer

Variable	D F	Sum of squares ss	Variance MS	Contribution
V	2	44.68	22.34	17.3
T	2	125.39	62.70	43.9
C%	2	32.86	16.43	11.5
D	2	82.21	41.11	28.8
Errors	0			
Total	8	285.14		101.5

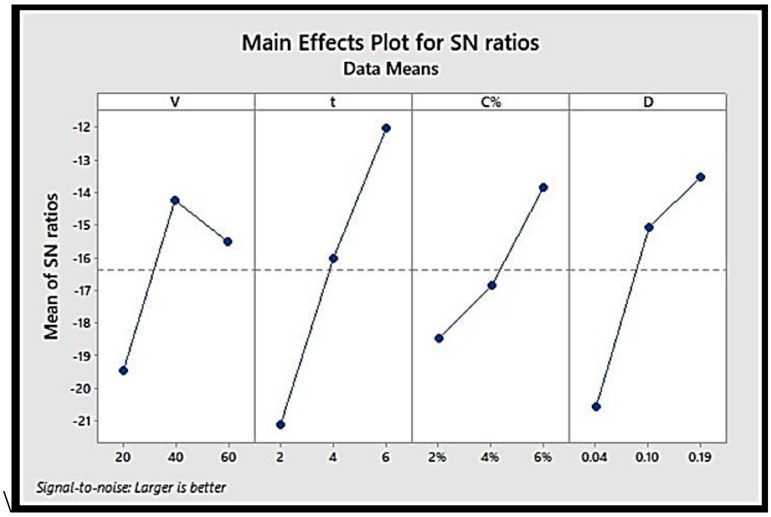


Figure 15: Mean of SNs response for Composite roughness for different variables and levels

III. Adhesion test

The adhesive tape test was used to evaluate the qualitative bonding between NiTi SMAs substrate and single and milt layer coating, the samples were tested for single layer HA, TiO_2, composite. Optical images of these different coatings after the adhesion test are shown in Figure 16. The percentage of the area removed from the coating layer was calculated with scale 2mm. It was found that the percentage of removal coating area for three samples is (8.8%, 4.9%, 6.9%) respectively. This is meant that the coating of Tio_2 of the sample of the 180p surface has the best adhesion. This is because it exhibited a less percent removal coating area (4.9%) and Tio_2 characterized by a wide bandgap and exhibits good chemical, thermal and mechanical stability. This is an indicator that there is a good bonding between coating layers at the 180 degrees of grinding e substrate roughness. The increase in the TiO_2 phase significantly affects the coating adhesion.

HA **TiO_2** **Composite**

Figure 16: Removal area for three coating layers

4. Conclusions

a) From evaluating the results of the optimum conditions for deposit HA layer, it was 20 V, 4 min 2 g/L, 180 degrees of grinding.

b) From evaluating the results of the optimum conditions for deposit TiO_2 layer, it was 20 V, 4 min, 4 g/L and, 180 degree of grinding.

c) Conditions for deposition composite ($HA+TiO_2$) were obtained at 60 V, 4 min, 4 g/L and, 180 degrees of grinding.

d) Coating with TiO_2 gives good bonding between the coating and substrate in comparison with the hydroxyapatite layer known for its weak mechanical properties. This is the purpose of using TiO_2.

e) The sample coated with composite ($HA+TiO_2$) It is of better specification than a coating layer with HA or TiO_2.

References

[1] S. Khanmohammadi, M. O. Ilkhchi, “Effect of suspension medium on the characteristics of electrophoretically bioactive glass coatings on titanium substrate,” Journal of Non-Crystalline Solids, 232-242, 2019.

[2] A. Braem, T. Mattheys, B. Neirinck, M. Ceh, S. Novak, J. Schrooten, O. Van der Biest, J. Vleugels, “Bioactive glass-ceramic coated titanium implants prepared by electrophoretic deposition,” Material Science Engineering ,32 2267-2273, 2012.

[3] M. Mehdipour, A. Afshar, M. Mohebali, “Electrophoretic deposition of bioactive glass coating on 316L stainless steel and electrochemical behavior study,” Appl. Surf. Science, 258 ,9832-9839, 2012.

[4] F. Pishbin, V. Mourino, S. Flor, S. Kreppel, V. Salih, M.P. Ryan, A.R. Boccaccini, “Electrophoretic deposition of gentamicin-loaded bioactive glass/chitosan composite coating for orthopedic implants,” Appl. Mater. Interfaces, 6 ,8796-8806, 2014.

[5] E. J. McPherson, L. D. Dorr, T. A. Gruen, M. T. Saberi, “Hydroxyapatite-coated proximal ingrowth femoral stems. A matched pair control study,” Clin. Orthop, 315 ,223-230, 1995.

[6] M. Farrokhi-Rad, Y. B. Khosrowshahi, H. Hassannejad, A. Nouri, M. Hosseini, “Preparation and characterization of hydroxyapatite / titania nanocomposite coatings on titanium by electrophoretic deposition,” Materials Research Express, 1-25, 2018.

[7] M. H. Abdulkareem, A. H. Abdalsalam, A. J. Bohan, “Influence of chitosan on the antibacterial activity of composite coating, (PEEK /HAp) fabricated by electrophoretic deposition,” Progress in Organic Coatings, 130,251-259, 2019.

[8] O.O.V. Biest, J.L. Vandeperre, “Electrophoretic Deposition of Materials,” Annual. Reviews. Material. Scince, 29,327-52, 1999.

[9] S. Put, J. Vleugels, O. Van der Biest, “Microstructural engineering of functionally graded materials by electrophoretic deposition,” Journal of Materials Processing Technology, 143 ,572-577, 2003.

[10] R. T. Candidato, P. Sokołowski, L. Pawłowski, G. Lecomte-Nana, C. Constantinescu, A. “Denoirjean, Development of hydroxyapatite coatings by solution precursor plasma spray process and their microstructural characterization,” Surf. Coat. Tech, 318 ,39-49, 2017.

[11] C.S. Chien, C.L. Chiao, TF. Hong, T.J. Han, TY. Kuo, Chwee Teck Lim, “Synthesis and characterization of TiO2 + HA coatings on TI-6AL-4V Substrates by Nd-YAG Laser Cladding,” James C.H.Goh(Eds.): ICBME; proceedings 23,1401-1404,2009.

[12] T.J. Webster, Richard W. Siegel, Rena Bizios. “Osteoblast adhesion on nanophase ceramics,” Biomaterials, 20,1221-7, 1999, 2012.

[13] K. M, Fujii H. The corrosion resistance of pure titanium in organic acids,” Biomaterials, 22,2931-6, 2001, 2015.

[14] L. Mohan, D. Durgalakshmi, M. Geetha, T.S.N. Sankara, R. Asokamani, “Electrophoretic Deposition of Nanocomposite (Hap +TiO2) On Titanium Alloy for Biomedical Applications,” Ceramics International, 1-32, 2009.

[15] H. Farnoush, J.A. Mohandesib, H. seyin¸ “Micro-scratch and corrosion behavior of functionally graded HA-TiO2 nanostructured composite coatings fabricated by electrophoretic deposition,” Journal of the mechanical behavior of medical materials, 6,31-40,2007.

[16] M. J. Khadim, N. E. Abdullateef, M. H. Abdulkareem, “Optimization of Nano Hydroxyapatite/chitosan Electrophoretic Deposition on 316L Stainless Steel Using Taguchi Design of Experiments,” Al-Nahrain Journal for Engineering Sciences (NJES), 209,1215-1227, 2017.

[17] M. J. Khadim, N. E. Abdullateef, M. H. Abdulkareem, “Evaluation of Surface Roughness of 316L Stainless Steel Substrate on Nanohydroxyapatite by Electrophoretic Deposition,” Al-Nahrain Journal for Engineering Sciences (NJES), 10,28-35, 2018.